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EXTENSIVE USE OF ISOTOPE HYDROLOGY FOR WATER RESOURCES DEVELOPMENT AND MANAGEMENT

Report by the Director General to the Board of Governors and to the General Conference

I. Introduction

1. The thirty-ninth regular session of the General Conference in 1995 adopted resolution GC(39)/RES/16 which, inter alia, requested "the Director General to continue to integrate the available expertise and resources of the Agency and Member States and to direct them towards concrete programmes for producing a visible impact by improving the quality and availability of water". It also requested the Agency to continue to explore the possibility of further collaboration with other concerned international organizations and to solicit their technical and financial co-operation.

2. Document GOV/2805-GC(39)/2, submitted by the Secretariat to the Board of Governors and the General Conference in 1995, contained background information on the initiatives to enhance the impact of isotope applications in water resources development and management, along with specific tasks on the measures envisaged to provide more effective end-user benefits in socio-economic development of Member States through Technical Cooperation projects.

3. The present document provides, as requested by resolution GC(39)/RES/16, an overview of the progress achieved and new endeavours since the last General Conference, and illustrates some of the results obtained during this period. It is being issued for the attention of both the Board of Governors and the General Conference.

II. Programme overview and expected impact for improved water resources management through isotope techniques

4. The Agency's 1995/96 programme in development of water resources involves 71 national TC projects being implemented in 56 Member Countries, and 4 regional TC projects (1 in Africa, 2 in West Asia and 1 in Latin America). Among these, two national projects and one regional project were designed within the "Model Project" concept, and their scope and work plan emphasize applications to selected systems of immediate practical importance for the countries involved to arrive at improved management of water resources. These model projects are:

- Model Project Regional Africa (RAF/8/022) - "Use of Isotopes in Water Resources Development"
- Model Project in El Salvador (ELS/8/005) - "Isotope Hydrology and Geochemistry in Geothermal Fields"
- Model Project in Venezuela (VEN/8/010) - "Groundwater Hydrology of the Caracas Aquifer".

5. The other national TC projects are also concerned with specific issues of water resources development and management, including the protection of water resources and strengthening national capabilities for isotope applications in the water sector. These projects involve isotope applications in different aspects of groundwater resources, surface waters, geothermal resources and soil erosion in catchment basins with resulting sedimentation problems in reservoirs. Of these, 32 TC projects were successfully completed during 1995 with their initial objectives fully achieved. Summary information on the progress of implementation of the above model projects and specific achievements in TC project implementation is provided in the latter sections of this document.

6. The main component dealing with further refinement and improvement of isotope methods within the programme is the implementation of coordinated research programmes (CRPs) in specific application areas. The programme includes CRPs designed on the basis of the need for further research and development assessed through specific Consultants' and Advisory Group meetings and the findings and recommendations of the external review of the whole programme on development of water resources, carried out during 1995. Some of the coordinated research programmes are related to applied field research which is expected

to provide site-specific information for improved assessment/management of water resources, as well as refinement and improvement of isotope techniques. Thus, the CRPs will directly contribute to more effective implementation of the respective TC programme in this field.

7. Two coordinated research programmes have been concluded during 1995, and two new CRPs in the water sector were initiated at the beginning of 1996. These new CRPs are:

- CRP on "Use of isotopes for flow and transport dynamics", which aims at the use of isotopes for verification of dynamics of flow and pollutant transport in groundwater through use of modern numerical flow modelling procedures and calibrated models with the aid of isotopes, will enable a decision-support system for pollution control management. 12 institutions are taking part in the CRP.

- CRP on "Groundwater renewal in water scarce regions", which aims at an improved and reliable estimate of the replenishment rates of groundwater resources, through the use of isotopes in the unsaturated zone of selected sites in arid regions. These estimates will provide the basis for sustainable extraction amounts from groundwater without causing "mining" of the source and excessive decline of the groundwater table, which is presently a common problem in most of the water-scarce regions. The results of the programme are envisaged to be compiled in a publication for wide-scale distribution to all Member countries in the arid zones. A special training workshop, with the participation of all the institutions to be involved in the CRP, was held in Wallingford, UK, in December 1995. All the procedures of soil coring in the unsaturated zone, required equipment for this purpose, laboratory procedures for extraction of soil moisture for subsequent analyses, and other relevant technical issues were discussed and standardized to ensure consistent and reliable results from the CRP. 14 institutions representing all major arid zones in the Middle East, Africa and Latin America are taking part in the implementation of the CRP.

8. Along with ongoing programmes previously initiated, a total of six CRPs directly related to improved management of water resources, are presently operational. Their main themes and their relation to the four projects of the Agency's sub-programme on Water Resources Development, the sectoral distribution of the ongoing TC programmes in water resources, and links between the CRPs and the TC programme, are listed in the Annex to this document.

III. Highlights of progress and achievements to date

(i) Model Project Regional Africa - RAF/8/022

9. Considerable progress was achieved in implementing phase I (1995 and 1996) of this model project, in which four countries are currently participating, namely Egypt, Ethiopia, Morocco and Senegal. Among the major activities carried out in 1995, field investigations including two sampling campaigns for the collection of water samples for isotope and chemical analyses were carried out in all four countries, in most cases with the involvement of IAEA regional field experts. The samples collected from the investigation areas for analyses of different isotopic species are being measured by specialized laboratories in France, India, South Africa and the United Kingdom, and by the Agency's Isotope Hydrology Laboratory. The major part of the equipment requested by the counterparts has been supplied, and expert services have been provided as planned. To strengthen the capability of counterpart institutions with regard to hydrochemical analyses to be carried out locally, a regional training course on analytical techniques for water chemistry was organized by the Agency and held in Senegal in August 1995. The course was attended by 12 participants from Egypt, Ethiopia, Morocco and Senegal. The training provided and the laboratory intercomparison carried out in conjunction with the course will have a significant impact on the improvement of the work performance of the laboratories and the accuracy of the hydrochemical results to be used within the framework of the project.

10. The second coordination meeting of the project was held in March 1996 in Cairo and showed, among other things, that the isotope and geochemical data gathered so far in all four countries has proved relevant to water resources management in the regions under investigation. For example, isotope data from Morocco indicates a prevalence of palaeowater in one of the study areas, disproving the existence of recent replenishment of the groundwater system. This information is useful in the management of resources, in particular with respect to preventing over-exploitation of a given aquifer system. Achievements were also made in Egypt in investigating, among other things, the interaction between groundwater in the Nile aquifer system and that in the adjacent Nubian sandstone deep aquifer. This problem is relevant to securing sustainable water supply for newly reclaimed land on the fringes of the Nile flood plain. Distinct isotopic signatures of the two aquifers have been found which, after further enhancement of the database in the current study, including isotope-based hydrogeological modelling, will enable an estimation of the recharge sources of the aquifers under exploitation and, consequently, ensure sustainability of the resources, both in quantity and quality. In the Moyale investigation area of Ethiopia, where a large

proportion of the human population of 3 million and one of the largest concentrations of cattle on the African continent are entirely dependent on groundwater, the first isotope results indicate the potential of isotope techniques to tackle such important questions as (i) recharge conditions in the sedimentary and fractured rock aquifers and (ii) continuity and discontinuity of groundwater in the sedimentary aquifer systems under investigation. For example, the groundwater samples so far collected show distinct variations in the concentrations of the environmental isotope tritium, and this makes it possible to distinguish between renewable and non-renewable resources and thus to estimate the potential of the resources for the water supply in the area. Finally, in Senegal, a considerable amount of isotope and geochemical data has been gathered through field and laboratory activities. In accordance with the project's work plan, modelling approaches based on this isotope data and complementary hydrogeological information will be initiated in April 1996 to re-assess the groundwater resources around Dakar. The areas of active recharge with the potential of sustainable extraction of water delineated by isotope results will be used as sites for future drilling of extraction wells within the scope of a World Bank financed development scheme for Dakar.

(ii) Model Project in Venezuela (VEN/8/010) - "Groundwater Hydrology of the Caracas Aquifer"

11. The water supply in the city of Caracas is progressively decreasing, particularly during the dry season due to the adverse climatic conditions during the last years, the dependency on water derived from reservoirs of limited capacity, and the steady increase in population. Restricting the water supply to several districts is a common measure taken by the authorities every year to preserve water for the long dry season. To reduce the dependency on surface water resources, the exploitation of the Caracas aquifer is the main alternative. For the proper management of this resource, a comprehensive knowledge of the aquifer's properties and groundwater dynamics is essential. The ongoing project is focused on providing key information for the rational exploitation of the aquifer based on the availability and quality of groundwater.

12. Hydrogeological, chemical and isotopic data has been used to identify and characterize the sources of recharge to the different sectors of the Caracas aquifer. The results obtained so far indicate that the shallower part of the aquifer (down to a depth of 50 m) is characterized by rapid groundwater renewal, where water from different sources is found (including leakage from the drinking water distribution system), and the most serious pollution problems have been identified. At greater depths, the so-called "passive zone" is

found, which is characterized by slower groundwater dynamics and better water quality. Through exploitation of selected wells (extracting water from specific depths) it will be possible to provide additional drinking water to the existing distribution system.

13. Based on the information contained in this study, which has been provided to the local authorities responsible for water resources management, the location and design of new wells has been proposed. During the last months of 1994, fifteen wells were drilled, and another fifty will be drilled during 1996. It is expected that these wells will contribute to reducing the present water restrictions (up to 12 hours a day in some districts), providing more than 112,000 m³ per day (around 43% of the existing water deficit). Therefore, these wells, together with other measures to reduce waste of water and leakage to groundwater, will improve the availability of water to the population, especially in some marginal areas of the city where water is still distributed with trucks. The laboratory in charge of controlling the quality of groundwater pumped from the Caracas aquifer is also being upgraded with the Agency's assistance in order to be able to measure additional physical and chemical parameters, and to guarantee that existing quality criteria for drinking water are met.

(iii) Model Project in El Salvador (ELS/8/005) - "Isotope Hydrology and Geochemistry in Geothermal Fields"

14. The TC model project ELS/8/005 "Isotope Hydrology and Geochemistry in Geothermal Fields" commenced in 1995 with the aim of integrating isotope hydrogeochemical techniques in the investigation for the development of Ahuachapan and Berlin geothermal fields. The project assists the end-user, Comisión Ejecutiva Hidroeléctrica del Río Lempa (CEL), in understanding the hydrology and processes affecting the fluids in the geothermal areas. This information enables the formulation of scientifically sound strategies for geothermal energy utilization as well as for appropriate disposal of waste water through reinjection.

15. The first year of the project brought about a preliminary baseline hydrological model for the subsequent development of the Berlin geothermal field. Steam and water samples collected from geothermal wells and surface manifestations were analyzed for chemistry at CEL, for oxygen-18 and deuterium at the Agency's Isotope Hydrology Laboratory, and for gases and isotopes in gases at the Istituto Internazionale per le Ricerche Geotermiche (IIRG), Pisa, Italy. This data indicates that the hottest sector produces at least 280°C fluids originating from a mixture of predominantly meteoric water and an isotopically very heavy

water, probably andesitic in nature. As the fluids rise from that sector of the field, a fraction (25%) of steam separates at about 220°C and flows towards the north. The residual cooler fluids are tapped by the rest of the wells. The meteoric water recharge is postulated to originate from two sources but will subsequently be validated by isotope data from samples collected from six rain stations installed under this project.

16. In 1995, two wells were drilled while 16 others are scheduled for drilling during the third quarter of 1996 to meet the 1997 projected 50 MWe expansion of the Berlin geothermal field. Suitable areas for reinjection of waste waters to reduce environmental pollution are also being evaluated.

17. The development of other potentially productive areas was re-assessed in connection with the loan to CEL from the Inter-American Development Bank (IDB). The IDB supports the development of the steam field with drilling of additional wells in Berlin and Ahuachapan. It was decided to use Chipilapa, 4 km from Ahuachapan, as a reinjection area. The hydrological connection of the two sectors is being determined to prevent premature cooling while at the same time inducing artificial recharge of the reservoir. Radioactive tracing by I-131 and I-125 in this regard will be implemented in the coming months to determine the preferential flow paths of fluids, their rate of flow and the interconnection between the reinjection and production sectors. The information will indicate potential reinjection sites at a sufficient distance from the production area to allow re-heating of fluids and yet communicating with the reservoir to induce recharge to the system.

IV. Selected examples of other projects and activities in water resources:
Highlights of progress and achievements

18. In view of the severe shortage of freshwater resources in arid and semi-arid regions and water resources management problems stemming from the present water utilization pattern, the Agency's programmes in the field of isotope hydrology have placed special emphasis on the application of nuclear technology in such water scarce regions. Several regional TC projects dealing with water resources in arid zones of Africa, the Middle East and Latin America have been designed and are being implemented, and a number of Coordinated Research Programmes specifically dealing with problems of arid zone hydrology are presently operational.

19. In this context, a regional TC project in the West Asia region (RAW/8/002) dealing with isotope applications directed towards improved groundwater management in selected major aquifer systems was initiated in 1995. The subject matter of the project includes isotope field investigations dealing with:

- (i) estimation of recharge rate from rainfall through studies in the unsaturated zone at selected sites (Saudi Arabia, Syria) as a means of establishing allowable water extraction amounts without causing decline of the water table;
- (ii) identification of sources of pollutants and their transport in the groundwater, and development of predictive pollutant transport models as a means of arriving at management decisions to minimize water quality degradation (Lebanon, Jordan, Saudi Arabia);
- (iii) study of sources and processes of water salinization in coastal aquifer systems so that proper engineering decisions to prevent sea-water encroachment into groundwater can be made (Lebanon, Syria, Turkey, UAE).

20. Initial findings of isotope field investigations so far conducted under problem area (i) of the project indicate that recharge at an average rate of 15 mm/year is occurring at two sites in Saudi Arabia. This indicates a safe extraction rate of 15 million cubic meters per year from groundwater for every 1000 km² surface area of the aquifer. The studies will continue at different sites to give a representative coverage, thereby enabling the results obtained to be spatially extrapolated for a reliable estimate to be made of major aquifer systems being exploited at present.

21. Isotope investigations in the unsaturated zone are a unique methodology for estimation of such low recharge rates. The new coordinated research programme initiated in 1996, as cited earlier, which aims at the application of the method in representative sites covering major arid zones, will also contribute to the achievements expected from the TC projects being implemented in water-scarce regions.

22. Complementing ongoing field studies addressing problem areas (ii) and (iii) of the Regional Project RAW/8/002, a group training activity on the "Use of numerical models for the simulation of flow and pollutant transport" was recently conducted. Through this training, capability was provided to the participating countries for the development of site-

specific predictive models of pollutant transport and sea water intrusion dynamics. The models form a basis for the proper management of groundwater resources as regards the protection of its quality.

23. Isotope hydrological studies being conducted in the Peruvian Altiplano (PER/8/010) have provided key information on origin and dynamics of groundwater as a basis for an appropriate exploitation of the Capillune aquifer. The construction of additional wells in selected areas of the southern part of Peru is linked to the project, in which the potential of the aquifers to alleviate the present water shortage is being assessed. The results obtained so far indicate that the region is composed of small-scale groundwater systems, often separated by intrusive volcanic formations, with limited potential for groundwater exploitation. In other areas with more favorable conditions, the discharge of geothermal fluids is responsible for the high content of contaminants, mixing with fresh water and leading to water of unacceptable quality even for irrigation. Areas of preferential recharge have been found by examining the structure of the geological formations and the tritium content of the groundwater. These areas are envisaged for extraction of groundwater.

24. In 1995, a project in Cuba (CUB/8/013) devoted to the evaluation of the effectiveness of a 20-km dike constructed in a coastal area was completed. The combined use of hydrochemical and isotopic techniques proved that the dike is effective in retaining river and flood water during the rainy season and facilitates its recharge to the aquifer in the coastal sector, leading to the displacement of the freshwater-sea water interface by the infiltration of fresh water. The changes produced by the dike in groundwater flow and the effects in the mangrove area were investigated. The dike proved to be effective in restoring the mangrove zone that was seriously affected by intense exploitation of groundwater near the coast. The study provided key information for the assessment of the effects of the dike in the groundwater system and will be considered in planning the extension of the dike by another 30 km.

25. Through a TC project in the Philippines (PHI/8/018), environmental isotopes are being used to validate a hydrological model dealing with conjunctive use of surface and groundwater resources for water supply in the Metro Manila area. Based on the results of isotope field studies conducted in Laguna Bay and groundwater aquifers adjacent to the Laguna lake which are being extensively used for the domestic water supply of Manila, it was verified that the assumed recharge of 26 million cubic meters per year from the lake to the wells of the adjacent aquifers is not taking place under the present climatic conditions.

Thus, the observed water level decline and resulting sea water intrusion is being re-evaluated through findings of isotope data. Based on the findings of these isotope-aided field studies, the model is being revised so that optimum pumping rates can be achieved.

V. Outlook for the 1997/98 programme

26. The Agency's sub-programme on "Development and Management of Water Resources" was designed with a re-orientation to focus on the integration of isotope techniques in applied research and practical applications on a wider scale to achieve efficient development and management of water resources to meet the growing demand for water and improved protection of water quality. The projects in the 1997/98 programme which are of direct relevance to isotope applications for improved water availability and management are:

Project F.4.01:	Human impact on water resources
Project F.4.02:	Water resources in regions of water scarcity
Project F.4.04:	Advances in isotope methodologies

27. Specific tasks included in the above projects have been designed taking into account the results to be achieved from the ongoing projects, and development and application needs in areas of immediate practical significance in the water sector. Specific new initiatives included in the 1997/98 programme are:

- CRP on "Application of isotope techniques in urban hydrology", with the objectives of groundwater assessment in rapidly growing urban areas and megacities; predicting and identifying hazards to urban water resources, such as surface pollution, sea/lake water intrusion and subsidence/aquifer degradation problems associated with (over)exploitation; assessment of leakage from reticulation/sewage systems; and improved modelling and resource evaluation.
- CRP on "Responses of hydrological systems to long-term exploitation", with the objective of studying hydrological responses to long-term extraction of water and its implications on natural processes related to water quality; improving resources management through the refinement of conceptual and numerical modelling with the aid of isotope data.

- CRP on "Use of isotope techniques in problems related to geothermal exploitation", with the objective of improving and developing drilling strategies through better estimates of physical and chemical parameters of geothermal reservoirs, and development of isotope methods to identify the origin of acidic fluids involved.
- Development of an "Isotope and Geochemical Database in Hydrological Systems", which will provide all the data collected by the Agency through TC field applications as basic information for the design and implementation of future isotope field investigations.

28. The 1997/98 programme on development and management of water resources makes provisions for specific activities directed towards the integration of isotope field investigations in large scale water projects in water-scarce regions. Meetings of senior management level staff of water institutions are scheduled to be held in 1997 and 1998 for the Middle East and North Africa, respectively. The results and findings of the ongoing regional TC projects will be discussed and communicated to the senior staff of the water institutions in these regions to facilitate the incorporation of findings as a decision support system for management and development of scarce water resources in the Middle East and Africa.

29. A group training for local technical staff involved in these regional TC projects will be conducted during 1997 in Vienna, for a duration of two months, to ensure a core of well trained staff is created for future similar isotope studies to be incorporated and integrated in national activities related to water resources development and management.

30. In the appraisal of new TC project proposals for the 1997/98 programme, due consideration is being given to assigning higher priority to those proposals with immediate practical impact on the assessment/management of water resources.

VI. Initiatives for improved cooperation with other related international organizations

31. The 16th Session of the ACC Subcommittee on Water Resources held in October 1995 in New York provided an excellent forum for continuing the efforts to strengthen co-operation between UN organizations concerned with water resources. In this meeting, the following organizations were represented: 10 UN departments and commissions, 7 specialized UN agencies, namely FAO, UNESCO, WHO, WB, WMO, UNIDO and IAEA, and the Asian Development Bank, the Stockholm Environment Institute, and the Water Supply and

Sanitation Collaborative Council. The Subcommittee was briefed on current activities of the IAEA relevant to the water sector of Member States, as described in the recently produced booklet "Isotopes in Water and Environmental Management" which was distributed among the participants. Information was also provided on the strategy of the IAEA's programme on water resources development as stressed in the respective resolution of the 1995 General Conference. In individual consultations with representatives of other organizations, specific possibilities for co-operation with regard to the water sector in Africa (UNECA, FAO), and concerning hydrological networks and data banks (WMO, WHO, UNESCO) were discussed.

32. A specific project to be developed jointly by FAO and UNECA concerns the use of isotope methods for impact assessment of pollution due to agricultural water use in selected major aquifer systems. Consultations with a representative of FAO were held in this regard in March 1996.

33. The need to establish a comprehensive water quality database, including isotope data, and future joint actions by UNESCO, WHO and IAEA were delineated during the meeting of "Arab National Committees of the UNESCO-IHP Programme", which was held in Cairo in December 1995. Further actions required in this regard and a plan of action will be worked out in the course of consultations between the Secretariats of the organizations involved .

34. The Fourth Annual meeting of the Inter-Agency Group for Water in Africa (IGWA) organized by the UN Economic Commission for Africa (UNECA), was hosted by the IAEA in November 1995. The following agencies were represented at the meeting: FAO, IAEA, UNCHS, UNECA, UNHCR, UNIDO, WHO, WMO, African Development Bank (ADB), Southern African Development Community (SADC), Zambezi River Authority (ZRA), the Global Runoff Data Centre (GRDC), and representatives of Development of Water and Environment (DHV Consultants), Amersfoort, The Netherlands, were present as observers. The major objective of the meeting was to further enhance inter-agency co-operation. The meeting stressed the importance of system-wide coordination and harmonization of activities to reduce duplication and overlap of activities at a time of financial constraints for the United Nations and all other international organizations. One of the major achievements of the meeting was the consensus reached on joint activities. It was agreed that an informal process of project formulation should be undertaken in order to develop one or more project proposals for presentation at the next IGWA meeting. Three agencies - FAO, IAEA and UNECA - offered to participate in taking the lead in organizing appropriate proposals.

35. Furthermore, the Agency took part in the Intergovernmental Coordination Council meeting of the UNESCO International Hydrology Programme (IHP) where the planning of the next phase of the IHP-V (to be implemented during 1996-2001) was considered in detail. A background document on IAEA activities in isotope hydrology and possible cooperation with UNESCO was submitted. Potential areas of mutual interest for cooperation between the two organizations were delineated. The first specific activity to be jointly undertaken will be the preparation of teaching material in the field of isotope hydrology. During recent meetings (April 1996) held for this purpose, the scope and contents of six different manuals covering both surface and groundwater hydrology were designed. Preparation of the manuals is scheduled to be completed by the end of 1997.

36. At the Sixth Regional Meeting of the Arab National Committees of the International Hydrological Programme (IHP) of UNESCO, held from 3-6 December 1995 in Amman, Jordan, a paper on "Development of Scarce Water Resources - The Role of Environmental Isotope Techniques" was presented. In an ad-hoc meeting held with representatives of ACSAD and UNESCO, a programme of joint efforts of Arab countries, UNESCO and IAEA was set up aimed at the establishment of a regional isotope monitoring network and an isotope hydrological database for the Arab region. First steps in the realization of the programme are envisaged to be taken at a forthcoming meeting at UNESCO-ROSTAS in Cairo in June 1996.

37. The Agency participated in the UNEP/ESCWA Expert Group Meeting on "Implications of Agenda-21 for Integrated Water Management in the ESCWA Region" (Amman, 2-6 October 1995) and presented a background paper entitled "Isotope methodologies in water resources and examples of applications in the ESCWA region". As ESCWA is planning to expand their hydrological activities, particularly concerning water resources management under water scarcity conditions in the ESCWA region, The Agency's cooperation in incorporating isotope methodologies in these ESCWA activities will be further pursued to define a concrete action plan.

F.2.- DEVELOPMENT OF WATER RESOURCES



