WHYMAP
World-wide Hydrogeological Mapping and Assessment Programme

RIVER AND GROUNDWATER BASINS OF THE WORLD

1 : 50 000 000

Special Edition
for the 6th World Water Forum,
Marseille

March 2012

WHYMAP: Global Map of River and Groundwater Basins at the scale of 1 : 50 000 000 (Special Edition for the 6th World Water Forum, Marseille, March 2012)

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Rationale for Map

Global population growth, rapid urbanisation, increasing industrialisation, agricultural intensification and tourism are all putting water resources under increasing stress - and this situation is further aggravated by accelerating climate change. Such pressures are impacting on water resource availability, whilst at the same time water resource degradation is having significant negative feedback for economic production, public health and livelihoods, and the natural environment. By 2025, 1.8 billion people are predicted to be living in regions with pressing water-scarcity problems and it is thus vital that all freshwater resources are managed effectively. This is becoming an increasingly challenging task, because hydrologically-extreme events (droughts and floods) are expected to become more frequent.

In order to address the multi-faceted nature of water resources management, many countries are endeavouring to apply the Integrated Water Resources Management (IWRM) process at both the national and river-basin level in a complementary tiered fashion. IWRM aims to improve institutional arrangements and working practices, promote good governance including stakeholder participation, and to consider equity issues, gender concerns, environmental needs and economic assessments. For this purpose coordinated cross-sector action on water resources is required to deal explicitly with land-use management - since urbanisation, agriculture, forestry, industrial development (all of which can seriously impact water resources) are usually governed by policies and drivers outside the conventional scope of water policy.

In some parts of the world at least, the management of river basins is progressing, and in others the path that needs to be followed is clear - but all too widely underlying groundwater resources are neglected. Thus the interdependence of the surface and subsurface part of the natural water-cycle requires more attention.

GLOBAL WATER PARTNERSHIP (GWP)

GWP is an international network whose vision is of a water-secure world, and it acts to support the sustainable development and management of water resources at all levels. GWP was created in 1996 to foster IWRM (Integrated Water Resources Management) as the process by which water resources sustainability and efficiency, and thus water-security, could be achieved.

IWRM endeavours to promote the ideal of coordinated management of water, land and related resources by maximising economic and social welfare, whilst not compromising the sustainability of vital environmental systems. The IWRM process helps to manage and develop water resources in a sustainable and balanced way, taking account of social, economic and environmental interests - endeavouring to work across sectors and interest groups, and at scales from local to international as appropriate. It emphasises the need for involvement in national policy and law-making processes to establish sound governance provisions and to create effective institutional and regulatory arrangements. A range of tools, including social and environmental assessment, economic instruments, and information and monitoring systems, support this process.

The GWP Network is open to all organisations involved in water resources management, both in industrialised and developing countries - including government ministries and agencies, international agencies, bilateral donors and development banks, professional associations, research institutes, non-governmental organisations and the private sector.

More information about the GWP and access to its Catalyzing Change Handbook, Policy & Technical Briefs and TEC Background Papers are available via www.gwpforum.org. The IWRM ToolBox can be accessed at www.gwptoolbox.org.

Many basins extend over more than one country, and these present unique challenges. Historically, the transboundary nature of flowing water has generally encouraged cooperation, but there is the risk that with increasing scarcity there will be potential for discord. However, the 'Convention on the Law of the Non-navigational Uses of International Watercourses' as well as the 'Law of Transboundary Aquifers' adopted by the UN provide guidance to countries to address their shared water resources in harmony.

The present map has been prepared to help water resource policy makers and planners visualise, at the broad scale and in general terms, the potential interaction between surface water systems and the underlying groundwater resources for their conjunctive uses.

Groundwater in Integrated Water Resources Management

Taking an 'integrated approach' to water management not only involves looking at resource issues from both cross-sectoral and multi-disciplinary perspectives, but also requires coherent and consistent consideration of both surface water and groundwater. Organisations implementing the IWRM process usually have as their focus major river or lake basins, with the management unit usually being the corresponding surface water catchment area. Thus, while the IWRM concept explicitly includes groundwater, aquifer systems are often neglected in practice. The reason for this can be that awareness of this 'invisible resource' is sometimes insufficient or that the complexity of groundwater flow systems is inadequately understood. The reality is that groundwater has to be conjunctively managed with all water resources, since aquifers are a major source for drinking water-supply, agricultural irrigation and industrial production, and are vital for sustaining the natural environment.

Shallow groundwater and surface water are usually intimately linked facets of the natural water cycle, with groundwater discharging into surface water bodies or receiving recharge from them, according to local conditions. Groundwater system 'health' is thus, at the same time, critical for river baseflow and other 'dependent' aquatic ecosystems, and also critically affected by the status of ecosystems (including streams) in aquifer recharge areas.

The dynamics of the range of possible interactions between rivers and shallow groundwater bodies is schematically illustrated in Figure 1, but such variations are impossible to represent on maps at the global scale, and considerable variation can even occur over short distance, and also seasonally at the same location.

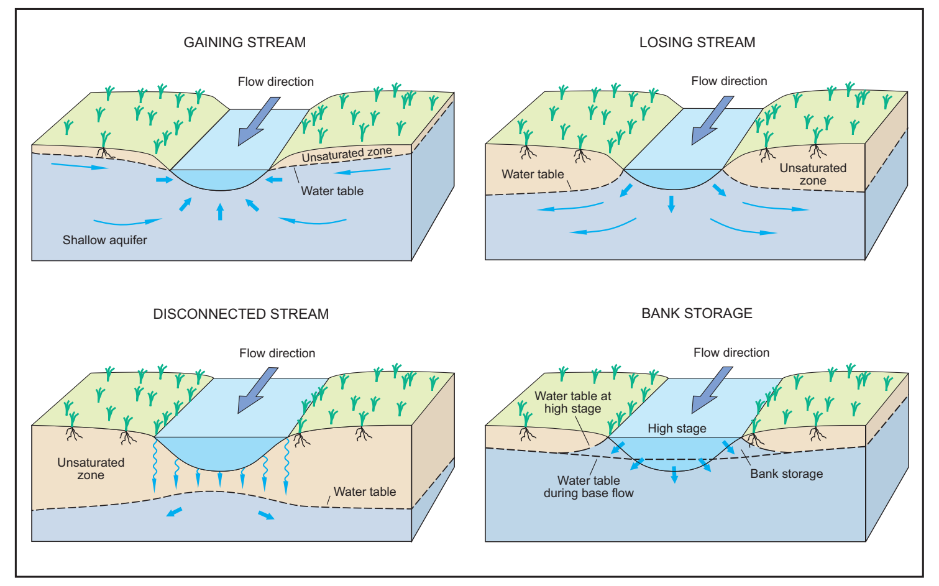
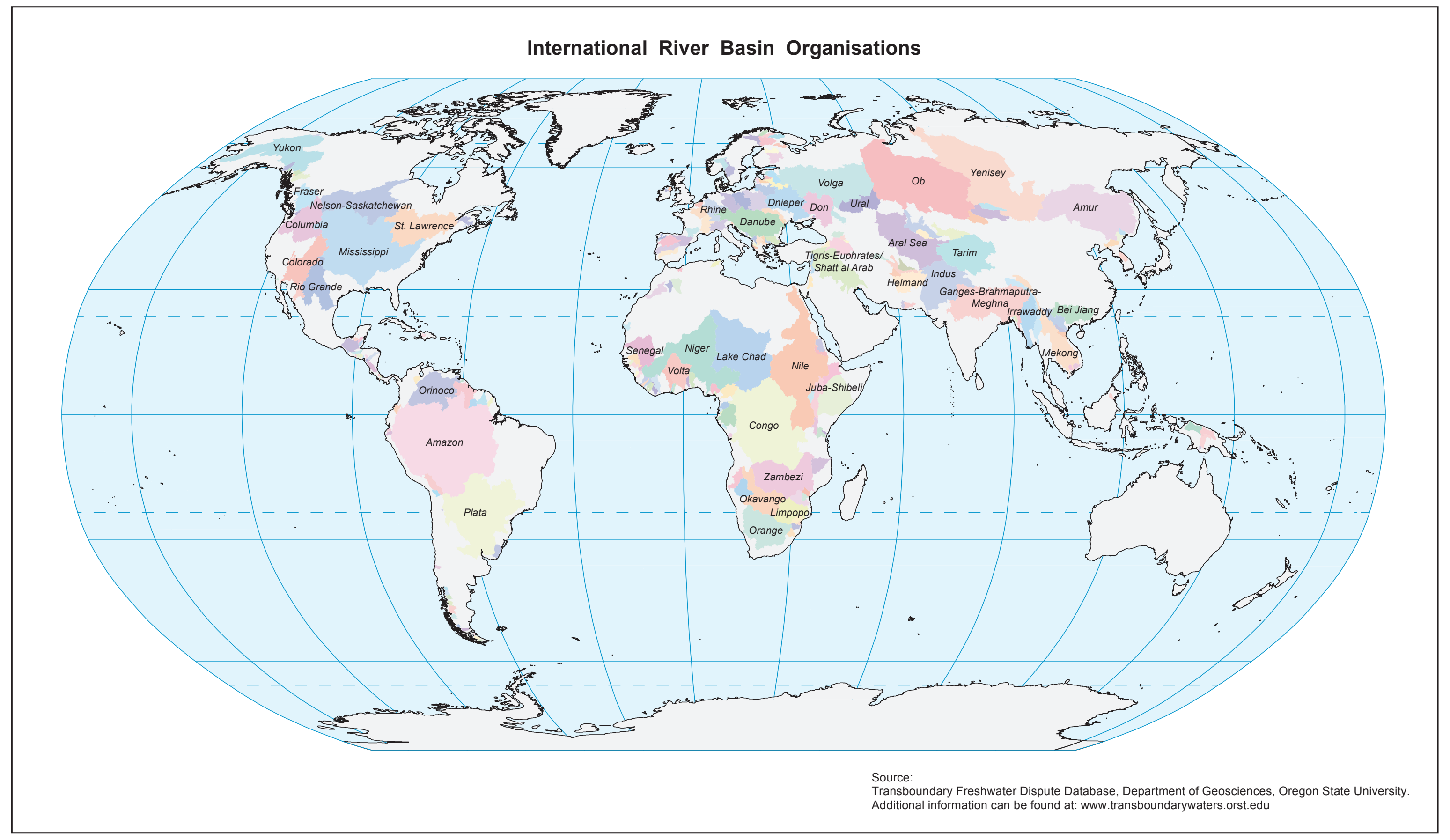


Figure 1. Interaction of groundwater and surface water (USGS Circular 1139, 1998)

On the broader scale, the lower tracts of major alluvial basins are predominantly 'groundwater discharging environments' but as such systems are traced upstream to more elevated terraces these are important areas for groundwater recharge from surface water, especially in more arid climates and at the foot of mountains.

The level of interaction between surface water and groundwater tends to decrease in volume and change radically in form from humid to arid climatic settings, and in deeper confined aquifer systems. In humid areas shallow aquifers are annually replenished and have shallow water tables, with multiple discharges to the surface water environment, whilst in more arid regions significant groundwater replenishment to deeper water tables can have a return-time of decades or centuries (and in some cases groundwater resources can be essentially non-renewable), and groundwater discharge is limited to isolated oases and salt marshes.

An important outcome of this is that the areal extent of surface water drainage basins and underlying groundwater systems often differs radically in such regions, and this necessitates a variation of the physical framework appropriate for IWRM.



Source:
Transboundary Freshwater Dispute Database, Department of Geosciences, Oregon State University.
Additional information can be found at: www.transboundarywaters.orst.edu

This is well illustrated at continental scale from Africa, by comparison of the surface water drainage basins (Figure 2 - upper right) and the underlying groundwater basins (Figure 2 - lower left), with the pseudo-perspective diagram in the centre highlighting the complexity of their detail.

Considerable differences between the surface water and groundwater settings can also occur at the more local scale in karstic limestone terrains where geological structure (and not land topography) predominates over the form of 'drainage basins'.

While the 'water-cycle continuity' paradigm represents a solid base for the integration of groundwater into IWRM, there are some additional issues, and differences between groundwater and surface water systems, that have to be specifically addressed:

- In potential groundwater recharge areas the 'connectivity' of surface water to groundwater exhibits extremely wide variation with aquifer type and present climatic setting - for example, in some shallow karstic aquifer systems groundwater residence times are less than 100 days (allowing the potential penetration and survival of fecal micro-organisms), whilst in the large sedimentary aquifers beneath parts of the Sahara groundwater with residence times well in excess of 10,000 years is still slowly circulating to desert oases.
- Surface water systems tend to be flow-dominated, whilst most aquifers are characterised by very large storage (stock) and much lower flow rates (flux), with only a small fraction of groundwater being replenished and discharged in the annual hydrological cycle - globally it has been very approximately estimated that surface drainage (calculated by deducting an allowance for groundwater baseflow from total surface run-off) is some 3-8 times greater than groundwater flow, but fresh groundwater storage is more (and perhaps very much more) than 50 times that of all surface water systems.

These differences have major practical implications for water resources management:

- Whilst for rivers upstream-downstream considerations are well defined, such relations may neither predominate nor are necessarily fixed for groundwater.
- The huge 'storage buffer' of aquifers makes their groundwater resources of strategic importance for drought mitigation and climate-change adaptation.
- For groundwater bodies uncertainties in management decision-making relating to water resource withdrawals are usually easier to accommodate.
- Very different time-scales have to be contemplated in the management of rivers and groundwater bodies (Table 1) - decades or more for groundwater compared to months or less for rivers. This has important consequences, especially for groundwater quality with slow penetration but very long residence of non-degradable pollutants in groundwater systems.

Thus groundwater resources management requires a monitoring plan and protection measures that cover a very wide range of temporal and spatial scales - and is as a result considerably more costly to establish and to operate. It also has to take into careful consideration the possible occurrence of elevated salinity in parts of some groundwater systems. This may arise from a variety of different mechanisms, from the mobilisation of paleo-saline or connate waters at depth to the intrusion of modern sea-water, or to essentially surface processes related to irrigation water returns or soil water-logging due to rising water table (Figure 3) - which require in-depth investigation and careful diagnosis before they can be managed effectively.

Table 1. The time-frame of meteorological variation, surface water and groundwater response in relation to typical water management planning cycles

TIME-FRAME logarithmic timeline (years)	0.01 *days*	0.1 *months*	1 *years*	10 *decades*	100 *centuries*	1000 *millenia*	10000
Weather	rainfall event	seasonal cycle	annual cycle	'El Niño' phenomena	mesoscale climate change	long-term climate change	
Surface Water	pond	stream, creek	river, small reservoir	large reservoir, some lakes	very large lake		
Groundwater		shallow and karstic aquifers	annual water table fluctuation	small aquifer residence time	large aquifer residence time	'fossil' groundwater	
Cycle of Water Management		emergency plan	short-term plan	long-term plan	climate change adaption		

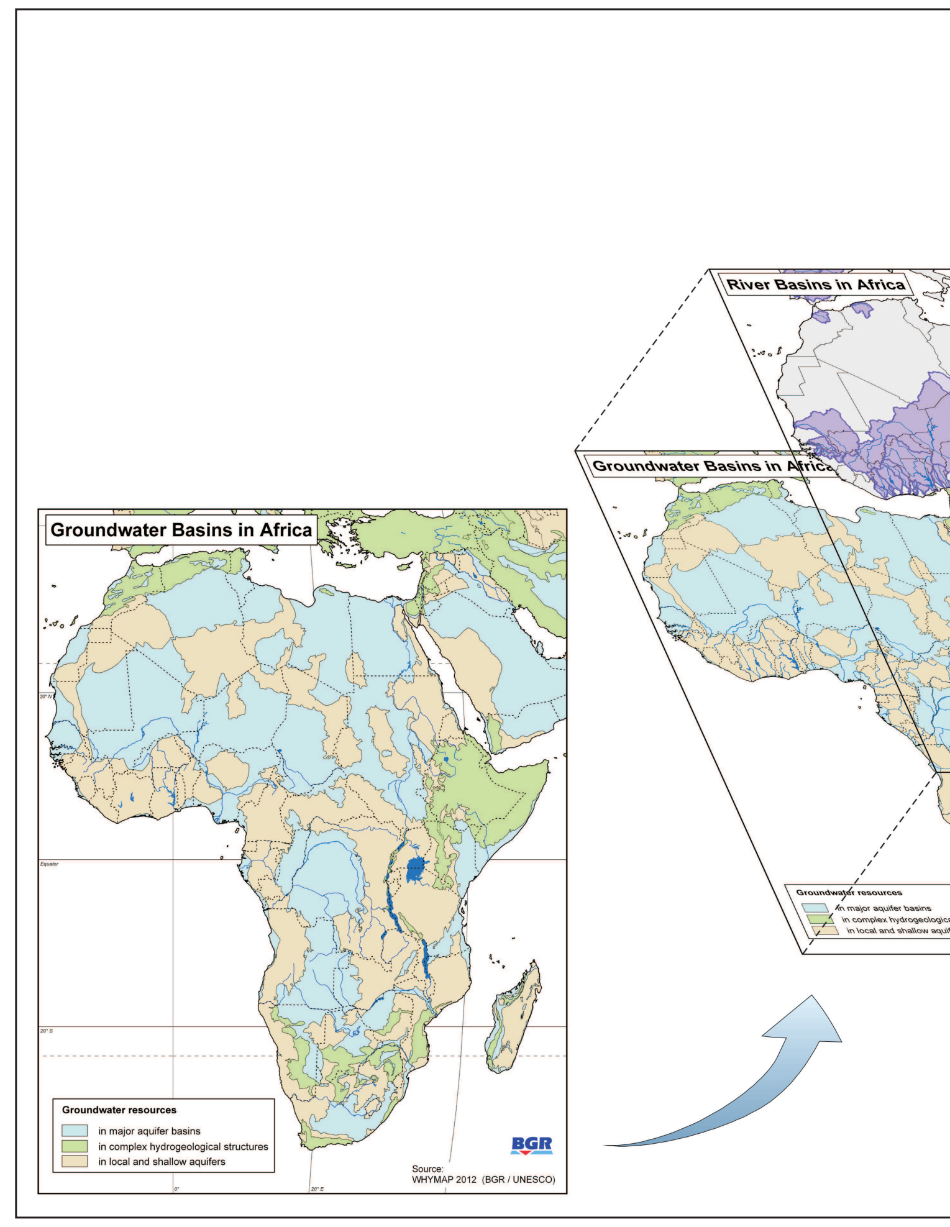


Figure 2. Pseudo-perspective diagram of river and groundwater basins in Africa derived from maps of river basins (upper right) and groundwater basins (lower left)

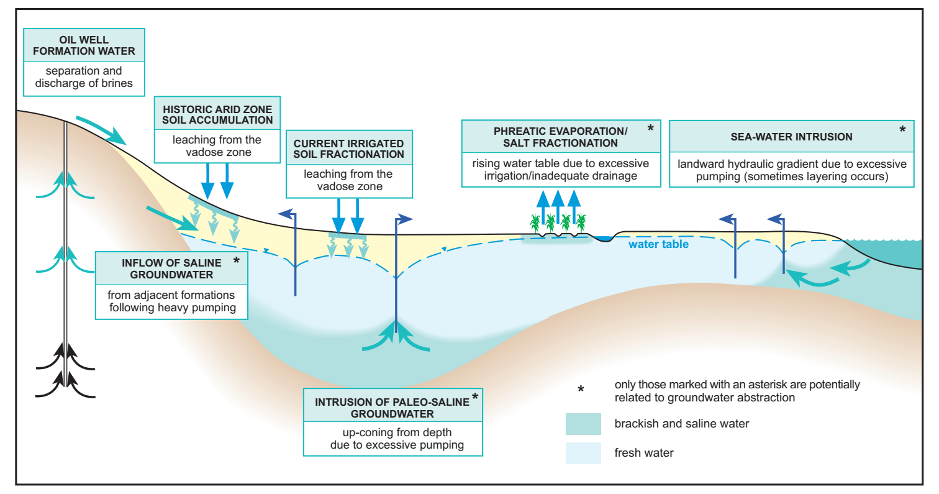


Figure 3. The possible origins of groundwater salinity and mechanisms of aquifer salinisation (World Bank GW-MATE Briefing Note Series 2, 2003)

INTERNATIONAL NETWORK OF BASIN ORGANIZATIONS (INBO)

'Basin organisation' is the generic term used for all types of institution that manage drainage basins - and can be anything from large formal agencies to small informal committees. They vary in purpose according to their mandate and/or legal arrangement of establishment, but may have the functions of water resources investigation, monitoring and regulation, water resources development and management, and planning and finance of specific management measures. Some 47% of the total global continental land area (excluding Antarctica and Greenland) is covered by river and lake basins reported to be under 'basin management agreements' - about two thirds of which are within large international or national basins, with the remaining one third not yet covered mainly because of their very arid climate.

INBO was established in 1994 as an international network supporting the implementation of IWRM primarily in river basins. It links basin organisations and other government agencies responsible for water resources management, in order to promote exchange of experience and develop suitable tools for better management at the transboundary, national and local level.

INBO is organised through regional networks in Africa, Asia, Central and Eastern Europe, Central Asia, Latin America, the Mediterranean and North America, and is also co-ordinating the Network of International Commissions and Transboundary Basin Organisations. INBO-Europe is helping to facilitate implementation of the EU-Water Framework Directive. INBO also has a long-term action plan to support the creation and strengthening of basin organisations around the world.

More information about INBO activities and members is available at www.inbo-news.org.

Integrating groundwater into broader water resources management has to respect the above considerations and differences, and rise to this challenge. An approach to reconciling hydrogeological diversity with river basins would recognise at least four different conditions with implications for water resources management:

- the existence of important aquifers of limited extent underlying only part of river basins - requiring independent local groundwater management plans which are then integrated into the overall river basin plan;
- the existence of river basins underlain by extensive shallow (but sometimes thick) aquifer systems - requiring a fully integrated appraisal of groundwater and surface water resources and their man-made perturbations, whilst recognising probable spatial variation in the groundwater/surface water relationship;
- the existence of extensive deep sedimentary aquifer systems in arid regions - where groundwater flow will predominate and the aquifer basin (not river basin) is the rational water resources management unit;
- the existence of minor aquifers of shallow depth and patchy distribution, where the impacts of groundwater development are very localised, and are unlikely to be significant in terms of river basin dynamics.

Once again it is not feasible to show all such variations on a global-scale map, but they need to be borne in mind when viewing the need for improved integration of surface water and groundwater management.

Beyond the issue of spatial definition of appropriate units for water management, a major practical outcome of the existence of large aquifer storage has been the spontaneous conjunctive use of groundwater as a 'coping strategy' in times of surface water drought, when groundwater systems show more resilience. This has occurred very widely for agricultural irrigation on the alluvial plains of more tropical latitudes with highly-seasonal rainfall of less than 1,000 mm/year. The move to planned conjunctive management in regions with this potential can be deduced from this map and it offers significant response to the challenges of climate-change. Managed aquifer recharge (MAR), which involves a variety of physical and management measures to enhance groundwater recharge rates during the wet season, is a significant further extension of this principle.

With fewer new surface water reservoirs due to unsuitable dam sites, high capital costs and environmental concerns, the use of underground water storage offers new options for greater water security. Developing aquifer storage reduces evaporation losses and presents low-cost measures with local ownership, but suitable sites for MAR must be carefully selected and conjunctive management of water resources assured.

Approach to Comparative Mapping of Basins at Global Scale

The present map delineates and superimposes river/lake basins on the land surface, and the hydrogeological class of underlying aquifer. This requires representing a three-dimensional reality on two-dimensional paper in an easily readable way - which is far from straightforward.

Hatching has been used to show the surface form of river/lake basins, and colour shading to indicate class of aquifer, albeit that the global representation only allows inclusion of extensive systems, together with some smaller systems of more local relevance without detail. Different hatching has been used to indicate probable linkages between groundwater and surface water systems:

- **Dense hatching (SW-NE)** symbolises areas with large river/lake basins within which underlying aquifers are contained. In these areas integrated management of surface water and groundwater can be more simply formulated, because the boundary of the river/lake basin encompasses the natural extent of underlying aquifers, and the recharge of surface water into the aquifer or the discharge from aquifers are fully contained within the river/lake basin.
- **Lighter hatching (NW-SE)** has been used for areas in which underlying aquifer basins depart considerably from those of the river/lake basins. The fact that an aquifer extends into an adjacent surface water basin is a challenge for integrated water resources management, since 'external groundwater issues' may influence the water budget or water quality situation. In these areas the interlinkages between surface water and groundwater regimes need to be mapped and monitored in detail in order to identify potential externalities.
- **Stippling** is used for limited surface water catchments, mainly in coastal regions, where the situation may be comparable to the previous category, but cannot be portrayed in detail.

In areas where the surface water situation is not relevant because of erratic rainfall and run-off, the underlying hydrogeological situation can be clearly seen on the map. In arid areas no active river/lake basins are present, but they can be underlain by important deep aquifers containing large groundwater reserves and some groundwater flow. Hence groundwater basins should form the basis for water resources management.

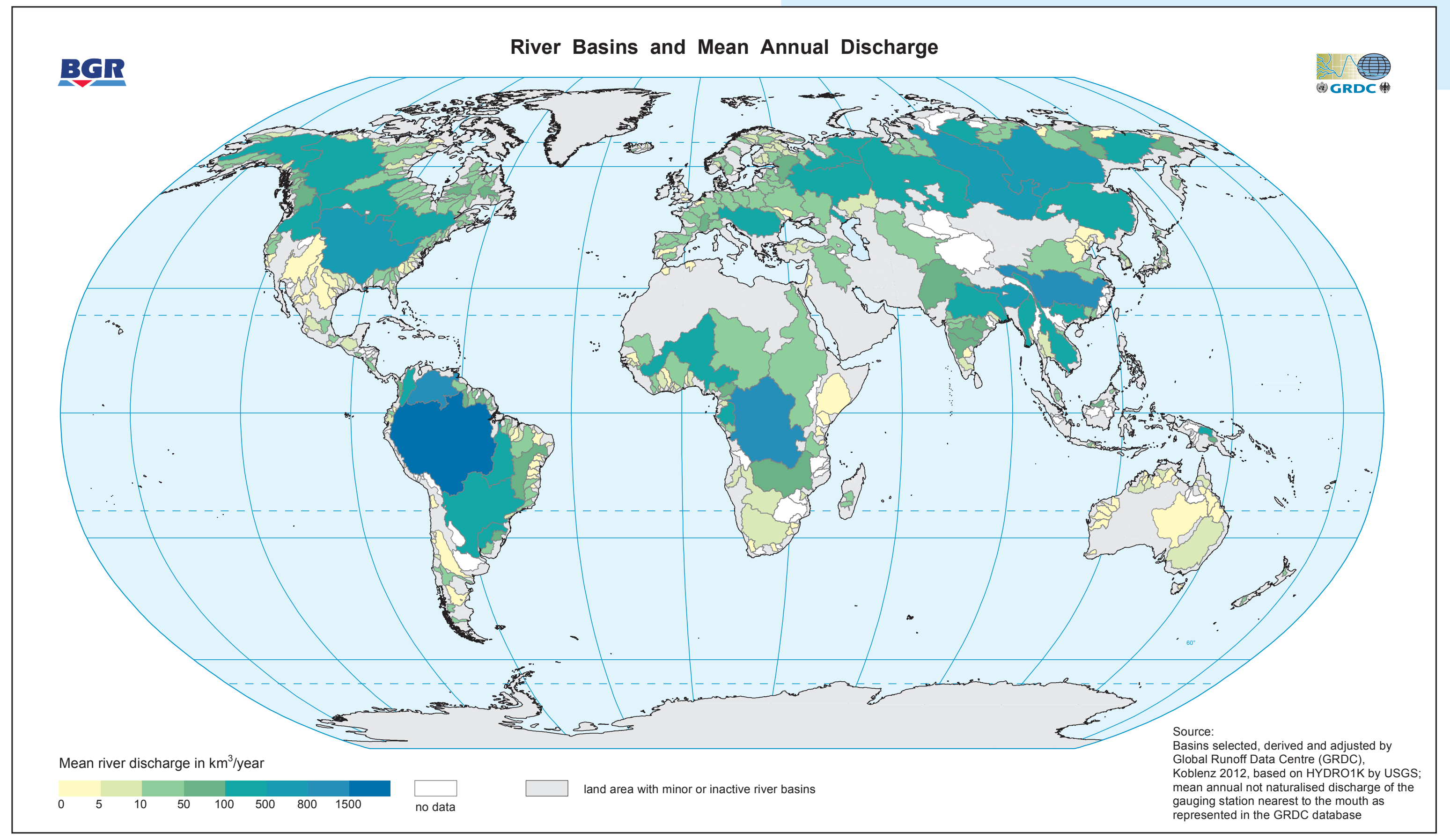
For groundwater, the aquifer class is indicated by colour shading, according to the classification of the WHYMAP Groundwater Resources Map of the World:

- **Blue shading:** large relatively uniform aquifer systems
- **Green shading:** areas with complex hydrogeological structure
- **Brown shading:** areas with minor, shallow and local groundwater

The most important groundwater resources at global scale are related to the former (blue and green shaded) areas.

A number of surface water and geographical features are also shown on the map according to current global datasets - such as major rivers and freshwater lakes, saltwater lakes, continuous ice sheets as well as selected major cities and country borders to provide map orientation.

The Global Runoff Data Centre (GRDC) is an international archive of river discharge data operated by the Federal Institute of Hydrology (BfG) in Koblenz, Germany under the auspices of the World Meteorological Organisation (WMO). The GRDC holds mean daily and monthly river-discharge data up to 200 years old for currently more than 8,000 stations in 157 countries. These data are collected from cooperating National Hydrological Services and maintained in direct support of the climate-related programmes and projects of the United Nations and their special organisations and the international research community on global change and transboundary water resources management.
Freshwater input from continents into the oceans is of major interest to research concerned with global monitoring of freshwater resources, the flux of matter into coastal areas and the sea, or the influence of freshwater fluxes on circulation patterns. A first spatial assessment of these freshwater inputs can be obtained from the map 'River Basins and Mean Annual Discharge'. The mean annual discharge of the gauging stations nearest to the mouth of the rivers as represented in the GRDC database has been used for compiling the map. The timeframe and length of discharge time-series varies according to the data provided to the GRDC. It should be noted that the visualised discharge has not been naturalised.



Source:
Basins selected, derived and adjusted by Global Runoff Data Centre (GRDC), Koblenz 2012, based on HYDRO1K by USGS; mean annual not naturalised discharge of the gauging station nearest to the mouth as represented in the GRDC database

Key Messages

Groundwater should play an equal part in the management of water resources, since aquifers are a major source for drinking water-supply, agricultural irrigation and industrial production, and are critical for sustaining the natural environment.

Groundwater is usually flagged-up as part of the river basin agency mandate - however groundwater systems have to be different from the simple input-output controls as applied to surface watercourses.

Whilst many facets of surface water resources management do not pertain to groundwater (for example navigation, fisheries, and energy generation) the impact of related construction measures on the surface water regime (for example dams or irrigation canals) can also have a major impact on groundwater.

In the more arid regions of the world the boundaries and size of surface water drainage basins and underlying groundwater systems rarely coincide - and the more rational basis for IWRM in such areas is the groundwater basin.

Elsewhere, the 'water-cycle continuity' paradigm is generally a solid base for the integration of groundwater into IWRM, but there are a number of aquifer specific issues and differences that have to be specifically addressed.

Multiple time-scales have to be contemplated in the management of rivers and groundwater bodies (decades or more for groundwater compared to months or less for flowing rivers), which has very important implications for groundwater quality protection and management.

Groundwater system 'health' can be critical for river baseflow and other dependent aquatic ecosystems, and itself is critically affected by the status of ecosystems (including streams) in aquifer recharge areas.

Groundwater resources management requires a monitoring plan and protection measures that cover a very wide range of temporal and spatial scales - and also the possible occurrence of elevated salinity in parts of some groundwater systems has to be taken into careful consideration.

Successful integrated water resources management can only be achieved if both surface and groundwater systems data are available and are comparable. Nevertheless there remains a lack of adequate information on groundwater in many parts of the world. Consequently there is a distinct need for investment to improve capacity for groundwater assessment and monitoring.

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

WHYMAP PROGRAMME

WHYMAP (World-wide Hydrogeological Mapping and Assessment Programme), a joint programme of UNESCO (United Nations Educational, Scientific and Cultural Organization), CGMW (Commission for the Geological Map of the World), IAH (International Association of Hydrogeologists), IAEA (International Atomic Energy Agency) and BGR (Federal Institute for Geosciences and Natural Resources, Germany), was established in 1999 as a contribution to management of the earth's water resources, especially groundwater.

WHYMAP collects, compiles and collates groundwater-related hydrogeological information, at continental and global scales, to aid global discussion of water issues by making underground water resources more visible. To achieve this it synthesizes the very large amount of hydrogeological mapping undertaken at regional and national level, and is gradually building a geographic information system (WHYMAP-GIS) in which groundwater data can be managed and visualised. The following major products have been derived from WHYMAP:

- 2003: first small scale overview at the scale of 1 : 100 000 000 published in the 1st World Water Development Report;
- 2004: first global groundwater resources map at the scale of 1 : 50 000 000 released at the 32nd Int. Geological Congress;
- 2006: world map focusing on transboundary aquifer systems for the 4th World Water Forum in Mexico City;
- 2008: educational wall map of 'Groundwater Resources of the World' at the scale of 1 : 25 000 000 published as a contribution to the International Year of Planet Earth.

Additionally an internet based map is available, which combines WHYMAP data with an information system on national, regional and continental hydrogeological maps (WHYMIS).

All products and services are accessible via the programme web site www.whymap.org.