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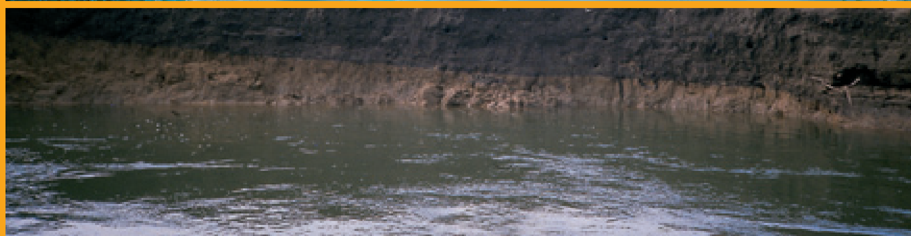
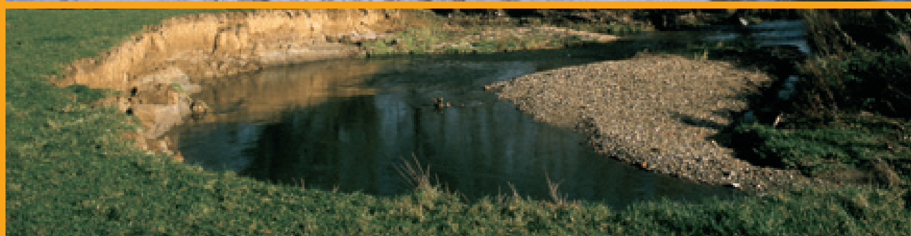
Groundwater - *reservoir for a thirsty planet?*

Earth sciences for society





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Prospectus for a key theme of the International Year of Planet Earth

planetearth®
Earth Sciences for Society

What is this brochure for?

This brochure is a prospectus for one of the main scientific themes of the International Year of Planet Earth.

It describes, in accessible terms, why this particular theme has been chosen - why the research that the Year hopes to support under this theme is of such vital importance to our understanding of the Earth System, and to society at large.

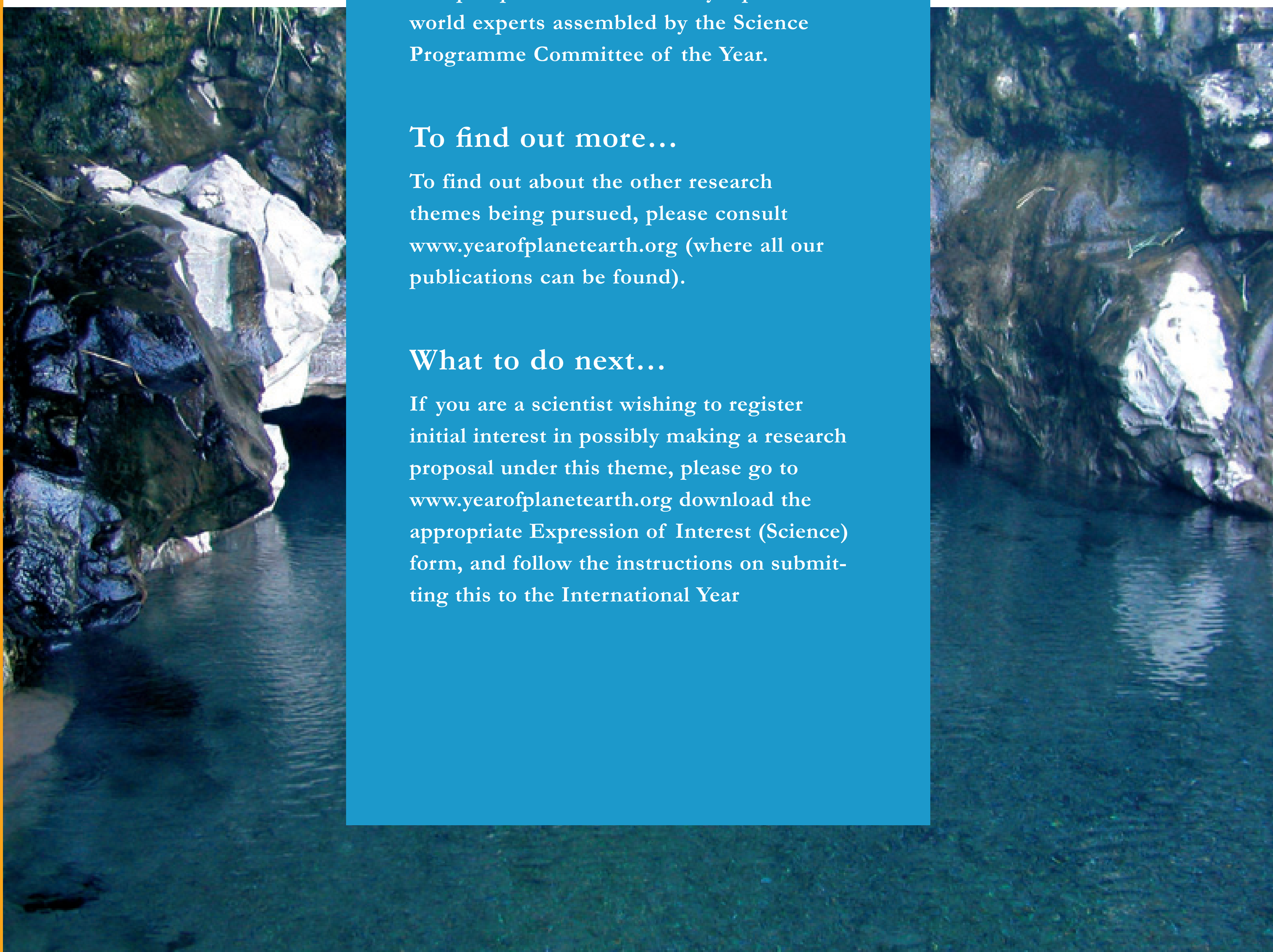
The prospectus was written by a panel of world experts assembled by the Science Programme Committee of the Year.

To find out more...

To find out about the other research themes being pursued, please consult www.yearofplanetearth.org (where all our publications can be found).

What to do next...

If you are a scientist wishing to register initial interest in possibly making a research proposal under this theme, please go to www.yearofplanetearth.org download the appropriate Expression of Interest (Science) form, and follow the instructions on submitting this to the International Year



up to 80 % of drinking

water in Europe and Russia

is groundwater

Groundwater - towards sustainable use

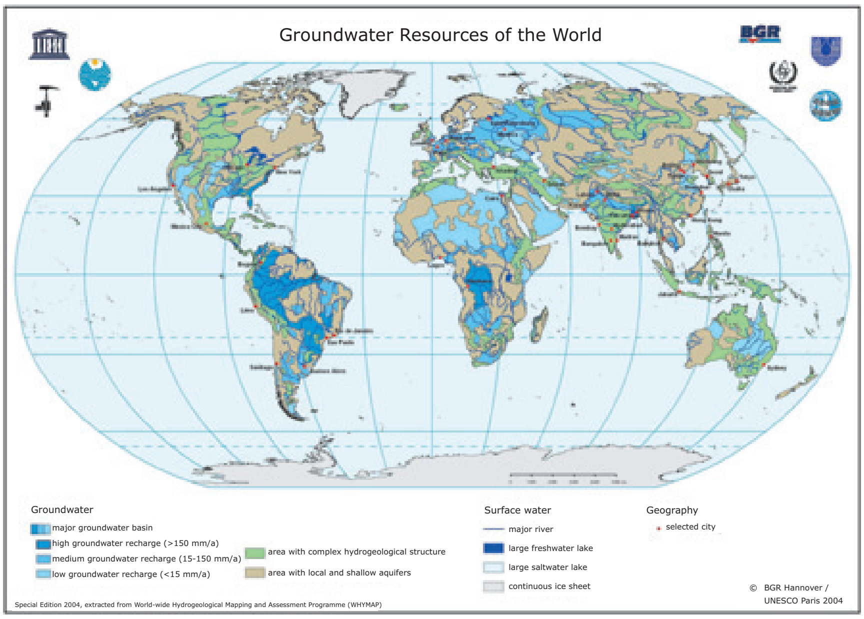
People's lives and livelihoods depend on water. Demand for clean water increases continually in line with world population growth. People in many areas of the world lack the fresh, drinkable water essential to their survival; if they are to prosper, more secure and low cost water supplies are needed. Maintaining secure water supplies for drinking, industry and agriculture would be impossible without groundwater, the largest and most reliable of all fresh-water resources. In many areas most drinking water is groundwater - up to 80 % in Europe and Russia, and even more in North Africa and the Middle East.

Unlike other natural resources or raw materials, groundwater is present throughout the world. Possibilities for its abstraction vary greatly from place to place, owing to rainfall conditions and the distribution of aquifers (rocks, sand layers and so on, in whose pore spaces the groundwater sits). Generally, groundwater is renewed only during a part of each year, but can be abstracted year-round. Provided that there is adequate replenishment, and that the source is protected from pollution, groundwater can be abstracted indefinitely.

Groundwater constitutes the underground part of the 'water cycle' (see below). Therefore, it is closely related to atmospheric or climatic processes, to the surface water regimes of rivers and lakes, and with the springs and wetlands where groundwater naturally discharges onto the surface of the ground. All these resources are complementary, but they can be extremely varied - extending from arid areas with virtually no water to humid tropical zones with abundant surface water and rainfall.

The groundwater involved in the present day water cycle is comparatively small compared to the volume of groundwater 'in stock', stored in porous or fractured strata down to a depth of a few thousand metres below the surface.

Figure 1: The fresh water resources of the Earth (after UNESCO 2003)



Who is behind the International Year?

Initiated by the International Union of Geological Sciences (IUGS) in 2001, the proposed International Year of Planet Earth was immediately endorsed by UNESCO's Earth Science Division, and later by the joint UNESCO-IUGS International Geoscience Programme (IGCP). The Year also boasts a large number of Founding Partner institutions, which are listed on the inside back cover.

The main aim of the International Year - to demonstrate the great potential of the Earth sciences to lay the foundations of a safer, healthier and wealthier society - explains the Year's subtitle: Earth sciences for society.

Groundwater forms the invisible, subsurface part of the natural water cycle

The Earth's fresh water resources consist mostly of ice, snow and groundwater. Rivers and lakes constitute a tiny part of the total global freshwater volume.

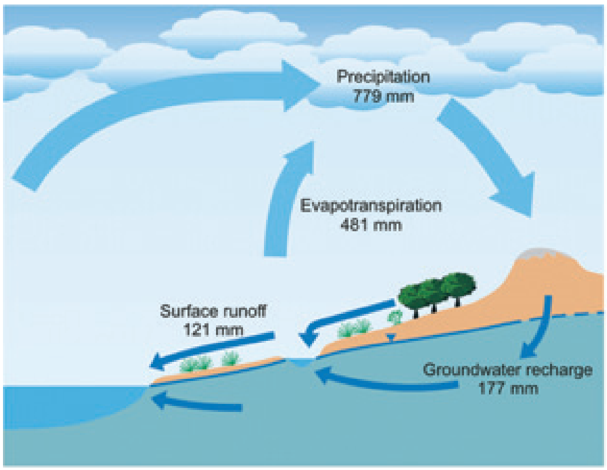
Earth's total resources of fresh groundwater are estimated at about 10,000,000 cubic kilometres - more than two hundred times the global annual renewable water resource provided by rain. This is because most groundwater resources have accumulated over centuries - or even millennia. In some places they bear witness to wetter climates in the past. These unique freshwater resources can be found even in present-day desert areas.

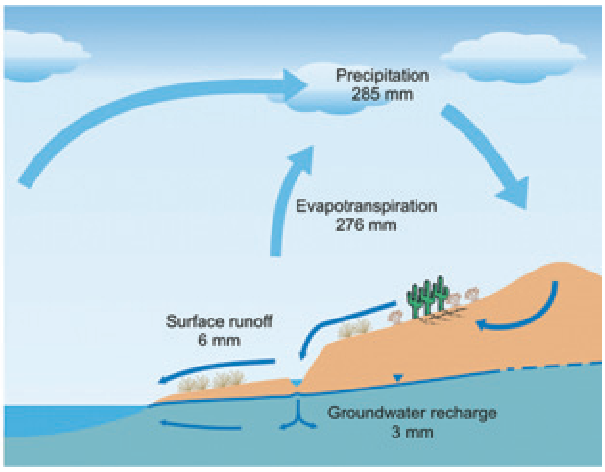
The overwhelming fresh water resource is the annually renewed input of precipitation around the globe. Rivers are of prime importance in distributing this water.

In the world's drylands, renewable fresh water is usually sparse, forcing local populations to use any groundwater available. Such 'mining' of groundwater is best avoided, however, as it is not sustainable and may lead to geo-hazards such as land subsidence and fissuring. 'Mining' groundwater is practicable only in the relatively rare cases in which the static groundwater reserve is very large in proportion to the resident population.

As renewable fresh water is measured using flow rate (cubic kilometres (km^3) per year, cubic metres (m^3) per second, etc.), while non-renewable fresh water reserves are measured by their volume or mass (km^3, m^3), the two are difficult to compare quantitatively.

Figure 2: The water cycle in different climatic zones of the world, demonstrated by the examples of Germany (left) and Namibia (right)





Groundwater and the water cycle

Groundwater, although second to rivers as a distributor of fresh water, is much the largest regulator of fresh water resources. Groundwater forms the invisible, subsurface part of the natural water cycle, in which evaporation, precipitation, seepage and discharge are the main components. The "visible" components are all strongly affected by weather and climate, and although they can be contaminated quickly, they generally recover quickly too. By contrast, the subsurface processes of groundwater are much slower and longer lasting, ranging from years to millennia. However, with careful management, these different timescales can be used to create an integrated system of water supply that is robust in the face of drought.

The groundwater regimes in humid and arid regions differ fundamentally from each other (Fig. 2). In humid climates, with their high rainfall, large volumes of water seep into the groundwater, which contributes actively to the water cycle feeding streams, springs and wetlands during periods when the rainfall is lower.

In semi-arid and arid climates, there is by contrast practically no exchange between the surface water and groundwater regimes because the small volume of seepage from the occasional rainfall only rarely penetrates the thick and dry (unsaturated) soils. In these areas groundwater resources are only minimally recharged. These differences must be considered in any concept of regionally integrated water resource management.

Scientists' attempts to achieve robust numerical characterisations of the groundwater component of the water cycle require adequate measurements and observations over decades. Furthermore, exchange between slowly moving groundwater and the faster water cycle operating in the atmosphere and on the Earth's surface must be adequately quantified.

Fresh groundwater

Groundwater availability is regionally very variable. Climatic conditions - precipitation especially - determine how much the groundwater is recharged. However the volume of water that can be stored is controlled by the reservoir characteristics of the subsurface rocks. Groundwater may be present today even in places with very dry climates because of the nature of the local geology and the local climate history. Water resources can be used sustainably only if their spatial extent and their variation through time are properly understood. However such information is often lacking, even in so-called developed regions.

Our data and knowledge base therefore needs to be constantly improved. This can be achieved by acquiring data and organizing it on maps, in geographical information systems (GIS), and through mathematical models. Models allow us to understand the data and analyze the effects of different management options. Modern hydrogeology has powerful tools for modelling water transport and flow together. Models integrating the full range of hydrological processes are emerging.

"Sustainable development"

The term 'sustainable development' came from opposition between those who supported policies preserving the 'sustainability' of the Earth's environment and those who advocated economic development. Environmentalists acknowledged that economic development was necessary (in part to avoid imposing the costs of environmental protection on those least able to afford them) but also because economic stagnation often reduces support for environmental protection efforts.

(continued...)

About 30% of the area of the continents (excluding Antarctica) is underlain by relatively homogeneous aquifers containing important groundwater reserves. About 19% is endowed with groundwater, some of which is extensive, in geologically complex regions. Half of the continental area contains generally minor occurrences of groundwater that are restricted to near-surface unconsolidated gravels, sands, and rock debris; but these groundwater resources are still sufficient to sustain small to medium-sized population centres.

Fifteen percent of the world's land area receives less than 200mm average annual precipitation (c. 200 litres per square metre). In these low rainfall regions there is normally very little groundwater recharge, so groundwater used will not generally be replaced for hundreds - perhaps thousands - of years. Extraction in these areas must therefore be considered as "mining" a limited resource, rather than tapping a continuous supply.

The geological conditions and hydrogeological characteristics of the rocks are critical controls on groundwater quantity, quality and flow regime. With the exception of the so-called 'karst' conditions characteristic of limestone areas (where groundwater can flow rapidly through tunnel and cave systems) flow rates in aquifers are very slow: generally only millimetres to metres per year (or a few kilometres over spans of centuries or even millennia).

Huge but limited

According to the UN, Planet Earth's mean annual renewable volume of water is 43,000 cubic kilometres. This is about half of all the fresh water contained in all the Earth's natural lakes and about ten times the volume of all man-made reservoirs. Groundwater recharge accounts for about 10,000 cubic kilometres annually, (c. 0.1% of all groundwater resources). Thus, only a tiny proportion of the total volume of groundwater reserves is recharged each year, compared to the large volume in stock.

Some groundwater systems are non-renewable under current climatic conditions because they formed under much wetter climates that prevailed perhaps 1000 or 10,000 years ago. These groundwater reservoirs are being increasingly "mined" in the arid zones of the world. For example, in the north-eastern Sahara, the Nubian Sandstone Aquifer System underlies an area of more than two million square kilometres in Chad, Egypt, Libya and Sudan, and contains huge amounts of fresh groundwater. It is thought to contain about a hundred times the present annual global water consumption.

Giant groundwater deposits of comparable size and limited recharge are thought to exist on nearly all continents, but the amount of groundwater that can be pumped out is unknown. Information about the age, travel times and flow of the water under ground, and other features such as chemical characteristics and processes are needed.

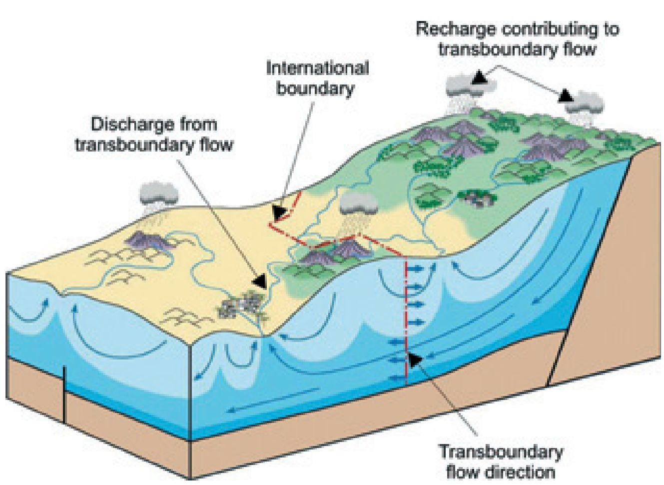
In most cases, groundwater is cleaner than surface water

This need is being served by two important initiatives: led by UNESCO IHP and inplemented with the Worldwide Hydrogeological Mapping and Assessment Programme (WHYMAP, UNESCO www.whymap.org) led by UNESCO IHP and implemented in cooperation with the International Association of Hydrogeologists (IAH), the International Atomic Energy Agency (IAEA) and the German Federal Institute for Geosciences and Natural Resources (BGR); and the International Groundwater Resources Assessment Centre (IGRAC - www.igrac.nl) sponsored by UNESCO and WMO.

No boundaries

Groundwater does not stop at political borders. Pumping in one country can dramatically affect the water in another. In such circumstances groundwater management requires international cooperation and the existence of appropriate governmental and legal institutions. Since groundwater moves according to physical laws, hydrogeological structures must be investigated, exploited and managed in their entirety. This means that investigation must also cross national borders – a fact particularly important in sensitive arid regions, where surface catchment areas of rivers might differ considerably from groundwater occurrences at depth. Owners or managers of groundwater resources that extend across political boundaries must agree on a common strategy for its exploitation for the common good.

Figure3: Political boundaries cut across groundwater systems (after ISARM 2001)



Likewise, those who advocated economic development recognized a parallel between the protection of environmental endowments and the concept of protecting capital in a sustainable economy. A viable economy must live off its income without a net reduction in capital over time. Similarly, a population must live within the carrying capacity of its ecosystem, which represents a form of natural capital.

careful and sustained exploitation
is a vital requirement for overcoming
the looming global water crisis

Groundwater pollution

Polluted water can transmit diseases and carry poisonous chemicals. Such water can make people sick and even kill. Clean water is therefore an important cross-cutting theme within the United Nations' Millennium Development Goals (www.un.org/millenniumgoals/).

In most cases, groundwater is cleaner than surface water. Groundwater is usually protected against contamination from the surface by soils and covering rock layers. This is why most drinking water in many areas of the world is groundwater. However, rising world population, changes in land use and rapid industrialisation (or de-industrialisation) increasingly place groundwater in jeopardy.

Polluted groundwater can be decontaminated only by expensive long-term procedures. In the worst cases, complete abandonment for a very long time is the only available course of action. These facts are becoming more widely recognised by the international community, and science and technology are increasingly engaged in helping to avoid the worst effects. Precious groundwater resources increasingly need to be protected and well managed to allow sustainable long-term use.

In some areas groundwater may contain enhanced levels of natural substances that can restrict its use. For example, seawater may invade the aquifer. Groundwater may also contain soluble natural substances like arsenic, fluorine, nitrate or sulphate, which restrict or even prevent its direct use because of health concerns. Suitable treatment processes can usually be found to diminish or remove harmful substances, but this often entails financial cost. In general, therefore, the groundwater quality must, in all cases, be controlled both before and during its use.

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Outreach Programme

The Outreach Programme of the International Year is faced with a particular challenge of scale. With a potential $10m to spend, it is inconceivable that it could operate in a prescriptive way. No individual or committee can think of enough wise ways of spending such a sum globally. So the Outreach Programme will, like the Science Programme, operate as a funding body, receiving bids for financial support - for anything from web-based educational resources to commissioning works of art that will help reinforce to the general public the central message of the year. It will enable things to happen locally under the umbrella of an international scheme, lending profile and coherence.

A special Outreach Prospectus in this series (number 11) is available for those who are interested in applying for support.

In many arid regions,
water management policies
aggravate the problem

Science programme

A panel of 20 eminent geoscientists from all parts of the world decided on a list of ten broad science themes - Groundwater, Hazards, Earth & Health, Climate, Resources, Megacities, Deep Earth, Ocean, Life and Soils.

The next step is to identify substantive science topics with clear deliverables within each broad theme. A 'key-text' team has now been set up for each, tasked with working out an Action Plan. Each team will produce a text that will be published as a theme prospectus like this one.

A series of Implementation Groups will then be created to set the work under the ten programmes in motion. Every effort will be made to involve specialists from countries with particular interest in (and need for) these programmes.

For more information - www.yearofplanetearth.org

Scarce

In many parts of the world, groundwater crucially underpins sustainable development. Drinking water is drawn mainly from groundwater in many countries because it is a naturally protected, of high quality, and reliable. It is clear that the relative importance of groundwater resources will increase considerably – and that careful and sustainable exploitation must be regarded both as a vital requirement for its own sake and as a means of overcoming the looming global water crisis.

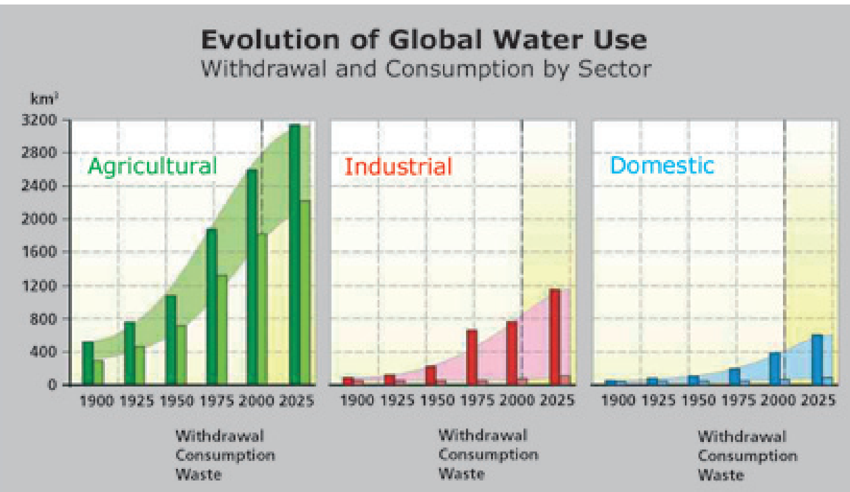
Consumption increasing; resources shrinking

The demand for water is rising as population, economic activity and agricultural irrigation grow. However, worldwide resources of accessible water are decreasing, due to overuse or pollution. The balance between demand (consumption) and supply (resource) is becoming unstable. More than 30 countries suffer from serious chronic water shortage, and groundwater is increasingly being used to cover the demand.

Agriculture is the greatest single worldwide consumer of water (70%), followed by industry (20%) and homes (10%). Considerable efforts have been made to reduce consumption in industry and homes; but much remains to be done in improving the efficiency of irrigation. The increasing use of non-renewed groundwater for irrigating of marginal farmland in arid zones is of particular concern.

The proportion of water used in these three sectors varies region to region, and between levels of economic development. In Europe and North America, water is used primarily by industry. In Asia and Africa, agricultural irrigation is the primary consumer. Thus in many semi-arid and arid regions about 30% of groundwater is extracted for irrigation, and the trend is increasing.

Figure 4: Groundwater use by sector



Groundwater is used by about two billion people worldwide, making it the single most used natural resource

What does the International Year's logo mean? The International Year is intended to bring together all scientists who study the Earth System. Thus, the solid Earth (lithosphere) is shown in red, the hydrosphere in dark blue, the biosphere in green and the atmosphere in light blue. The logo is based on an original designed for a similar initiative called Jahr der Geowissenschaften 2002 (Earth Sciences Year 2002) organised in Germany. The German Ministry of Education and Research presented the logo to the IUGS.

In many of the world's arid regions, current water management policies aggravate the problem. Although it is essential to reduce exploitation of irreplaceable fossil groundwater resources, many dry countries subsidise its exploitation. The re-use of treated effluent waters offers at least a partial solution.

No matter what conservation measures are taken, the extraction of groundwater is largely unavoidable. Groundwater is often the only cost-effective water supply. Advances in drilling, well construction and pumping technologies - as well as increasing electrification in rural areas – mean that ever-increasing volumes of groundwater are being exploited without adequate planning. Since groundwater flows very slowly, the consequences of over-exploitation may only become apparent after years or decades. Thus, future water strategies will have to include well planned monitoring of abstraction and quality.

Decision makers should issue licences for the exploitation of groundwater only after a reliable planning base has been established and suitable regulation procedures are in place. In this way, deterioration of the volume and quality of groundwater can be avoided, and the multiple benefits of groundwater resources for the ecology of the Earth sustained.

Valuable resource

Groundwater is used by about two billion people worldwide; making it the single most used natural resource. The estimated annual production of groundwater is between 600 and 700 cubic kilometres (billion cubic metres, or billion tonnes). In comparison, the worldwide annual consumption of sand and gravel is about 18 billion tonnes, while worldwide oil consumption is a mere 3.5 billion tonnes.

Groundwater is considered public property in many countries. Where it is scarce, groundwater could be considered an economic commodity; but in most cases no value is assigned to it. However, the costs of groundwater exploitation, treatment and supply need to be covered through water charges to maintain sustainable supplies. No figures are currently available on wealth creation resulting from providing groundwater to consumers worldwide. The only available global data pertain to the most valuable final (i.e. processed) products, namely drinking water and bottled waters (Table 1).

Discussion about public supply, cost recovery, agricultural irrigation, liberalisation of water markets and private investment continues at all levels in society. The Millennium Development Goal formulated by the United Nations, designed to halve the number of people without access to safe drinking water by the year 2015, will be attained only with considerable financial investment, currently estimated at €15bn per year between now and at least 2015.

Groundwater is considered public property in many countries

Table 1: Groundwater production compared to other natural resources (2001)

Resource	Annual Production (million tonnes)	Total Value (€m)
Groundwater (general)	> 600.000	300,000*
Sand and gravel	18,000	90,000
Hard coal	3640	101,900
Oil	3560	812,300
Lignite	882	12,300
Iron	662	16,400
Rock salt	213	4500
Gypsum	105	1500
Mineral and table water	89	22,000
Phosphate	44	3000

* at a notional price of €0.5 per cubic metre. Prices in Europe are typically €0.8 to €1.4 per cubic metre.

Water has very different values according to who is consuming it; although the products are often derived from the same natural resource. Groundwater for irrigation is not treated and costs only a few cents per cubic metre - if anything. Treated domestic drinking water supplied by pipe costs up to €2 per cubic metre, and bottled mineral or table water can cost €1000 per cubic metre or more.

If society continues to use up precious groundwater resources without recompense or replenishment, the water crisis will only deepen. Strategies for sustainable use must take into account the characteristics of all compartments of the water cycle, and guarantee that full use is made of the scientific basis that can provide a much fuller understanding of the world's vital but invisible groundwater resources.

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Key issues

In spite of the widespread and increasing use of groundwater for human and animal consumption, irrigation and industry in past decades, the knowledge base concerning groundwater resources and their sustainable use is inadequate, because hydrogeology is still a rather young science. In 2005, the United Nations proclaimed a Decade for Water, to foster cross-cutting water issues implied in the Millennium Development Goals (MDGs). Groundwater will undoubtedly play a significant role in this new UN Decade.

The following actions are being taken as part of this program:

- Mapping and quantifying fresh groundwater resources, including the identification of trans-boundary groundwater basins shared between countries;
- Investigating the recharge, flow and discharge processes in fresh groundwater systems and their role in supplying ecosystems;
- Improving the environmental impacts arising from groundwater abstraction or degradation of groundwater bodies, by protecting affected wetlands, preventing groundwater deterioration in quantity and quality, and long term monitoring of groundwater systems;
- Recognising the value of water in different environments and implementing strategies to conserve and safeguard water resources.

Key questions

- How much groundwater is there and how can it be used sustainably?
- How can unsustainable exploitation of "fossil" water reserves be identified and managed so as to minimise depletion and associated disastrous human/ecological consequences? This requires a better understanding of recharge in general.
- How can vulnerable groundwater resources be protected from pollution and how can vital polluted resources be restored?

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Further reading

- Internationally Shared (Transboundary) Aquifer Resources Management. A framework document. IHP-VI Series on Groundwater, Document SC-2001/WS/40, UNESCO 2001, Paris, http://unesdoc.unesco.org/images/0012/001243/124386e.pdf
- UNEP - United Nations Environmental Programme 2003. Vital Water Graphics. www.unep.org/vitalwater
- UNESCO-WWAP 2003. Water for people – Water for life – The United Nations World Water Development Report. UNESCO Publishing, Paris

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International Union of Geodesy and Geophysics (IUGG)
International Union of Soil Sciences (IUSS)
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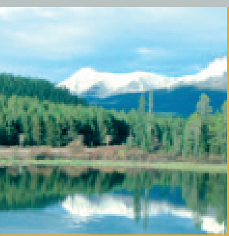

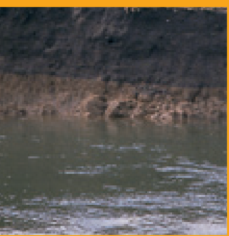

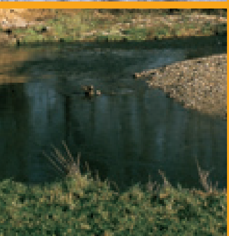

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