Isotopes for Management of Transboundary Rivers and Aquifers

A. Introduction

Management of transboundary fresh water resources (also known as trans-national, international, or internationally shared water resources) is of increasing concern across the world. Transboundary water resources include visible surface water bodies, such as lakes and rivers that cross borders, and groundwater systems (or aquifers). Globally, over 260 transboundary river basins have been identified. These basins cover 45% of the land surface of the earth, affect ~40% of the world's population, and account for ~60% of the global fresh water supply [III-1]. Aquifers, including transboundary aquifers, account for the rest of freshwater supply. Some of the large transboundary aquifers include the Nubian and northwest Sahara aquifers in northern Africa and the Guarani aquifer in Latin America. However, in many areas no inventory of transboundary aquifers exists. The widespread occurrence of these systems is exemplified by a recent UN survey that identified eighty nine transboundary aquifers in Europe [III-2].

Although management of transboundary rivers and lakes has been an issue for many years, transboundary groundwater issues have largely been overlooked. This is partly because surface water and groundwater historically have been regulated as separate resources. However, the situation is starting to change. For example, a recent Agency co-sponsored conference "Groundwater and Climate in Africa" that was held in Kampala, Uganda in June 2008, clearly demonstrated that predicted climate change scenarios will lead to an increased reliance on groundwater resources in Africa. Africa is already struggling with over exploitation of groundwater in some locations and some of the largest transboundary aquifers are essentially non-renewable [III-3] which increases the potential severity of climate change effects.

Cooperation for the sustainable management of transboundary aquifers is difficult to achieve in the absence of information regarding the links between surface water and groundwater, as well as groundwater recharge, residence times, and hydrologic flow paths. Most conflicts over water between countries have generally been addressed by non-violent means. However, the lack of sufficient technical information regarding water resources increases the chances of misunderstanding and confrontational situations, especially under scenarios of decreased water availability and/or food scarcity (see discussion in [III-4] and references therein).

Much can be gained through the application of traditional hydrologic characterization such as measurement of water levels, river discharge measurements etc. Despite the high value of such information, ambiguities about how these systems function and/or unacceptably large uncertainties about a particular water system all too often occur. This is why the application of isotope techniques (i.e., isotope hydrology) as part of the characterization process, can be an extremely important complement to traditional methods. Isotope hydrology can provide key information to build and test conceptual models of transboundary systems, and can also be extremely valuable for testing or parameterizing numerical models of hydrologic flow systems.

B. Mapping Transboundary Water Bodies and Their Characteristics

The first step in addressing key transboundary problems is to identify and map transboundary water bodies [III-2]. One important ongoing hydrological mapping effort is the World Hydrogeological Mapping and Assessment Programme known as WHYMAP (http://www.whymap.org/). An important product of WHYMAP relative to this transboundary discussion is a global scale map of major transboundary aquifers (Fig. III-1). This map shows the frequency of transboundary groundwater across the world. This kind of global scale mapping is typically too coarse for actual transboundary management purposes, but it does have an important role in raising awareness and educating policy makers and the general public about the fact that groundwater doesn't follow national borders. Another effort to make aquifer characterization data and maps (including transboundary related data) available to water resource managers is through the UNESCO initiated International Groundwater Resources Assessment Centre in the Netherlands (IGRAC, http://IGRAC). IGRAC is compiling detailed groundwater information from studies across the globe. The goal is to make key data and maps available to the public and at scales meaningful to water managers and stakeholders.

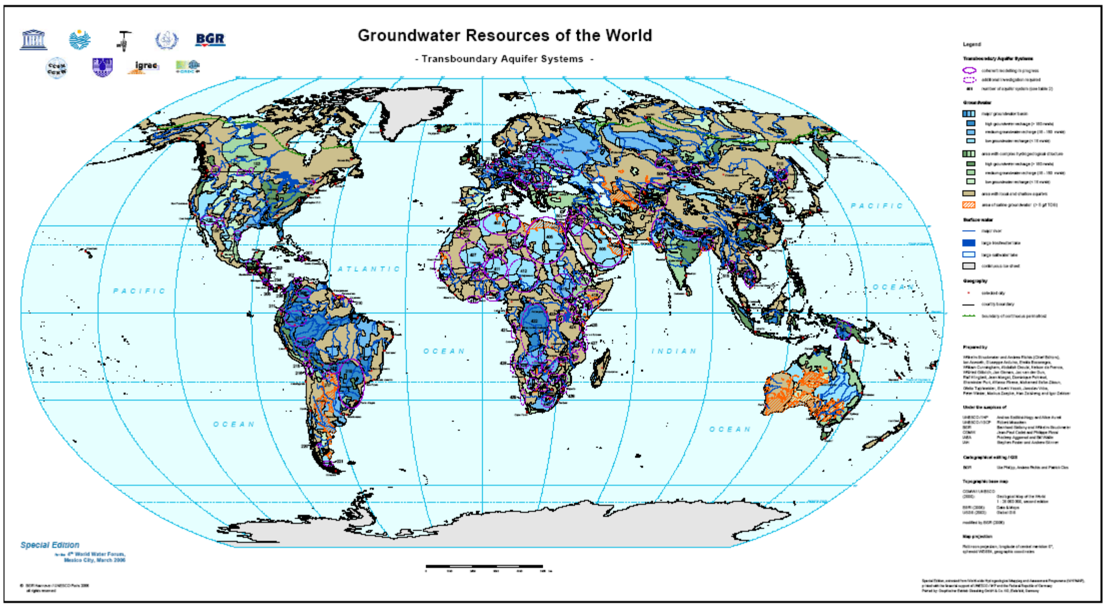

FIG. III-1. Transboundary aquifers of the world from the WHYMAP programme. While the term "transboundary" often refers to two or more countries, it may also refer to internal boundaries within a country such as between states, provinces, or districts.

With regard to maps of isotopes and isotope data in general, the Agency has recently expanded its Water Isotope System for Data Analysis, Visualization, and Electronic Retrieval (WISER) worldwide web application (accessible through http://www.iaea.org/water/). WISER is a GIS-based information system which makes a large amount of isotope hydrology data available for addressing local and regional scale transboundary water issues (as well as other water resource problems). The mapping application in WISER includes high quality cartographic representation, processing of topographic and thematic data, interactive manipulation and visualization of data. Various query, exploration and analysis tools are included to lead the user towards customised results. WISER contains unique isotope databases and spatial products that will increasingly play an important role for addressing transboundary water issues in the future (additional details are provided in references [III-5, III-6]). During roundtable discussions at the 2007 International Isotope Hydrology Symposium in Vienna, participants clearly indicated that the Agency's efforts involving WISER are very relevant. For example, the Global Network of Isotopes in Precipitation (GNIP) and the Global Network of Isotopes in Rivers (GNIR) databases within WISER were cited as examples of critical resources for isotope data at local, regional, and global scales. Because new data are continually added to the WISER system, its usefulness in understanding spatial relationships between isotopes and hydrological systems and temporal impacts from such factors as land use and climate change make WISER highly relevant to transboundary problems as well as other water resources issues [III-6]. An example of an isotope map for the Guarani aquifer in South America is shown below (Fig. III-2) and additional discussion of this map is provided later in this annex.

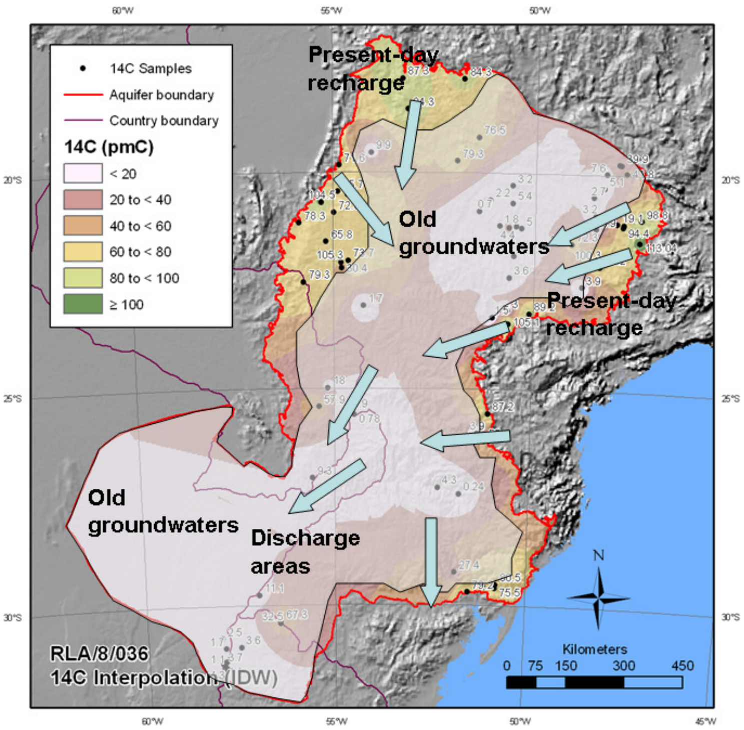

FIG. III-2. Carbon-14 distribution (percent modern Carbon, pmC) in the Guarani aquifer system in South America. Light colored areas (low values of C-14) indicate parts of the aquifer with old groundwater (> 10,000 years). The arrows indicated inferred directions of groundwater movement, with aquifer recharge in the north and discharge in the south.

C. Developing Conceptual Models of Transboundary Systems

The simple conceptual models of transboundary water systems shown in Fig. III-3 below illustrate some of the basic characteristics that need to be understood for a given transboundary location. It is clear from the figure that simple questions such as where does the water come from, and where is it going, need to be answered if transboundary resources are to be used in a sustainable and cooperative way. However, in many transboundary cases around the world, it is currently not clear which of these simple models applies to a given hydrological system. In addition, in cases where the basic conceptual model is known, important details about the rates of movement, locations of recharge, or sources of contaminants may not be known. As illustrated in the examples below, future uses of isotope methods will contribute significantly to the development of conceptual models of transboundary water systems and help refine the quantitative aspects of such systems which are necessary for sustainable management. Such approaches are now being used to address transboundary water problems through various international collaborations. Two prominent examples are the Agency and UNDP/Global Environmental Facility collaborations on the Nubian and Nile systems in Africa (see reference [III-3] for a review of these two transboundary systems). New collaborative efforts similar to these will certainly be utilized as an effective way to deal with transboundary problems in the years to come.

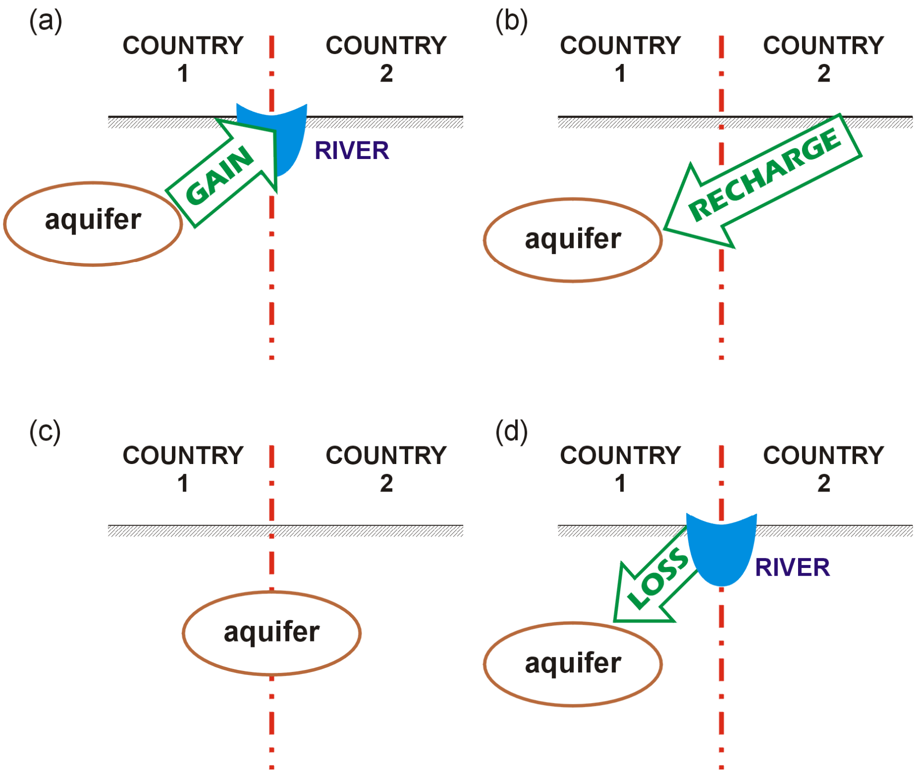

FIG. III-3. Conceptual models of groundwater and groundwater-surface water interactions in transboundary water bodies (modified from [III-4] and references therein). The dashed, red vertical line the delineations between countries. Model A shows an aquifer in one country that discharges into a river on the boundary between two countries. Model B shows an aquifer in one country with a recharge zone in another country. Model C shows a groundwater aquifer that extends across a political boundary. Model D shows a shared border river that recharges an aquifer in only one of the countries.

The effective use of isotope methods to understand a large transboundary aquifer system is well demonstrated by recent work in the Guarani aquifer of South America (Fig. III-2). The Guarani is one of the world's largest aquifers (over 1.2 M km2) covering parts of Argentina, Brazil, Paraguay, and Uruguay [III-7]. It is an important water source for industry, agriculture, and domestic supplies, and a better understanding of the functioning of the aquifer is required for sustainable management. A conceptual model of the aquifer based largely on carbon-14 analyses is shown in Fig. III-2. The carbon-14 results revealed that much of the aquifer contains old groundwater, thus the system is vulnerable to groundwater mining. The presence of old water was also noted by [III-7] using chlorine-36 and uranium isotopes. Some present-day recharge also occurs, so the aquifer management strategy must account for both of these situations. It is also important to note that some countries contain the present-day recharge areas, while others contain the discharge areas. Thus, the information shown here can significantly aid the four Guarani aquifer countries in their efforts to build a cooperative transboundary management strategy.

Radon-222 is another isotope technique that is expected to see increasing use in the near future to address transboundary and other hydrological problems. Radon-222 has been used for hydrological studies for many years [III-8] and its particular usefulness lies with the fact that most groundwaters are enriched with radon-222, while activities in surface waters are typically very low. Thus, it can be used to map and quantify groundwater discharges into lakes and streams, and also into marine coastal zones [III-8, III-9, III-10]. For example, a groundwater discharge zone in a river typically has substantially higher radon-222 activities than nearby river reaches above or below the groundwater discharge zone.

Knowing where groundwater discharge is occurring is an important conceptual and quantitative factor when addressing transboundary water problems as indicated by the conceptual models in Fig. III-3 (e.g., model A). However, the short half life of radon-222 (3.83 days) has hampered its broader use because of the need to conduct liquid scintillation analyses within a few days after sampling to avoid excessive decay. On the other hand, the availability of a relatively low cost, portable, yet high precision and accuracy 222Rn detector capable of analyzing a wide range of radon-222 activities in water (Fig. III-4) should increase the use of radon-222 in hydrological studies. The detector can be used to analyze collected water samples [III-10] or make in situ measurements directly within a surface water body [III-9]. The instrument and associated water analysis attachments (Fig. III-4) will make it far easier for investigators to obtain radon-222 in groundwater and surface water with out the need for rapid transport and analysis and if desired without collection of samples at all. The in situ measurement capability makes it possible to obtain high resolution distribution information on the spatial variability of radon-222 in a surface water body and also to collect temporal data at a 30 minute or less time resolution.

FIG. III-4. Photo of the RAD-7 radon detector (small dark box with printer on top) and RAD AQUA system (blue cylinder) in operation on board the Joint Danube Survey ship Argus in 2007. River water is being pumped through the RAD AQUA where it releases radon gas that is then pumped into the RAD-7 for detection of radon-222.

As a transboundary application example, the Agency supported the International Commission for the Protection of the Danube River (ICPDR) to help improve understanding of the basin surface water and groundwater system through the application of isotope techniques. In the summer of 2007, the ICPDR launched the second Joint Danube Survey (JDS-2) to collect information regarding water quality and ecological sustainability of the Danube. The survey entailed collection and analysis of samples for a wide variety of water quality, hydrologic, and other parameters. The survey began in Regensburg, Germany and finished 50 days later in the Black Sea. Samples were collected by ship at over 90 points along 2,375 km of the river covering ten different countries. The radon-222 data were collected to identify potential locations with significant groundwater inputs and also to examine mixing between the Danube and its tributaries. The radon-222 profile along the Danube has some interesting features as shown in Fig. III-5. Overall, the values are low and the lowest values are effectively at the limit of detection as is typical for surface water. However, there are significant differences between some parts of the Danube and between the Danube and some of its tributaries. The overall trend is for higher radon concentrations in the upper Danube which suggests that this is the area where groundwater contributions to the river are the largest. Some of the tributaries (e.g., the Sava, Velika Morava, and Siret) also have high radon-222 which suggests they have groundwater inputs in the vicinity of the JDS2 sampling points. In terms of mixing, the Sava appears to have the largest impact on the Danube radon-222 values although values drop off quickly until the Velika Morava and then they decrease rapidly again. Although the Siret has relatively high radon-222, its impact on the Danube appears to be minor and is within the measurement error. This lack of impact is probably related to the low discharge of the Siret relative to the Danube.

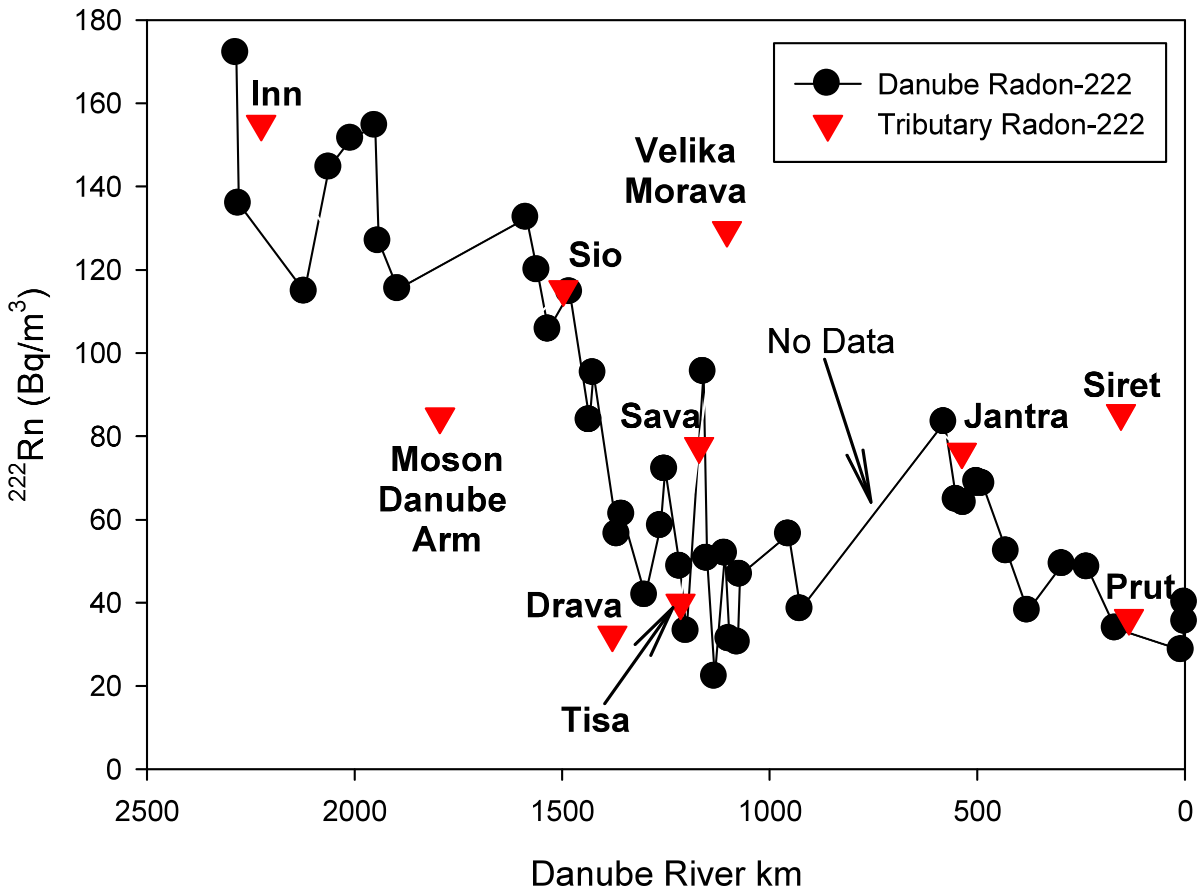

FIG. III-5. Radon-222 in the Danube Basin. Uncertainties are better than 30 Bq/m3.

D. FINAL DISCUSSION AND CONCLUSIONS

There are other important areas and approaches where the use of isotopes for solving transboundary water issues is expected to grow. One such example involves nitrate, one of the most common transboundary contaminants. Isotope analyses of nitrate are now used to identify contaminant sources and evaluate the extent of biodegradation which are key factors in the prevention and mitigation of nitrate contamination. For example, nitrate isotopes from a transboundary aquifer system in western part of Canada and the USA showed that much of the contamination was originally derived from manure with an increasing contribution from inorganic fertilizers [III-11].

The use of isotope hydrology will continue to grow because of the increasing need to properly assess and manage water resources. This is especially true for transboundary water systems where a sound, scientific understanding of the hydrology and geochemistry is essential for sustainable resource management, but also to further peace and cooperation between countries using shared water resources.

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