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 particularly in the semi-arid and arid regions of the world 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, aquifer resources constitute the only reliable water resource for drinking water supply and irrigated food production in the semi-arid and arid regions of the world.

However, in spite of the outstanding importance and 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. The sixth phase of the IHP (2002-2007) concentrated on the contribution of knowledge of the water resources at risk and the development of strategic plans about the effects of human activities on groundwater resources and the current phase (2008-2013) is titled “Water dependencies: Systems under stress and societal responses”.

In order to contribute to the world-wide efforts to better study and manage aquifer resources, UNESCO-IHP 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 must be considered a great innovation, which permits overview and comparison of the major aquifer systems of the world with an idea of their stress situation. It is therefore recognised as a cross-cutting programme of the IHP.

Historical Development and Project Design

Several agencies joined UNESCO and CGMW and provided their specific contribution to WHYMAP. A consortium was established in 2002, consisting of the UNESCO International Hydrological Programme (IHP), 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 focusing 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.

The WHYMAP Consortium agreed on an iterative approach. This consists in the first instance of providing global data sets of topographic and general hydrogeological information; then, collecting and capturing consolidated, up-to-date information and also, establishing and maintaining a comprehensive Geo-Information System (WHYMAP-GIS) for groundwater relevant data on a global scale as a global network on groundwater. A printed wall map at the scale of 1:25 000 000 should finally be derived from this GIS, together with a digital map server application on the internet, and an explanatory booklet with a CD-ROM.

![Fig. 1: The WHYMAP network](image)

The WHYMAP Geo-Information System (WHYMAP-GIS)

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. The design and creation of the GIS had to consider two aspects at the same time: the data structure had to prove useful for both the handling and processing of the digital data as well as for the representation of cartographic aspects for the output of high quality thematic maps.
In its final form the WHYMAP-GIS is supposed to 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

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

In addition an internet based map server application is being developed which integrates WHYMAP data and integrates an information system on national hydrogeological maps (Worldwide Hydrogeological Mapping Information System, WHYMIS). UNESCO will ensure that all data compiled by the WHYMAP could be accessible in the UNESCO Water Portal. WHYMAP will also serve as an entry gate for more detailed, regional hydrogeological map information in particular in less developed countries.

The Process of Developing a GIS-based Global Groundwater Map

The compilation and printing of appealing global groundwater maps is closely interrelated with the gradual installation of the WHYMAP Geo-Information System (GIS) for the storage, processing and visualisation of groundwater relevant information and other data on a global scale. The process of (digital) map compilation can be summarised as follows:

- select a topographic base map and projection
- develop the legend and representation concept
- design and create the GIS structure
- review information from existing data sources
- compile continental drafts at scale 1:10 000 000
- digitize continental drafts and add attributes in GIS
• prepare first drafts of the global groundwater map and other thematic layers
• discuss and improve drafts with members of WHYMAP steering committee, IAH vice-presidents, CGMW vice-presidents and IHP regional offices
• complete and optimise WHYMAP-GIS information including cartographic layout
• compile and print the final global groundwater resources map at scale 1:25 000 000.

The main output consists of a representation of the general hydrogeological situation on the globe aiming at comparable quality representation of all continents, so as to permit a global view and comparison.

The selection of the appropriate data sources became a very sensitive aspect in the beginning. BGR started to evaluate existing national, regional and continental maps at small to very small scales from 1:1 000 000 to approximately 1:15 000 000, existing data bases and statistical material concerning groundwater, surface water, precipitation and population density (as an expression of the stress on the fresh water resources) chiefly collected by the members of the Steering Committee. The statistical material available poses some problems since data relates to countries as an entity rather than to the actual geographic distribution within the country. Caution therefore is recommended in cases of vast territories or extremely variable hydrogeological conditions.

However a world map must be much more inter- or supranational, although all input data originate from national files and data banks, even if stored in regional or international data centres. Therefore, the information depicted on the map is necessarily as good as the data delivered and there is no doubt that the quality of data differs, despite efforts to impose an international standard for the collection and treatment of data.

In addition to making use of the data archives of national institutions and international organisations primarily the following existing maps at global, continental and regional scale have finally been thoroughly studied:

• Geological Map of the World 1:25 000 000 (CGMW 1990, digital version 2000)
• Maps of the World Environment during the Last Two Climatic Extremes 1:25 000 000 (CGMW & ANDRA 1999)
• World Map of Hydrogeological Conditions and Groundwater Flow 1:10 000 000 (compiled by the Water Problems Institute, Russian Academy of Sciences under UNESCO supervision 1999)
• Maps of the WaterGAP model of the Universities of Kassel and Frankfurt (P. Döll et al, 2003, 2006)
• A number of regional or continental small-scale maps.

Very striking is the fact that very often geological and hydrological zonations do not correspond to hydrogeological units. Particularly in arid regions, surface water catchment basins differ completely from the underground system. As a matter of consequence, an integrated water management by catchment / river basin is unsuitable in arid areas where surface water catchments and deep aquifers are totally different. No-recharge areas are posing a particular problem for water managers since only the aquifers and groundwater systems can be considered to constitute the relevant water management regions.

Another crucial point was the selection of a suitable cartographic projection. The WHYMAP Consortium wished to achieve utmost compatibility with existing map products of Consortium members. Therefore, the WHYMAP Steering Committee studied a number of projection systems: Finally the Robinson projection, widely in use in the UN system, was found to be the most appropriate projection for the world groundwater map, while the Mercator projection was considered unsuitable since it exaggerates the regions in the north and south of the globe, usually remote from the populated areas and usually of minor concern for groundwater.
The information held in the WHYMAP-GIS in geographical coordinates has been plotted on a global map in the Robinson projection, whereas it can be transformed into various other kinds of projections.

The hydrogeological information is based on existing continental and regional maps that had to be transferred and captured in the GIS to be able to use this information for the global map. Continental and regional work sheets at the scale of 1:10 000 000 constitute key elements in the preparation of the global maps. Eight work sheets were provided to selected experts from all continents and relevant scientific agencies and suggestions for changes and amendments incorporated (see Figure 2).

![Position and extent of the "continent files"](image)

**Fig. 2: Subdivision of the global map into continental work sheets at the scale of 1:10 000 000**

A world map serves for general orientation and information for the advanced general public, such as politicians, decision makers and, last but not least, the media, but less for scientists. The map contains a message and this message must be brought to the intended readership without any ambiguity. Lastly, the map must harmonise with maps on other themes, and the general public in first hand will think of climatological and geological maps but also maps of population density and their water demand. Here again, the political focus of the map becomes visible. The synthesis of population pressure, groundwater availability and recharge results in the risk assessment and is an indispensable basis for sustainable groundwater management.

**First Results and Products**

Important activities regarding water on the global scene, in particular the 3rd World Water Forum in Japan, March 2003 and the 4th World Water Forum in Mexico, March 2006 as well as the establishment of the first and second World Water Development Report, called for global groundwater maps in various formats. This required a very flexible approach from the editorial team.
Different kinds of map products have been produced so far which present a very general visualisation of the global distribution of groundwater and aquifers in an attractive and convenient format and are intended to raise awareness of groundwater and generate additional input to WHYMAP:

- a first, very preliminary draft of an educational wall map at the scale of 1:25 000 000 to fit into the series of earth science maps of UNESCO
- 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. the World Water Development Report (see Figure 3)
- a first special edition of the global map at the scale of 1:50 000 000 issued for the International Geological Congress and the CGMW meeting at Florence, Italy, in August 2004
- a second special edition of the global map at the scale of 1:50 000 000 focussing on the Transboundary Aquifer Systems of the world, issued for the 4th World Water Forum in Mexico City in March 2006

Description of Maps Published so far (Special Editions)

Two so-called special edition map publications have already been printed for important international meetings. Both maps have used the same format, with a global map at the scale of 1:50 000 000 and an explanation on the reverse side of the map (see Figure 4a, b and Figure 5a, b). The map users thus enjoy a very handy and concise source of information.

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 nature of the
groundwater regime and whether or not they are regularly recharged. This is shown by colour wash. The groundwater basins have been shown in blue colour, 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 and to light blue/green where recharge is very little. 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.

Fig. 4: View on the 1st WHYMAP Special Edition for the International Geological Congress, August 2004
a) Global Groundwater Resources Map
b) Explanation on the reverse side of the map
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 dark green line on the map.
The surface water features should provide a general idea about the relationship between groundwater, lakes and large rivers. The course of the rivers and size of lakes have been updated in places. They have also been checked by the Global Runoff Data Centre (GRDC) on the basis of long term average runoff data. Accumulations of inland ice and large glaciers have been shown by grey colour wash. About two thirds of the global freshwater resources are represented by these ice sheets, however they are generally confined to remote and unpopulated areas and are thus of less importance for water supply.

The topographic features shown on the map should allow orientation on the continents. Major population centres usually represent points of peak water demand. 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.

The reason for showing political boundaries on the map is twofold; firstly for geographic orientation, but also, and even more importantly, to highlight that most of the groundwater areas worldwide cross political borders, forming shared transboundary aquifers. To deal with this situation, UNESCO and IAH have launched the Internationally Shared Aquifer Resources Management Programme (ISARM) within the frame of the IHP.

**Outlook**

This CD documents the actual status of an educational wall map at the scale of 1:25 000 000, which will be published in spring 2008. For the 33rd International Geological Congress in Oslo in August 2008 there will also be a more handy size of this map available together with an accompanying explanatory booklet.

In addition the following steps are planned within the next years:

- completion and enhancement of the WHYMAP Geo-Information System
- add more thematic layers; some 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.
- extension and consolidation of the web-based components / Internet tools www.whymap.org

With the WHYMAP achievements, the essential groundwater resources will receive an improved profile on the global water agenda. This is particularly necessary, because groundwater is a hidden, invisible asset for mankind and nature, and more awareness needs to be created in order to manage it properly and protect it from degradation.

The small-scale does not allow recognising detailed individual issues and one of the conclusions might be to embark on maps at much larger scales, particularly for zones at risk and for disputed internationally shared resources. However, such more applied maps will benefit from the experience which can be drawn from the WHYMAP enterprise and they may be easily linked into the WHYMIS system.

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The global Groundwater Resources Map contains only selected information related to groundwater. For reasons of comparison between the main Groundwater Resources Map and the four thematic small-scale maps should help to understand the global picture of groundwater and surface water resources and provide insight to their pressures, in particular the priority use for drinking purposes. It reveals essential geographic differences over the globe in the groundwater recharge (mm/a) system (WHYMAP GIS) in which the groundwater data are managed and visualised.