GROUNDWATER RESOURCES OF THE WORLD

1 : 50 000 000

Special Edition

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WHYMAP and the Groundwater Resources Map of the World at the scale of 1:50 000 000

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Background and motivation

The demand for clean water is continuously rising, mainly due to population growth on a global scale. In contrast, water resources at the surface are decreasing gradually because of contamination and climatic changes and hazards. This produces additional stress on the groundwater resources, which are vital for the water supply particularly in semi-arid and arid regions.

In the nineteen sixties the United Nations Educational, Scientific and Cultural Organization (UNESCO) launched its International Hydrological Programme (IHP) and the World Meteorological Organisation (WMO) started its Operational Hydrological Programme (OHP). These important global programmes stimulated the monitoring and quantification of surface water resources and precipitation. However groundwater was rather marginally covered, because it is a hidden underground resource and difficult to measure and therefore compared to surface water, groundwater is generally less known and surveyed. From the point of view of a raw material, because of its low economic value, groundwater was neglected in some regions of the world. As a consequence investments in groundwater investigation and management remained rather low.

During the last decades of the 20th century the interest in groundwater increased considerably due to water shortage problems on local, regional and even global levels. The intensive use of groundwater for agricultural irrigated crop production – referred to as the silent green revolution – is putting groundwater resources under stress. Therefore, to support its sustainable management, it is essential to know where important groundwater resources are located, to map, model and quantify the stored volume and the average annual replenishment and to determine the chemical quality of groundwater. In addition, 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 safeguarded.

In order to contribute to the world-wide efforts to better manage the groundwater resources a number of agencies joined together in a major venture, the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP).

Project design

WHYMAP is a joint programme of a consortium, consisting of UNESCO, the Commission for the Geological Map of the World (CGMW), 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 the BGR provides important resources in terms of manpower, mapping capabilities and data. All partners are committed to supply relevant scientific input.

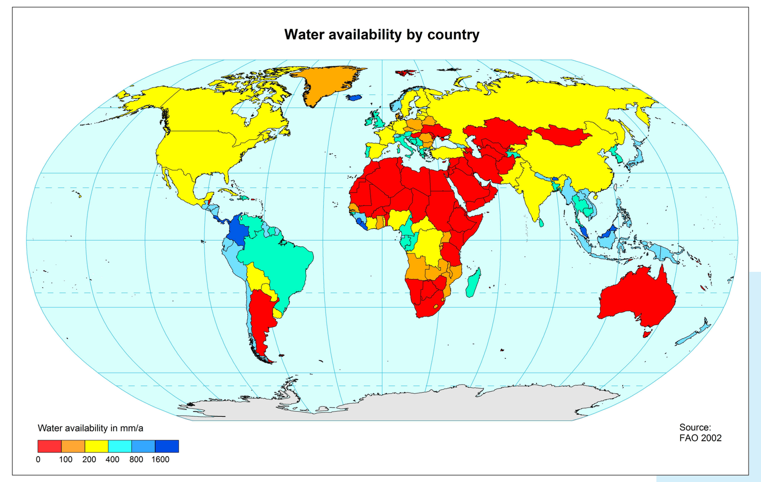
WHYMAP was formed in 1999 at the CGMW General Conference. The Programme aims at collecting, collating and visualizing hydrogeological information at the global scale, to convey groundwater related information in an appropriate way for global discussion on water issues and to give recognition to invisible underground water resources within the World Heritage Programme. WHYMAP thus brings together the huge efforts in hydrogeological mapping, at regional, national and continental levels.

The WHYMAP Consortium agreed on an iterative approach: This consists in the first instance of providing global data sets of hydrogeological and topographical information; then, collecting and capturing consolidated, up-to-date information supplied by regional co-ordinators and National Committees within the frame of the International Hydrological Programme (IHP) and finally, establishing and maintaining a comprehensive Geo-Information System for groundwater relevant data on a global scale (WHYMAP-GIS) as a global network on groundwater.

Project design (continued)

The participation of regional experts, focussing on the relevant regional groundwater knowledge and information was considered crucial for WHYMAP. A Steering Committee of eminent international experts was established under the supervision of the Consortium. It held its first meeting in Koblenz, Germany in June 2003, followed by a second session at UNESCO House in Paris in March 2004. In addition, the continental Vice Presidents of the IAH and CGMW, the UNESCO Regional Offices and the National Committees of UNESCO's IHP have been invited to contribute. The IGCP (International Geoscience Programme) jointly driven by the International Union of Geological Sciences (IUGS) and UNESCO also contribute to the joint venture of WHYMAP.

Co-operation with the International Groundwater Resources Assessment Centre (IGRAC) is assured through UNESCO, and the WHYMAP data are shared with IGRAC. BGR will ensure that the WHYMAP one day will constitute the entry gate for subsequent, more detailed regional hydrogeological information.



The development of the global groundwater maps

Important activities regarding water on the global scene, in particular the 3rd World Water Forum in Japan, March 2003 and the establishment of the first World Water Development Report, called for global groundwater maps in various formats, even before the WHYMAP-GIS was operational. This required a very flexible approach from the editorial team.

Three kinds of map products have been produced so far:
§ a first, very preliminary draft of an educational wall map at the scale of 1:25 000 000 (1/25 M) to fit into the series of earth science maps of UNESCO
§ a set of very 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 first World Water Development Report
§ a special edition of the global map at the scale of 1/50 M issued for the International Geological Congress and the CGMW meeting at Florence, Italy, in August 2004. This map presents a very general visualisation of the global distribution of groundwater and aquifers in an attractive and convenient format. It is also intended to raise awareness of groundwater and generate additional input to WHYMAP

The process of map compilation can be summarised as follows:
§ select topographic base map and projection
§ extract information from existing maps
§ develop legend and representation
§ design and create GIS structure
§ compile continental drafts at scale 1/10 M
§ digitize continental drafts and add attributes in GIS
§ prepare first draft of the global groundwater map
§ 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 the scale of 1/25 M

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.

Data sources

The maps are based on existing regional/continental maps at small to very small scales from 1/1 M to approximately 1/15 M, existing data bases, and statistical material chiefly collected by the members of the Steering Committee. The Steering Committee noted that 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. It is anticipated that the final version of the map will be complemented by a number of insert maps depicting such country-based data.

As well as making use of the data archives of national institutions and international organisations primarily two groups of existing maps have been thoroughly studied.

Global maps:
§ Geological Map of the World 1/25 M (CGMW/UNESCO 1990, digital version 2000)
§ Maps of the World Environments during the Last Two Climatic Extremes 1/25 M (CGMW/ANDRA 1999)
§ World Map of Hydrogeological Conditions and Groundwater Flow 1/10 M (compiled by the Water Problems Institute, Russian Academy of Sciences under UNESCO supervision, 1999)
§ Maps of the WaterGAP model of the University of Kassel (Alcamo, Döll and Lehner, 2002)
§ Lithological Map of the World 1/25 M (compiled by Dürr, Meybeck, Vörösmarty and Green, 2003)

Continental maps:
§ International Hydrogeological Map of Africa 1/5 M (OAU/OACT 1992)
§ Hydrogeological Map of the Arab Region and Adjacent Areas 1/5 M (UNESCO/ACSAD 1988)
§ Hydrogeological Map of Asia 1/8 M (compiled by the Institute of Hydrogeology and Engineering Geology, Chinese Academy of Geological Sciences 1997)
§ Hydrogeological Map of Australia 1/5 M (Bureau of Mineral Resources, Geology and Geophysics, Department of Resources and Energy 1987)
§ Hydrogeologic Map of North America 1/13.3 M (Heath, USGS 1988)
§ Hydrogeological Map of South America 1/5 M (UNESCO/CPRM 1996)
§ International Hydrogeological Map of Europe 1/1.5 M (UNESCO/BGR, since 1972)
§ other modern regional or national hydrogeological maps

Continental and regional work sheets at the scale of 1/10 M 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.

The WHYMAP Consortium wished to achieve utmost compatibility with existing map products of Consortium members. Therefore, the WHYMAP Steering Committee studied the Geological Map of the World, published 1990 by CGMW, UNESCO and BRGM, to test its suitability for the global groundwater map, and made the following observation: Despite its wide application, 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. In the form of the Robinson projection, a more appropriate projection has been found, widely in use in the UN system. However, the information held in the WHYMAP-GIS can be transformed into various other kinds of projections.

Water availability by country

United Nations Food and Agriculture Organization (FAO) provides data showing an overall picture of national water resources by country, e.g. the annual internal renewable water resources (IRWR; see left). IRWR include the average annual flow of rivers and the recharge of groundwater (aquifers) within a country's borders. The volume of groundwater stored in deep basins underground and usually formed centuries and millennia ago is however not considered. This additional water resource is still insufficiently known, although exploitation has started locally without an adequate basis for its sustainable management.

The WHYMAP Geo-Information System

The main focus of the WHYMAP Programme is the establishment of a digital Geo-Information Systems (GIS) in which all data relevant to groundwater is stored together with its geographic reference. In its final form the WHYMAP-GIS will cover the following thematic layers, a selected number of which will be shown on the maps at the scale of 1/25 M and 1/50 M:

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

From this WHYMAP-GIS database a variety of thematic maps at different scales and complexity can be derived to satisfy the individual requirements of special users.

An internet based map server application has been developed which integrates WHYMAP data and images of national hydrogeological maps.

Features shown on the map (Special Edition)

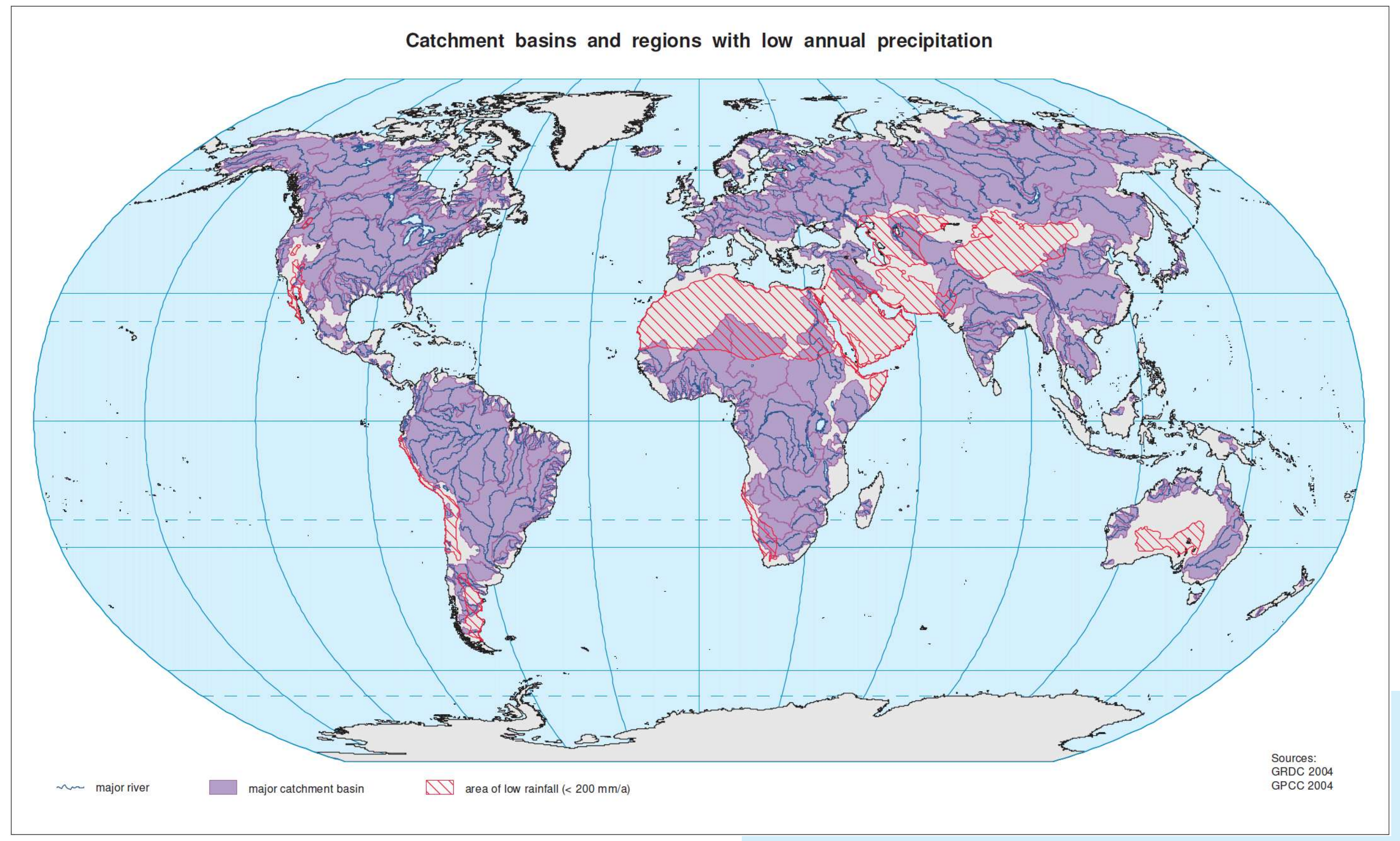
Restriction of features to be represented on the Groundwater Resources Map of the World at the scale of 1/50 M was necessary to keep it easily readable. The selected features chiefly cover the nature of the groundwater regime and whether or not they are regularly recharged. This is shown by colour wash. Detailed studies have to be carried out to quantify the volume of the resources stored underground, and measures must be taken to assure that the resources are managed in the most sustainable way.

The most **important groundwater basins** have been **shown in blue colour**, and the intensity of blue colour decreases from dark blue in high recharge areas (generally more than 150 mm per year) to medium blue (generally between 150 and 15 mm per year) and to light blue symbolising groundwater basins receiving very little recharge (generally less than 15 mm per year). This latter category is merely suitable for groundwater mining.

Green colour symbolises hydrogeological environments of complex structure. These are areas where productive aquifers may occur in close vicinity to non-aquiferous strata. In these areas remote sensing techniques as well as detailed ground surveys coupled with spring and stream flow analysis may help identify zones of high yielding aquifers.

Brown colour outlines areas with local and shallow aquifers in which relatively dense bedrock is exposed to the surface. In these areas groundwater is comprised to the alteration zone of the bedrock and overlying shallow layers of weathered bedrock.

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.



Features shown on the map (continued)

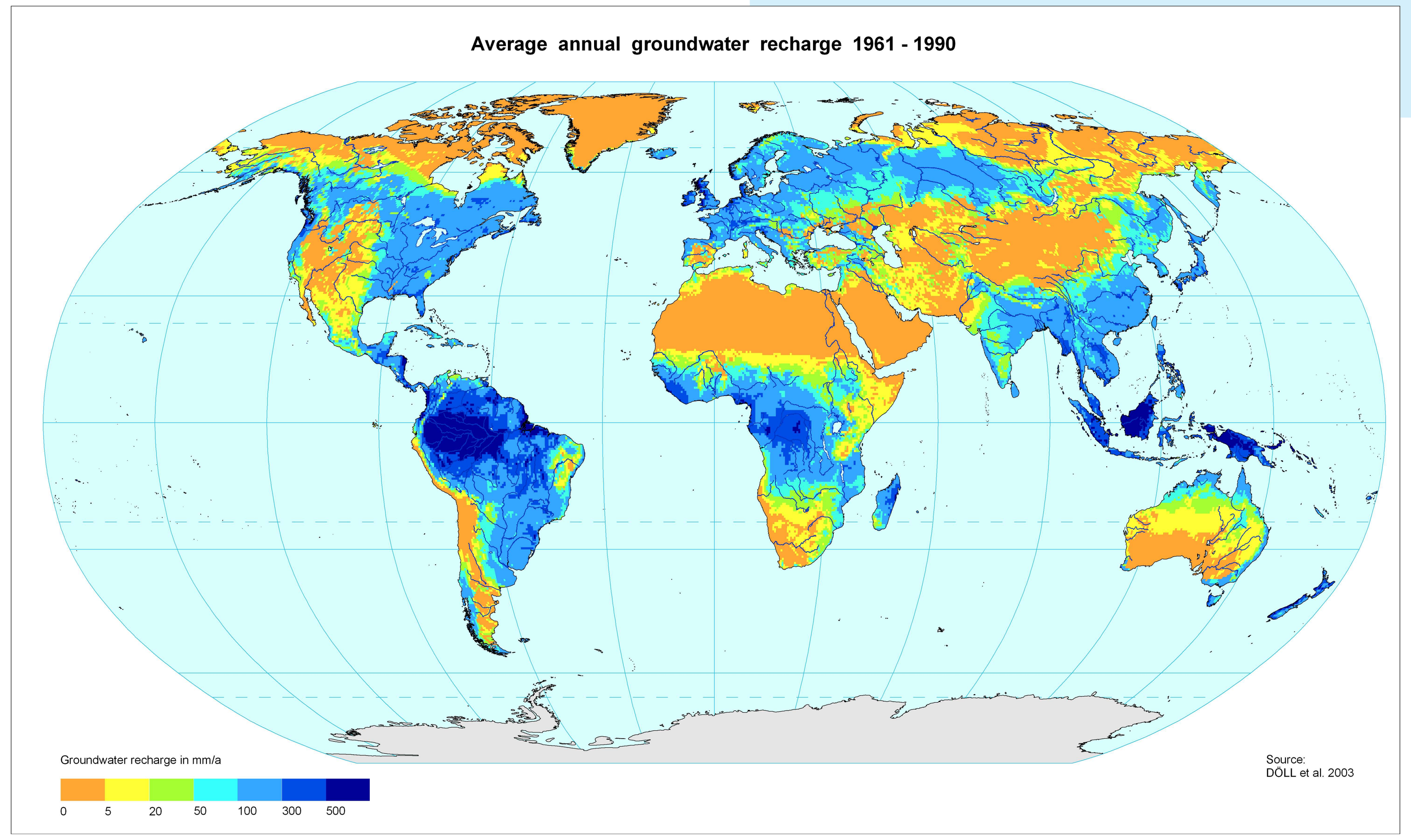
The **surface water features** originate from the Geological Map of CGMW. The course of the rivers and size of lakes have been updated in places. This should provide a general idea about the relationship between groundwater, lakes and large rivers which will further be checked by the Global Runoff Data 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 chiefly answer the need for orientation and geographic reference. **Major population centers** usually represent points of peak water demand. In the first instance, the cities with a population exceeding 3 million inhabitants were shown, but a number of smaller population centers have been added for the sake of geographic reference.

The **political boundaries** are taken from the global data sets of ESRI. The 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 trans-boundary 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.

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.



Catchment basins and regions with low annual precipitation

The Global Runoff Data Center (GRDC) in Koblenz, Germany, an international institution under the auspices of UNESCO and WMO, collects, interprets and provides a wealth of river runoff data throughout the world. It aims at providing standardized global and regional data sets of river runoff measured at several hundreds of gauging stations on all continents. GRDC has compiled a new global map showing the major river basins of the World (see above).

Compared to the Groundwater Resources Map of the World it becomes obvious, that surface water catchments of river basins rarely coincide with the underground hydrogeological structures. As a consequence integrated water resources management units have to be chosen carefully to pay due attention to the complementary water resources both surface water and groundwater.

Particularly in the areas receiving less than 200 mm of average annual rainfall (based on data provided by the Global Precipitation Climatology Centre GPCC), groundwater features must be adequately considered. These areas generally represent regions in which groundwater recharge is very low, i.e. the groundwater resources are prone to mining.

Average annual groundwater recharge 1961-1990

Groundwater recharge is the major limiting factor for the sustainable use of groundwater. Average annual diffuse groundwater recharge for the climate normal 1961-1990 (see below) is estimated by the hydrological model WGHM (WaterGAP Global Hydrological Model; DÖLL et al. 2003). With a spatial resolution of 0.5° latitude by 0.5° longitude, WGHM first computes total runoff based on a time series of monthly climate variables as well as soil and land cover characteristics. Groundwater recharge is then calculated as a fraction of total runoff using data on relief, soil texture, geology and permafrost/glaciers. For semi-arid and arid areas, the model has been tuned against estimates of groundwater recharge derived from chloride and isotope data.

The groundwater recharge data of the final Groundwater Resources Map of the World at the scale of 1/25 M are developed under the guidance of IAEA.

IGRAC's Map of Global Groundwater Regions

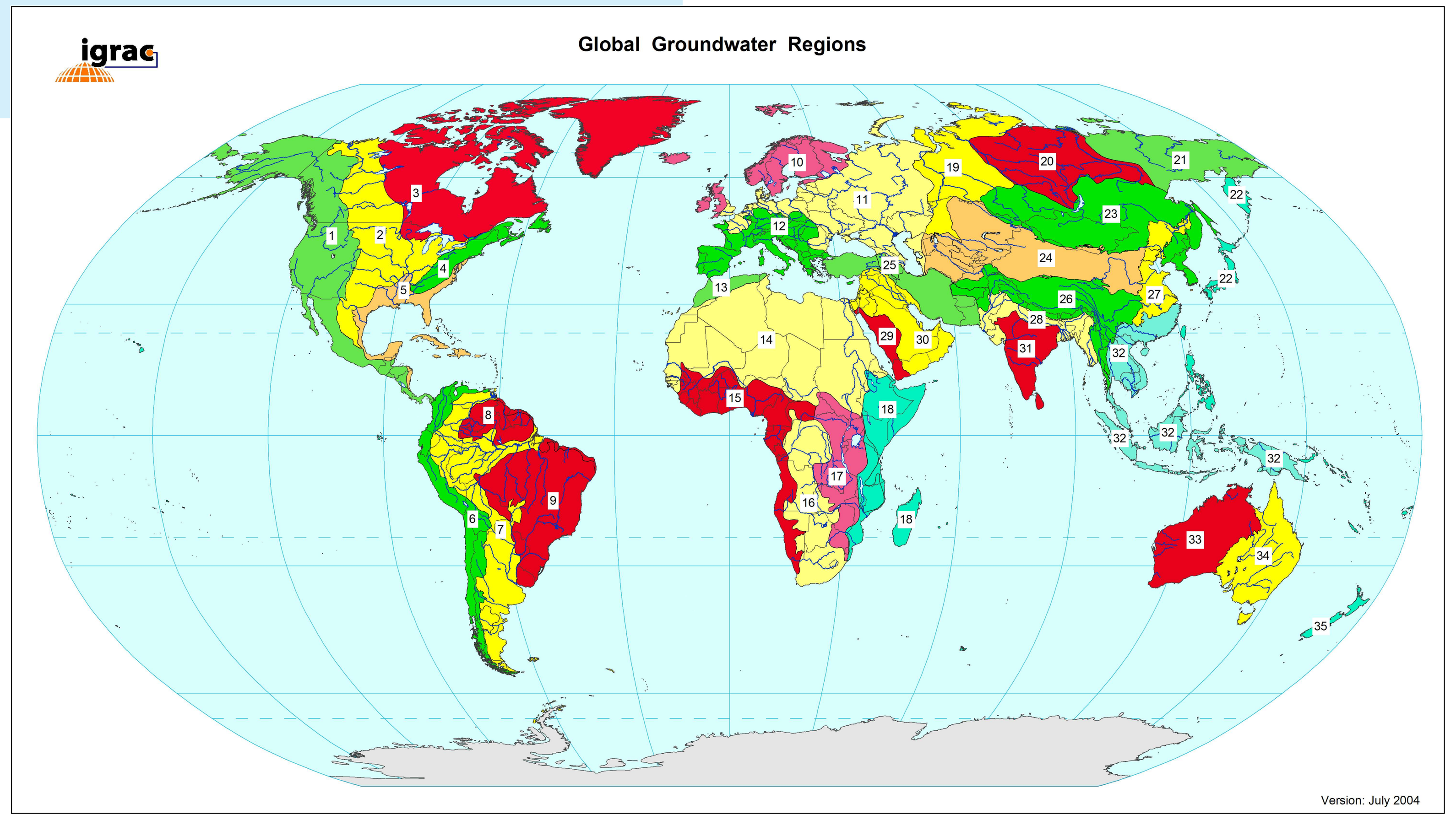
The International Groundwater Resources Assessment Centre (IGRAC), hosted at TNO at Utrecht, The Netherlands, operates under the auspices of UNESCO and WMO. The overall objective of IGRAC is to include groundwater fully in the assessment of freshwater resources of the world in order to encourage and enhance the conjunctive and sustainable utilisation of both groundwater and surface water.

To promote understanding of the World's groundwater systems, IGRAC developed a Map of Global Groundwater Regions. The basic concept underlying this map is the assumption that large-sized territories can be identified having an overall groundwater setting that is contrasting with that of neighbouring regions. The purpose of a division into groundwater regions is to organize the complexity of global groundwater occurrence into simple patterns to provide a practical framework for an overview of groundwater resources.

The division is primarily based on the tectonic setting, reflected by present-day geomorphology and the spatial extent of rock formations with contrasting hydraulic properties. The groundwater regions are distinctive in groundwater occurrence and groundwater characteristics on a very large scale. Four main categories are distinguished:

1. *Precambrian Shield Regions (red tints on the map)*
   Tectonically stable areas with Precambrian crystalline (plutonic igneous and metamorphic) rocks at or near the land surface. Groundwater is usually restricted to local pockets in weathered or fractured hardrock, or to shallow sedimentary layers on top of hardrock. Hence, stored volumes of groundwater are modest. High concentrations of fluoride are not exceptional.
2. *Postcambrian Sedimentary Basin Regions (yellow tints on the map)*
   Areas containing thick accumulations of material deposited in various environments during different geological periods. The groundwater systems with largest storage on earth are found within regions belonging to this category. In some arid regions, these reserves constitute very important sources of groundwater, in spite of the lack of recent recharge.
3. *Hercynian and Alpine Orogenic Belt Regions (green tints on the map)*
   High-elevated areas with complex geological structures consisting of sedimentary and igneous rocks deformed and metamorphosed according to their position in the belt. The aquifers often are fragmented and of limited spatial extent, but extensive aquifers may be found in alluvial and colluvial fills.
4. *Postpaleozoic Volcanic Regions (blue tints on the map)*
   Areas strongly affected by relatively recent volcanism outside the orogenic belts. Extrusive rocks cover large areas in these regions. Groundwater occurs in fractured zones and in sediments interbedded between lava flows. Groundwater may contain high fluoride concentrations; sometimes it is hot and/or brackish.

Altogether, 35 regions have been distinguished; their names are associated with salient geomorphologic features and with their topographic position. None of the regions is homogeneous, which means that all of them include sub-regions or zones that have characteristics different from the dominant features of the region's category. On the other hand, some territories have been split into different regions of the same category, mainly for the sake of acknowledging boundaries between continents.



1 Western mountain belt of North and Central America
2 Central plains of North and Central America
3 Canadian shield
4 Appalachian highlands
5 Caribbean islands and coastal plains of North and Central America
6 Andean belt
7 Lowlands of South America
8 Guyana shield
9 Brazilian shield and associated basins
10 Baltic shield and Caledonides
11 Lowlands of Europe
12 Mountains of Southern Europe
13 Atlas Mountains
14 North African basins
15 West African basement
16 Sub - Saharan basins
17 East African basement
18 East Africa rift and associated basins
19 West Siberian platform
20 Central Siberian plateau
21 East Siberian highlands
22 Northwestern Pacific margin
23 Mountain belt of Central and Eastern Asia
24 Basins of West and Central Asia
25 Mountain belt of West Asia
26 Himalayas and associated highlands
27 Plains of Eastern China
28 Indo - Gangetic - Brahmaputra Plain
29 Arabian shield
30 Levant and Arabian platform
31 Peninsular India and Sri Lanka
32 Peninsular and Islands of South - East Asia
33 Western Australia
34 Eastern Australia
35 Islands of Pacific

Conclusions derived from WHYMAP

Although the information shown on this first global groundwater map is still rather weak in places, a number of conclusions can already be drawn:

1. Aquifer regions shown on the map were chiefly derived from existing small scale maps. The majority of these are rather old and only available in printed format. It would be desirable to update them in digital versions.
2. Quantitative information on the volume stored in aquifers and the portion of groundwater annually recharged is greatly lacking. The number and quality of regional groundwater models must undoubtedly be improved.
3. Most of the large groundwater units form shared trans-boundary aquifers. Cooperation between all countries participating in such shared aquifer resources is essential in order to manage the resources sustainably and avoid environmental, economic and social damage.
4. River basins and groundwater units rarely coincide in area. Therefore, the delineation of integrated water resources management areas must be carefully selected, to avoid misconceptions for water management. Groundwater features must be adequately considered, particularly in low rainfall areas where surface water resources are random and unreliable.
5. Groundwater quality in area and depth is often unknown. More and better data about the variation of groundwater quality in space and time must be collected and published in order to encourage regional hydrogeological models as a basic requirement for vulnerability assessment and sustainable groundwater management.

Further conclusions can be drawn from the final map at the scale of 1/25 M, which is expected to be issued before the 50th anniversary of IAH in 2006.

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Need for improvement

The step-by-step approach to develop the Groundwater Resources Map of the World already has been mentioned. The Consortium, although relying greatly on the knowledge and experience of eminent international experts, would highly appreciate critical comments, suggestions and scientific input so that the final map at the scale of 1/25 M will eliminate any shortcomings in the present version (Special Edition). 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 messages and drafts for the correction of the map should be sent to:

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