ISOTOPE HYDROLOGY

REPORT ON THE INTERNATIONAL SYMPOSIUM
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INTRODUCTION

The International Symposium on Isotope Hydrology was jointly organized by the IAEA and UNESCO, in co-operation with the National Committee of the Federal Republic of Germany for the International Hydrological Programme (IHP) and the Gesellschaft für Strahlen- und Umweltforschung mbH (GSF). Upon the invitation of the Federal Republic of Germany the Symposium was held from 19–23 June 1978 in Neuherberg on the GSF campus. The Symposium was officially opened by Mr. S. Eklund, Director General of the IAEA.

The symposium – the fifth meeting held on isotope hydrology – was attended by over 160 participants from 44 countries and four international organizations and by about 30 observers from the Federal Republic of Germany. Due to the absence of scientists from the USSR five papers were cancelled and therefore only 46 papers of the original programme were presented in ten sessions.

INTERRELATIONS BETWEEN SURFACE WATER AND GROUNDWATER

In the first session T. Dinçer (Botswana) and E. Eriksson (Sweden) reported on studies about the origin of groundwater by analysis of the stable isotopes of the water molecule. In the case of Okavango Swamp (Botswana) the isotopic composition indicated that the groundwater derived from the swamp, while in the case of Itezhitezhidam (Zambia) isotopic analysis ruled out any hydraulic connection between recent reservoir water and artesian water in the bedrock downstream of the dam. By a new approach using the stable isotope salinity relationship it could be shown that within the swamp area water losses by transpiration are negligible in winter and can reach the level of the evaporation losses in summer.

ISOTOPE STUDIES IN MINING HYDROLOGY AND CIVIL ENGINEERING

The second session revealed the value of all isotope techniques and their partly unique role when applied to próblems encountered in hydro and geo-engineering studies. An isotopic survey made it possible to identify the recharge mechanisms of waters of different origin and age and to assess their relative importance for the leakage to a salt mine in a Zechstein dome (A. Zuber, Poland) and for the dewatering operation at an iron-ore mine that is bedded in Kalahari sands and underlain by dolomitic rock (T. Verhagen, South Africa). By analysis of the stable isotopes ratio of mineral waters in Western Bohemia V. Šmejkal (ČSSR) could prove that sulphates originated from Miocene formations and thus ascertain the balneologic importance of the waters.

During the last decades there has been an increasing trend in the pollution of surface waters which affects galleries pumping bank filtrate. Based on an environmental isotope study F. Boreli (Yugoslavia) determined the contribution of river water to a well battery and the residence time of bank filtrate in the soil.

ORIGIN OF GROUNDWATER AND AQUIFER CHARACTERISTICS

In a groundwater exploration programme important data are those relating to the natural recharge and discharge of aquifers. The value of isotope techniques in estimating both these factors was shown in the third session by providing a better understanding of the fundamental principles of occurrence and movement of groundwater in aquifer systems. The environmental isotopic approach offers the potential to achieve the mean altitude of recharge and therefore to differentiate between various sources of recharge in order to draw up a general scheme of the flow pattern from which the groundwater parameters can be derived. In addition, artificial tracer techniques provide access to the aquifer properties in recording the various strata in terms of depth.

The easy applicability of isotope techniques and the self-contained interpretation of their results was illustrated by a recharge study in the Chimbo River Valley, Ecuador (B.R. Payne, IAEA), by geotechnical investigations in the Andes (O. Rodriguez, Colombia) and by groundwater studies in the Sabarmati Basin (S.K. Gupka, India). P. Trimborn's (Federal Republic of Germany) presentation on the use of single borehole techniques proved their applicability to well-defined groundwater problems encountered in geoengineering studies.

By an in situ survey of the evolution of artificially injected tracers B. Andreu Ibarra (Mexico) could localize leaky spots in a reservoir bed and therefore elucidate leakage to the downstream aquifer system.

REGIONAL INVESTIGATIONS

Regional investigations are studies in hydrogeologic provinces, each having common geomorphologic characteristics where the aquifers have been formed by similar geologic processes. The general aim is to build up the groundwater inventory by considering surface and subsurface waters not as separated sources. Particular research concentrates on the clarification of the mechanism of recharge and its origin, on the application of the stable isotopic chronology to dating waters exceeding the ^{14}C range, and on the suitability of sulphur isotope ratios for groundwater mapping.

P.L. Airey (Australia) could prove the meteoric origin of groundwater up to 350 000 years old in the Great Artesian Basin of Australia but not the desired fluctuations in the stable isotope ratio as an indication of major cycles of the climate. J. Deák (Hungary) reported on an increase with depth of the ^{14}C age of groundwaters in the Great Hungarian Plain and by an environmental isotope survey was able to establish the general flow pattern of karst waters in the Hungarian Central Mountains. By the use of environmental tritium and stable isotopes G. Conrad (France) was able to elucidate the seasonal hydraulic connection between the groundwaters in the chalk aquifer of the Haute-Normandie and the river Seine. In an extensive review of an environmental isotope survey in Central Europe H. Hübner (German Democratic Republic) described the temporal variation of deuterium in precipitation and the mathematical treatment of the data by Fourier analysis showing annual harmonic oscillations for the majority of the stations with continental climate and non-periodical events for stations under maritime influence. The question of the value of the $^{34}S/^{32}S$ ratio for hydrological research was answered by K.U. Weyer (Canada) in reporting on groundwater investigations in the Great Slave Lake Area, Canada. The proof of the results relies on the number of sulphur suppliers and the interpretation of the data is made difficult by isotopic fractionation due to differences in chemical reaction rates.

GROUNDWATER IN FISSURED AND FRACTURED ROCKS

Unlike water movement in unconsolidated porous aquifers, the groundwater flow in fissured and karst rock cannot be described by generally valid laws. However, the capacity of conducting water through the open spaces of such a consolidated aquifer can be much higher than in soft rock. Consequently, great attention has to be paid to the location of the span system and its vertical extension in order to understand the groundwater circulation from the recharge to the discharge areas.

By a tritium survey J.W. Lloyd (UK) could support the view that the groundwater flows within a thin fissured system of the chalk aquifer of Lincolnshire, of which saline waters encroachments have been dated by the ^{14}C method as of ancient origin when the area was covered by seawater. In a study of a karst basin in the Maritime Alps of Italy G.M. Zuppi (Italy) determined two types of groundwater circulation, a deep base flow with homogeneous isotopic composition, and a shallow one replenished by snowmelt, as indicated by the isotopic altitude effect. U. Schotterer (Switzerland) could distinguish three periods in the annual cycle of the karst spring system in the Rawil Region, a snow-melt dominance from spring to mid-summer indicated by depleted ^{18}O values, fast conveyance of summer rains with enriched ^{18}O values and receding base flow in winter. In the confined part of the Ribeiro Preto Aquifer, Brazil, the ^{14}C method and stable isotope analysis determined velocities of a few metres per year for the circulation of groundwater that is recharged by local precipitation (G. Gallo, France). The application of environmental isotope techniques to investigate the water flux in the Mont Blanc Massiv revealed independent circulation systems superimposed by direct vertical infiltration of which the isotopic excess is dependent on the difference between surface temperature and the normal geothermal gradient (J.C. Fontes, France).

GROUNDWATER IN ARID ZONES AND PALEOWATERS

The alternating sequence of humid and arid periods in desert regions implies parallel, cyclic variations of the isotopic composition of precipitation and, as a consequence, of the groundwater recharge. Thus the study of interactions between groundwater bodies of different age, and especially between modern and old groundwater practically isolated from the currently active hydrological cycle (paleowaters), can be often successfully undertaken with isotope techniques.

W.J. Shampine (USA) reported on the isotope concentrations found in the five major aquifers of the Arabian Shelf Area of Saudi Arabia, each of them identified within local areas by the isotopic fingerprint. Both ^{14}C and ^{18}O analyses reflect the large variations of atmospheric temperatures in the Arabian Peninsula. In Qatar Y. Yurtsever (IAEA) studied mixing processes between seawater, deep confined aquifers and a shallow phreatic aquifer in estimating the recharge of the latter by environmental tritium. A. Marcé (France) used isotopic methods to study the recharge mechanism and the behaviour of the three main aquifers of Morocco. In Northern Chile high groundwater ages were found at a distance from the Andes and on the basis of their stable isotope contents individual groundwater bodies and their potential recharge areas were delineated (C.A. Silva Hennings, Chile). A.H. Bath (UK) applied geochemical and isotopic data to derive a paleoclimatic model of a Triassic sandstone aquifer in eastern England, which provides

a much more reliable basis for dating the groundwater over the past 35 000 years than does radiocarbon data alone. C. Sonntag (Federal Republic of Germany) presented a study of ^{14}C dated groundwaters from the northern Sahara, where the stable isotope composition proves the continental effect and indicates a lower moisture deficit of the air over the ocean during the last ice age in comparison with modern data.

GEOTHERMAL WATERS AND GEOCHEMICAL INTERPRETATION OF ISOTOPIC DATA

Isotope techniques are a necessary complement of the classic geochemical methods in formulating models of geothermal systems and are often a unique tool for shedding light on the origin of the geothermal fluid components and their circulation patterns. A. Marcé (France) informed on geochemical investigations of thermal springs in the eastern Pyrenees and in the Vosges, in which the isotopic analyses proved the thermal waters to be of meteoric origin and provided a better understanding of the mixing processes between cold and hot waters. According to a study in the Laderello geothermal field by S. Nuti (Italy), the hydrogen, oxygen and carbon isotopic compositions in the gas components appear capable of recording the temperatures experienced by the geothermal fluids in different parts of the system; however, the exact data interpretation relies on a knowledge of isotopic fractionation processes and the isotopic equilibrium reached by the Fischer-Tropsch reaction.

M.A. Geyh (Federal Republic of Germany) attempted to revive the interpretation of ^{14}C ages in estimating, together with ^{14}C diffusion, the effect of artificial hydraulic impacts. According to his conclusions, an interpretation of the ^{14}C ages of groundwater from confined aquifers is only admissible if the pressure in the confined aquifer is not lower than in the upper shallow aquifer.

There are several aspects of the use of the uranium disequilibrium to date old water (older than 50 000 years). By using a mathematical model based upon analytical isotopic and geochemical data G.E. Barr (USA) could date the age of underground brines in the Delaware Basin. By assuming no significant leaching processes and by demonstrating the rock fluid interactions it was ascertained that the brine pocket was severed from the original deposits at least 500 000 years ago.

Because of chemical processes underground in which carbon is involved, accurate measurements of ^{14}C in groundwater are not sufficient to determine ages accurately. Therefore geochemical models of the aquifer derived from measurements of water chemistry and the ^{13}C content of the water and the rock are essential for the correct interpretation of ^{14}C analyses. J.F. Barker (Canada) reported on groundwaters from the Allison Sand Aquifer, which are seriously

affected by methanogenesis and an associated dissolution of carbonates. The corrected ^{14}C ages, based on a simple conceptual model for groundwater evolution which includes methanogenic processes, appear considerably less than the raw ^{14}C ages. In a similar study G.V. Evans (UK) developed a simplified formula for correcting ^{14}C measurements when the groundwater has been affected by incongruent dissolution. In addition, he and his co-workers found an approximate relationship between the age and the stable isotope content for groundwaters in the British Isles.

GROUNDWATER RECHARGE STUDIES, UNSATURATED ZONE

This session concentrated on understanding the complex process of infiltration and movement of water through the unsaturated zone towards the water table, which involves an analysis of time-dependent changes of water flow and chemistry within an aquifer. C.T. Rightmire (USA) pointed out that studies of the constituent chemistry and the isotopic composition of gases in the unsaturated zone give an indication of the chemical reactions that occur in recharging waters and enhance the length of time for the unsaturated zone to recover following the termination of recharge.

P.E. Smith (South Africa) attempted to relate recharge measurements in the Kalahari by tritium profiles to the amount of annual rainfall. Tritium and ^{18}O measurements on the moisture content identify the bomb tritium rise and successive drier and wetter periods. G. Thoma (Federal Republic of Germany) proposed a new soil air suction method with soil water vapour adsorption by a molecular sieve, which provides an isotope profile resolution of about 10 cm. P. Moutonnet (France) reported on the use of heavy water (D_2O) as tracer in the unsaturated zone. Detection is made by the $D(\gamma,n)p$ reaction with a precision of better than 1%. S.M. Rao (India) noted during recharge investigations in alluvial areas good agreement of moisture transport rates determined by using radioactive cobalt as tracer with those determined by using tritium as reference tracer. Similar findings were reported by G. Matthess (Federal Republic of Germany) in the framework of lysimeter studies.

SURFACE WATERS

In surface water investigation environmental isotope analysis was applied to problems encountered in runoff determination, in hydrograph separation and in the pollution of lakes. Artificial isotope techniques are still of promise for studies on the dynamics and behaviour of flowing media and on the behaviour and accumulation of sediments.

The report of W. Ambach (Austria) aimed at establishing a model for the runoff from a glaciated catchment in the Ötztal Alps based on the analysis of environmental isotopes in order to achieve the annual net balance from previous years. Using the radioactive tracer ^{82}Br E. Baonza (Spain) studied the dynamics of and the dispersivity in an estuary in Southern Spain for different tidewater conditions. J. Guizerix (France) presented a paper by Courtois et al. that reported on the movement of sediments in off-shore swells, which have been traced by radioisotopes at various depths. The results revealed that the sediment transport mainly depends on the energy balance of the large rolling waves. The presentation of R.S. Barnes (USA) stressed the importance of ^{210}Pb geochronology, of which the equilibrium is disturbed when lead pollutants enter a lake system.

PROGRESS AND INNOVATION IN ISOTOPE HYDROLOGY

New perspectives were opened by using environmental isotopes other than those of hydrogen, carbon and oxygen. The accumulation of certain products of radioactive decay in the groundwater can be used as an index of age and is therefore considered as a new tool of isotope hydrology. Although several possibilities exist, at present the only element used thus far is helium. The application of the T-^3He tracer pair in hydrologic systems was discussed by T. Torgersen (USA). This method can be used to calculate a model age which may be interpretable as a residence time. In closed systems this model age represents the ^3H residence time in the system. In semi-closed or open systems the model age is equivalent to the helium residence time and therefore is a lower limit on the water residence time. This opens the possibilitiy of direct groundwater dating, in particular in permafrost regions.

From a practical point of view ^{85}Kr and ^{39}Ar dating of groundwater lacks the large volume of water (300 l or 15 m^3) necessary for analysis. However, the experimental procedure for both isotopes has been developed to a point where the activity measurements provide reliable results. T. Florkowski (Poland) reported on the possibility of ^{85}Kr dating of groundwater, by which the mean residence time in the system was calculated on the basis of a known ^{85}Kr input function and in assuming the exponential model. H.H. Loosli (Switzerland) showed that calculated ^{39}Ar and ^{14}C ages disagree significantly. This cannot be explained by simple models assuming mixing of different water layers.

CONCLUSIONS

An essential aspect of the Symposium was that 19 of the field studies were carried out in developing areas of the world. This demonstrates the growing

economic importance of isotope hydrology, which offers easy applicability to areas of difficult access. In addition, nine of these studies were performed by research groups of the developing countries. This is an indication of the useful implementation of the isotope techniques, which in many cases have been launched by assistance programmes of the UN organizations.

In most of the studies isotope techniques have been applied within a multidisciplinary approach. Clear evidence was given that maximum benefits from the use of isotope hydrology will only grow when interdisciplinary support is given. Processes of reaction and exchange between the liquid and solid phase in an aquifer can only be approached by the isotope techniques if the geochemistry of the system is well known.

Artificial isotope techniques have reached a developing stage of routine applicability to well-defined small-scale problems. Their potential warrants further studies and the parameters determined can easily be used by hydrologists for further system analyses. There is a need to make commercially available field probes that hitherto have only been constructed by a few groups for their own use.

Among the environmental isotope techniques the interpretative spectrum for T, D and ^{18}O data seems now fully exhausted and should be introduced as a standard method into the curriculum of teaching in hydrology.

Further research work should be devoted to making groundwater dating more precise and clear. This is not only to overcome discrepancies in the groundwater ages determined by different dating techniques but also to span time periods that are not yet covered by the existing techniques.

The proceedings of the Symposium will be published shortly by the International Atomic Energy Agency in Vienna under the title "Isotope Hydrology 1978".