GROUNDWATER RESOURCES OF THE WORLD

TRANSBOUNDARY AQUIFER SYSTEMS

1 : 50 000 000

Special Edition

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WHYMAP and the World Map of Transboundary Aquifer Systems at the scale of 1 : 50 000 000
(Special Edition for the 4th World Water Forum, Mexico City, March 2006)

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Introduction to the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP)

The availability of, and access to, fresh water is an important issue on the agenda of planners, politicians and executives all over the world. Although there seems to be an abundance of water in global calculations, surface and groundwater resources are increasingly under stress at regional and local scale, although 96 % of all freshwater is found in aquifers, many of them transboundary in extent. Rising demands from population growth and food production call for larger and reliable quantities of water on the one hand, but declining resources due to pollution, over-pumping and climatic changes on the other hand reduce the per capita usable water resources. In addition, the needs of ecosystems are essential and must be sustained. Although groundwater is found practically everywhere, particularly in the semi-arid and arid regions of the world, aquifer resources constitute the only reliable water resource for drinking water supply and irrigated food production. However, in spite of the sharply increasing use of aquifers in the past decades, the knowledge about the groundwater in aquifers and its management is still weak in many places. Investments in groundwater schemes are frequently founded on inadequate aquifer information in terms of quantitative data, reliable models and poor monitoring.

In the mid 1970s the United Nations Educational, Scientific and Cultural Organization (UNESCO) established its International Hydrological Programme (IHP). Since 1974 the UNESCO IHP has developed significantly the understanding of aquifer system characteristics. Nevertheless the investments on the assessment of groundwater resources and the adoption of sound resource management tools remain insignificant.

In the last decades of the 20th century governments and funding agencies increased aquifer exploration for groundwater, due to water shortage problems at local and regional levels. Meanwhile the intensive use of groundwater by farmers for irrigated crop production – referred to as the silent green revolution – has now placed groundwater resources under stress.

To support sustainable management of aquifers, essential quantitative, national and transboundary, information is needed to map, model and quantify the stored volume as well as the average annual replenishment; in addition the chemistry of groundwater must be fully understood. Further, the vulnerability of groundwater resources to drought, over-abstraction and quality deterioration must be assessed, and the natural functions of groundwater for river runoff and ecosystems support safeguarded.

In order to contribute to the world-wide efforts to better study and manage aquifer resources UNESCO and the Commission for the Geological Map of the World (CGMW) launched the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP). WHYMAP aims at collecting, collating and visualizing hydrogeological information at the global scale, to convey groundwater related information in an appropriate way for global discussion on water issues and to give recognition to the invisible underground water resources within the UNESCO Programme on World Heritage. WHYMAP also brings together the huge efforts in hydrogeological mapping at regional, national and continental levels.

WHYMAP structure

Several agencies joined UNESCO and CGMW and provided their specific contribution to WHYMAP. A consortium was then established in 2002, consisting of the UNESCO International Hydrological Programme as lead agency, the Commission for the Geological Map of the World (CGMW), the UNESCO/IUGS International Geoscience Programme (IGCP), the International Association of Hydrogeologists (IAH), the International Atomic Energy Agency (IAEA) and the German Federal Institute for Geosciences and Natural Resources (BGR). The consortium is responsible for the general thematic outline and the management of the programme. UNESCO provides financial support for the venture, and BGR provides important resources in terms of manpower, mapping capabilities and data. All partners are committed to supply relevant scientific input.

The participation of regional experts, focussing on the relevant regional groundwater knowledge and information is considered crucial for WHYMAP. A Steering Committee of eminent international experts was established under the supervision of the consortium.

Its first meeting was organized by the UNESCO IHP National Committee of Germany in Koblenz in June 2003, followed by a second session at UNESCO House in Paris in March 2004 and a third meeting, again in Paris, in April 2005. The UNESCO regional offices and the National Committees of the UNESCO IHP, the continental vice presidents of the IAH and CGMW have provided a valuable contribution to the project.

Close cooperation with the International Groundwater Resources Assessment Centre (IGRAC) is assured through UNESCO, and the WHYMAP data are shared with IGRAC. Furthermore the Global Runoff Data Centre (GRDC) has become part of the network providing valuable global and regional data sets of surface water systems. Other regional centres, scientific organisations, universities and freelance experts in hydrogeology may also participate in WHYMAP in the future.

The structure of the WHYMAP network is shown in Figure 1.

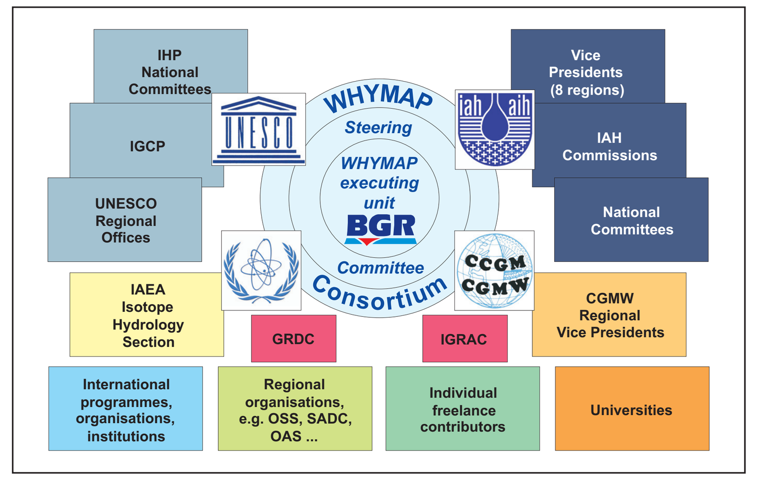


Figure 1. The WHYMAP network

The WHYMAP Consortium agreed on an iterative approach. This consists in the first instance of providing global data sets of hydrogeological and topographic information; then, collecting and capturing consolidated, up-to-date information; and finally, establishing and maintaining a comprehensive Geo-Information System (WHYMAP-GIS) for groundwater relevant data on a global scale as a global network on groundwater.

The WHYMAP Geo-Information System

The main focus of the WHYMAP Programme (www.whymap.org) is the establishment of a modern digital Geo-Information System (GIS) in which all data relevant to groundwater is stored together with its geographic reference. In its final form the WHYMAP-GIS will contain a number of thematic layers, e.g.:

- structural hydrogeological units
  - sedimentary basins
  - coastal aquifers
  - complex hydrogeological regions with important aquifers
  - karst aquifers
  - local and shallow aquifers
- transboundary aquifer systems
- aquifer properties
- groundwater potential
- storage volumes
- accessibility and exploitability of groundwater resources
- groundwater recharge (renewable/non-renewable)
- groundwater runoff, discharge, climatic dependence
- groundwater exploitation (sustainable/mining)
- depth/thickness of aquifers
- hydrodynamic conditions (groundwater divides/flow directions/ confined - artesian conditions)
- groundwater vulnerability
- interaction with surface water bodies
- land subsidence
- permafrost
- geothermalism
- hydrochemistry
- stress situations of large groundwater bodies
- "at risk" areas

Most of the thematic information is prepared by the Commissions of the International Association of Hydrogeologists (IAH) with the aim of compiling coherent global visions of the thematic issues that are focussed on, e.g. karst, hard rocks, vulnerability, coastal areas and others.

From the WHYMAP-GIS database a variety of high quality thematic map products at different scales and complexity can be derived to satisfy the individual requirements of different users.

For instance, the map Groundwater Resources of the World at the scale of 1:50 000 000 has been printed, as a first special edition for the International Geological Congress in Florence/Italy in August 2004, and the present world map of Transboundary Aquifer Systems at the same scale constitutes the second special edition within the WHYMAP family. WHYMAP also provides various small scale global maps showing the global groundwater situation for use as figures in reports and publications with a global water perspective, e.g. in the World Water Development Reports. By autumn 2007 an educational wall map at the scale of 1:25 000 000 accompanied by an explanatory booklet will be published to fit into the series of earth science maps of UNESCO. In addition an internet based map server application has been developed which integrates WHYMAP data and information on national hydrogeological maps.

UNESCO will ensure that all data compiled by the WHYMAP could be accessible in the UNESCO Water Portal. UNESCO with the support of BGR will pay attention that the WHYMAP could constitute the entry gate for subsequent development of more detailed, regional hydrogeological map information in particular in less developing countries.

The Federal German Ministry for Economic Cooperation and Development (BMZ) has also shown great interest in this common endeavour and encourages the groundwater community to carry on with the WHYMAP Programme.

The ISARM Project

At its 14th Session in June 2000 the UNESCO's IHP Intergovernmental Council adopted a resolution to promote studies in regard to transboundary aquifer systems and consequently to launch the Internationally Shared (Transboundary) Aquifer Resources Management Project (ISARM). The aim of the project is to improve the existing scientific knowledge, provide a comprehensive assessment of transboundary aquifers and formulate common principles for transboundary aquifer resources management. To conduct this project UNESCO has, since 2002, established close cooperation with the United Nations Economic Commission for Europe (UNECE), the Food and Agriculture Organization (FAO), the United Nations Economic and Social Commission for Western Asia (UNESCWA), the Organization of American States (OAS), IAH and other national and international institutions.

Transboundary Aquifer Systems

Just as there are many well-known transboundary river basins, so also there are less widely recognised transboundary aquifers. Such regional aquifers sometimes extend over large areas and their flow paths, crossing national boundaries, can extend over tens or hundreds of kilometres. The extension of the largest systems known on our planet can even reach over two million square kilometres and can be shared by several countries. With thick saturated sediments of 1000 m and more they form huge underground water reservoirs. Although there could be massive groundwater resources in stock, in arid regions, with little contemporary renewal from rainfall, aquifers can be particularly vulnerable to over-exploitation. Nevertheless they are mined, just like other deposits of natural raw materials (cf. Table 1). Many of the large transboundary aquifers of Northern Africa and the Arab Peninsula were replenished during the last ice age and contain good quality water, but they do not receive contemporary recharge. As the demand for water resources reaches higher levels, in arid regions these transboundary aquifers are often the only resource for human needs, agricultural production and some aquatic ecosystems.

Table 1. Selection of major aquifer systems containing predominantly non-renewable groundwater resources (FOSTER & LOUCKS 2006, modified)

Countries	Aquifer System	Extension (km^2)	Exploitable Reserves (km^3)
Egypt, Libya, Sudan, Chad	Nubian Sandstone	2 200 000	6 500
Algeria, Libya, Tunisia	North Western Sahara	1 000 000	1 280
Algeria, Libya, Niger	Murzuk Basin	450 000	60 - 80
Mauritania, Senegal, Gambia	Maastrichtian	200 000	480 - 580
Mali, Niger, Nigeria	Iullemeden Multilayer Continental	500 000	250 - 2 000
Niger, Nigeria, Chad, Sudan, Cameroon, Libya	Chad Basin	600 000	170 - 350
Botswana, Namibia, South Africa	Central Kalahari Karroo Sandstone	80 000	86
Saudi Arabia, Bahrain, Qatar, United Arab Emirates	various including Saq Aquifer	225 000 - 250 000	500 - 2 185
Jordan (only)*	Qa Disi Aquifer	3 000	6
Australia	Great Artesian Basin	1 700 000	170

* extends into Saudi Arabia, where it is known as the Saq Aquifer which is included in entry above

For a long time, hydrogeologists and other natural scientists have recognised that man-made boundaries infrequently coincide with structures of aquifer systems. Groundwater flows in such aquifers obeying the laws of hydraulics and crosses international boundaries to discharge into streams or lakes and ensures the stability of aquatic ecosystems especially during droughts. This transboundary and shared nature of aquifers calls for a harmonised approach to resource evaluation, planned exploitation, based on sound modelling, for sustainable management of the resources (cf. Figure 2). Before the year 2000 and the launch of the ISARM Project, there was little information on transboundary aquifers in the world. A significant global inventory programme was prepared for the 3rd World Water Forum (Kyoto). By the time that the 4th World Water Forum takes place (Mexico, March 2006), the inventories of Europe, the Americas and Africa have shown that in these continents, there are transboundary aquifers whose joint and sustainable management is essential to maintain human and environmental needs.

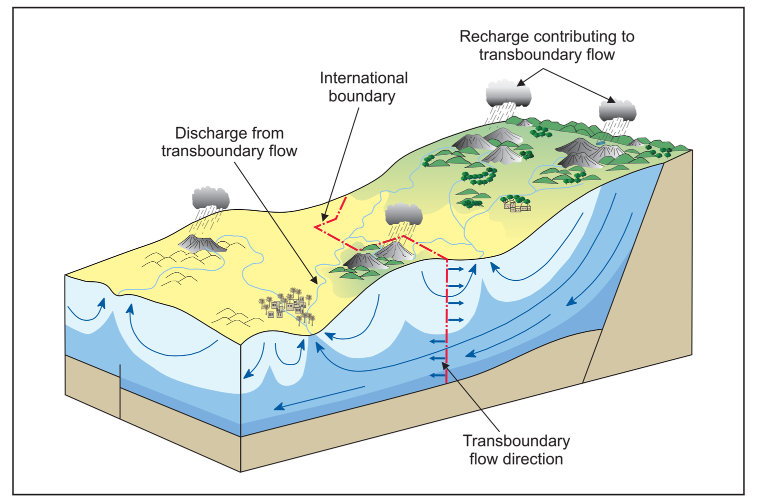


Figure 2. Schematic diagram of a Transboundary Aquifer System (PURI et al. 2001, modified)

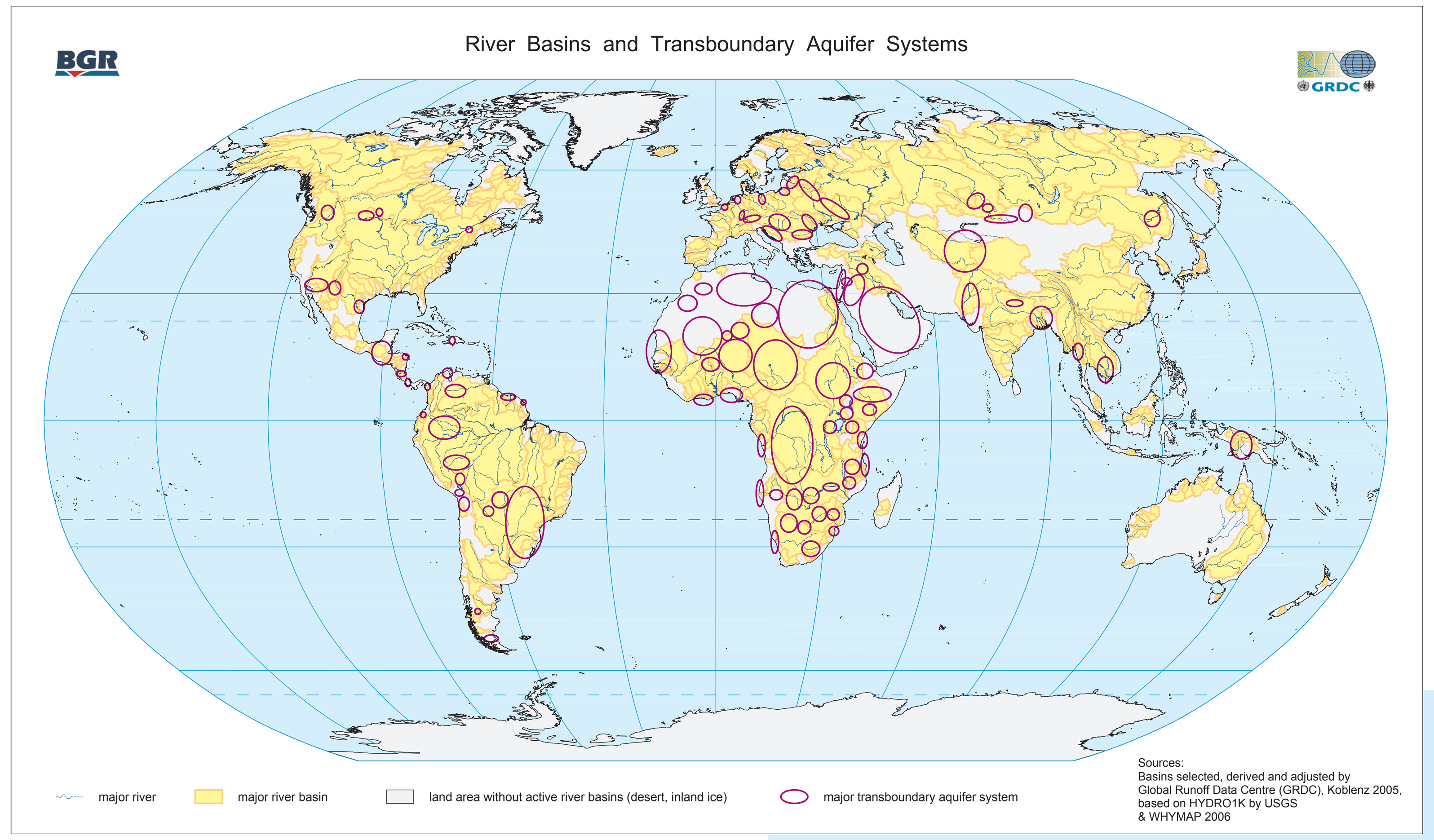
Need for a global map representing the Transboundary Aquifer Systems

The special edition map on Transboundary Aquifer Systems has been prepared to provide a global overview about the location and regional distribution of the more significant Transboundary Aquifer Systems. Its main audience is expected to be non-specialist map users, mainly decision makers at the political, planning and executive positions in countries where transboundary aquifers are found. The plan to prepare a global map of Transboundary Aquifer Systems was approved during the meeting of the WHYMAP Steering Committee in Paris, April 2005. The stakeholders in that meeting concluded that the map was very useful and timely, because

- the strongly increasing withdrawal of groundwater from transboundary aquifers in a particular country could unwillingly affect the resources in the neighbouring countries, unless such maps were available,
- the issue of shared, transboundary water resources has started to receive its due attention on the international political agenda, where the emphasis has been on transboundary rivers, and the Transboundary Aquifer Systems map would complement the available information,
- governments can be made aware, in order to develop common strategies with their neighbouring country or countries for the sustainable use of the shared resources,
- groundwater is an invisible, hidden resource, and impacts of transboundary groundwater systems are particularly subtle, slow to develop and longlasting. Therefore the natural groundwater conditions must be made transparent as a basis for good governance of groundwater.

Available data and compilation of the global map of Transboundary Aquifer Systems

The issue of transboundary groundwater was first addressed in the late nineteen-nineties, mainly in relation with the UNECE survey of transboundary aquifers in Europe and UNESCO's ISARM Project. UNECE published its first results in 1999 (cf. Figure 3). Based on the replies of 25 European countries to a questionnaire, some 90 transboundary aquifers have been recognised. However, many more are supposed, and a new inventory is currently underway.



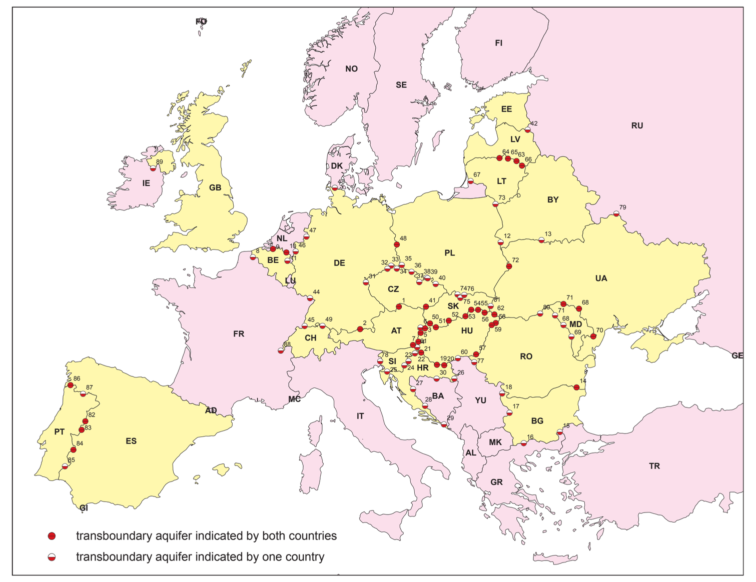


Figure 3. UNECE inventory of European transboundary aquifers (UNECE 1999)

A first inventory of the UNESCO/OAS ISARM Americas Programme has yielded some 60 transboundary aquifers in the Americas, but in a recent meeting in Sao Paulo (December 2005) additional units were mentioned. An atlas of these Transboundary Aquifer Systems is in compilation. UNESCO and OAS have foreseen to complete the inventory in 2007. Information can be downloaded from the OAS web site (www.oas.org/usde/isarm).

Both inventories rely upon information of Member States in Europe or the Americas to questionnaires distributed by the leading organisations. In consequence, a large number of rather small and merely locally important aquifers have been indicated besides the larger ones covering an area of several thousand square kilometres. Hence, most of the minor transboundary aquifers are too small to be depicted on a global map at the scale of 1: 50 000 000.

Two regional ISARM projects (UNESCO/ISARM Africa and UNESCO/ISARM Mediterranean and South Eastern Europe) have also published their results. While the African study only identifies less than 40 Transboundary Aquifer Systems for the whole continent (UNESCO/ISARM 2004b), the Balkan area highlights almost 50 transboundary aquifers, though several of them are very small (cf. Figure 4; www.inweb.gr/workshops/balkan_aquifers_map.html). One reason for this difference is certainly the fact that geological units in Europe are particularly small.

For more information on the ISARM initiative and regional activities see the ISARM portal (www.isarm.net) developed by IGRAC.

Figure 4. Inventory of transboundary aquifers in the mediterranean and southeastern Europe (UNESCO/ISARM 2004a, modified)

Groundwater, surface water and water in the atmosphere usually form a coherent entity known as the hydrological cycle. This strong interlinking of water resources gives rise to the common appreciation of the systems being geographically almost identical, especially in the humid regions of the world. However, in semi-arid and arid areas such congruence is not found, when flows in aquifers, especially the deeper ones, are largely decoupled from the surface water system. If this is not adequately recognised and fully appreciated at the level of the decisions makers, the consequences may be excessive use and unsustainable environmental impacts, leading to loss of livelihoods and poverty. While the transboundary river basins of the world have been mapped and information on their resources is better appreciated, there is a significant need for the transboundary aquifers to be mapped as well. More importantly, there is also the need for the juxtaposition of the two – so that decision makers can be assisted in making sound judgements, taking full account of all water resources.

The WHYMAP Steering Committee started with the assumption that all major groundwater basins or coherent hydrogeological complexes that are intersected by political borders on the map Groundwater Resources of the World should be considered as potential Transboundary Aquifer Systems. In most cases this was confirmed during the compilation of the global map of Transboundary Aquifer Systems.

Description of the map of Transboundary Aquifer Systems at the scale of 1:50 000 000 (overleaf)

On a global map at a scale of 1:50 000 000 only a selection of features can be represented in order to keep it readable. These features chiefly cover the location and approximate size of regionally important Transboundary Aquifer Systems, symbolised by circles or ellipses. The minimum size is generally in the order of several thousand square kilometers, however the largest ones are about two million km^2. In some cases the circles encompass a number of associated subbasins, which could not be shown individually.

The Transboundary Aquifer Systems shown on the map are numbered and have been listed in Table 2 together with suggested names, the countries sharing the systems, the type of aquifer system and the approximate sizes.

Solid lines of the circles or ellipses are shown for all Transboundary Aquifer Systems where recent and reliable data on their extent and thickness exists, and where reliable regional hydrogeological models are available or are in an advanced state of preparation, which allow simulations for a sustainable use of the groundwater in each of the sharing countries. In all other cases where such useful and indispensable tools do not exist, the lines are broken. These systems require up-to-date investigations and modelling, before further groundwater abstraction should be considered.

In the background a new version of the map Groundwater Resources of the World is shown by colour wash. The groundwater basins have been shown in blue colour, and hydrogeologically complex areas with important aquifers in green colour. The intensities of the colour wash decrease from dark blue or green in high recharge areas (generally more than 150 mm per year) to medium blue/green (recharge generally between 150 and 15 mm per year) and to light blue/green where recharge is very little (generally less than 15 mm per year). This latter category is merely suitable for groundwater mining. Brown colour outlines areas with local and shallow aquifers in which relatively dense bedrock is exposed to the surface. In these areas groundwater is limited to the alteration zone of the bedrock that may contain locally productive aquifers.

Orange hatching has been applied in areas where the salinity of the groundwater regionally exceeds 5 g/l. In these places the groundwater is generally not suitable for human consumption, but some livestock may find it drinkable.

Parts of the northern latitudes close to the Arctic are affected by permafrost. Here even the groundwater is generally frozen and unusable for water supply. The boundary of permafrost therefore has been indicated by a green line on the map.

The topographic and surface water features originate from the map Groundwater Resources of the World (Special Edition 2004). The course of the rivers and size of lakes have been updated in places. The topographic features shown on the map should allow orientation on the continents. In the first instance, the cities with a population exceeding three million inhabitants were shown, but a number of smaller population centres have been added for the sake of geographic reference. The political boundaries are taken from the global data sets of the Environmental Systems Research Institute (ESRI). The WHYMAP Consortium cannot be made liable for any errors in this data set whatsoever.

Table 2. Transboundary Aquifer Systems of the World (numbers according to map, overleaf)

No.	Name of Transboundary Aquifer System	Countries sharing this aquifer system	Type of aquifer system *	Extension [km^2]
North America				
101	Okanagan-Osoyoos / Grand Forks	Canada, USA	1	
102	Poplar	Canada, USA	1	
103	Estevan	Canada, USA	1	
104	Châteauguay	Canada, USA	2	2 500
105	Basin and Range Aquifer System (Mexicalli, Upper San Pedro)	USA, Mexico	1	
106	Rio Grande Aquifer System (Hueco-Mesilla)	USA, Mexico	1	10 800
107	Gulf Coastal Plain Aquifer System	USA, Mexico	1	10 000
Central and South America				
201	Masacre / Arbonito / Pedernales	Haiti, Dominican Republic		
202	Various Transboundary Aquifer Systems	Mexico, Guatemala, Belize, Honduras, El Salvador		
203	Honduras - Nicaragua Aquifer System	Honduras, Nicaragua		
204	Nicaragua - Costa Rica Aquifer System	Nicaragua, Costa Rica		
205	Sixaola / Coto	Costa Rica, Panama		
206	Juradó	Colombia, Panama		
207	Táchira / Paranaguachón / Carrapia / Monguí / Cretácico	Colombia, Venezuela		
208	Llanura Río Arauca / San Antonio-Cucuta / Río Pamplonita / Guayabo / Carbonera / Mirador	Colombia, Venezuela		
209	A-Sand / Cosewijne / Zanderij	Guyana, Suriname, French Guiana		
210	Costeiro	Brazil, French Guiana		
211	Tulcán	Colombia, Ecuador		
212	Ica / Machala / Zurumilla / Tumbes	Brazil, Colombia, Peru, Ecuador		
213	Solimoes	Brazil, Peru, Bolivia		
214	Titicaca	Peru, Bolivia		
215	Ignimbritas Cordillera Ocidental / Concordia-Escritos / Caplina-La Yarada / Laguna Blanca-Maure	Bolivia, Peru, Chile		
216	Silala / Ascotal / Ollague	Bolivia, Chile		
217	Yrendá-Toba-Tarijeño Aquifer System	Paraguay, Argentina, Bolivia	1	350 000
218	Pantanal / Islas	Brazil, Bolivia, Paraguay		
219	Guaraní Aquifer System	Brazil, Paraguay, Argentina, Uruguay	1, 2	1 200 000
220	Chile - Argentina Aquifer System	Chile, Argentina		
221	El Condor	Chile, Argentina		
Europe				
301	Carboniferous Limestone Aquifer	France, Belgium	3	
302	Northwest Germany - Netherlands Aquifer	Germany, Netherlands	1	
303	Northeast Germany - Pommeranian Aquifer	Germany, Poland	1	
304	East Prussian Aquifer	Russia, Poland, Lithuania	1	
305	Latvia - Lithuanian - Estonian Aquifer System	Latvia, Lithuania, Estonia	2, 3	
306	West Russian Aquifer System	Russia, Latvia, Belarus	1, 2, 3	
307	Southwest Russian Aquifer System	Russia, Ukraine	1, 2, 3	
308	Upper Rhine Graben	Germany, France	1	
309	Forealpine Depression / Northern Limestone Alps	Germany, Austria, Switzerland	1, 2, 3	
310	Dinarides (numerous aquifers)	Croatia, Slovenia, Bosnia and Herzegovina, Serbia and Montenegro	2, 3	
311	Pannonian Basin	Hungary, Romania, Ukraine, Slovakia, Austria, Slovenia, Croatia, Serbia and Montenegro	1	
312	Cretaceous Aquifer	Bulgaria, Romania	3	
313	Moldovian Aquifer System	Moldova, Ukraine, Romania	1, 2	
Africa				
401	Tindouf Aquifer	Algeria, Morocco		
402	Errachidia Basin	Algeria, Morocco		
403	Northwest Sahara Aquifer System (NWSAS)	Algeria, Libya, Tunisia	1, 2	1 030 000
404	Mourzouk-Djado Basin	Chad, Libya, Niger		
405	Nubian Sandstone Aquifer System (NSAS)	Chad, Egypt, Libya, Sudan	1, 2	2 000 000
406	Senegalo-Mauritanian Basin	Gambia, Guinea-Bissau, Mauritania, Senegal		
407	Taoudéni Basin	Algeria, Mali, Mauritania		
408	l'Air Cristalline Aquifer	Algeria, Mali, Niger		
409	Tin-Séririne Basin	Algeria, Niger		
410	Liptako-Gourma Aquifer	Burkina Faso, Niger		
411	Iullemeden Aquifer System (IAS)	Mali, Niger, Nigeria		525 000
412	Chad Basin	Central African Republic, Chad, Cameroon, Niger, Nigeria		
413	Coastal Sedimentary Aquifer	Ghana, Côte d'Ivoire		
414	Coastal Sedimentary Aquifer	Benin, Nigeria, Togo		
415	Upper Nile Basin	Ethiopia, Sudan		
416	Awash Valley Aquifer	Djibouti, Ethiopia		
417	Rift Aquifers	Kenya, Tanzania, Uganda		
418	Ogaden-Juba Aquifer	Ethiopia, Kenya, Somalia		
419	Mount Elgon Aquifer	Kenya, Uganda		
420	Merti Aquifer	Kenya, Somalia		
421	Coastal Sedimentary Basin	DR Congo, Angola	1	
422	Congo Intra-cratonic Basin	DR Congo, Angola	1, 2	211 000
423	Kagera Aquifer	Tanzania, Uganda		6 000
424	Kilimanjaro Aquifer	Kenya, Tanzania	2	15 000
425	Coastal Sedimentary Basin	Kenya, Tanzania	1	23 000
426	Karoo Sandstone Aquifer	Mozambique, Tanzania	2, 3	13 000
427	Coastal Sedimentary Basin	Mozambique, Tanzania	1	23 000
428	Coastal Sedimentary Basin	Angola, Namibia	1	1 500
429	Cuvelai Basin	Namibia, Angola	1	205 000
430	Northern Kalahari / Karoo Basin	Angola, Botswana, Namibia, Zambia	1, 2	144 000
431	Nata Karoo Subbasin	Botswana, Namibia, Zimbabwe	2	91 000
432	Medium Zambezi Aquifer	Zambia, Zimbabwe, Mozambique		125 000
433	Shire Valley Alluvial Aquifer	Malawi, Mozambique		5 000
434	Southeast Kalahari / Karoo Basin	Botswana, Namibia, South Africa	1, 2, 3	166 000
435	Ramotswa Dolomite Basin	Botswana, South Africa	3	7 000
436	Tuli Karoo Subbasin	Botswana, South Africa, Zimbabwe		14 000
437	Limpopo Basin	Mozambique, South Africa, Zimbabwe		20 000
438	Incomati / Maputo Basin	Mozambique, Swaziland, South Africa	1	
439	Coastal Sedimentary Basin	Namibia, South Africa	1	1 000
440	Karoo Sedimentary Aquifer	Lesotho, South Africa	2	129 000
Asia				
501	Upper Jezira / Mesopotamia	Iraq, Syria, Turkey	1, 2	100 000
502	Eastern Mediterranean	Israel, Jordan, Lebanon, Palestinian Territory, Syria	1, 2, 3	48 000
503	Hauran and Jabal Al-Arab (Basalts, Neogene to Quaternary)	Jordan, Saudi Arabia, Syria	2	15 000
504	Syrian Steppe	Iraq, Jordan, Saudi Arabia, Syria	1, 2	> 1 600 000
505	Eastern Arabian Peninsula (Paleogene)	Bahrain, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen	1, 2	> 1 600 000
506	Ertix River Plain	Russia, Kazakhstan	1	120 000
507	West Altai	Russia, Kazakhstan	1, 2	40 000
508	Yili River Plain	China, Kazakhstan	1	53 000
509	Yenisei Upstream	Russia, Mongolia	1, 2	60 000
510	Heilongjiang River Plain	China, Russia	1	82 000
511	Central Asia (numerous aquifers)	Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan, Turkmenistan, Afghanistan	1, 2, 3	660 000
512	India River Plain	India, Pakistan	1	560 000
513	Southern of Himalayas	Nepal, India	1	65 000
514	Ganges River Plain	Bangladesh, India	1	300 000
515	South Burma	Burma, Thailand	2	53 000
516	Mekong River Plain	Thailand, Laos, Cambodia, Viet Nam	1	220 000
517	New Guinea Island	Indonesia, Papua New Guinea	1, 2	870 000

* Type of aquifer system: 1 - porous, 2 - fissured/fractured, 3 - karst

Conclusions derived from the map of Transboundary Aquifer Systems thus far

Although the information shown on this first global map of Transboundary Aquifer Systems have to be improved in many places, a number of conclusions can already be drawn:

1. Transboundary Aquifer Systems of sizeable extent exist on almost all continents except for Australia that is not divided into different countries. In many areas of large size countries, e.g. in North America (Canada, USA), South America (Brazil, Argentina), Asia (China, Russia) the number of Transboundary Aquifer Systems is by nature of definition relatively small, compared to the rest of the world.

2. Many Transboundary Aquifer Systems are located in the semi-arid to arid regions of the world, where surface water is limited and the supply unreliable. Several Transboundary Aquifer Systems form large groundwater reservoirs, however with non-renewable groundwater resources that can be exploited for only limited periods. Such aquifers require a particularly careful mapping, resource evaluation and reservoir modelling, to allow the sustainable use of the precious resources.

3. Detailed information about the groundwater flow systems on either side of the border are a basic requirement for sound groundwater management. Therefore this information should be exchanged among the countries sharing a Transboundary Aquifer System, and there must be a willingness to cooperate in the joint management of the water resources.

4. There are merely very few examples of well-studied Transboundary Aquifer Systems and coherent hydrogeological modelling projects, e.g. in South America (the Guaraní Aquifer System) and North Africa (the Nubian Sandstone Aquifer System, the Northwest Sahara Aquifer System and the Iullemeden Aquifer System). The wealth of Transboundary Aquifer Systems is yet to be studied in detail, which will require important investments in funding regional investigation, drilling and monitoring. This is a particular challenge both to international funding organisations and to national governments.

5. The common study of Transboundary Aquifer Systems is regarded as an important tool to foster regional cooperation in many regions of the world, and the important shared water resources should be adequately capitalised in order to recognise their value for sustainable development of the participating nations.

Further conclusions can be drawn from the final map at the scale of 1:25 000 000, which is expected to be issued prior to the UNESCO General Conference in 2007.

Need for improvement

The WHYMAP Consortium, although relying greatly on the knowledge and experience of regional and international experts, would appreciate comments, suggestions and scientific input to help eliminate any shortcomings in the present version and the continuous improvement of the WHYMAP-GIS. Map makers and hydrogeologists experienced in national or regional hydrogeological mapping are invited to contribute to the WHYMAP Programme and provide their regional hydrogeological knowledge for this common endeavour.

The consortium requests that any notes and drafts for the correction of the map should be sent to:

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For additional information on WHYMAP see www.whymap.org.

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