

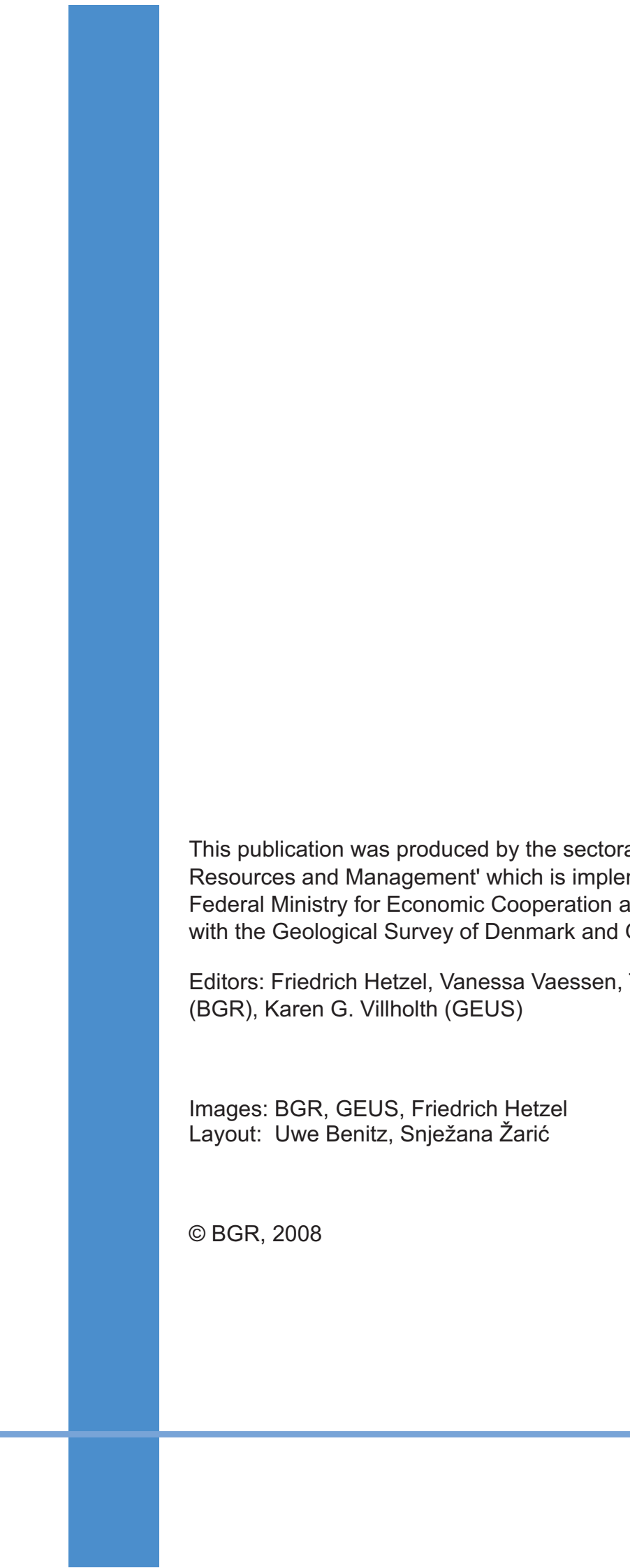
## Groundwater and Climate Change: Challenges and Possibilities



Commissioned by:



Federal Ministry  
for Economic Cooperation  
and Development



This publication was produced by the sectoral project 'Policy Advice Groundwater – Resources and Management' which is implemented by BGR on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), and in cooperation with the Geological Survey of Denmark and Greenland (GEUS), Denmark

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# Groundwater and Climate Change: Challenges and Possibilities

Groundwater resources and their long-term replenishment are controlled by long-term climate conditions. Climate change will therefore have a great impact on groundwater resources.

Groundwater has to be used and managed in a sustainable way in order to maintain its buffer and contingency supply capabilities as well as adequate water quality for human consumption, also under predicted climate changes.

Land use planning has to consider groundwater resources as a precious and finite resource, and take all possible measures to protect groundwater resources and their recharge mechanisms in the long run.

## Introduction

This paper gives information concerning the impacts of climate change on water resources, and particularly groundwater. It provides an overview of the current insights and knowledge on possible impacts and associated technical and management challenges due to climate change. Furthermore, it gives an overview of best options for developing and safeguarding groundwater resources and the human benefits derived from them.

Ist objective is to support decision makers in setting priorities for technical as well as institutional interventions to mitigate and adapt to climate change. Partners may be governmental development agencies, non-governmental organisations, partner countries and international partners in development cooperation, and other third parties.

This paper highlights the know-how and activities of the Federal Institute for Geosciences and Natural Resources (BGR), Germany and the Geological Survey of Denmark and Greenland (GEUS), Denmark concerning the impact of climate change on groundwater development, protection and management.

Bearing the complexity of the linkage between climate change and groundwater in mind, it is necessary to adapt groundwater management accordingly and to consider the particular resilience of most larger aquifers as a buffer for climate change.



## Climate change is a global challenge to human development

The highly industrialised countries are the most responsible for the emission of green house gases, that is made responsible for climate change. Therefore it is now essential that they react to climate change in order to cope with its impacts. It is fundamental to find ways of mitigating climate change and to look for possibilities of adaptation.

For developing countries, climate changes will be more severe, hitting already the most vulnerable populations of the world. While at the same time the need for development and resilience is greater in these countries, the capacity to encounter and anticipate the effects are generally inadequate.

Higher temperatures increase evaporation and therefore reduce water availability for humans and ecosystems. Climate change

more costly in many regions of the world and reinforce already existing water shortages and economic inequalities.

Globally, locations most at risk of freshwater supply problems due to climate change are small islands, arid and semi-arid developing countries, regions whose freshwater is supplied by rivers fed by glacial melt or seasonal snowmelt, and countries with a high proportion of coastal lowlands and coastal megacities, particularly in the Asia-Pacific region.

Therefore, even if there are still uncertainties of the immediate and long-term climate changes, measures, tools and strategies have to be developed in order to mitigate the impact and adapt to the changes that are taking place.

It is time to act.

***“It is the poor countries which will suffer most from climate change even though they are least responsible for global warming.”***

***“It is also becoming increasingly clear, in North and South alike, that there is an inextricable mutual relationship between environmental sustainability and economic development ”***

Ban Ki-Moon, Secretary-General of the United Nations<sup>1</sup>

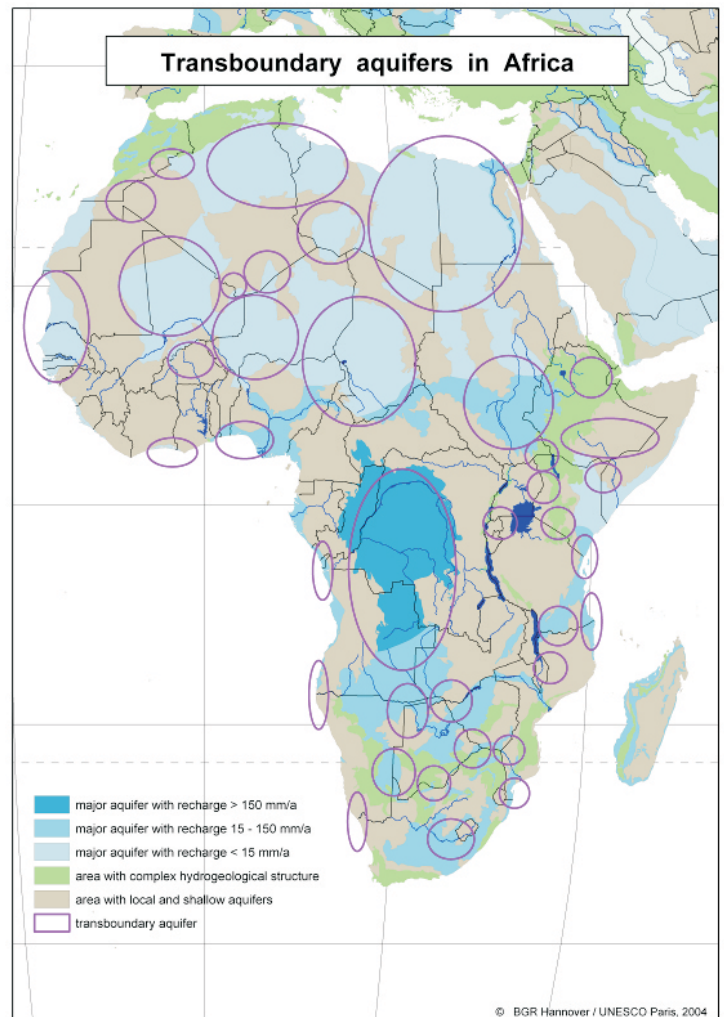
<sup>1</sup>During the UNEP Governing Council/Global Ministerial Environment Forum in Nairobi, Kenya, February 6, 2007.

## Groundwater is a key resource for human development

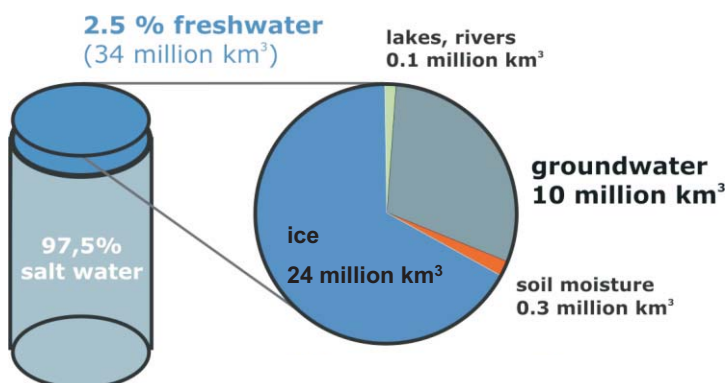
On a global scale, one third of the population depends on groundwater for their drinking water, in urban as well as rural areas.

Groundwater also plays a pivotal role in agriculture, and an increasing portion of groundwater extracted is used for irrigated agriculture. It is estimated that at least 40% of the world's food is produced by groundwater-irrigated farming, both in low-income as well as high-income countries.

In arid and semi-arid areas, the dependency on groundwater for water supply is between 60 and 100%. Therefore, the aim of halving the number of people without sustainable access to safe drinking water and basic sanitation (Millennium Development Goal, MDG 7) depends very much on how groundwater resources are developed and managed.



## Water on earth (1.4 billion km<sup>3</sup>)



However, the importance of groundwater has been marginalised and often neglected in many development strategies and projects. In general, support for groundwater management has not yet received much attention from donors. Only few activities in groundwater management have been supported, and this only marginally. For instance, in Africa, there are at least 38 transboundary aquifer systems. Groundwater management is supported in six basins with very limited financial commitments. Little donor support has been contributed to this resource and remained stagnant over the last decades (GTZ, 2007).

**Groundwater is likely to play an even greater role for human development under changing climatic conditions.**

A general change in the approach to water and groundwater management is required including groundwater within Integrated Water Management Resources (IWRM) concepts. In many cases, groundwater provides a secure, sufficient, and cost-effective water supply, often more reliable than traditional surface water-based supplies.

However, groundwater, as with surface water, is increasingly stressed due to human development, population growth, increased reliance on groundwater, and climate change. Also, once groundwater resources are contaminated, it is very difficult and costly to clean them. This reinforces a development in which water is treated as a luxury item, where only those who can afford it will have access, which means the gap between rich and poor will widen extensively.

**“Despite the critical importance of groundwater resources in many parts of the world, there have been very few direct studies of the effect(s) of global warming on groundwater recharge.” (IPCC 1996, p. 336)**

**“Although the effects ... on groundwater resources are not adequately understood at present, they cannot be ignored.” (IPCC 1998, p.122)**

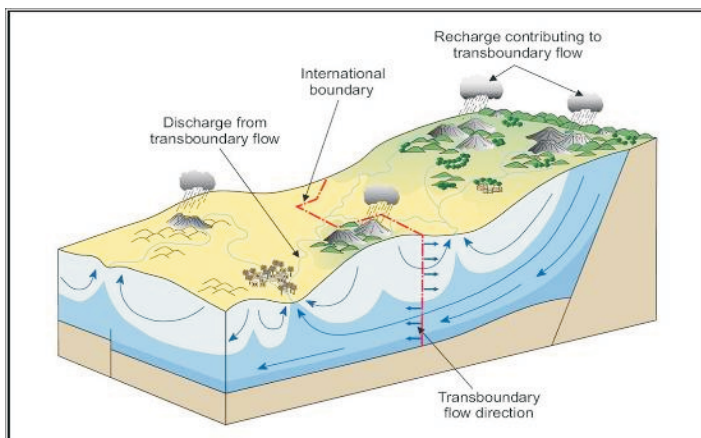
**“Groundwater is the major source of water across much of the world, particularly in rural areas in arid and semi-arid regions, but there has been very little research on the potential effects of climate change.” (IPCC 2001, p. 199)**

**“There is a need to improve understanding and modelling of climate changes related to the hydrological cycle at scales relevant to decision making. Information about the water-related impacts of climate change is inadequate - especially with respect to water quality, aquatic ecosystems and groundwater - including their socio-economic dimensions.” (IPCC 2008, p. 4)**

A new understanding of what climate change means and what impacts it has on this very special resource, upon which we all depend, should be promoted as a basis for better management.

It is evident that the efficient and sustainable use of groundwater calls for an integrated approach. Although the concept of IWRM must include groundwater, unfortunately this is not considered in practice.

Questions on water availability, access to water, and cooperation between states sharing transboundary aquifer systems are essential. Good governance, based on an informed knowledge about groundwater resources and of climate change impacts, should be promoted hand in hand with cooperation and participatory processes.



## How will groundwater be affected by climate change?

We predict the climate to be less predictable, which is a paradox, but yet something we have to relate to and base our planning on.

Despite the lack of detailed knowledge, there is consensus on qualitative changes of climate. Higher variability in precipitation is very likely to occur along with more frequent extreme events, like storms, floods and droughts.

Groundwater will be less directly and more slowly impacted by climate change, as compared to e.g. rivers. This is because rivers get replenished on a shorter time scale, and drought and floods are quickly reflected in river water levels. Groundwater, on the other hand, will be affected much slower. Only after prolonged droughts groundwater levels will show declining trends.

This is also why increased groundwater pumping can -for a limited time span- serve as contingency supply scenario in order to mitigate water shortages during droughts when water courses have run dry.

Groundwater levels of many aquifers around the world show a decreasing trend, but this is generally due to groundwater pumping exceeding groundwater recharge rate, and not to a climate-related decrease in groundwater recharge.

**Neglecting the importance of groundwater in the process of IWRM and climate change adaptation can result in the mismanagement of surface water with severe effects on the population and the environment.**



Groundwater is the intricate, but often overlooked, link between surface waters and many freshwater and terrestrial ecosystems. As many groundwater systems both discharge into and are recharged from surface water, impacts on surface water flow regimes are expected to affect groundwater. Thus neglecting the consideration of groundwater in the process of IWRM can result in the mismanagement of surface water with severe effects on the population and the environment.

Increased variability in rainfall may decrease groundwater recharge in humid areas because more frequent heavy rain will result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff. In semi-arid and arid areas, however, increased rainfall variability may increase groundwater recharge, because only high-intensity rainfalls are able to infiltrate fast enough before evaporating, and alluvial aquifers are recharged mainly by inundations during floods.

An excessive or unwise exploitation of groundwater in combination with climate change makes a lethal cocktail.

In many places, groundwater wells are already contaminated, unprotected or close to becoming dysfunctional due to a lowering of the groundwater table close to or below the bottom of the well or due to low and poor maintenance. Those wells, which serve as the basic water supply to millions of livelihoods, will not be able to supply water in times of disasters and emergencies. They will either be contaminated by floods or dry up due to droughts.

Projected sea-level rise and excessive groundwater extraction in coastal areas and on small islands combine to increase the risk of salinity problems in water supplies.

The volume and the quality of groundwater depends always directly on recharge conditions. The latter is not only controlled by the amount of annual precipitation, but is also governed by land surface characteristics, vegetation cover, and soil properties.

All these arguments call for a better and continuous monitoring of the resource, both to detect water quantity as well as quality changes and to enable proper and timely interventions.



Global warming as part of climate change will affect groundwater indirectly. Vast areas of permafrost at high latitudes will thaw releasing huge quantities of methane gas and acidic pore water. Glaciers and snow caps on mountains, previously giving rise to runoff during prolonged seasonal periods, may disappear and rivers will be fed more by intermittent rains. Groundwater resources will be less recharged from such rivers and may in fact loose rather than give water from such streams.

Higher temperatures will mean higher evaporation and plant transpiration rates and hence, more drying up of soils. This will entail higher losses of soil moisture and groundwater recharge and greater exposure to desertification and soil erosion in already hot and arid areas; these are all negative impacts for the integrity of groundwater storage systems.

On the other hand there may be more rain in certain semi-arid regions, e.g. the Sahel zone. However, it will be a challenge to capture this rain for the benefit of groundwater recharge.



Thus, climate change mainly results in further straining already stressed water resources, eco-systems, and derived systems, which used to service us.

Besides an increased frequency and degree of extremes, and foreseeable trends like sea level rise, other yet unforeseeable but significant changes and trends can be expected.

Overall, climate change has already and will increasingly have an impact on groundwater quantity and quality. Adaptation is substantial for a sustainable use of the precious groundwater resource.



## Strategies to use and develop groundwater resources under climate change

Safeguarding and enhancing the benefits from groundwater under climate change will only be possible through dedicated efforts and intelligent development and management strategies.

Within the aim of poverty eradication (Millennium Development Goal, MDG 1), the focus should lie especially in the delivery of water supply for the poorest.



## Measures of adaptation and mitigation

Both, the mitigation and adaption to climate change are essential. They are both interconnected and not mutually exclusive.

The driving force for global warming is the emission of greenhouse gases. Thus, more efforts in mitigating climate change should be undertaken to reduce emissions and to develop new technologies.

A lot of energy is used for groundwater extraction. In this context, large potential lies in the promotion of renewable energie, like solar energy which can be used for both groundwater extraction and for the distillation of water of inferior quality.

Also, the large and long-term storage capacities of natural groundwater systems offer a wide range of adaptation measures.

## Protection of groundwater

Groundwater needs to be protected, and its use and maintenance adapted to climate change. Preventing groundwater degradation and unwise exploitation will prove more cost-effective than trying to clean up and restore mismanaged aquifers.

Monitoring and research have to be done to achieve a better understanding of groundwater systems and their dynamics.

Wise land use, the protection and maintenance of groundwater systems and technical installations for the simple access to groundwater resources are key to prevent groundwater contamination, ensure sustainability of economic investments, and groundwater availability during extreme (flood or drought) conditions.



BGR supports partner countries in delineating and implementing groundwater protection zones

## Securing soil infiltration

Land use and human activities greatly influence groundwater conditions. Changing land use from e.g. forests to agricultural crops may have significant impacts on groundwater levels. Because these effects are long-term and not directly obvious, they are often disregarded or only perceived and recognised once discerned.

Most urbanisation processes come along with vast soil sealing together with sewers and storm water drainage systems which are associated with very rapid peak discharge of very often bad chemical water quality. Both, the reduced groundwater recharge and the bad quality of the discharged water, represent a threat to underlying groundwater bodies. Therefore, measures to reduce these effects, e.g. through dedicated polder areas, green areas and parks, where flood water can be attenuated and infiltrated, could be considered as integral solutions to make cities also more green and pleasant.

In rural areas, soil management, soil moisture retention measures, and continuous vegetation help support soil infiltration and groundwater recharge besides reducing erosion risk.

Especially in hilly areas, forests should be protected. Forestation in these areas represents always the best measure to improve the physical soil properties and to increase infiltration.

Furthermore, forests in catchment areas improve the dynamics of discharge by subduing fast peak discharge events reducing the menace of flooding for the population living downstream. Erosion in hilly regions can be avoided by terracing farmland and earth mounds along the contour lines. Wherever possible, monocultures should be converted into ecologically sound arable land.

A very important alternative or supplement to the preservation or restoration of natural infiltration conditions is artificial groundwater recharge. Artificial groundwater recharge is also described as a kind of (ground)water banking. Protected from evaporation and contamination recharged water can be used for different purposes but first of all for drinking water supply.

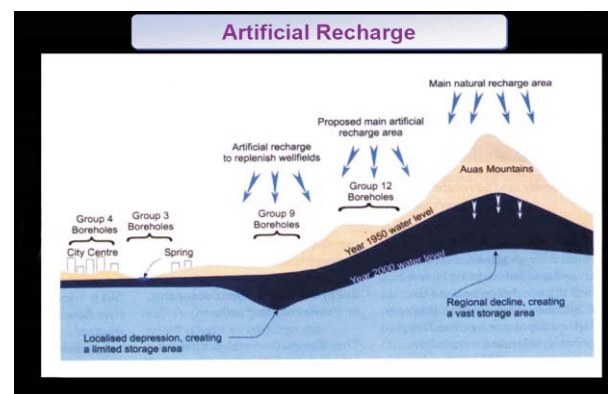
Generally, the costs of artificial groundwater recharge are less than investments necessary for large traditional dams.

In poor arid rural areas, the local population can build small earth dams for surface water retention and infiltration. Surface water will be treated while percolating through the soil horizons; a natural effect which is for free. However clogging may occur and therefore the infiltration basin has to be cleaned during the dry season. The substrate can be used as a valuable fertilizer when free of contaminated substances.

Water can be stocked in the upper aquifer layers and thus the energy needed to pump it up again is limited. Depending on the amount needed, cheap solar energy pumps or wind pumps can be used.

**Managed Aquifers Recharge schemes (MAR):**

**Many different technologies and principles exist for the managed recharge of ground-water, from the local scale capture of surface water runoff into derelict wells to restore groundwater levels, to large scale engineered infiltration galleries with recycled wastewater. All serve the same purpose of increasing the availability of groundwater and securing access in times or seasons of water shortages.**



## Water saving

Advocated strategies of water saving and the use of recycled, treated water becomes even more relevant in times of climate change.

Instead of relying on precious and finite groundwater for all kinds of water supply, groundwater usage for irrigation purposes should be reduced and substituted with treated municipal wastewater for irrigation in peri-urban areas. By using good quality groundwater preferably for drinking water, the resource is used in a more sustainable way.

The amount of water needed for agricultural use is still incredibly high and today is estimated to be 70% of all human water extraction. Therefore, sound irrigation systems could contribute to avoid the waste of this precious resource. Open canals should be replaced by closed pipes in order to protect against evaporation. To reduce evaporation the soil should be covered completely with plants, and therefore a multilayer storey is suggested.

Virtual water stored in agricultural products makes up part of our “water footprint”. Whatever we eat, a certain amount of water was used to make our food grow. Efficient water use must be the main objective in agriculture and the cultivation of drought resistant plants could be an option.

Ecosystems must be protected because they serve as water catchment areas and natural infiltration basins. Gallery forests play an important role for the river flora and fauna. Furthermore, erosion is very limited when gallery forest are well developed and dense.

These “no regret” measures are steps that can be taken anytime, both to combat climate change and to reduce general stress on water resources.





## Strategies for policy-making

Many principles applicable for the sustainable management of surface water is equally valid for groundwater management.

Thus, capacity development, good governance and transparency are keystones which have to be considered. Often, the insufficiency of supplying drinking water and sanitation is driven by an inefficient supply of services rather than by water shortages. Mismanagement, corruption, lack of appropriate institutions and a shortage of new investments in building human capacity and physical infrastructure contribute to this development (Water Governance Facility, 2008).

For decision makers the available data and information concerning the water balance and changes due to climate change have to be comprehensive and easily accessible. Still, not only knowledge should increase and data collected, but it is absolutely important that the data is comprehensive and easily accessible.

Due to increasing investments in the global 'water market', governments should support strong regulatory systems which are based on monitoring, data collection and sharing of knowledge by national water authorities.

In rural areas of semi arid or arid regions, conflicts concerning the access to groundwater are not unusual. Often it is the extraction of groundwater resources of different conflicting parties heavily dependent on already stressed groundwater resources which spark off violent conflicts.

One state's solution becomes another state's problem. This calls for a cooperative and a regulatory approach beyond the principle of 'first come first serve'.

For the transboundary management of groundwater resources, the exchange of data and relevant information has to be institutionalised. Thus, a harmonisation of national laws across borders is critical.

Overall, good water governance and the political will to implement common agreements are the fundamental cornerstones for adaptation and mitigation measures.

The use of non-renewable (fossil) groundwater resources has to be avoided as far as possible. However, in humanitarian emergency situations, the use of non-renewable water resources can be the only option in order to save lives if available renewable water resources are quantitatively and qualitatively not sufficient.

For long-lasting humanitarian interventions, alternative options are to be introduced to slow down the excessive use of fossil groundwater (e.g. desalination, reuse, purification). Where non-renewable groundwater resources are already an elementary component of water use, every opportunity must be utilised to improve the water balance. In particular, the use of fossil water must always be subject to a comprehensive evaluation of alternative options (BMZ 2006).

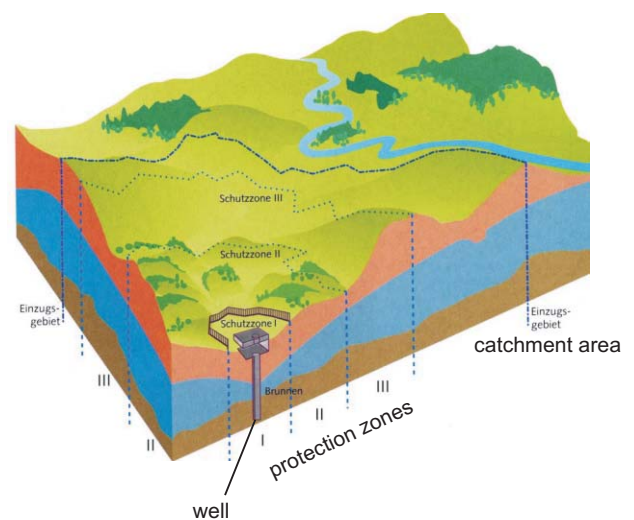
Technical know-how is fundamental in assuring that land use planning takes groundwater conditions into account. In order to be prepared, financing facilities have to be made available to construct dams for infiltration basins, infiltration wells, and for the renaturation of riverbeds and wetlands.

Open areas have to be made available in order to catch water in polder and inundation plains. Promoting public parks and reducing soil sealing to a minimum necessary could be an option to increase infiltration.



Rainwater harvesting should be increased by catching runoff in basins or by infiltration wells in the underground. Every new settlement should take groundwater resources into account and the protection of the aquifer should have high priority.

Dump sites and solid waste handling also have to do with groundwater. This also applies to fertilizer and pesticide use in agriculture. Measures need to be developed in order to prevent the excessive leaching of contaminants into groundwater resources.



**Every new settlement should take groundwater resources into account and the protection of the aquifer should have high priority.**



## How much does it cost?

Water is a precious and a finite resource. So why not paying for it? Water prices should be affordable for all. However, different tariff-systems should assure that the poor also have access to clean and affordable water. Water prices should be subsidised for the poorest. Water supply in emergencies must be free for all. Industrial water use has to be regulated.

Over-exploitation should be discouraged. Water savings result in a reduction of water prices. Part of the income from regular water payments should be used for groundwater protection and adaptation measures.

## Expertise of BGR & GEUS

BGR and GEUS as state geological surveys with substantial experience in groundwater management are key players in advising and supporting development cooperation and partner countries when it comes to the exploration, development, use, protection and management of geological and groundwater resources.

Both have extensive know-how and long-lasting experience from a wealth of programmes and projects around the world. Their services range from activities such as groundwater resources monitoring, resource evaluation, groundwater protection and vulnerability assessment, pollution rehabilitation, and the development and application of modelling tools.

Feasibility studies of dams, artificial groundwater recharge, rainwater harvesting, and capacity building at various levels contribute to an effective cooperation. Therefore, BGR and GEUS are ideal partners for supporting geo-services in partner countries through international cooperation.

## References and further reading:

Appleton, 2003. *Climate Changes the Water Rules*. Dialogue on Water and Climate. Printfine Ltd., Liverpool, UK.

BGR, 2007, Strategies for the Sustainable Management of Non-renewable Groundwater Resources  
Available at: [www.bgr.bund.de](http://www.bgr.bund.de)

BMZ 2006, Sektorkonzept Wasser.  
Available at: [www.bmz.de](http://www.bmz.de)

Burns, W.C.G. 2002. The potential impacts of climate change on the freshwater resources of Pacific Island developing countries. In: Gleick, P.H. (Ed.). *The World's Water 2000-2001: The biennial report on freshwater resources*. Washington, DC. Island Press, pp. 113-131.

GTZ.2007: Donor activity in transboundary water cooperation in Africa; Results of a G8-initiated survey 2004-2007, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn 2007.

IPCC. 1996. *Climate Change 1995, Impacts, adaptations and mitigation of climate change: Scientific-technical analyses*, London, Cambridge Uni. Press.

IPCC. 1998. *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, London, Cambridge Univ. Press.

IPCC. 2001. *Climate Change 2001, Impacts, Adaptation and Vulnerability*.  
Available at: [http://www.grida.no/climate/ipcc\\_tar/wg2/pdf/wg2TARchap4.pdf](http://www.grida.no/climate/ipcc_tar/wg2/pdf/wg2TARchap4.pdf)

IPCC. 2008. Climate Change and Water. IPCC Technical Paper VI.  
Available at: <http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf>

Moench, M. & S. Stapleton, 2007. *Water, Climate, Risk and Adaptation*. Working Paper 2007-01. Institute for Social and Environmental Transition (ISET). ISBN: 978-90-78988-01-4. 80 pp.

UNDP Water Governance Facility, 2008  
Available at: <http://www.watergovernance.org/index.html>  
in Transparency International, 2008. Global Corruption Report 2008: Corruption in the Water Sector. edited by Dieter Zinnbauer and Rebecca Dobson. Cambridge University Press, UK

UNESCO, 2006, Jean Margat « Les eaux souterraines – une richesse mondiale »





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