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# **GLOWA**

## Global change and the Hydrological Cycle



IHP - International Hydrological Programme of UNESCO  
HWRP - Hydrology and Water Resources Programme of WMO



Federal Ministry  
of Education  
and Research



**Bundesministerium für Bildung und Forschung**

**GLOWA**

Global Change and the Hydrological Cycle

*Towards Sustainable Development*

A programme funded by the German Federal Ministry of Education and Research



German IHP/HWRP - National Committee



IHP – International Hydrological Programme of UNESCO



HWRP – Hydrology and Water Resource Programme of WMO



BfG – Federal Institute of Hydrology, Koblenz

German National Committee for the  
International Hydrological Programme (IHP) of UNESCO and the  
Hydrology and Water Resources Programme (HWRP) of WMO  
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## Preface BMBF

Securing an adequate supply of qualitatively good water for people around the world is without doubt one of the great challenges of the future. As much as 50% of the world's population currently rely on water supplied from transnational water systems. Added to this is the risk posed to water availability by large-scale climate and land use changes that have a significant impact on the global and regional water cycles. All these aspects lead to a series of new challenges concerning sustainable water management concepts.

The German Government and its Federal Ministry of Education and Research (BMBF) play an active role in addressing these challenges. GLOWA is an outstanding example for Germany's engagement and support for application oriented research and the development of technologies and strategies for better water management concepts. This includes instruments to simulate expected trends and their implications, and to evaluate solutions for their impacts and outcomes. Hence Germany reaffirms its commitment to the United

Nations International Decade for Action: Water and Life and to the Millennium Development Goal of halving the proportion of people without access to safe drinking water by 2015. GLOWA is a prime example for this.

Ongoing internationalization, both of the problems and the areas of conflict, requires strong partnerships to implement and organize research activities that will lead to sustainable and long lasting solutions. Local partners and stakeholders, from different research disciplines as well as policy making, industry and society must be an integrated part of this process right from the start in order to assure the acceptance and application of the research findings. We are grateful to have found such partnerships within the GLOWA partner countries.

Publishing the brochure in close collaboration with the UNESCO highlights the significance of the GLOWA contributions to meet the global challenges and its international dimension.

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## Preface UNESCO

Water management affects our environment, society and culture. Finding solutions to mitigate negative impacts and adapt to different geographical conditions and climate regions, requires an approach that unites sound and unbiased science with social and policy considerations. To meet this challenge the Federal Ministry of Education and Research (BMBF) of Germany launched a major international programme called GLOWA (Global Change and the Hydrological Cycle) in 2000. The objectives of the programme were to develop, test and apply new integrated, interdisciplinary models to assess the impact of global change at a basin scale. The improvement of our understanding of hydrological processes will lead to reduced uncertainty in future water management and design practice.

In 1999 UNESCO initiated the Hydrology for Environment, Life and Policy (HELP) project within the framework of the International Hydrological Programme. Within the HELP project, UNESCO provides an international framework for scientists,

managers, law and policy experts and stakeholders to come together to address locally defined “water related issues”. UNESCO’s global call for basins was very well received in the scientific community and resulted in a global network of catchments with the aim to improve the links between hydrology and the needs of society. Here, the research concepts of GLOWA were in line with the HELP programme and therefore became part of UNESCO’s HELP programme. Currently two GLOWA basins: Drâa and Upper Ouémé are operational UNESCO HELP basins.

The GLOWA initiative of the German government and the international co-operation which it has stimulated is an excellent example of a national contribution to the International Hydrological Programme of UNESCO. The GLOWA project has successfully demonstrated the benefit of research for application-oriented solutions of imminent water-related problems under global change. This initiative is unique in establishing a long-term research strategy to mitigate the anticipated impacts of global change in the water sector.

**Siegfried Demuth**

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# 1 Introduction

## 1.1 The global water crisis

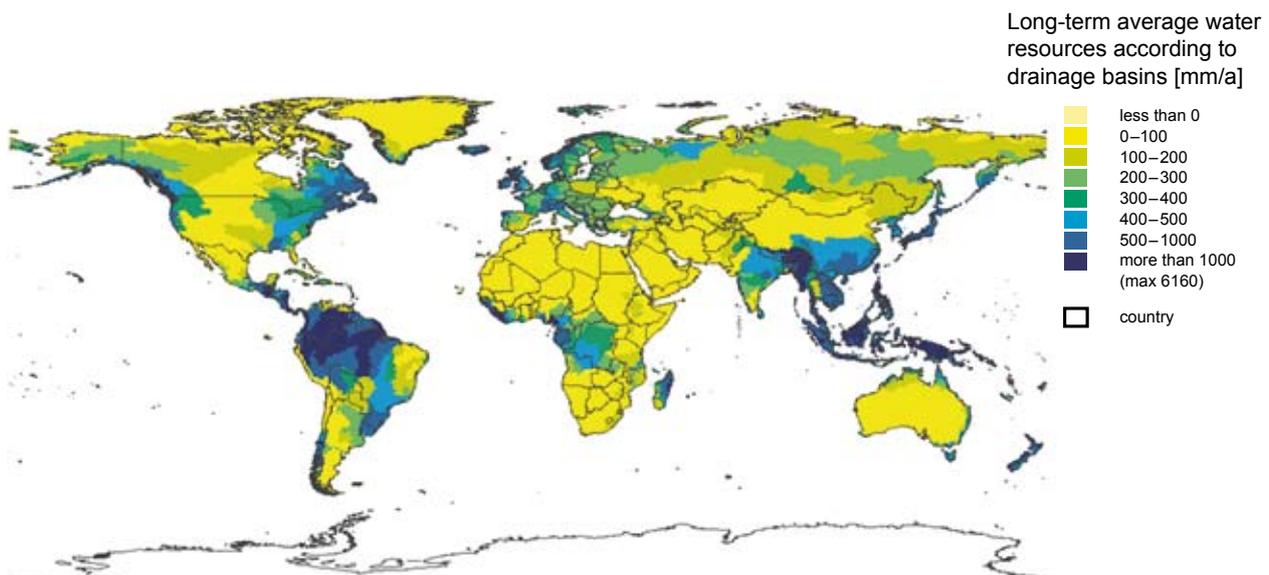
More than seventy per cent of the Earth's surface is covered by water and it is therefore logical to assume that our Blue Planet has an endless water supply. However less than three per cent is fresh-water of which two-thirds are locked up in glaciers and permanent snow cover leaving a limited amount accessible to people and ecosystems. The problem is exacerbated by the uneven spatial distribution of freshwater across the world (Figure 1.1).

Approximately 1.1 billion people are without access to clean drinking water. Some 6,000 people – mainly children under five – die every day from the effects of using contaminated water. Climate change, land use change, population growth, water pollution and rising per capita water consumption all have an adverse effect on water supply and water quality. In the UN World Water Development Report 2003 (hosted by the UNESCO International Hydrological Programme-IHP) it was estimated that by the middle of this century, at

worst seven billion people in sixty countries will suffer from water scarcity, at best two billion in forty-eight countries. The report highlights the global water crisis: **'At the beginning of the twenty-first century, the Earth, with its diverse and abundant life forms, including over six billion humans, is facing a serious water crisis. All the signs suggest that it is getting worse and will continue to do so, unless corrective action is taken.'**

The United Nations has long recognised the importance of environment and development. Water issues receive broad attention in Agenda 21, the Programme of Action for Sustainable Development which was the official outcome of the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992.

Under the heading 'Protection of the Quality and Supply of Freshwater Resources: Application of Integrated Approaches to the Development, Management and Use of Water Resources', Chapter 18 of Agenda 21 sets out the related objectives and activities.



**Figure 1.1** Average annual (1961–1990) available water resources.  
(GWSP Digital Water Atlas 2008, available online at: <http://atlas.gwsp.org>)

Ten years on, at the 2002 World Summit on Sustainable Development in Johannesburg the Millennium Development Goals were defined. The water issues – and especially those concerning the supply of drinking water – moved even further into the spotlight. One of the key aims of the Summit’s Millennium Development Goals was **‘to halve by 2015 the proportion of people without access to safe drinking water and adequate sanitation.’** This need was again emphasized at the Fourth World Water Forum in Mexico in 2006. To help achieve this goal, the European Union has made some €1.4 billion available for water-related action programmes, approximately 25% of which will come from Germany.

### 1.2 GLOWA: a German initiative to meet a global challenge

The German Federal Government established the German Advisory Council on Global Change (WBGU) in 1992 as an independent advisory body. The interdisciplinary Council comprises representatives from both natural and social sciences. Since about 1996, the Council’s work has fostered a paradigm shift which culminated in an international debate. The issue central to this debate was a new research approach which involves using integrated, interdisciplinary methods to tackle the challenges of the complex system of global change. In practice, this means that different research disciplines apply their respective methods and instruments to global change-related issues.

The instruments are then aligned and subsequently combined into a complete system that allows an integrated approach to decision making. This makes it possible to tackle specific problems – for example reduced precipitation in West Africa – together with their wider socio-economic impacts. The research outcomes then form the basis for recommendations for action to secure sustainable development.

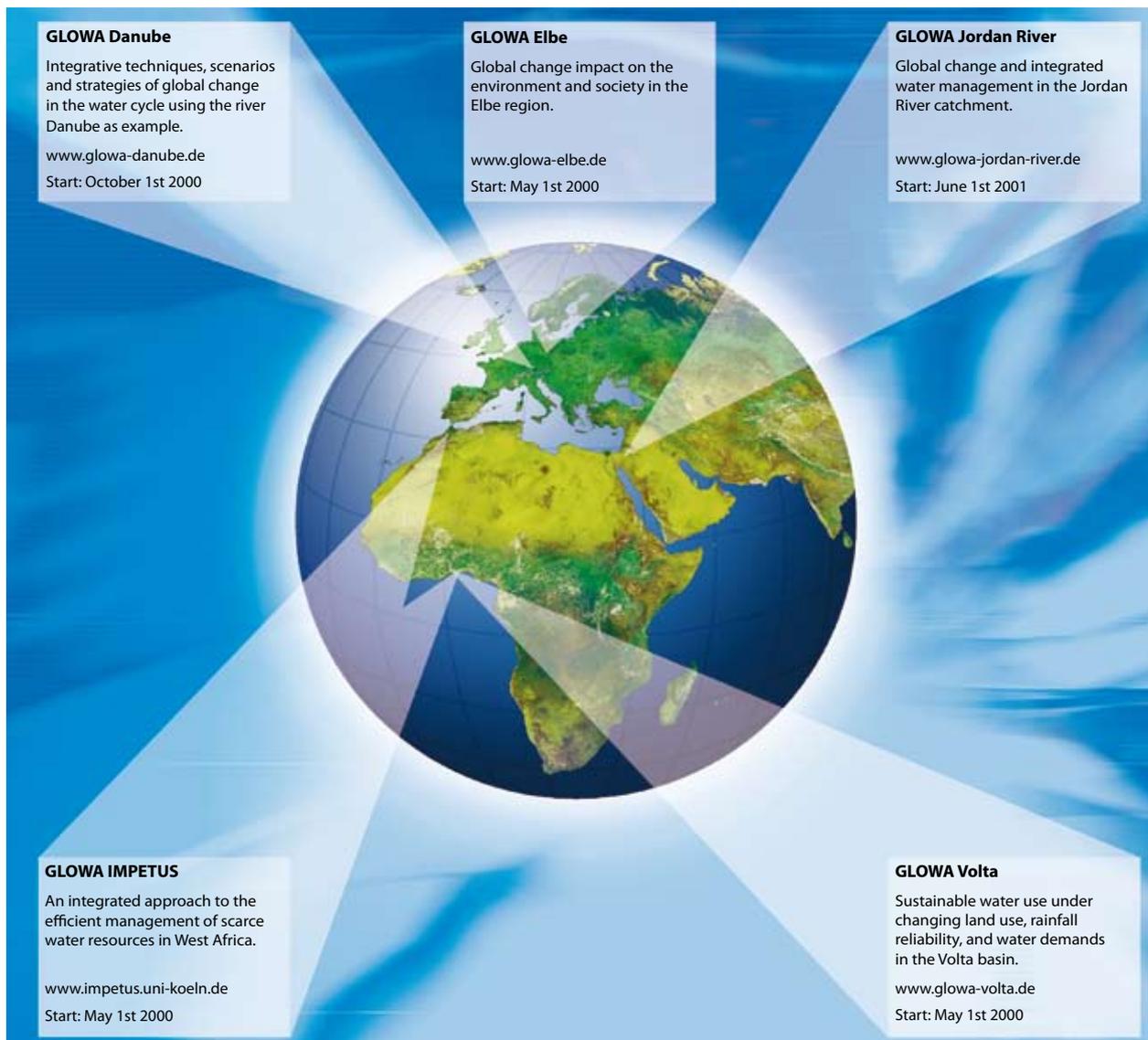
The Johannesburg Plan of Implementation states the necessity of implementing strategies which should include targets adopted at the national and regional levels to protect ecosystems and to achieve integrated management of land, water and living resources, while strengthening local, regional and national capacities. The Johannesburg Plan identified several lines of action including:

- the need to develop integrated water resources management and water efficiency plans,

- the need to support developing countries and those with economies in transition in their efforts to monitor and assess the quantity and quality of water resources,
- the need to improve water resources management and scientific understanding of the water cycle through cooperation in joint observation and research, and for this purpose encourage and promote knowledge transfer and capacity-building.

The UN World Water Development Report 2006 underlines that decision makers are confronted with the challenge of managing and developing water resources in a sustainable fashion in the face of the pressures of climate change, economic growth and major population increases. Because global environmental changes alter the current and future living conditions of people, there is an increasing need to shift research towards more direct practical applications to provide answers to the questions raised by stakeholders and decision-makers. Managing the global water crisis demands integrated case studies including all aspects of the hydrological cycle in river catchments with different climatic and socio-economic conditions.

To address these global issues Germany’s Federal Ministry of Education and Research (BMBF) launched a pilot programme known as GLOWA (Global Change and the Hydrological Cycle). GLOWA is part of the BMBF framework programme on research for sustainability with the objectives of developing, testing and applying new integrative, interdisciplinary methods and models in individual GLOWA projects. The methodologies and simulation tools developed will contribute to long term sustainable water management at local and regional (river basins of approximately 100.000 km<sup>2</sup>) scales taking into account global environmental changes and socio-economic conditions. These GLOWA ideas, especially with respect to the implementation of interdisciplinary research and integrated modelling, are also incorporated in international cross-cutting initiatives such as the Global Water System Project (GWSP) of the Earth System Science Partnership ESSP [a joint initiative by the four Global Change Programmes WCRP (World Climate Research Programme), IGBP (International Geosphere Biosphere Programme), IHDP (International Human Dimension Programme) and DIVERSITAS (an integrated programme of biodiversity science)] and the project Hydrology for Environment, Life and Policy (HELP) of UNESCO’s International Hydrological Programme.



*Figure 1.2 The GLOWA projects (M. Schmidt, PT-DLR)*

### 1.3 The innovative GLOWA approach

Within the GLOWA programme six river catchments were selected in five projects: Danube, Elbe, Jordan, Impetus (Rivers Drâa and Ouémé) and Volta (Figure 1.2 and Table 1.1). The two basins Drâa and Upper Ouémé are operational UNESCO HELP basins. At the outset the projects were developed in close collaboration with scientists and stakeholders from the partner countries.

A common theme was to integrate and transfer knowledge, tools and complex interdisciplinary research results to stakeholders by developing user-friendly decision support systems (DSS). With its main focus on changes in the water cycle under

global change conditions and on the problem of water scarcity, research considered the great variability in climate, its effects on the biosphere (especially due to changes in land use) and the conflicting claims that ensue from changes in water availability. In particular the GLOWA projects combine competence and capacities of natural and social science disciplines to provide sound user orientated techniques and services. They have contributed to advancing scientific collaboration across different national and international programmes and promoted increased staff competence in Germany and in the GLOWA partner countries. This has included support for young researchers, for education and training and exchanges of scientists in developing countries.

The various GLOWA projects started in 2000 with three separate phases. The first phase involved on-site set up, assembly of measuring systems, data collection and evaluation, alignment of the models to specific research regions and coordination between the participating disciplines. The second phase developed scenarios and tested initial applications of a wide range of simulation models used to make realistic projections of future conditions. A high priority was given to involving local people in this phase to ensure that the simulation systems will serve long term sustainable water management in the respective regions. In the ongoing third phase, the implementation phase, decision makers in the river basins are being given the opportunity to act out and assess the effects of specific decisions. This final phase also focuses on the transfer of project outputs, infrastructure and scientific tools to the local community of scientists, planners, managers and stakeholders. The simulation systems are designed in a generic way that allows their transfer to similar river basins elsewhere.

Society needs to adapt to changing conditions in a sustainable way taking into account regional living conditions. Strategies have to be developed which allow for adaptation to change and enable the impact of change to be mitigated, based on a sound knowledge of not only global environmental systems but also their regional setting. Programmes like GLOWA demonstrate that global change research is essential to provide these strategies.

The GLOWA initiative of the German government was one of the first long-term research programmes aimed at mitigating the anticipated impacts of global change in the water sector. It is also a good example of a national contribution to the International Hydrological Programme of UNESCO.

GLOWA's integrated approach to environmental and socio-economic sciences and the considerable resources invested (approximately 75 million €) is a unique contribution to developing sustainable resource management.

**Table 1.1 Approximate values of key comparative water and socio-economic indicators for the six GLOWA catchments**

	Danube	Elbe	Drâa (IMPETUS Morocco)	Ouémé (IMPETUS Benin)	Jordan River	Volta
<b>Area: km<sup>2</sup></b>	77 000	148 000	29 500	46 500	18 000	407 000
<b>Mean annual rainfall: mm</b>	1 240	733	167 (varies from 43 in the south to 718 in the north)	1 127 (varies between 968 and 1 481)	varies from 20 to 1 000	500 (north) to 2 000 (south)
<b>Mean annual actual evaporation: mm</b>	400	558	189 (varies from 30 in the south to 600 in the north)	883 (varies from 757 to 1 009)	20 to >500	815 (south) to 680 (north)
<b>Total population: millions</b>	11.2	24.5	30.5	8.8	Israel: 6.9 PA: 4.0 Jordan: 5.9	20.0
<b>Population density: persons per km<sup>2</sup></b>	145.5	165	70.5	55.7	Israel: 302.2 PA: 624.9 Jordan: 62.1	Between 9 (Mali) and 87 (Ghana)
<b>Annual population growth rate: %</b>	Germany: 0.1 Austria: 0.4	Germany: -0.19 Czech Republic: -0.13	1.2	3.1	Israel: 1.8 PA: 3.2 Jordan: 3.0	Between 3 (Mali) and 1.8 (Ghana)
<b>Population younger than 25: %</b>	Germany: 35.0 Austria: 32.6	Germany: 19.0 Czech Republic: 21.3	51	46 (younger than 15)	Israel: 44.0 PA: 65.2 Jordan: 57.6	Between 48 (Mali) and 39 (Ghana)
<b>GDP per capita: US\$</b>	Germany: 32 000 Austria: 36 200 Switzerland: 37 500 Italy: 29 300 Czech Republic: 22 100	Germany: 33 093 Czech Republic: 14 868	3 800	1 141	Israel: 18 354 PA: 1 152 (est.) Jordan: 2 229	Ghana: 2 480 Cote d'Ivoire: 1 648 Togo: 1 506 Burkina Faso: 1 213 Benin: 1 141 Mali: 1 033
<b>Total actual renewable water resources per capita: m<sup>3</sup>/ year</b>	Germany: 1 870 Austria: 9 570 Switzerland: 7 470 Italy: 3 340 Czech Republic: 1 290	Germany: 1 870 Czech Republic: 1 290	936	3 820	Israel: 240 PA: 203 Jordan: 148	Benin: 3 820 Burkina Faso: 930 Cote d'Ivoire: 4 790 Ghana: 2 490 Mali: 7 460 Togo: 2 930

## 2 Global change and impact assessment

### 2.1 Introduction

The GLOWA programme has addressed a number of issues of global importance including water scarcity, climate, land use and socio economic change. The GLOWA approach has been to develop multidisciplinary research teams working with local stakeholders to address problems of local, regional and international importance. Basin orientated water resource assessment is now recognised as the most sustainable approach for addressing water resource issues and has been adopted in this programme. Common to all the individual GLOWA studies has been the need to understand and model key aspects of the hydrological cycle (Figure 2.1) and the main components are summarised in this chapter. The planet’s hydrological cycle is the process that transfers water from the oceans and land to the

atmosphere and then returns water back to land surfaces and the oceans. A division can be made between “blue water” associated with aquatic ecosystems, rivers and groundwater and “green water” that supplies terrestrial ecosystems and rain fed crops and is transpired by plants to the atmosphere. This natural cycle is influenced by the impact of man including reservoir construction, water transfers, and river abstractions, effluent discharges, urban and changing land use for agriculture and forestry. These influences are particularly significant in arid and semi arid areas and in humid regions where water availability is low due to population pressures. Figure 2.2 illustrates that 97.5 % of the world’s water is in the oceans and that of the remaining freshwater component 99.6 % is stored in glaciers, rocks and as permafrost, leaving a very small percentage in rivers, wetlands and the soil.

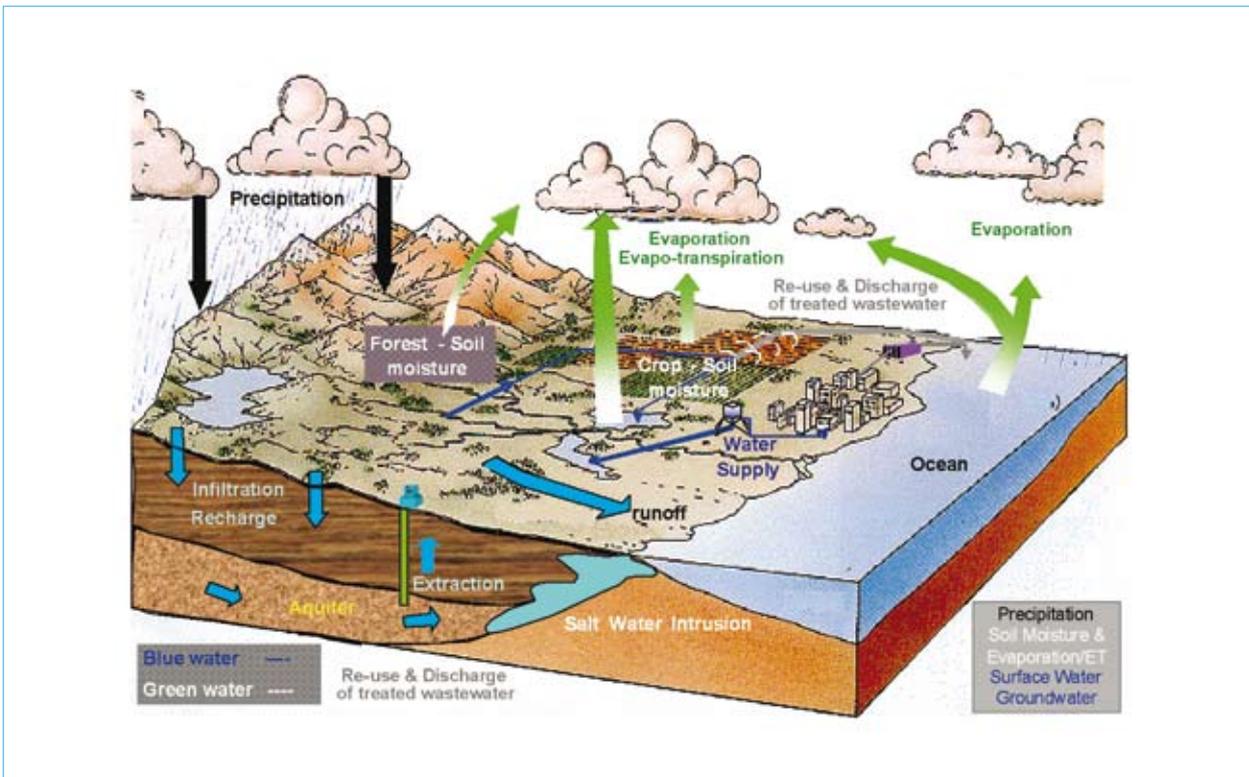
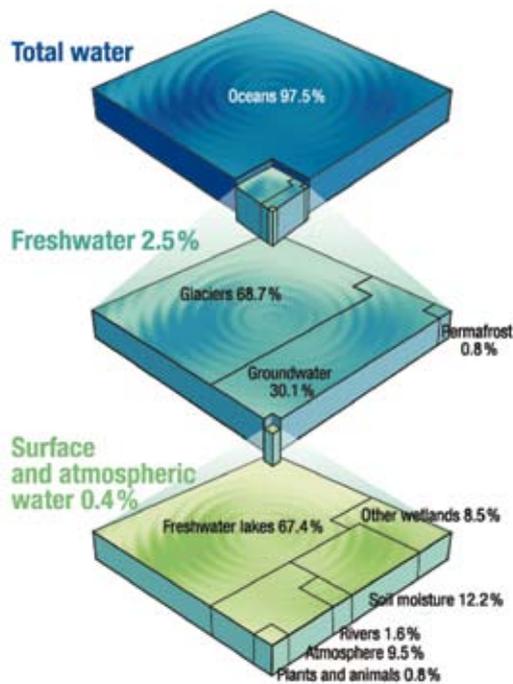


Figure 2.1 The Hydrological Cycle (Source: UNESCO 2006)

As a result any changes to the global cycle can have large impacts on the availability of water for a wide range of ecosystem use. The main components are precipitation, infiltration and soil moisture, groundwater, river flow and evaporation from water bodies and transpiration from vegetation.



**Figure 2.2** Global distribution of the world's water  
(Source: UNESCO 2006)

## 2.2 Hydrological processes

### Precipitation

Precipitation falls primarily as rain or snow. The total amount of precipitation reaching the ground during a given period is expressed as the depth in mm which would cover a horizontal projection of the Earth's surface (WMO, 1994). Precipitation is most commonly sampled by individual rain gauges read daily or monthly or automatic gauges giving data typically at 15 minute or hourly intervals. Observations are only representative of precipitation falling over a limited area in the immediate vicinity of the gauge, and, therefore to understand the spatial distribution of precipitation over a drainage basin, data should be obtained from a network of gauges. The absence or low density of measurements of rainfall and of snow cover (Section 5.4) particularly in developing countries leads to high uncertainty in the input to hydrological models.

### Evaporation and transpiration

Evaporation from open water surfaces and transpiration from vegetation are important components of the hydrological cycle. It is not possible to measure evaporation directly on a basin wide scale and so indirect methods are used incorporating solar (short-wave) and long-wave radiation, air temperature, vapour pressure and wind speed. These data are used to calculate evaporation from lakes and reservoirs or potential evaporation (PE), which assumes unlimited availability of water from a vegetated surface. Actual transpiration (ET) may then be estimated from a relationship between PE and ET that depends on the available soil moisture. The combination of the two distinct processes of evaporation and transpiration are often referred to as evapotranspiration and are expressed as a daily or annual water depth in mm.

### Infiltration and soil moisture

The process by which precipitation enters the soil is termed infiltration and is determined by the permeability of the soil and rainfall intensity. Soil moisture content expressed in mm controls rain fed and irrigated food production and is important for maintaining natural biodiversity. It has a direct influence on transpiration rates which decline rapidly as the soil becomes drier even when the potential evaporation rate is high. A variety of direct and indirect methods is used to measure soil moisture the most common of which is to use a soil moisture accounting model with daily precipitation and potential evaporation as input data.

### Groundwater

Groundwater stored and transmitted through rocks provides regional and local supplies of water and is often the source of river flow particularly during dry periods. Groundwater level data (in metres) describe the variation of hydraulic head within an aquifer, and can be readily measured using observation wells, bore holes or hand-dug wells.

Hydrological models require parameters describing the storage and movement of groundwater and these are normally derived by carrying out pumping tests and measuring the aquifers response or they are estimated from the lithology of the rock type. The most important groundwater variable is the annual recharge rate – the depth of water expressed in mm per annum that recharges an aquifer. It provides a benchmark against which all artificial abstractions must be compared to ensure that the aquifer is managed sustainably.



**Figure 2.3** Hydrological Extremes. Left: Extreme floods on River Elbe August 2002.

Right: Extreme low flows on River Rhine August 2003 (Source: IHP/HWRP Secretariat).

### River flows

River flow (synonymously streamflow, discharge or runoff) is normally estimated by measuring the hourly or daily water level (or stage) and converting it (through a stage discharge relationship) to give a continuous record of discharge known as the hydrograph. Discharge expressed in  $\text{m}^3 \text{s}^{-1}$  is the volume of water that flows through a river cross section per unit of time. Many monitoring networks are very extensive for example in the Upper Danube there are 150 flow measuring stations in an area of 77 000  $\text{km}^2$  and in the Jordan basin 55 stations in an area of 18 000  $\text{km}^2$ .

However in developing countries networks are often limited in spatial density and record length leading to greater uncertainty in water resource design and in estimating the impact of global change. The Volta basin for example is five times larger than the Upper Danube with an area of 407 000  $\text{km}^2$  but has only 91 flow measuring stations. Figure 2.3 illustrates the impact of hydrological extremes causing flood inundation on the river Elbe in Germany in August 2002. In the following August extreme low flow caused problems with navigation and restricted cooling water for thermal power plants on the Rivers Rhine and Danube.

### Anthropogenic data

Few basins remain unaffected by human activity. The operation of impounding reservoirs, public water supply and sewerage systems, irrigation schemes, land-drainage schemes and hydropower plants, and land-use change all disturb natural flow regimes. The net effect on flows is often profound and unadjusted gauged flows can be very unrepresentative of the natural conditions. In many highly developed catchments, the artificial component of flow regularly exceeds the natural component at low flow.

## 2.3 Impact assessment

### Hydrological models

Most modelling studies that investigate potential changes in river flows take a physical hydrological modelling approach to simulate continuous time series of river flows. Climatic input data series (principally precipitation, potential evaporation and temperature) are used to generate river flow time series for both the current conditions and for selected time periods in the future. The models are run under current and future climate or land use scenarios. The degree and complexity of these scenarios depends on the type of analysis being undertaken.

For example, studies that seek to understand the sensitivity of flows might use simple monthly factors of change in rainfall and evaporation. More detailed studies should use a combination of methods for constructing scenarios and some of the key issues are summarized below with respect to climate change modelling.

### Downscaling

Global Circulation Models (GCMs) provide the most reliable and robust method available for assessing the response of the climate system to changes in atmospheric forcing. GCMs are, however, subject to a number of limitations the most serious is the coarse grid of a GCM and the associated inadequacy to model short-time scale variability which is essential for most hydrological applications. This problem is addressed by using techniques to “downscale” the results of the GCM integrations to the appropriate time and space scales that are required in impact assessments. Figure 2.4 shows a 3D schematic of a typical GCM over Europe. Internally-consistent and spatially explicit scenarios can also be developed by using higher resolution climate models. These have two forms; high-resolution global Atmospheric General Circulation Models (AGCMs); and high-resolution Regional Circulation Models (RCMs).

### Uncertainty

Estimating the impact of climate change includes several stages each with their own level of uncertainty (IPCC 2001). This uncertainty is increased when considering extreme rainfall events causing flooding or the duration and extent of low rainfall which causes water shortages. Many regions of the world experience relatively flood-rich and flood-poor periods, a variability that remains poorly understood. Similarly there are extended periods of below average rainfall at the decadal time scale followed by wetter interludes. An important issue is to identify the likely change in this variability. In many cases the current knowledge-base is unlikely to be able to provide complete understanding. Data and knowledge about the nature of the processes may be lacking. This is a particular problem when there are feedback mechanisms; for example changing climate influencing the land use which in turn impacts on the hydrological response.

In addition there is the direct influence of rainfall and evaporation changes. Box 2.1 illustrates the way in which uncertainty cascades through the process of estimating climate change impacts.

The relative contribution to uncertainty from a number of sources has been investigated by Prudhomme et al (2005). The largest single source of uncertainty was found to be due to the choice of GCM. However hydrological uncertainty and that due to downscaling are also significant sources and uncertainty of greenhouse gas emissions becomes significant beyond the 2050s.

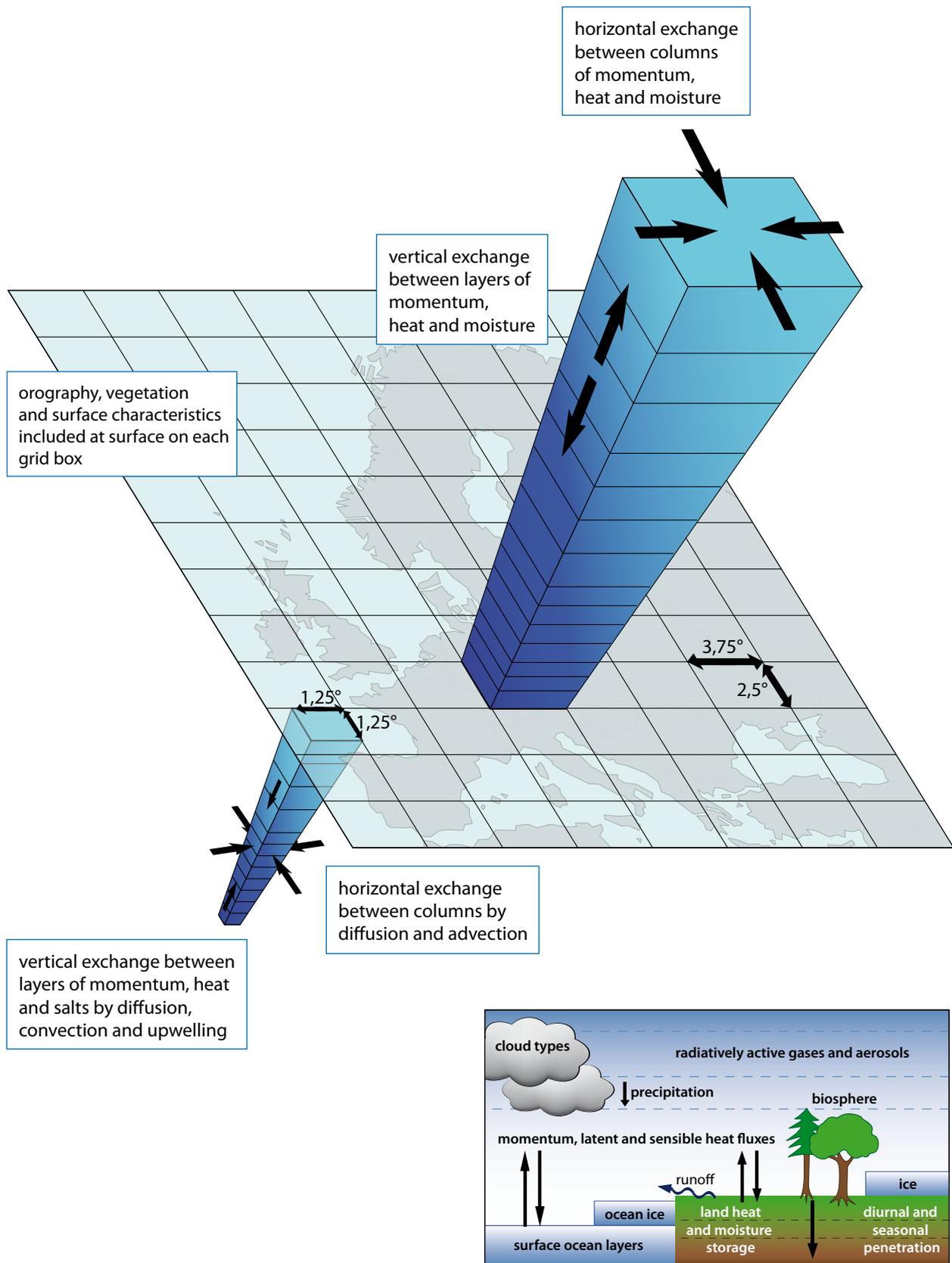
### Summary

One of the key aims of the GLOWA programme has been to reduce the uncertainty in estimating the impact of climate and land use change and other environmental and socio-economic impacts. The long term aim has been to improve the livelihoods of those people influenced by change. The following Chapters present some examples from GLOWA projects, the region where they are based, the methods used and some lessons for long term sustainable development.

#### Box 2.1 The uncertainty cascade

The uncertainty associated with applying modelling procedures cascades through an impact study to produce an overall uncertainty. For climate change impact assessments these include:

- Future emissions of greenhouse gases.
- Atmospheric concentrations of greenhouse gases. There is uncertainty about how emissions of greenhouse gases translate into concentrations in the atmosphere, and are therefore “available” to affect the Earth’s radiative balance.
- Global climate response. Scenarios derived from different GCMs produce not only different quantities of change in precipitation, but also changes in different directions (Jenkins and Lowe 2003).
- Local/ small-scale climate response. Global models produce climate change scenarios that are generally too coarse in both space and time for application to catchment impact models. “Downscaling” is required, adding additional uncertainty.
- Natural climate variability is high and this must be incorporated.
- Hydrological impacts require the calibration of a hydrological model and this introduces further uncertainty in model structure and calibration.



**Figure 2.4** A 3D schematic of a typical global circulation model  
 (Source: Dr. David Viner 1989, 2002; Climate Research Unit, UK [modified])

## 3 GLOWA case studies

### 3.1 Danube

#### Impact of Global Change on the Upper Danube

Global Climate Change will have significant long term impacts on water resources. These will include an increase in extreme events (floods and low flows), a decline in snow cover, deglaciation in the Alps and changes in natural vegetation and agriculture in the Upper Danube. In order to plan future investments in water resources, energy, agriculture, tourism and industry a detailed analysis of the impact of Climate Change is required.

The GLOWA-Danube project ([www.glowa-danube.de](http://www.glowa-danube.de)) focuses on the mountainous regions of the Alps and the forelands of the Upper Danube. (Figure 3.1). The Upper Danube is the headwater of Europe's second largest river, has more than 11 million inhabitants, and extends from temperate lowlands to glaciated mountain ranges higher than 3500m. For further details see Box 3.1.

The Upper Danube has a current water surplus serving the large downstream regions of the Danube. Water resources are optimised to meet the demands of transport, tourism, irrigation, hydropower generation and industry using extensive reservoir storage and water transfer schemes. These demands will be sensitive to expected climate change because of the large altitudinal gradient (approximately 3000 m), the importance of both snow and glacial melt water (Figure 3.2) and the anticipated changes in seasonal water availability. Any change in water resources in the Upper Danube will also affect the large and developing population in downstream Central and Eastern European countries which have recently joined the European Union. These complex environmental, economic, social and political factors make it essential to study the impact of climate change.

No single scientific discipline is capable of understanding these complex interactions. This challenge



#### Box 3.1 The River Danube

- Overall length approx. 2,850 km
- Total catchment area 817,000 km<sup>2</sup>
- Size of the Upper Danube project area 77,000 km<sup>2</sup>
- Current population in the Upper Danube catchment of approximately 11.2 million (2006)
- Averaged annual rainfall in the catchment 1,240 mm (1971–2000)
- Averaged annual discharge at gauge Achleiten (near Passau) 1,430m<sup>3</sup>/s (1901–2005)
- Water quality in the region is currently among the best in Europe
- The Alps are currently the largest surplus water region in Europe

Figure 3.1 The Upper Danube Basin



**Figure 3.2**  
The confluence of the river Inn (coloured green by cold water from glaciers) and the river Danube at Passau, Germany.

was addressed within the GLOWA project by co-operation between a group of researchers from different natural and socio-economic science disciplines, consisting of hydrologists, water resources engineers, meteorologists, glaciologists, geographers, ecologists, environmental economists, environmental psychologists and computer scientists.

### 3.2 IMPETUS: Ouémé and Drâa

#### Introduction

Sub-Saharan West Africa has one of the most variable climates in the world and this variability has been particularly high during recent decades. Similarly the subtropical climates of Northwest Africa are characterized by considerable annual and decadal precipitation variability. The 4<sup>th</sup> Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) predicts an overall warming trend for Africa, with dryer conditions in subtropical North Africa and uncertainty in future rainfall trends in West Africa. In addition to climatic factors the water resource situation in West and Northwest Africa is aggravated by increasing water demand. This is due primarily to high population growth, which significantly reduces the water availability per capita. Food production, livelihood security, and the gross domestic product of the region depend to a large extent on crop yields and, thus, on rainfall variability. In tropical Africa,

various diseases, including malaria, dengue fever, meningitis, and diarrhoea are also directly affected by weather and climate conditions.

In order to solve present and future water supply problems an interdisciplinary approach was adopted covering natural, social, and medical sciences. For West and Northwest Africa, IMPETUS ('An Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa', [www.impetus.uni-koeln.de](http://www.impetus.uni-koeln.de)) a joint venture of the Universities of Cologne and Bonn in association with stakeholders in the region has adopted this integrated approach.

The wadi Drâa in south-eastern Morocco and the Ouémé river in Benin (Figure 3.3) have been selected because they both meet the following criteria: feasible size (<100.000 km<sup>2</sup>), availability of existing data, politically stable, relevant environmental and socio-economic conditions, and regionally representative in the following context. The Drâa catchment in southeast Morocco is typical of a gradient from semi arid subtropical mountains to their arid foothills; the Ouémé basin in Benin is typical of a wet to dry sub-humid climate of the outer tropics. The Ouémé river drains about half of Benin, whereas the wadi Drâa is the most important river flowing from the Atlas mountain chains towards the Sahara desert. For more details see Boxes 3.2 and 3.3.

### Box 3.2 Benin and the Ouémé catchment

Benin is located at the Guinea Coast of West Africa and has common borders with Togo, Burkina Faso, Niger and Nigeria. The country is 620 kilometres from south to north stretching from the Gulf of Guinea, a part of the tropical Atlantic Ocean, to the Niger river. Benin can be subdivided into five natural landscapes: The northern plains draining to the Niger and Volta rivers, the Atakora low mountain range in the northwest, the Precambrian basement with several inselbergs between the Atakora range and the city of Abomey, the “terre de barre” lowlands directly to the south, and the coastal plain. Benin is located in the sub-humid wet and dry tropics with a bi-modal rainy season in the south and a single rainy season peaking in August in the north. The mean annual rainfall varies from less than 800 mm in the north to 1400 mm in the southeast and the Atakora Mountains. During November to March much of the country is influenced by the dry and dusty Harmattan winds originating over the Sahara desert. The dominating vegetation type is Savannah and dry forest.

After independence from the French colonial rule in 1960, the country was called “Republic of Dahomey”. In 1975, former President Kérékou changed this name into the more impartial “Benin” which was a historical kingdom located in neighbouring Nigeria. Since 1990, Benin has been a Republic with a parliamentary presidential system. Following the decentralisation reforms in 2002 Benin is subdivided into 12 administrative regions called Départements.

On a lower level, the former “Sous-Préfectures” have been given increased responsibilities and now form 77 financially independent area-municipalities called “Communes”. IMPETUS estimated that Benin has a population of about 8 million with considerable ethnic diversity including a predominantly Islamic population in the north, and Christian, Voodoo and other traditional religions prevailing in the south. Benin’s economy is based on agriculture, trading and transport. The most important commercial crop and export product is cotton, accounting for up to 16.7% of the GDP in 2006 (EIU), followed by other crops like cashew, shea-butter, palm oil and pineapples. The UNDP Human Development Index, which measures health care, education and standard of living, ranks Benin at 163rd position out of 177 countries (UNDP).

The Ouémé river is the largest river of the country with a catchment area of about 46,500 km<sup>2</sup>. It reaches from the Atakora Mountains to the Guinea Coast. It consists of two main basins: the “Upper Ouémé basin” which is part of the Dahomey pediplain and the “Lower Ouémé” basin situated on the coastal sediments.

### Box 3.3 Morocco and the Drâa catchment

The Kingdom of Morocco (Al Mamlakah al Maghribiyah) is situated in North West Africa, bordering the North Atlantic Ocean and the Mediterranean Sea. At the transition zone to the Sahara desert it has common borders with Algeria and Mauritania. Morocco’s geography is diverse. The lowlands in the North and between the Atlantic Ocean and the Atlas Mountains are fertile and relatively well developed. Together with the industrialised urban conglomerations around Casablanca and other northern and coastal cities they form the economic backbone of the country. The mountainous areas and the region south of the Atlas Mountain chain have long been economically marginalised. In 2007 Morocco’s GDP per capita was 3,800 \$ with an annual growth rate of 2.1%. Today, tourism accounts for Morocco’s largest source of foreign revenue, second only to wages sent home by Moroccan workers abroad. In 2000, Morocco entered an Association Agreement with the European Union. The total population is about 31 million, of which 51 % are younger than 25 years (2008). 99 % of the population are Muslims with small minorities of Christians and Jews. Arabic is the official language and French is often the language of business, government, education and diplomacy. Approximately 12 million (40% of the population), mostly in rural areas, speak Berber. From 1912 until its independence in 1956 when Mohammed V ascended to the throne, Morocco was a French protectorate. Today Morocco is a constitutional monarchy. The present King, Mohammed VI followed his father Hassan II who ruled the country as a political and spiritual leader from 1961 to 1999. Administratively the country is divided into 16 regions and subdivided into 62 prefectures and provinces each led by a governor. Below the level of the provinces, 162 “cercles” are made up of 1497 communes, the latter headed by elected representatives. Morocco can be subdivided into at least four climatic zones: the Atlantic coastal zone including the inland plains, the Mediterranean coastal zone, the Atlas Mountains and a steppe or Saharan climate to the south of the main divide. The Atlantic and Mediterranean coastal regions receive most rainfall between November and March. Due to the relief, amounts vary between 300 mm at the somewhat drier Mediterranean coast to more than 700mm in the northwest. The mountain climate is characterized by higher rainfall on the windward (i.e. north-western) slopes and a strong decrease on the leeward side. Above 2500 m snow cover in winter is frequent and exceeds over six months on the highest parts of the mountains. The Saharan foothills receive less than 200 mm annually, mostly in the autumn and spring. The Upper and Middle Drâa basin extends from the High Atlas Mountains, whose summits exceed 4000 m a. s. l., to the pre-Saharan foothills at about 450 m a. s. l. The catchment size is 29,500 km<sup>2</sup> and includes the Ouarzazate basin, six river oases downstream and parts of the Anti-Atlas, Jebel Saghro, Jebel Siroua and Jebel Bani Mountains.

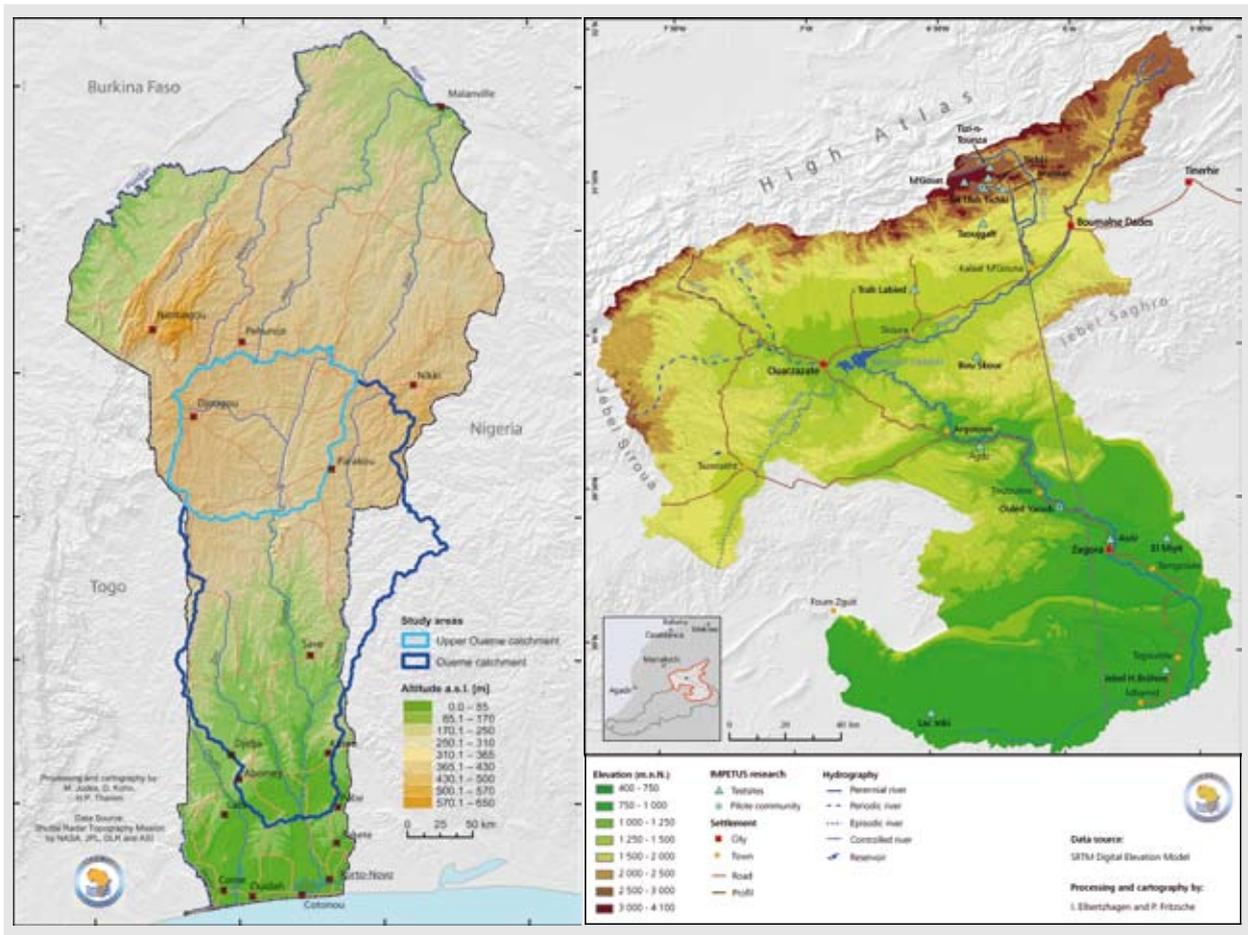


Figure 3.3 Left: The Ouémé catchment. Right: The Drâa catchment.

**The IMPETUS approach**

Sustainable water management in the watersheds of the Drâa and the Ouémé must be based on reliable data for regional planning and political decision making. A comprehensive diagnosis of the water cycle was carried out during the first project phase. In the second phase, qualitative and quantitative models were developed or existing models modified. Projections of future developments were derived from scenario analysis, process understanding, and from expert knowledge. In the final phase Spatial Decision Support Systems (SDSS), Information Systems (IS) and Monitoring Tools (MT) have been developed and applied to a set of “problem clusters”. Single solutions were not appropriate for the wide range of complex problems and thus a multi-disciplinary approach was essential. The techniques used in IMPETUS ranged from information retrieval, to advanced simulation with dynamically-coupled models for estimating the effects of policy interventions. The IMPETUS approach is summarised in Figure 3.4.

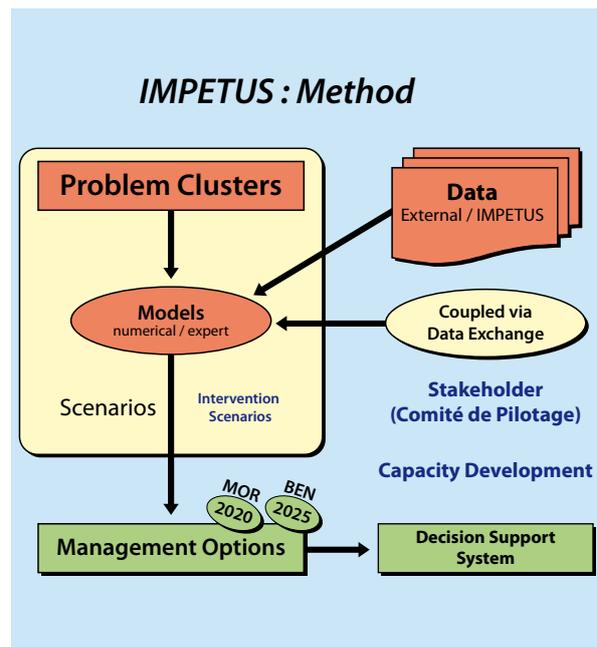


Figure 3.4 Schematic representation of the IMPETUS approach

## Scenarios

Scenarios are consistent and plausible images of alternative futures that are comprehensive enough to support the decision making process. A meaningful scenario shows different societal, environmental and technological aspects of the system under investigation. IMPETUS uses a two-step approach. The first was a thorough analysis based on detailed field studies and surveys, a pre-requisite due to sparse data in both catchments. On this basis, the major driving forces were identified and qualitatively and quantitatively described. In a second step, the driving forces were projected into the future. They included but were not limited to, economic, agricultural, environmental, political, and demographic development. Thus broad scenarios of possible future developments were covered: two reflected more extreme, yet still realistic developments, whereas the third one represents a business-as-usual scenario.

Target years were based on pre-existing long-term government strategy papers for 2025 for Benin and 2020 for Morocco. In order to account for variations in the driving forces within the catchments, the Ouémé and Drâa basins were divided into three sub-regions.

For Benin, the three scenarios are as follows:

1. **“Economic growth and consolidation of decentralisation”** describes a scenario of political stability and economic growth. Living conditions of the population improve and the overall pressure of resource depletion decreases due to technical innovations.
2. **“Economic stagnation and institutional insecurity”** sketches a development path of a continuing and mutually influencing spiral of political destabilisation and economic depression. Declining world market prices for the main export products, decreasing grants of donor assistance and declining rates of regional and local economic cooperation lead to negative overall economic development.
3. **“Business-as-usual”** extrapolates the current trends. The country is successful in maintaining its political stability but fails in improving its position on the world markets and its overall competitiveness. Population growth continues to decline and the traditional power structures on the local level remain unchanged.

For Morocco, the three scenarios are as follows:

1. **“Marginalisation – non-support of the Drâa-Region”** describes a scenario of stagnation and marginalisation in the industrial, agricultural, and tourist sectors. Productivity in the dominant agricultural sector remains low. This leads to deterioration of living standards and increased migration.
2. **“Rural development in the Drâa-Region through regional funds”** reflects a scenario of increased productivity in the agricultural sector, a strong growth of tourism, a decrease of migration due to alternative income possibilities, and a more sustainable use of natural resources including water and pastures.
3. **“Business-as-usual”** depicts a scenario of low-level industrialisation, tourism is restricted to a few areas, agriculture continues to dominate the economy but its further expansion is constrained by water scarcity. There is high population growth in a few urbanized areas despite high rates of migration and childhood mortality.

The three scenarios can be further refined by intervention scenarios which enable the impact of a change of policy and the actions of decision makers to be assessed. Finally, the climate scenarios described below are chosen as external driving forces to the three catchment-specific scenarios.

## Climate scenarios

The 4<sup>th</sup> IPCC AR report recommends that regional climate change projections should ideally be based upon information from four potential sources: global climate model simulations; downscaling of simulated data from these global models using techniques to enhance regional details; physical understanding of the processes governing regional responses; and recent historical climate change (Christensen et al. 2007, p. 849). Each of these has been pursued within IMPETUS for both basins. Dynamical and statistical-dynamical approaches have been employed in the project to enhance regional details. The hierarchy of models and the major climate forcing factors are shown in Figure 3.5.

Research within IMPETUS has identified that not all regional climate processes are adequately represented in the numerical models. In order to cover the

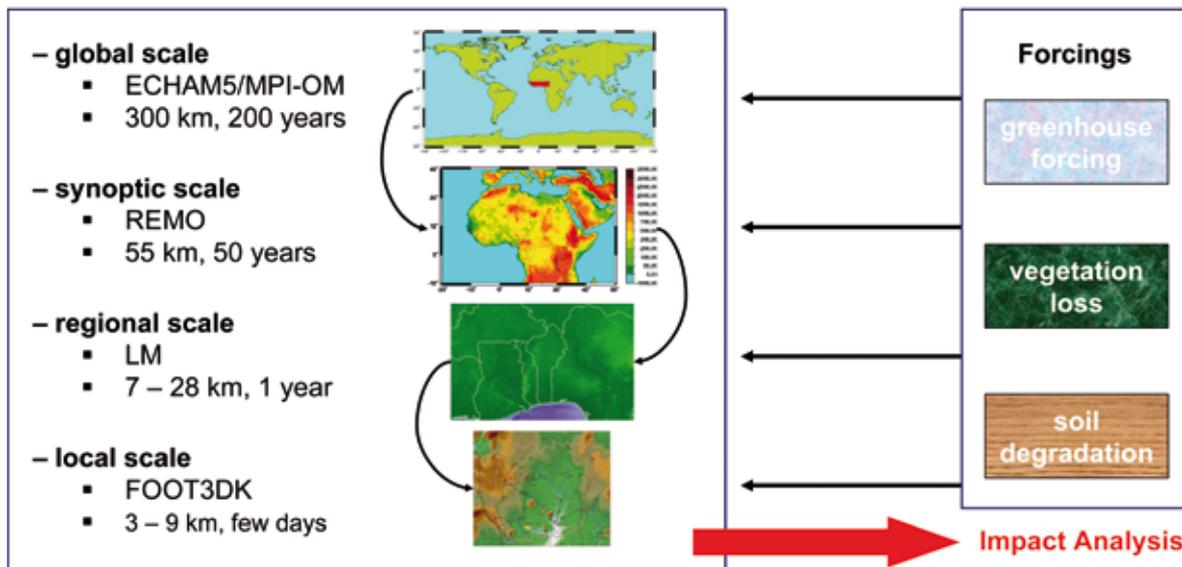


Figure 3.5 The IMPETUS model hierarchy and driving forces

reasonable projections of regional climate change, three climate scenarios were defined:

- “Transient climate model predictions”
- “Process understanding”
- “Persistence of recently observed trends (business-as-usual)”

To construct the scenario (a), ensemble model simulations driven by IPCC greenhouse gas emission scenarios A1B and A1 and by FAO-based land use changes were performed using the IMPETUS model hierarchy (Figure 3.5). This enables the simulation of a wide range of impacts, involving the application of numerical and expert models of other disciplines. Mathematical models could not be applied in the (b) and (c) scenarios, and thus the impact studies are somewhat limited.

#### Decision support systems

For each problem cluster IMPETUS has developed either one or more Spatial Decision Support Systems (SDSS), Information Systems (IS) or Monitoring Tools (MT) in order to provide tailored tools for decision making. The models are either numerical or expert and they are coupled via data exchange (“loosely coupled models”). A number of computer models were developed, in the disciplines of climatology, hydrology, agriculture, socio-economics, and health. SDSS are dynamic as they permit new information to

be generated by running the embedded models, whereas the information content in the IS is static. Monitoring tools (MT) complement the set of decision systems by providing near real-time data of the hydrosphere and biosphere based on remote sensing.

#### Stakeholder dialogue and capacity development

A high priority has been given to ensure that there is active participation in the development and use of all decision support tools by local stakeholders and this has been supported by capacity development of local partners.

The IMPETUS tools and systems can be used by:

- decision makers who would like to carry out scenario analysis on a range of options.
- scientists interested in improving the approaches, models, and the decision making process.

The stakeholder dialogue and capacity development measures involve national administrations, academic institutions, communes and individual users. This broad spectrum will foster the long term sustainable implementation of the tools in each country. This is completed by mirroring the extensive IMPETUS data base at various regional institutions and by making many tools available to everyone interested by means of both web-based digital atlases and printed versions of Benin and Morocco (Judex and Thamm 2008, Schulz and Judex 2008).



#### Box 3.4 the Jordan River

- Length: 320 km
- Catchment area: 18,000 km<sup>2</sup>
- Flows from its sources in Israel, Jordan, Lebanon and Syria through northern Israel into Lake Tiberias and on to the Dead Sea
- The Jordan River water resources are used almost to capacity for drinking and crop production
- Per capita water availability in the region is among the lowest in the world:

Israel	240 m <sup>3</sup> /year
Jordan	148 m <sup>3</sup> /year
Palestinian Authority	203 m <sup>3</sup> /year

(Source: World Resource Institute 2007)

**Figure 3.6** The Jordan River during an exceptionally wet year

### 3.3 Jordan River

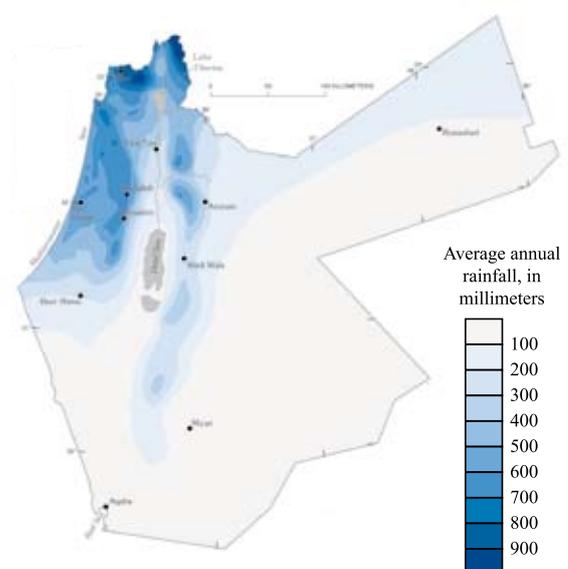
#### Introduction

The Middle East is one of the most water-stressed regions in the world where 5% of the world's population has to survive on only 1% of global fresh water resources. The availability of renewable water is well below the absolute water scarcity threshold of 500 m<sup>3</sup> per capita per year (Box 3.4, Figure 3.6). Decreasing water availability due to climate change and rapidly increasing demand will exacerbate the water gap and highlights the urgent need for sustainable water management.

The River Jordan's climate ranges from arid to a Mediterranean climate with seasonal, low annual rainfall, high evapotranspiration, low recharge to aquifers and low river discharge. Regional water management has to account for climatic conditions that are extremely variable in space and time. Climate varies over very short distances from extremely arid (20 mm mean annual rainfall) to a sub-humid Mediterranean climate (up to 1000 mm mean annual rainfall) (Figure 3.7).

Annual rainfall is very variable, ranging from 300% in the arid environments to 50% in more humid regions.

The steep climatic gradients are also associated with diverse ecological conditions which have made the region's plant and animal diversity unique and of global importance.



**Figure 3.7** Average annual rainfall in the GLOWA Jordan River project region (Source: EXACT 1998)

### Water resources

Groundwater provides more than 50% of the region's water and is the main source of water in the Jordan River basin (Figure 3.8 and Figure 3.9), particularly in the lower catchment. The *Mountain Aquifer* of the central West Bank and parts of Israel is the main groundwater source in the region. Withdrawal rates often exceed natural recharge and conjunctive surface and ground water management is urgently needed.

Surface water accounts for 35 % of the region's fresh water. The Jordan River basin is the main freshwater system and plays a major role for economic and social development. Israel, Jordan and the Palestinian Authority are the main beneficiaries of the Jordan River watershed. The Jordan River is fully utilised and the river flow downstream of the Lake Tiberias is negligible (Figure 3.10). This situation has resulted in two hydrologically separate watersheds – the upper and the lower catchment south of Lake Tiberias. Much of the water in the upper catchment is diverted to the Coastal Plain and the Negev desert via the Israeli National Water Carrier. The use of the upper Jordan River has been regulated in a bilateral agreement between Israel and Jordan.

As a consequence, Israel meets 40 % of its demand from these resources, as opposed to only 5 % for Jordan. Therefore, strategies for managing the upper catchment are most relevant for Israel and they must include areas which are outside the natural watershed. Downstream of Lake Tiberias, the Yarmouk River feeds the lower Jordan River from the East. However, this water is mostly used for agricultural purposes and diverted through the King Abdullah Canal in Jordan, leaving little water to maintain the base flow of the lower Jordan River.

### Value produced by the region's water

Most of the freshwater and groundwater resources are used for irrigated agriculture. However, in Israel and Jordan agriculture plays a minor role for the national economies. Even in the Palestinian Authority, there is a mismatch between the amount of water used for agriculture (approx. 70 %) and the value produced by agricultural products (approx. 13 % of GDP). An important though often overlooked value of water is ecosystem services including tourism, erosion control, fodder and nutrient cycling. Unfortunately, the quantification of the monetary value of ecosystem services is still rudimentary in the region.

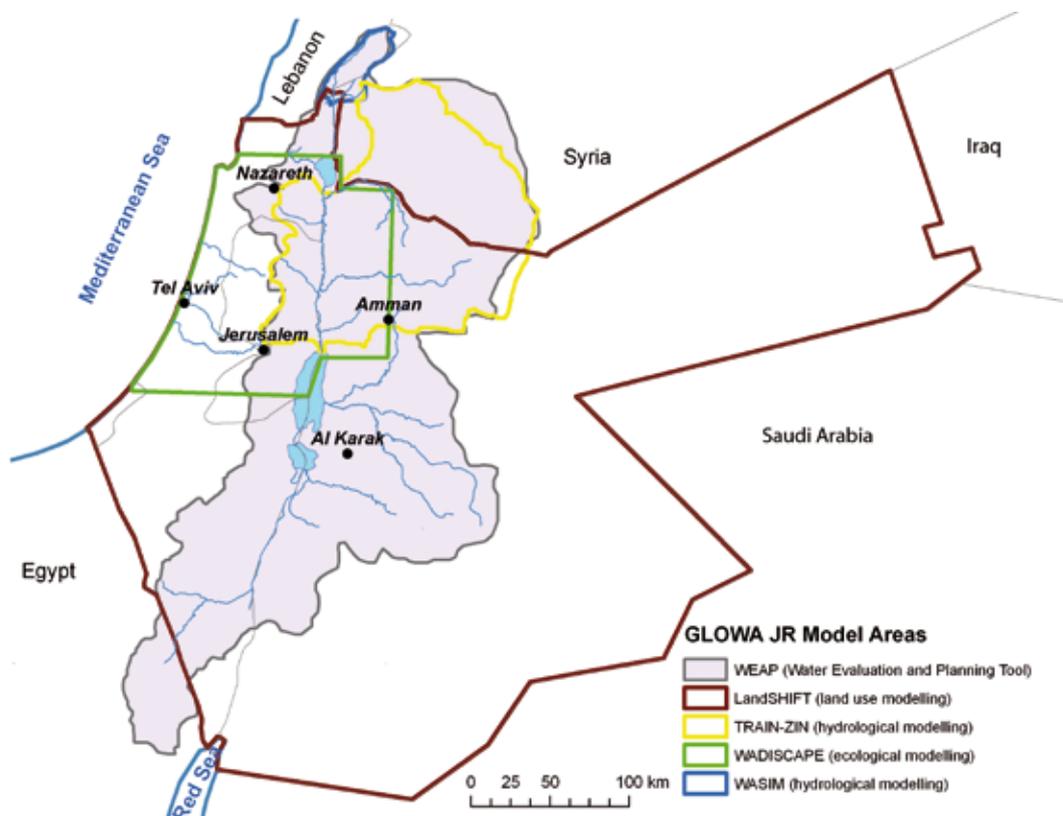


Figure 3.8 GLOWA Jordan River project area stretching out over Israel, the Palestinian Authority and Jordan



**Figure 3.9** Satellite image of the GLOWA Jordan River project region showing the climate-driven variation in vegetation cover  
(Source: NASA, 2000–2002)

**Figure 3.10** The Lower Jordan River in an average year

### Water demand – the water crisis

Amongst all GLOWA case studies, the Jordan River is perhaps the most challenging. Global climate models and regional GLOWA Jordan River models both indicate that the region will experience a decrease in average annual precipitation, an increase in temperature and increased probability of extreme events. The region's ground and surface water resources already suffer from over-exploitation with recurring water shortages during the dry season. For example the level of Lake Tiberias drops by up to one centimetre per day during the summer months and the Dead Sea (a world heritage site of global importance) by approximately 1 metre annually. This has resulted in negative consequences for the local tourism and detrimental environmental effects (Figure 3.11).

Annual population growth in the region is among the largest in the world (1.8–3.2%) and even without the predicted decreasing water availability, the gap between supply and demand will rapidly increase (Figure 3.12). Furthermore, general environmental problems and deterioration of water and land quality will be aggravated. Although water negotiations between countries have been maintained, the conflict

of interests over water resources will increase both within and between political boundaries.

### Management options

The water gap has to be closed through innovative solutions in all sectors aided by the long-standing tradition of coping with water scarcity. Traditional adaptation options include water harvesting techniques and cultivation of drought-resistant crops. In recent decades, the region has developed advanced technological solutions for increasing water productivity including efficient drip irrigation, use of greenhouses, re-use of treated wastewater and desalination. Desalination of seawater is now economically viable and desalination plants have been established on the Israeli Mediterranean coast and more are planned. Transboundary cooperation and knowledge transfer will result in further increases in water use efficiency in agriculture. Because natural water resources are insufficient for meeting current and future demand, more water is imported in agricultural products than exported. This “virtual water” may account for up to three times the amount that would be naturally available. In addition, real water imports, e.g. from Turkey, have been discussed.

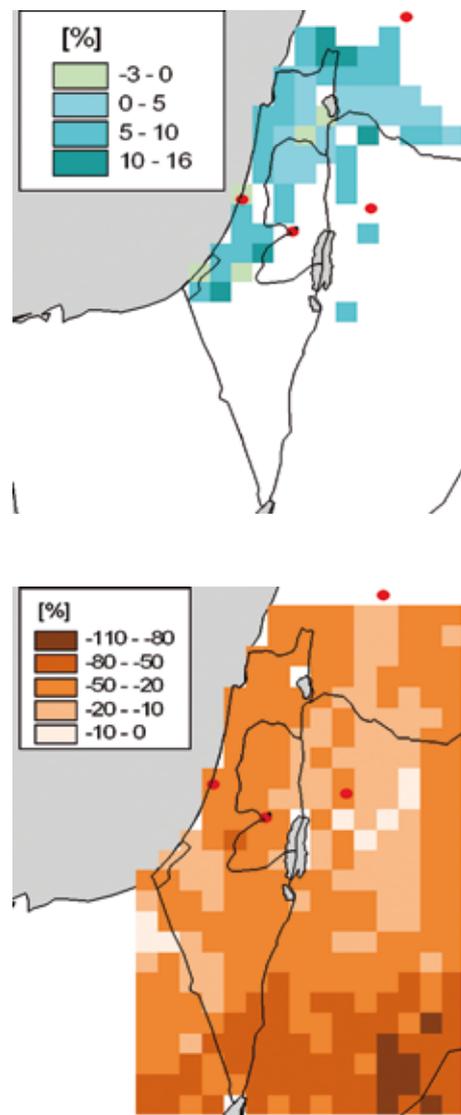
To overcome the dwindling natural water resources several ‘new’ water sources have been identified. A highly controversial proposal is the so-called Red Sea – Dead Sea Conduit.

Seawater flowing from the Red Sea (sea level) into the Dead Sea (400 m b.s.l.) could be desalinated and a fraction of this water could restore the Dead Sea. Because of potentially irreversible environmental impacts, a feasibility study of this project is currently being conducted by the World Bank and other international donors. GLOWA JR complements this study through the systematic evaluation of upstream alternatives to the Red-Dead Canal and “new water” solutions.

An amplified approach of integrated water resource management (IWRM) can be used to analyse the complex interactions between resource use, response of natural systems and land use change. In this context, GLOWA Jordan River fills a large gap in the development of sustainable water management strategies for the region.



**Figure 3.11** Sink holes at the bank of the Dead Sea have occurred due to the falling water level



**Figure 3.12** Top: Net irrigation water demand (%).  
 Bottom: Predicted mean water availability (%)  
 (2041–50 vs. 1961–90)  
 (Source: GLOWA JR, Menzel et al.)

The project is science-based and can thus integrate, across sectors and between supply and demand management options. Its unique focus on global change processes has increased the awareness of the efficient use of “green water” – the water in soils and plants that sustains rain-fed agriculture, pasture farming and natural ecosystems. The lessons learned from the project are highly relevant for other semi-arid areas and regions with transboundary water resources and provide the long term potential to contribute to the adaptation to global climate change.

### 3.4 Volta

#### Physical characteristics

The Volta Basin is a major West African river basin that drains an area of 407,000 km<sup>2</sup> into the Gulf of Guinea (Figure 3.13). It is situated in the sub-humid to semi-arid West African Savanna Zone, and shows distinct North-South gradients. The south of the basin is part of a larger forest zone, which transgresses into a tree savanna, and further north into dry woodland savanna (Figure 3.14). Annual precipitation rates vary from 2,000 mm in the south, to 500 mm in the northern parts of the basin. Potential evaporation rates are high, ranging from 1,500 mm in the south to more than 2,500 mm in the north, and less than 10 % of the precipitation becomes useable as river flow. With greater distance from the coast, aridity increases, the growing season becomes shorter, and rainfalls are more erratic. The basin is shared by six riparian countries, of which Burkina Faso (42 %) and Ghana (40 %) share the major portion, and the remaining 18 % are shared by Togo (6 %), Mali (5 %), Benin (4 %), and Cote d'Ivoire (3 %). (Barry et al. 2006).

The most significant hydrological structure is the Akosombo Dam, which holds back the water of the White Volta, Black Volta, and the Oti for the generation of hydro-power. Its construction was completed in 1965 and formed Lake Volta, which is still the second largest (8,500 km<sup>2</sup>) man-made lake in the world today. The Akosombo Dam is of strategic importance to the economy of Ghana. It generates 80 % of the power produced in the country. The presence of a reservoir of such dimension at the very downstream part of a major river basin is rather uncommon. In the vast upstream areas, irrigation constitutes the largest consumptive use of water, which competes directly with the hydropower generation in the south. For the next two decades, a dramatic increase in irrigation water demand is projected for the northern regions of the basin, which requires well developed transboundary water management. Its importance becomes apparent from the administrative segmentation of the basin. Burkina Faso, for example, occupies large upstream areas and seeks to develop its irrigation capacities and hydropower generation, whereas Ghana is the downstream riparian country depending on the inflow from their neighboring countries. However, essential data for the management of water resources is lacking and the institutional framework for the management of shared water resources both on the international as well as national level is still being developed.



**Figure 3.13** The Volta Basin, West Africa, and its physical characteristics.

#### Demography

It is estimated that the Volta Basin has a population of approximately 20 million people. Population settlement in the Basin countries is largely rural, the rate ranging between 56 and 83 %. The population density varies considerably, being highest in Ghana (87 persons/km<sup>2</sup>), and Togo (86 persons/km<sup>2</sup>), and lowest in Mali (9 persons/km<sup>2</sup>). Population density ranges between 40 and 60 persons/km<sup>2</sup> for all other countries.

The population of the countries of the Volta Basin is one of the fastest growing populations worldwide. The population of Benin, Burkina Faso, Togo and Mali is growing at an annual rate of between 2.5 and 3.0%; in Ghana and Cote d'Ivoire between 1.8 and 1.9%. The population of the Basin is young, in Benin, Burkina Faso and Mali 44–48 % of the population are between 0–14 years while in Ghana this share of the population is lowest (39 %).

However, the major portion of the basin population falls into the working age group (15–64 years). This points to a reduction of the population growth rate, especially in rural areas. Nevertheless, it is estimated that over the next 40 years, Benin, Burkina Faso, and Mali will more than double their populations, while all other countries will experience an increase of between 70 and 90 % (UNDP 2007).



**Figure 3.14** Vegetation zones in the Volta Basin. The southern part of the Basin is part of the forest zone (I). To the north it transgresses into a tree savanna (II), and into a dry woodland savanna (III). (See Figure 3.13 for spatial reference).

**Socio-economic development**

Social development in the basin’s countries remains problematic (see Box 3.5). Adult literacy rates remain low and range from about 24% in Burkina Faso and Mali to 57.9% in Ghana. Access to safe drinking water varies from 50 to 84%.

In general, access to safe drinking water is lower in rural areas than in urban areas. In the Basin countries, diseases such as tuberculosis, malaria, and diarrhoea are common, with HIV/AIDS being a serious problem. According to the World Development Report 2007, all of the Volta River Basin countries, except Ghana and Togo, are considered to have low human development

and are among the poorest nations in the world with an average per-capita GDP of about US\$ 1,500. In terms of populations below international poverty lines, Mali, Burkina Faso, Benin and Ghana have more than 70% of their population living below the US\$ 2 a day poverty line. However, during 2007, Benin, Burkina Faso, Mali and Ghana registered a robust GDP growth rate of 4–5%, while Côte d’Ivoire’s growth rate remained low (1.2%) in the aftermath of civil war. In general, the Basin countries have high debt burdens, with an annual total debt service ranging between 0.8% (Togo) and 2.8% (Cote d’Ivoire) of the GDP (UNDP 2007).



**Box 3.5 Trajectories of change**

High population growth, land degradation and climate change remain causes for concern in terms of food security, poverty alleviation, risk mitigation, disaster recovery, and environmental sustainability in the Volta Basin.

Annual population growth of up to 2.6%, poverty and a large dependence on agriculture leads to land cover and land use changes. Land degradation is rampant and 35% of Ghana’s land surface and 75% of Burkina Faso is under the threat

of desertification. While the effects of climate change are varied, model prediction for 2030-2039 points to an increase in temperatures (1.2–1.3°C), shorter and less reliable rainy seasons, and the increase of extreme events. Precipitation over West Africa has already decreased between 20–40% from 1931–1960 and 1968–1990 (IPPC 4) These trends will greatly increase pressure on aquatic ecosystems as well as other natural resources.

The Basin countries show some variability in terms of their livelihood sources. The agriculture sector contributes between 35 and 40% of the value-added to GDP in all countries, except Côte d'Ivoire (only 25%). The agriculture sector accounts for 86% of total employment in Mali, and 92% in Burkina Faso.

In Ghana, a country richly endowed with natural resources, the mining of gold, diamonds and bauxite adds significantly to the GDP. As the Basin countries are largely rural, the agriculture sector employs the largest share of the labour force (60–92%), with services next (6–30%), and industry ranking third (2–16%). The services sector is dominant in the urban areas, whereas agriculture dominates in the rural areas. Farmers in the Volta Basin depend largely on rainfed agriculture, while the proportion of crops produced through irrigated agriculture is still far below international standards.

Rainfed agriculture is, however, jeopardized by erratic and unreliable rainfall, which is likely to worsen due to global climate change. For this reason, knowledge of the ever more volatile onset of the rainy season is of great importance to reduce the risk of early crop failure in rainfed agriculture, and to improve food security (UNDP 2007).



Figure 3.15 The Elbe basin

### 3.5 Elbe

The river Elbe is the most easterly large tributary of the North Sea. The total Elbe basin has a catchment area of 148,268 km<sup>2</sup>, one third of it in the Czech Republic (see Figure 3.15). Water availability in the Elbe basin is the second lowest compared to other major European rivers due primarily to the low annual precipitation (Table 3.1). This makes the region vulnerable to climate change which has been characterised by three recent trends (Table 3.2): increasing mean annual temperatures, a shift in precipitation patterns towards increasing winter precipitation and a decrease of total precipitation in the central parts of the basin (Wechsung et al. 2005). A continuation of the current trends in the central part of the Elbe river basin would most likely lead to increased water conflicts and to the emergence of new ones.

Table 3.1 Elbe basin facts

Length of the main stream [km]	1,091
Area [km <sup>2</sup> ]	148,286
Population density [capita/km <sup>2</sup> ]*	193
Urban area [%]*	7.3
Agricultural land [%]*	61.3
Arable land [%]*	49.4
Forest [%]*	27.1
Water [%]*	1.4
Specific run off [l/km <sup>2</sup> s]*	5.3
Total water availability [m <sup>3</sup> /capita year] including the Czech part**	680

\* from Behrendt 2004 for 1993–1997

\*\* Stanners & Bourdeau 1995

The political agenda for water management is set by the European Water Framework Directive (EC 2000), which is strongly orientated towards the sustainable use of water resources with the main target to establish good ecological status of surface waters.

In the German Elbe basin as well as elsewhere, this involves addressing current sustainability deficits and adjusting to the challenges of future climate and socio-economic changes. A summary of present trends in welfare, the development of the water sector and the economy relevant to this adjustment is given in Table 3.3.



**Figure 3.16** A classical view down into the Saxonian Elbe valley in contrast to a devastated Lusatian landscape of open pit coal mining

Table 3.2 Recent climate characteristics and trends for the German Elbe river basin	
1951–2000 of 50 year average in	Median basin values*
Annual mean temperature [°C]	8.6
Annual precipitation total [mm]	616**
Annual climatic water balance [mm]***	22
of 50 year linear trend changes in	
Annual mean temperature [°C]	+1.1
Annual precipitation total [mm]	-1
Summer	-46
Winter	+50
Annual climatic water balance [mm]	-34

\* Median of basin means and linear trends (significant to more than 80%) from 369 climate stations

\*\* Uncorrected observations

\*\*\* Difference between precipitation and potential evapotranspiration calculated following Turc-Ivanov

Historically three key anthropogenic changes have occurred:

- The loss of wetlands and floodplains due to river canalisation, artificial drainage and river embankment. Since the 1800s, the wetland area decreased steadily from 280,819 ha to 21,408 ha in the state of Brandenburg where 80% of current water channels are artificial. In the entire German Elbe river basin, the area of flood plain has decreased from 617,000 ha to 83,654 ha in 1990.
- Pollution of surface water by nutrient emissions (nitrogen and phosphorus) from point and non-point sources, causing high nutrient loads to the North Sea. Since 1989 the water quality changed back from heterotrophic to autotrophic. Phosphorus and Nitrogen input to the North Sea decreased by 53% and 26% between 1983–87 and 1993–97. However, the chlorophyll-a concentration is still higher than 20 µg/l, the threshold set to achieve the good ecological state.

- Intensive withdrawal of ground water for lignite mining in the upper Spree region (Lusatia) has artificially increased downstream surface water discharge (see Figure 3.16). This has benefited ecosystems and the supply of water to urban areas especially Berlin. Brown coal mining activity decreased from 195 Mill t per year in 1989 to 55 Mill t in 2000. Ground water exports to surface water decreased and continue to decline. Berlin has to adjust to this decreasing river flow which approaches zero during dry summers. Furthermore, the water demand for flooding of abandoned mining pits (12,000 ha lake area) conflicts with water needs downstream (Berlin; flood plain forests, grasslands and peat in the Spreewald area).

All three issues need to be addressed in the future and there are two priorities:

- Further decrease of nutrient emissions from point and non-point sources
- Alleviation of agricultural runoff and an increase in the residence time of surface water in the basin

There have been important improvements in water quality in recent years and the flooding of abandoned open cast coal mines has increased the residence time of surface water in the lowland part of the basin. However, the strategies to address the issues above

**Table 3.3 Facts and trends for the socioeconomic change in East-Germany since the German reunification in 1990**

<b>Welfare</b>
Increase of average per capita annual income from 9.780 € (1991) to 16.057 € (2002) Net loss in working places of 3 Million.
Decrease in birth rate from 1.6 to 0.77, currently approaching national level (1.4) again with 1.3 Emigration of young women twice as extensive as those of young men
<b>Water sector</b>
Oversized infrastructure for a declining population  Decrease in the water consumption per capita and day from 142 litres to currently 93 litres High increase in boat tourism
<b>Economy</b>
Providers of gas, energy and water received an over-proportional share of the economic activity (35% of total revenue) GDP share of agriculture is 2.1 %, double the share in West-Germany

might have to be adapted due to global change. This gives the basic motivation for the research aim of GLOWA-Elbe. The goal of the project is to analyse the possible alteration of the surface water quantity and quality in the basin by global change and evaluate present and future adaptation strategies.

## 4 Meeting the challenge of the GLOWA programme

### 4.1 Danube: The future of low-flows in the Upper-Danube Basin

#### Introduction

It is the goal of GLOWA-Danube to develop and validate integration techniques, models and new monitoring methods to assess the impact of Global Change on the water resources of the medium-sized (area 77,000 km<sup>2</sup>) Upper Danube basin.

The project has developed the network-based decision support system DANUBIA (Figure 4.1) to identify strategies for the management of water by analysing different global change scenarios for the period 2011–2060. The results are iteratively discussed with key stakeholders to evaluate alternative options and outcomes for water allocation and use.

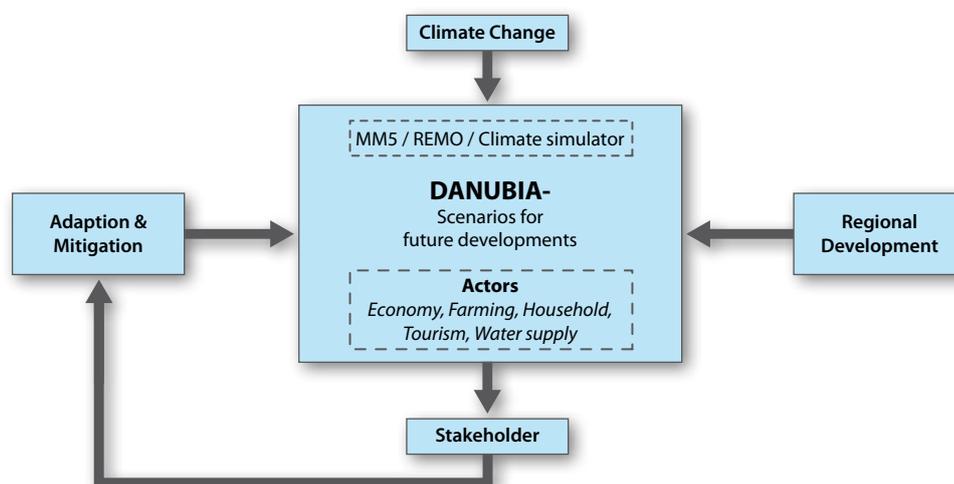
The following research questions were addressed:

- How large is the expected impact of climate changes on water-use?
- How will the changing water availability affect agriculture?
- How will demographic and technological change affect the water consumption of the population?

The environment in the Upper Danube is comparable to that in many other mountainous areas, and thus the approach is transferable to other regions such as the Pyrenees, Himalayas, Andes, Caucasus and Ethiopian Highlands.

#### The decision support system DANUBIA

DANUBIA is a coupled predictive simulation model. It includes for the first time model components for natural sciences, socio-economic processes and their interactions. The hydrological component is a spatially distributed, physically based hydrological model that uses inputs from regional climate models for predicting the impacts of Climate Change. Physical components describe the natural processes of hydrology, hydro-geology, plant physiology, yield and glaciology. The model enables the impact of different demand scenarios and decision making by the agriculture, economy, water supply, domestic and tourism sectors to be estimated by simulating decision making based on the structure of societies, their framework and priorities (Figure 4.1). All components of DANUBIA run parallel on an inexpensive LINUX-cluster. It was carefully and successfully validated with comprehensive data sets for the years 1970–2005. DANUBIA will be made available as “Open source” at the end of the third project stage in 2010. It will be of particular value to decision makers in policy, economics, and administration.



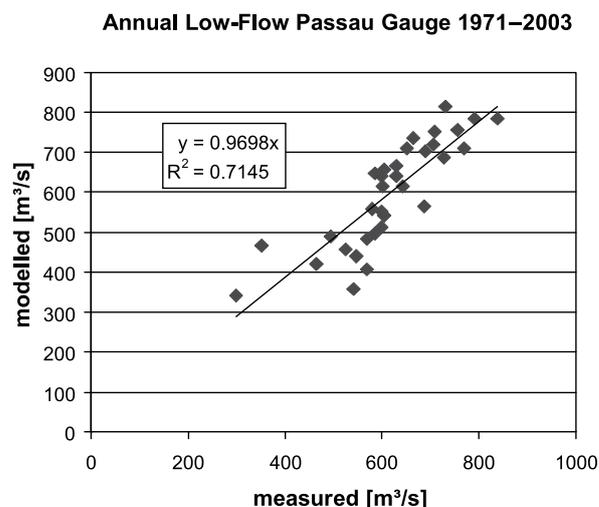
**Figure 4.1**  
Model of the scenario-based decision support system DANUBIA

### Scenarios of future low-flows in the Upper-Danube Basin

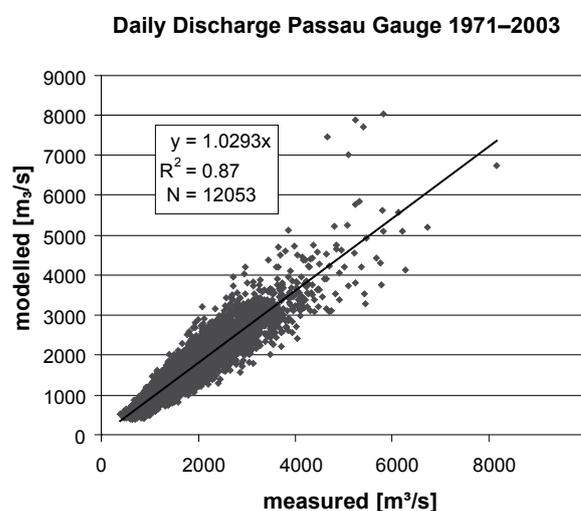
Low river flows are characterized by a prolonged period with below the seasonal average discharge and are a critical limiting factor for the utilization of water resources. Low-flows are the result of reduced storage of water in soils, rocks, snow packs, glaciers and lakes and are caused by prolonged dry periods, increased evaporation and freezing temperatures. They can reduce hydropower production, limit the availability of cooling water for thermal power stations, restrict navigation and lead to considerable financial costs. The impacts of low flows have been mitigated by reservoir construction which enable surplus water to be stored during periods of high river discharge and released during dry periods. Additionally water can be transferred from regions with a surplus to drier regions.

From a global perspective climate change is usually perceived as an expected long term increase in average air temperature, which is assumed to be estimated with low uncertainty in magnitude and spatial distribution. However predicted changes in rainfall are much less certain and for Central Europe IPCC expect no significant change in mean annual rainfall but significant increases in winter and a corresponding decrease in summer rainfall. A key question of global importance that GLOWA has addressed using DANUBIA is: "How serious will the impact of changing climate be on low flows and what are suitable adaptation strategies to mitigate adverse impacts?" (Mauser 2008). Figure 4.2 and Figure 4.3 show the results (not calibrated against historical river flow data) for the period between 1971 and 2003 for the Passau gauge (close to the outlet of the 77,000 km<sup>2</sup> Upper Danube basin). The daily discharge, annual minimum 7-day average flow and the annual variability of low-flows are well captured by the model compared with the measured historical data.

Based on these results the model was used to estimate scenarios of river flows for the period from 2011 to 2060 using the output of a stochastic climate generator. It used the IPCC-A1B scenario, which resulted in a 3 degrees temperature increase in the Upper Danube watershed by the year 2060. Using measured meteorological data a large number of possible rainfall and temperature series were derived which followed the predicted long term temperature trends. These were then used to model ensembles of predicted river flows. Seventeen of these were selected based on criteria

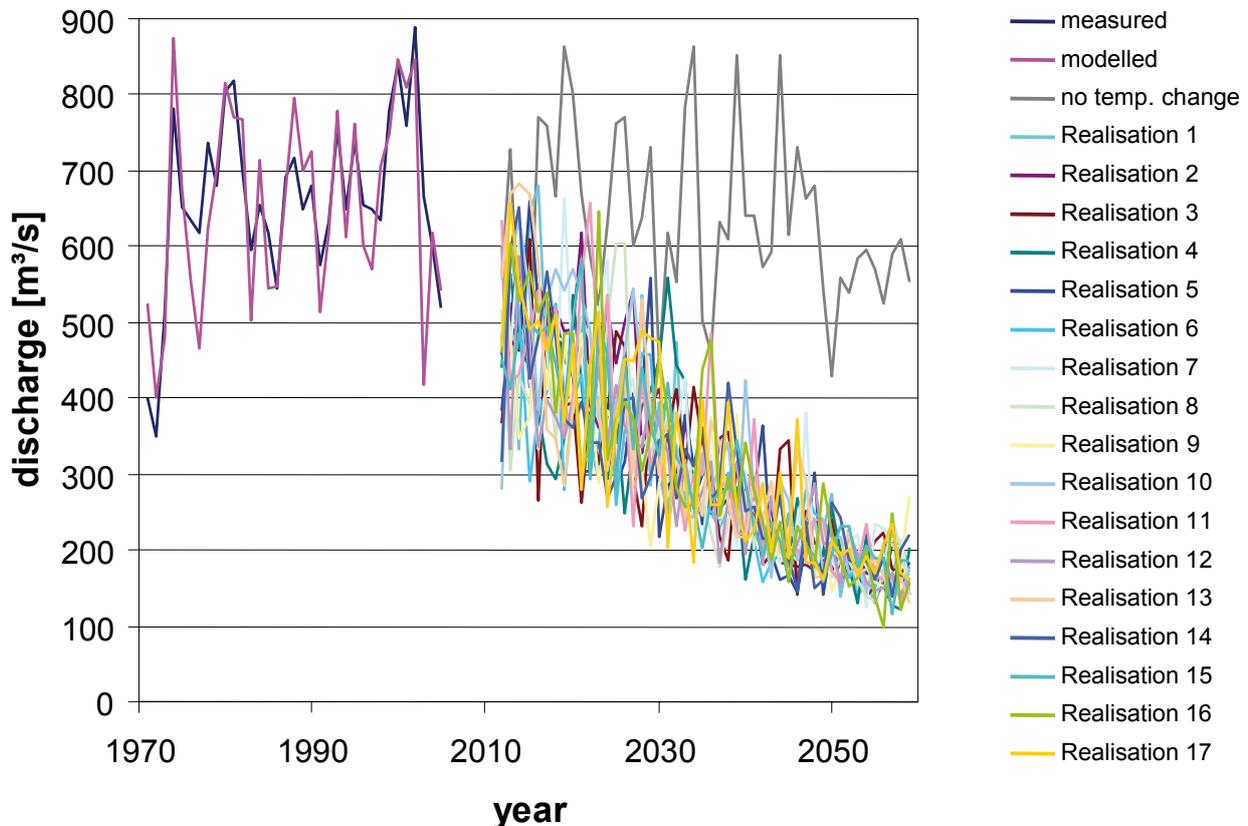


**Figure 4.2** Measured and modelled annual low-flow (minimum 7-days average discharge) for the reference period of 1971–2003 at Passau gauge, Upper Danube basin.



**Figure 4.3** Measured and modelled daily discharge for the reference period of 1971–2003 at Passau gauge, Upper Danube.

such as the driest 5-year period in the first 25 years or the hottest summer between 2035 and 2060. All selected scenarios were used together with a scenario which assumed that no further change in temperature will occur. Figure 4.4 shows the result of the ensemble model runs.



**Figure 4.4** Measured and modelled (left part of graph) and projected annual low-flow (minimum average 7-days discharge) for a scenario with no further temperature change (grey curve right part of graph) and an ensemble of 17 statistically equivalent realisations of the IPCC-A1B scenario at Passau gauge in the Upper Danube watershed.

The measured and modelled historical annual minimum low-flows are compared in the left part of Figure 4.4. As has already been shown in Figure 4.2 good agreement between observed and modelled flows was achieved with DANUBIA.

The right part of Figure 4.4 shows the results of a wide range of possible future scenarios of annual minimum low flows. It can be clearly seen that the no-climate-change scenario (grey line) produces a future very similar to the past. The ensemble of A1B scenarios shows a consistently high decrease in annual minimum low-flows for all ensemble members together with the uncertainty range caused by statistical fluctuations in the climate inputs. These statistical variations are very similar to variations which are observed today. Future low flows are estimated to be approximately one third of today's values – a considerable reduction. These important results are currently being discussed by local stakeholders to identify possible adaptation strategies, which will then be implemented in DANUBIA and tested for their effectiveness and efficiency.

#### Box 4.1 Summary

Scenarios of the regional consequences of climate change on the water resources form the basis both for a structured dialogue with stakeholders in the watershed and for the simulated decisions of actors in the social science context of GLOWA-Danube.

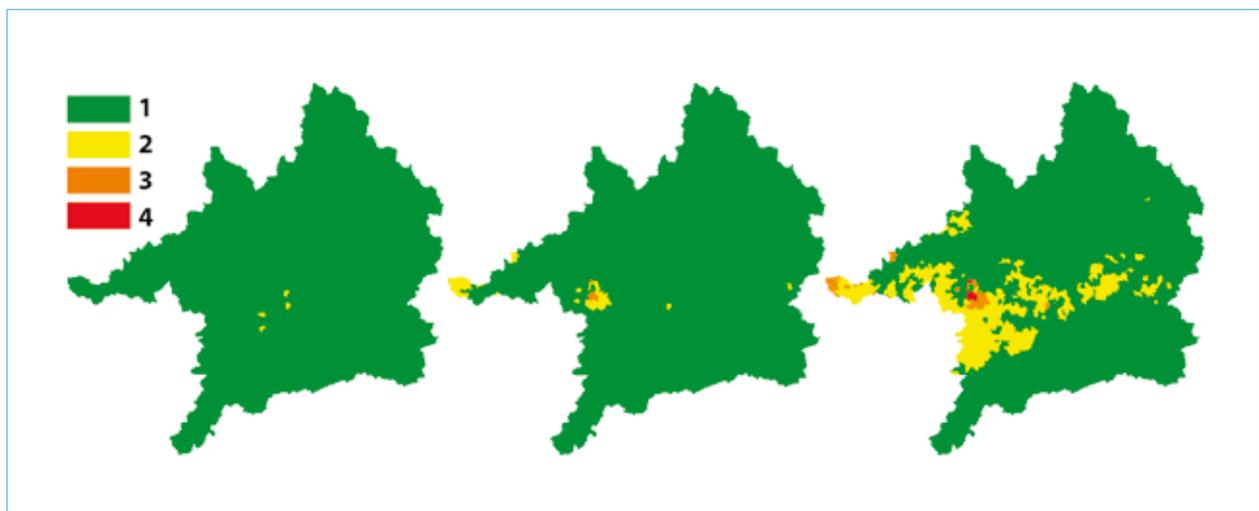
It is essential to develop uncalibrated but validated models of the hydrologic processes, to cover the full range of expected future hydrologic change. The example shows both the performance of the developed model as well as the analysis of future low-flow in the Upper Danube watershed based on an ensemble of 17 realisations of the IPCC-A1B climate scenario. The results were discussed with stakeholders, who will develop investment strategies for water related infrastructure.

#### 4.2 Danube: Modelling the human-nature interaction in DANUBIA

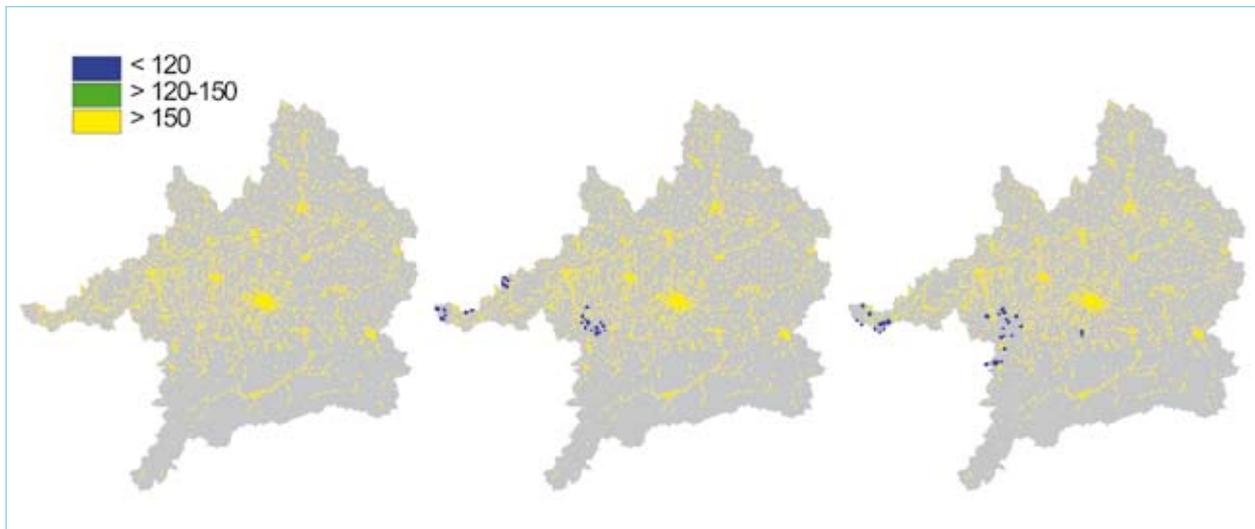
Global change research of the water cycle poses a special challenge, i.e. to describe in detail the intertwining of natural and social processes. Changes in natural drivers lead to adaptation needs and social reactions, which in turn are based on a very high number of individual preferences, decisions and learning processes each influencing each other. To represent such complexity and to allow for the integrated simulation of societal and natural processes in DANUBIA, the DEEPACTOR framework was developed. It provides a common conceptual and architectural basis for the modelling and implementation of the socio-economic simulation models in GLOWA-Danube. The framework applies the “agent-based” simulation approach used in modern social sciences, which is based upon concepts of distributed artificial intelligence. Decision making entities such as individuals, organisations, and companies are explicitly modelled and simulated as ‘actors’. An actor observes its social, economic and physical environment and selects one action from a set of alternatives as a reaction to its observations. The actions in turn have impacts on the natural environment and other stake holders. Different actors may respond differently depending upon their knowledge or access to data, their memory capacity, preferences, budget and location. Some of these parameters may vary over time, making agent-based models realistic social science process models.

To illustrate the interplay of natural and societal processes, it is interesting to observe the DANUBIA Groundwater, Water Supply, and Household models. Water Supply is an actor model of the water supply sector comprising water abstraction, treatment and distribution. Household is another actor model for modelling in detail the domestic water use. While the suppliers usually have good knowledge of the groundwater availability, the individual consumers simply consume without being fully aware of the technical issues of groundwater distribution and availability. Apart from delivering water to the modelled consumers in DANUBIA, the Water Supply model provides them with information about the state of the water supply system (Barthel, Mauser & Braun, 2008; Barthel, Nickel, Meleg, Trifkovic & Braun, 2005). This information is provided in a condensed form using “flags”. Flags assume integer values from 1 (good) to 4 (catastrophic). The Water Supply model calculates two flags at each time step based upon a set of physical parameters, interfacing Groundwater on one hand and the Households on the other. The ‘groundwater quantity’ and ‘groundwater quality’ flags describe the system state of the groundwater resources in a defined zone. The ‘drinking water quantity’ flag is a water supply evaluation of the quantitative changes in availability of drinking water resources that is committed to the water users.

The interpretation of changes in the state of the groundwater bodies by the water supply companies can vary depending on their sensitivity to sustainability



**Figure 4.5** Spatial distribution of the modelled drinking water quantity flags [from 1 (good) to 4 (catastrophic)] for the upper Danube catchment in July 2038 for the business as usual climate scenario and non-sensitive (left), middle (middle) and sensitive (right) behavioural modes of water supply companies.



**Figure 4.6** Spatial distribution of modelled domestic water use (in litres per household per day) in the upper Danube catchment in July 2038 for the business as usual climate scenario. As in Figure 4.5, the runs relate to non-sensitive (left), middle (middle) and sensitive (right) behavioural modes of water supply companies. The households show a high water consumption (July), except for the regions where flags have been shown.

threats and their willingness to communicate them to the water users. Currently, we consider three such interpretations, ranging from ‘non-sensitive’ (i.e. disregarding changes and not communicating them, and trying to satisfy demand by implementing supply side technical measures of higher abstraction rates) over ‘middle’ (i.e. taking a pragmatic and economically oriented approach) to ‘sensitive’ (i.e. giving higher priority to sustainability issues, communicating them immediately and taking appropriate measures). Figure 4.5 shows a comparison of the resulting spatial distribution of drinking water quantity flags for a “business as usual” type climate scenario.

The drinking water quantity flags communicated by the water suppliers can be interpreted as different levels of public awareness regarding water availability. They influence the households’ water use. The extent of this influence depends on the individual household’s lifestyle, budget, location, and technical infrastructure (Ernst, Schulz, Schwarz & Janisch, 2008). As can be seen from Figure 4.6, the affected households reduce their water use according to the information received.

In addition to societal reactions to water related changes, the Household model also incorporates the increased household distribution of water saving technologies, e.g. water-saving shower heads or rain-harvesting systems.

Political scenarios (like subsidising a technology) have also been applied and show the take up of innovation in the catchment over time, thus further reducing domestic water consumption (Schwarz & Ernst, in press).

#### Box 4.2 Summary

Modelling the human-nature interaction is one essential feature of DANUBIA. For the social process models, the technique of agent-based modelling is used and directly interfaced with the natural science process models. The example given here shows the Water Supply model conveying information about resource sustainability to the domestic water users, e.g. in the form of public statements or recommendations. This information is the result of an interpretation of natural states driven by the preferences of the respective water supply company.

The end users, represented in the Household model, in turn interpret the information given and translate it into individual behaviour, e.g. by changing water use habits. It also influences their investment in water saving technology in the household.



**Figure 4.7** Left: The snow covered High Atlas Mountains in spring 2004 (courtesy of O. Schulz).

Right: Typical agriculture in one of the date palm oases along the Middle Drâa (courtesy of S. Cappy).

### 4.3 IMPETUS: Coping with water scarcity in the Drâa catchment

#### Introduction

In common with other arid and semiarid regions, the Drâa river catchment is characterized by water scarcity. Water availability in the Upper Drâa catchment depends mainly on rainfall but the Middle Drâa catchment is mainly controlled by the Mansour Eddahbi Reservoir constructed in 1972. Inflow into the reservoir is fed from perennial and periodical streams and flood runoff and is highly variable. Over 50% of the precipitation at high altitude falls as snow, forming an important water resource in the High Atlas Mountains (Figure 4.7).

The annual water demand of irrigated agriculture in the downstream date tree oases of the Middle Drâa valley (Figure 4.7) amounts to 245 million m<sup>3</sup>. Managed by the regional agricultural authority ORMVAO (Office Régional de Mise en Valeur Agricole de Ouarzazate), controlled releases are periodically made from the reservoir. Their number and volume are regulated according to the reservoir volume. The mean annual volume of the outlets of 175 million m<sup>3</sup> may be reduced to less than 100 million m<sup>3</sup> in dry years. Agriculture in the oases depends increasingly on

groundwater abstraction. Thus, the risks of groundwater mining and irrigation-caused soil salinisation have to be addressed.

#### Modelling

To describe the spatial and temporal variability of water resources, data and models are merged into specially tailored Spatial Decision Support Systems (SDSS) and Monitoring Tools (MT) in close cooperation with Moroccan partners. For the rain-fed Upper Drâa catchment, discharge, groundwater recharge and reservoir volume are estimated for different climate and societal scenarios with the SDSS HYDRAA (Hydrologic model for the Drâa-catchment) and the MT PRO-RES (Prognosis of snowmelt runoff for the water reservoir). Efficient reservoir management enables the timing and magnitude of releases to downstream oases to be based on seasonal flow forecasts. The interaction between surface and groundwater availability is complex. This is addressed with the SDSS IWECS (Impact of Water Exploitation on Groundwater and Soil) using a suite of models to monitor the demand of the oases from reservoir and groundwater, the possible deterioration of the soil quality, groundwater recharge and storage, domestic water consumption and irrigation demand.

**Results**

The general shift of climate zones in Morocco caused by climate change already affects the snow cover in the High Atlas Mountains resulting in a reduction in snow melt runoff to the reservoir and climate change scenarios of drier and warmer conditions, suggest that this trend will continue. This may in part be offset by an altered rainfall distribution with fewer but more intense rainfall events. Although the yield of the reservoir might not change dramatically, sustainable agriculture in the Drâa oases requires altered management practices. Even a small 10% decrease in the average annual precipitation by 2020 (Paeth, 2004) will lead to significant depletion of groundwater levels ranging between one and two meters in the two northern oases, over 6 to 8 metres southern oases (Figure 4.8 a). These adverse impacts can be mitigated by transferring flood runoff directly into the oases without reservoir storage and by improved management of individual oases (Figure 4.8 b).

In summary, HYDRAA, PRO-RES and IWEGS, provide excellent tools for public authorities in Morocco including the Direction de la Recherche et de la Planification de l'eau (Rabat), the ORMVAO and the Agence du Bassin du Drâa (in course of formation). Similarly the SDSS IWEGS will be installed at the University Cadi Ayyad (Faculté des Sciences Semlalia), Marrakech.

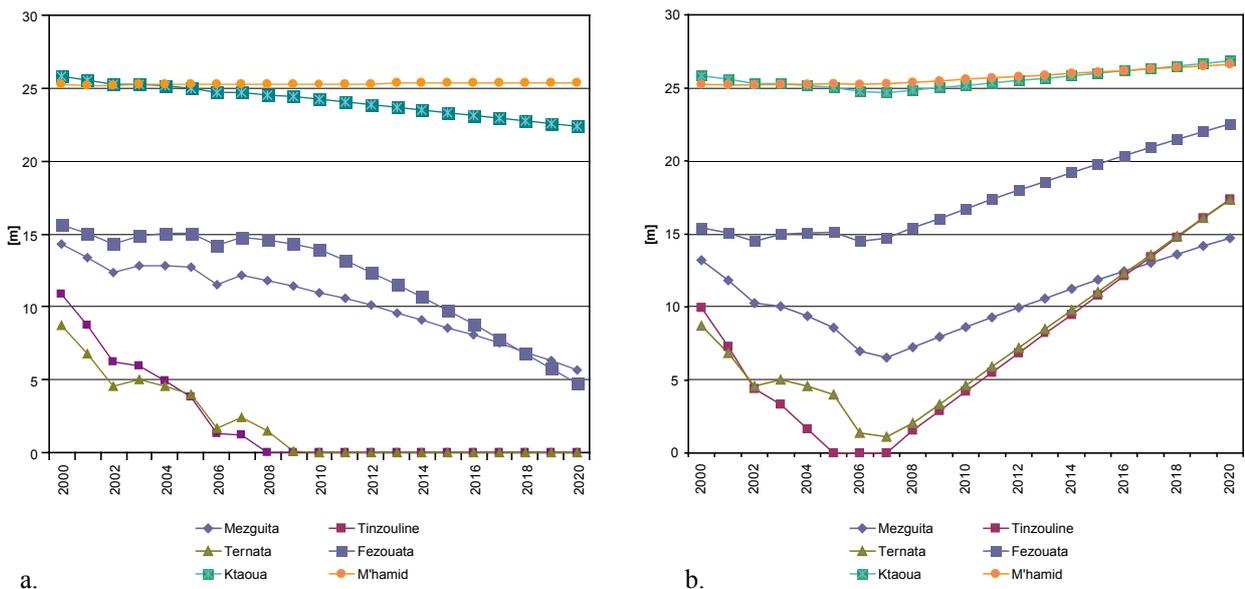
**4.4 IMPETUS: Modelling soil erosion risk in the Drâa catchment**

**Introduction**

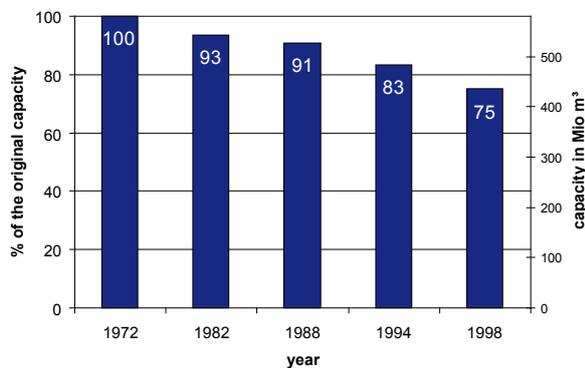
Due to high relief, sparse vegetation cover, overgrazing and intense precipitation, the Drâa catchment is particularly vulnerable to soil erosion. Soils are mostly shallow, have low organic content and high erosion rates cause significant soil degradation. Indirect effects include the silting of the Mansour Eddahbi reservoir, which lost 25% of its capacity between its construction in 1972 and the last survey in 1998 (Figure 4.9). This is indicative of an annual sediment delivery rate of 4.6 t/ha in the Upper Drâa basin and causes major problems for the irrigation of downstream agriculture (Section 4.3). Flood events (Figure 4.10) lead to intensified erosion.

The current return periods of such precipitation events (more than 30 mm per day) vary between once every 6 years in the south and 3 times per year in the north.

Climate change scenarios indicate that there will be fewer but more intensive rainfall events and this will lead to increased erosion especially in the Upper Drâa catchment due to its steep slopes and low vegetation density.



**Figure 4.8** Simulated saturated aquifer thickness for the six downstream oases (from north Mezquita to south M'hamid): a) with reduced annual precipitation; b) with an alternative reservoir management and an adjusted distribution scheme within the oases chain (courtesy of S. Klose).



**Figure 4.9** Capacity of the Mansour Eddahbi reservoir estimated from bathymetric surveys (data source: DRH Maroc, courtesy of A. Klose).

### Model approach and scenarios

The SEDRAA (Soil Erosion in the Drâa region) decision support system is based on the PESERA (Pan European Soil Erosion Risk Assessment) model and enables the extent and distribution of soil erosion in a catchment to be estimated. This physically-based raster model was initially developed to calculate monthly erosion rates (t/ha) in large catchments for all of Europe (Kirkby et al. 2004). It has been adapted within GLOWA IMPETUS for semiarid conditions and uses commonly available input parameters—topography, soil, vegetation and climate. The model can also estimate the sensitivity of soil erosion to climate change (using a relationship between climate and vegetation density) and to land use change. It is unlikely that the area of irrigated agricultural land will increase because of its dependence on water availability and it is proposed that erosion can be mitigated by planting shrubs and trees and by preventing grazing.

### Results

Figure 4.11 illustrates erosion rates under current conditions which correspond to results from an earlier model developed by Yassin (1996). The predicted increase in extreme precipitation events and the trend to an increasing amount of precipitation falling as rain (and not snow) will increase the flood runoff and therefore increase the siltation rate of the Mansour Eddahbi reservoir. Figure 4.11 b illustrates that a 30% increase in precipitation intensity will lead to an increase of mean annual soil erosion up to 9.2 t/ha. Finally Figure 4.11 c shows that if an area of 300 km<sup>2</sup>, representing only a fraction of 1.97% of the Upper

Drâa catchment, but exhibiting the highest erosion risk of above 30 t/ha, is afforested then the mean annual erosion rate in the upper catchment is reduced to 6 t/ha.

In summary the model applied by the GLOWA IMPETUS for assessing the effect of land use change on soil erosion is an excellent decision support tool for the public authorities in Morocco such as the resource management and planning division of MATEE (Ministère de l'Aménagement du Territoire, de l'Eau et de l'Environnement) and the HCEFLCD (Haut Commissariat aux Eaux et Forêts et la Lutte contre la Desertification).

## 4.5 Impetus: Impact of climate change on Malaria Risk in West Africa

### Introduction

Malaria is one of the most important infectious diseases in the world, causing about 273 million clinical cases and 1.12 million deaths annually, of which at least 90% occur in sub-Saharan Africa. More than 30% of the global population (>2.1 billion people) are exposed to malaria.

### Modelling

In order to assess the occurrence of malaria in West Africa, an existing model from the University of Liverpool, UK has been used. The Liverpool Malaria Model (LMM) simulates the daily spread of malaria using daily mean temperature and daily 10-day accumulated precipitation (Hoshen and Morse 2004). The model is sensitive to certain model parameters, and these are discussed below.

The proportion of the population that are carriers of the malaria parasite (the malaria prevalence) is strongly dependant on the applied mosquito survival scheme. The model uses a human malaria recovery rate, which results in a maximum level of malaria prevalence of 65%.

In areas where temperature is not a limiting factor, the simulated malaria transmission from mosquitoes to humans is mainly governed by rainfall. This parameter relates the 10-day accumulated precipitation to the oviposition (i.e. mosquito egg deposition) of female mosquitoes and ultimately determines the size of the mosquito population. At high altitudes, the sporogonic temperature threshold, i.e. the minimum temperature for malaria parasite development in the mosquito, is important. Unlike the LMM model described by



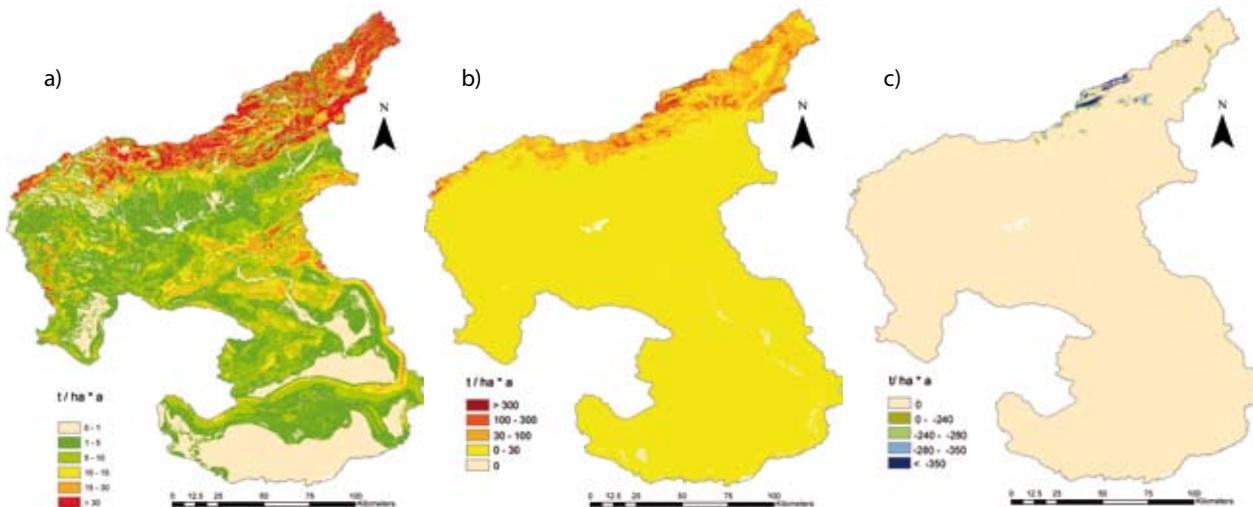
**Figure 4.10**  
Flooded and destroyed agricultural fields in the Atlas Mountains after a storm event on 27.10.2006 (courtesy of K. Born).

Hoshen and Morse (2004), the version used in the present study was parameterised with a different mosquito survival scheme and a sporogonic temperature threshold of 16°C.

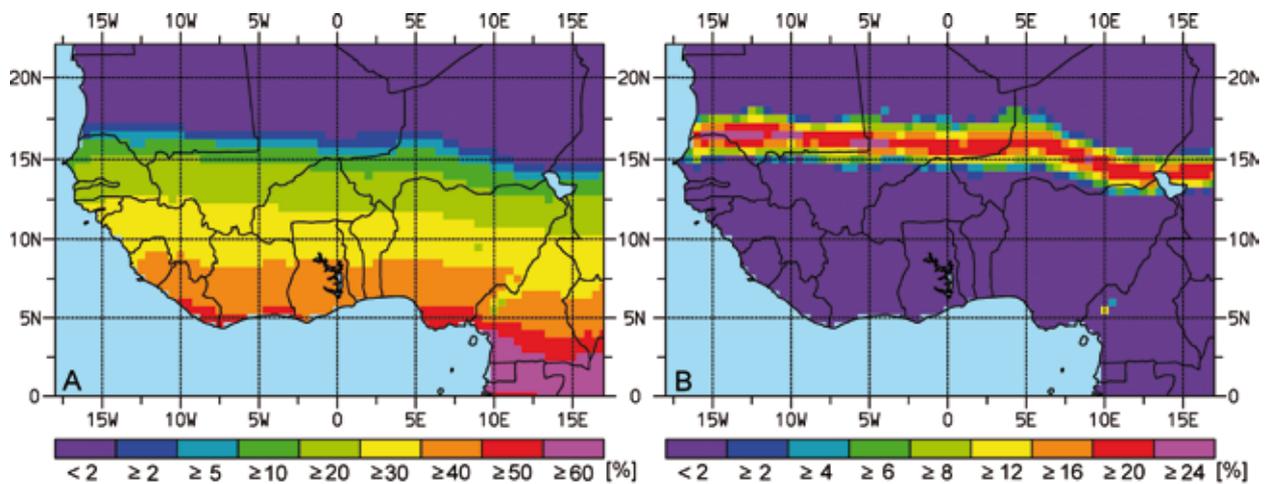
**Data**

LMM simulations were carried out along a north-south transect at about 2°E based on data from 10 synoptic weather stations from Benin, Niger and Mali. In addition two-dimensional present-day

ensemble runs were carried out on a 0.5° grid from 1960 to 2000 using high resolution data from the REgional climate MOdel (REMO). This takes into account land use and cover (cf. Figure 3.3). In addition, malaria projections were carried out for the period from 2001 to 2050 based on REMO simulations using the IPCC SRES climate scenarios A1B and B1, and land use and cover changes based on estimates from the Food and Agriculture Organization (FAO).



**Figure 4.11** Model results a) status quo with the actual climate and land use, b) difference map between status quo and a scenario of increased precipitation variability and c) difference map between status quo and an afforestation scenario (courtesy of A. Klose).



**Figure 4.12** a) Annual averaged malaria prevalence (in %) and b) standard deviation of the annual maximum of the prevalence (in %) for 1960 to 2000 based on LMM ensemble simulations (courtesy of V. Ermert and A. Fink).

## Results

The transect station data (1973–2006) show a decrease in the malaria prevalence and duration from Cotonou at the Guinean coast to Gao in the northern Sahelian zone. This is not surprising, since oviposition is directly proportional to the 10-day rainfall amount. The size of the mosquito population was shown to be clearly associated with the strength of the West African summer monsoon precipitation. At the most northern transect stations in Tillabéry (~14°N) the malaria season lasts only a few weeks and in Gao (~16°N) the disease occurs epidemically.

The decline of the malaria prevalence towards the Sahara is also shown by the two-dimensional LMM ensemble simulations. In agreement with the annual precipitation amounts, the LMM simulations show a decrease in the prevalence from the Guinea Coast towards the Sahel for the period 1960 to 2000 (Figure 4.12 a). The regions of epidemic malaria occurrence, defined by a large inter-annual variability of the annual prevalence maximum, lie between 13 and 18°N (Figure 4.12 b). Further south, the simulated spread of malaria is more stable from year-to-year and is thus classified as endemic.

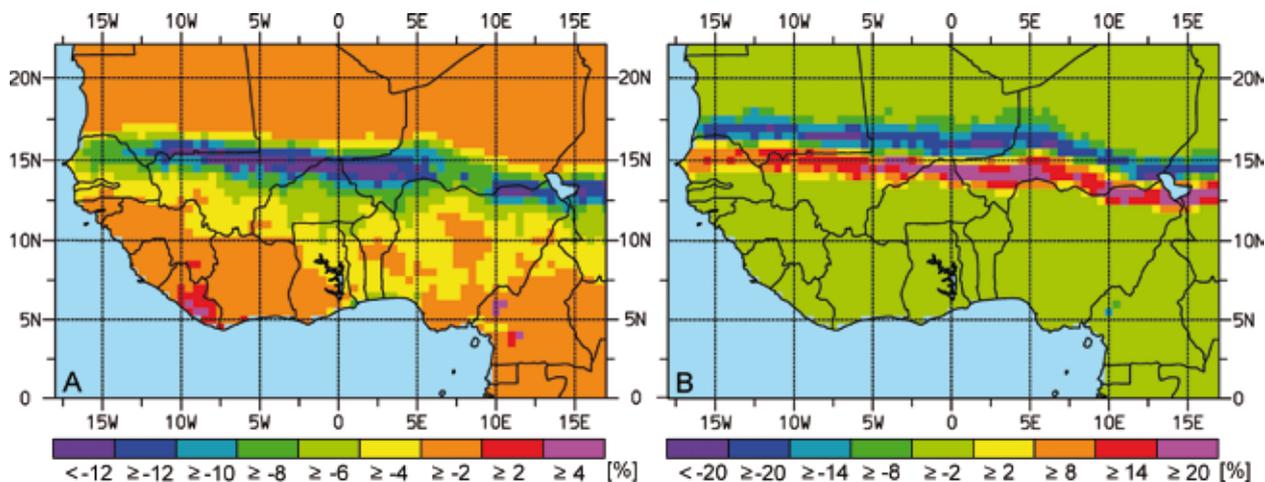
Largely due to land surface degradation, REMO simulates a prominent surface heating and a significant reduction in annual rainfall over most of tropical Africa in both climate scenarios A1B and B1. As a consequence, the projections in malaria disease decreased in most parts of West Africa for the decade

2041 to 2050 (Figure 4.13 a). In addition, the year-to-year variations of the seasonal maximum of malaria prevalence are reduced in the northern part of the Sahel. Therefore, fewer epidemics or even a malaria retreat from some regions are expected for these areas (Figure 4.13 b) but the variability is increasing in the southern part of the Sahelian zone (between 13 and 16°N). Epidemics in these more densely populated areas are becoming more likely as parts of the population will lose their partial immunity against malaria. The level of malaria transmission farther south, e.g. in Benin, remains stable. However, due to a drier and shorter rainy season the malaria transmission period will be shorter. The results from the LMM simulations are visualised in the IMPETUS Information System MalaRis and are made available to national and international health organisations and administrations.

## 4.6 IMPETUS: Modelling land use change in the upper Ouémé catchment

### Introduction

Detailed information about land cover and land use are required because they influence many aspects of the hydrological cycle, soil quality as well as ecosystems. In the upper Ouémé catchment, relatively undisturbed savannas and forests have been gradually transformed into agricultural use adjacent to major roads and settlements. The transformation was accelerated by the fast population growth augmented by immigration from neighbouring regions, predo-



**Figure 4.13** a) Differences in the annual average malaria prevalence (in %) and b) the standard deviation of the annual maximum of the prevalence (in %) between the last decade of the A1B scenario (2041–2050) and the period 1960 to 2000 (courtesy of V. Ermert and A. Fink).

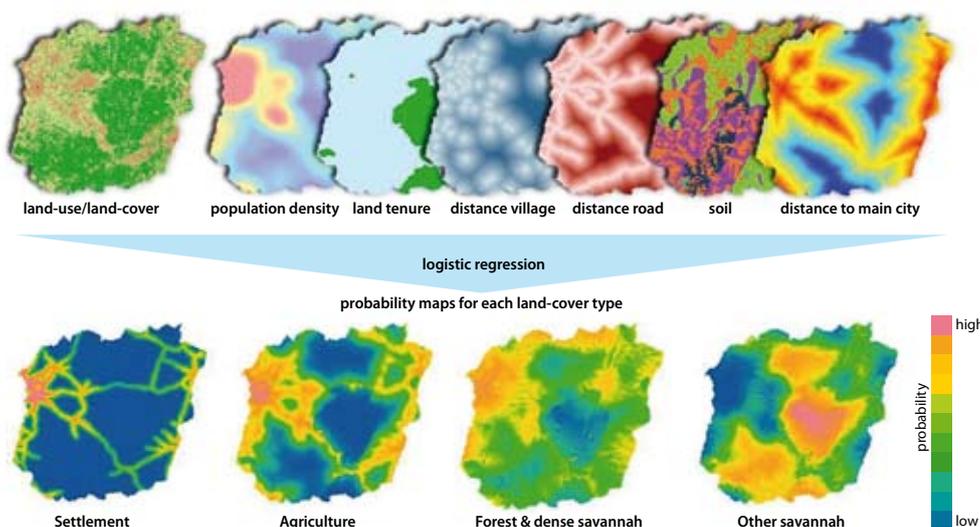
minately from the north. These land cover and land use changes are reflected by high deforestation rates influencing water, soil and biodiversity. The result is a decreasing availability of arable land in the vicinity of settlements, decline in soil fertility and rising conflicts over water and land. To meet the goal of sustainable development, accurate projections of land cover and land use changes are essential.

**The modelling approach**

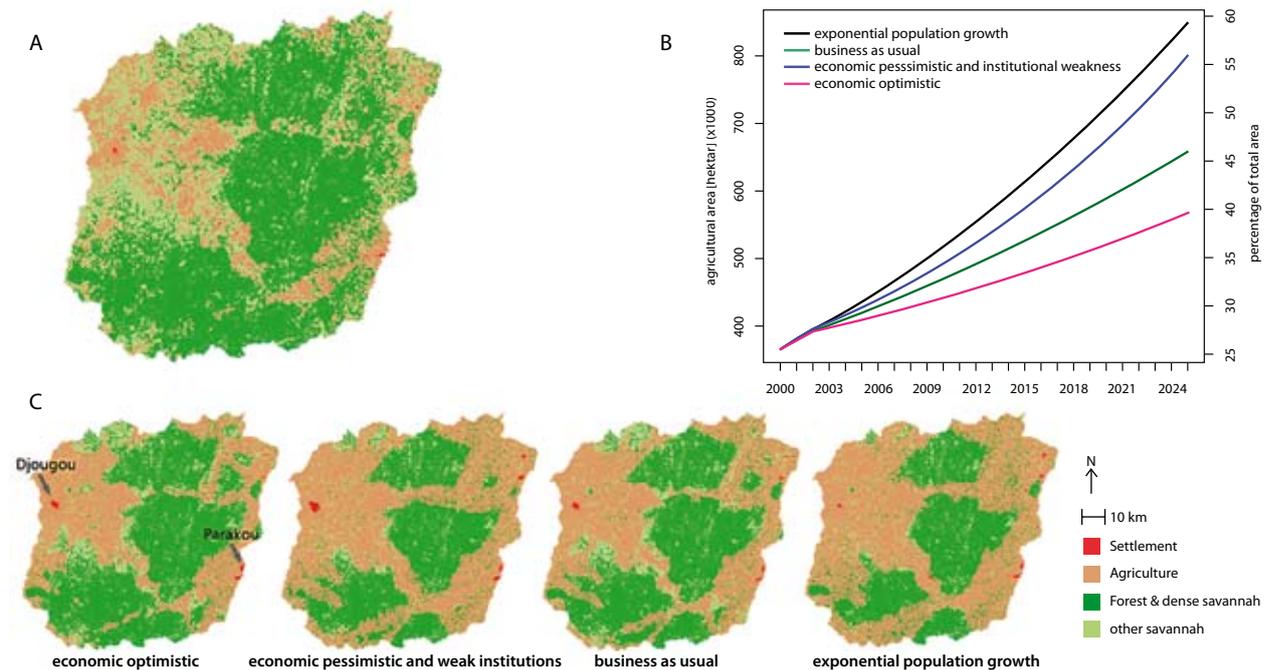
From a broad range of different land use models the CLUE-S framework (Conversion of Land-Use and its Effects at Small regional extent, Verburg et al. 2002)

was selected because of its dynamic, multi-scale potential, its spatially explicit raster-based procedure and experience of many successful applications in tropical regions. The following driving forces were used for the study area: population density, distance to roads, distance to important settlements, tenure, suitability of soils for agricultural production and topographic parameters (Figure 4.14).

From these spatial probability maps were produced for each land use category by logistic regression. The other parameters were determined with detailed user knowledge of the land use dynamics of the study area.



**Figure 4.14** Calculation of probability maps using logistic regression and spatial driving forces. The temporal resolution is annual (courtesy of M. Judex and H.-P. Thamm).



**Figure 4.15** a) Land use data from 2000; b) development of arable area for the four scenarios; and c) results for 2025 (Courtesy of M. Judex, H.-P. Thamm).

### Modelling recent and future land use change in the upper Ouémé catchment

The model was calibrated for the period 1991 to 2000 based on available land use data derived from satellite images so that the modelled and observed land use changes were as close as possible. Using statistical methods, it was found that the model result matched observations for 86% of the area. The boundary conditions of the modelled land use scenarios are driven by the IMPETUS baseline scenarios, which have a time horizon of 2025 (Section 3.2). The following IMPETUS scenarios were used: an economically optimistic scenario with strong institutions and resource-saving management, an economically pessimistic scenario with weak institutions, a business-as-usual scenario and a business as usual scenario with exponential population growth (Figure 4.15). The agricultural area was calculated based on population growth (from demographic projections), assumptions on area use per capita, and intensification of farming systems.

### Results

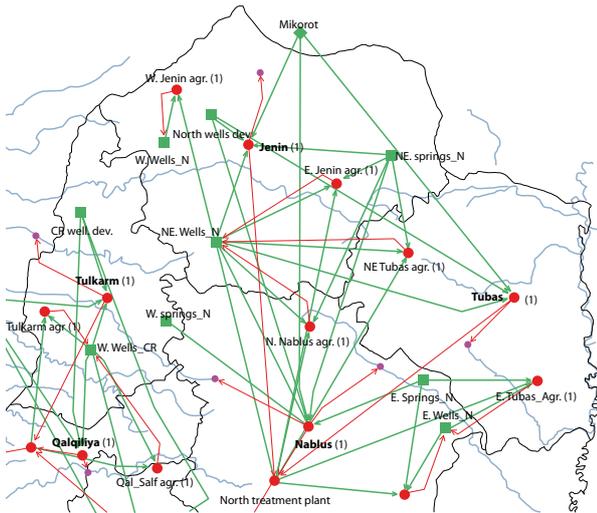
Every scenario shows an increase in agricultural area and a loss of natural vegetation (Figure 4.15). In areas with high population density (mostly near cities), all available land will be converted to agriculture in the near future. Further land use conversions develop

along roads near forest areas, where the probability of agricultural activity is high. This will lead to a high rate of deforestation in these areas. If the boundaries of the protected forests (in public ownership) are not controlled, the small ones will probably be converted to agricultural use in the economically pessimistic scenario. Adverse impacts can be mitigated by increasing agricultural productivity and by improving land use planning. In summary the land use change model is an excellent tool for public authorities in Benin such as INRAB (Institut National des Recherches agricoles du Bénin) and the University of Abomey-Calavi (Faculté des Lettres, Arts et Sciences Humaines).

### 4.7 Jordan River: Transboundary water management in a politically sensitive region

The GLOWA Jordan River project (GLOWA JR) provides scientific support for improved water management in a highly water-stressed region. Because most water sources are shared across political boundaries, both research and application must focus on transboundary solutions. Developing management across institutional and national boundaries has been a major challenge for GLOWA JR. Allocation of and access to water is subject to political decisions, leading to constraints on regional cooperation and data sharing.

To improve regional interaction and exchange, GLOWA JR gives a very high priority to workshops, training and meetings. The whole research process is facilitated by an intensive stakeholder dialogue involving all partner institutions. Active participation of stakeholders requires a pro-active presence in the region and a wide ranging programme of iterative discussions.



**Figure 4.16** Schematic view of the WEAP representing transmission links (green arrows) and return flows (red arrows) between groundwater-supply sites (green squares), surface water (blue lines) and water demand sites (red dots)

Contrary to our expectations, this has shown that collaboration among GLOWA JR scientists is possible and this co-operation has been facilitated by a neutral (i.e. German) partner. This enables us to communicate transboundary solutions derived from the project to the relevant stakeholders in each country. GLOWA JR is now well-known in the region as a science-based platform for regional communication and exchange about water management issues in the basin.

A second challenge resulting from a history of limited regional cooperation and political constraints is heterogeneity and restricted access to data. The reasons for this are three-fold:

- Excellent data may exist but are only accessible for use within a country but not for region-wide analyses.
- The spatial and temporal resolution and extent of data varies greatly between partner countries.

- Expert knowledge in the water sector is often provided in qualitative rather than quantitative terms.

To meet the challenges of differential accessibility and data quality, we have used integration tools that can account for heterogeneous datasets. To ensure constructive participation and co-operation the techniques used are modified to ensure that their structure and applicability are relevant to local circumstances. In cooperation with the German Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) and the Stockholm Environment Institute (SEI) WEAP– the Water Evaluation and Planning tool (Yates et al 2005) was established as the decision support system in the region (Figure 4.16). In the case of WEAP the regional needs for integrating both blue and green water management and conjunctive surface and groundwater management have been addressed by incorporating the groundwater model MODFLOW. Problems of variable data quality and data resolution have been resolved by using a nested scaling approach. Starting from isolated WEAP applications in small sub-catchments in the Jordan River Basin very specific questions have been addressed e.g. the sustainability of using treated wastewater. At a larger scale we have developed separate WEAP systems for each country involved. These local applications have the potential to make use of the full set of available data and address country-specific water management problems. At the broadest hierarchical level a regional WEAP integrates sub regional WEAP systems. Several demand and supply nodes are pooled for this purpose, and only secondary data (output of sub regional WEAPs) are used for further processing. This procedure helps to ensure that available data are consolidated and that the transparency, confidence and efficiency of water information are maintained.

The second approach that meets the challenge of variable data quality is the SAS (Story and Simulation) approach (Alcamo 2001) which integrates scientific information with stakeholder knowledge. The main products of SAS are a new set of comprehensive, coherent, realistic scenarios for the Jordan River region that:

- contain new knowledge about possible impacts of global and regional change on water resources in the region; and
- explore new ideas on how society can adapt to expected changes and increase the well-being of people living in the region.

Four scenarios have been developed between GLOWA JR scientists and stakeholders (Figure 4.17) and summarized as storylines, i.e. narrative scenarios about



Figure 4.17 Science-stakeholder dialogue and scenario development: SAS workshop in Jordan

how the future may unfold. The four GLOWA JR scenarios are located along two axes of major uncertainties affecting the water situation, i.e. cooperation vs. unilateral water sharing and economic growth vs. recession (Figure 4.18). With these scenarios, strategies for sustainable water management can be developed that take into account uncertainties in the future development of the region. The challenges and their solutions outlined above are typical for many regions of the world where water must be managed in a cross-boundary context.

**Box 4.3 Summary**

The sensitive political situation in the Jordan River region has resulted in constraints on regional cooperation in the water sector. This has led to a high regional variability in data quality and accessibility. GLOWA JR seeks to overcome these difficulties through its integration tools WEAP and SAS. WEAP can be built hierarchically to utilize data efficiently and is very flexible in integrating data with a wide range of spatial and temporal resolutions. The SAS approach integrates quantitative (scientific models) and qualitative (e.g. stakeholder knowledge) information.

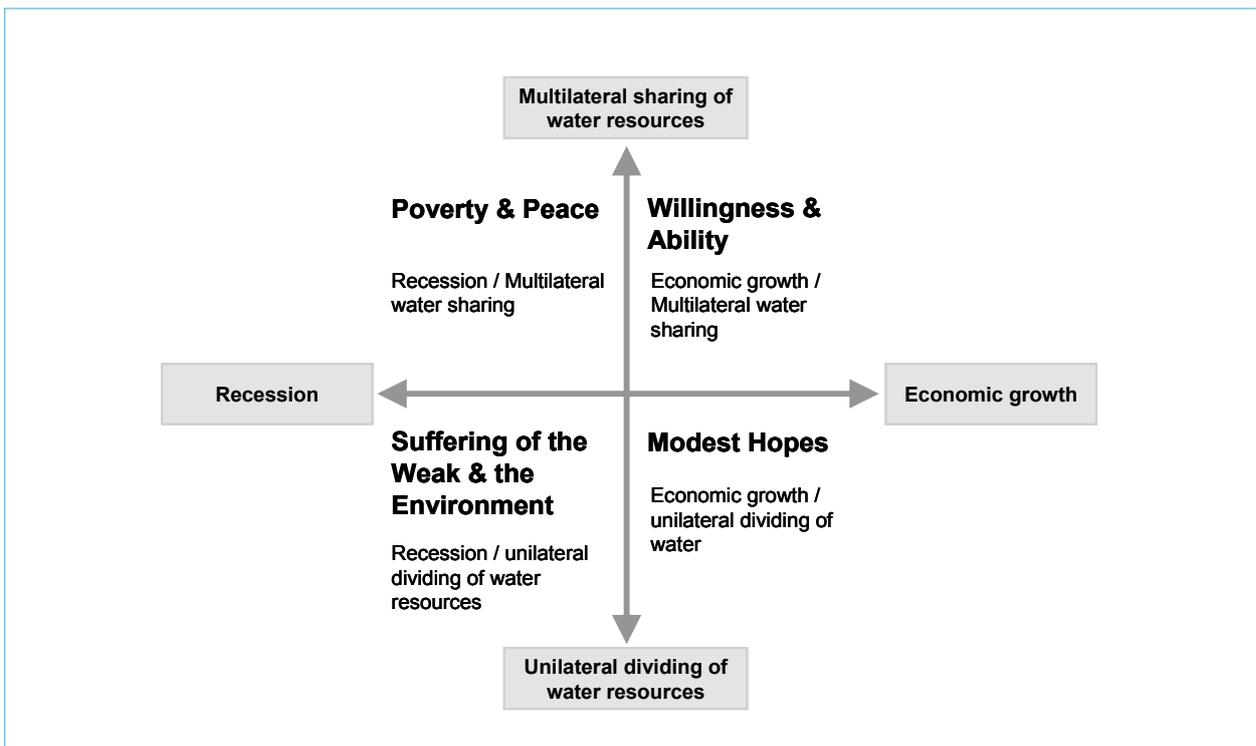


Figure 4.18 The four GLOWA JR scenarios located along two axes of major uncertainties affecting the water situation.

**Box 4.4 Summary**

Green water is the water from precipitation stored in the soil and transpired by plants. Though accounting for most of the water consumed by terrestrial agro-ecosystems, the blue-green water concept is still ignored in conventional IWRM.

Green water can be managed by wise land-use allocation including water-efficient practices and land use with low water demand and high monetary value. (Figure 4.19)



**Figure 4.19** Agriculture in the extreme desert via harvesting and redirecting of runoff water – an ancient technique developed by the Nabataeans.

#### 4.8 Jordan River: Establishing “green water” as an essential component in Integrated Water Resource Management

Green water – the water stored in plants and soil – is an important component of the hydrological balance and accounts for the majority of ‘productive’ water in agriculture and natural ecosystems and could triple the amount of blue water that is involved in food production (Falkenmark & Rockström 2006). However, the management of green water has been widely neglected in integrated water resources management. In particular, the value of water in open space (accounting for approx. 80% of the total land cover in the study region), and the effect of natural areas on the hydrological cycle has been largely ignored. This is surprising given that 70% of the global green water resources are consumed by terrestrial ecosystems and in the study region, rain-fed land use accounts for 80% of the land cover. Green water can be managed by means of land use management, i.e. water productivity can be considerably increased by wise land use allocation.

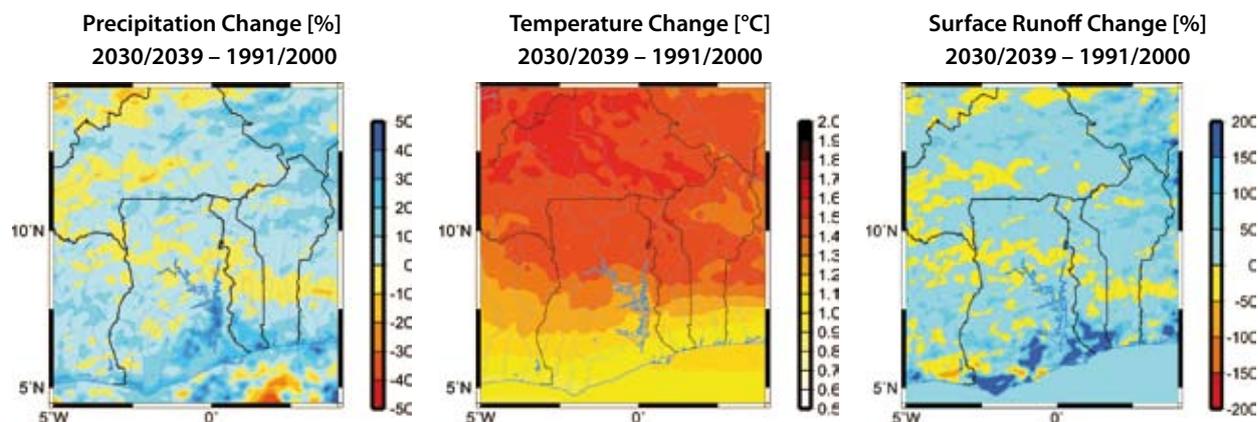
GLOWA JR meets this challenge in a joint approach of green and blue water management to emphasize precipitation as the key factor in water management. The project is unique in systematically addressing the

impact of land use on the hydrological cycle and water productivity for the entire range of land use types. WEAP allows testing joint-management options of green and blue water resources including allocation of water from irrigated agriculture and from rain-fed land use (e.g. open space, rain-fed crops, rainwater harvesting).

A central research goal of GLOWA JR is to derive the most productive land use allocation under global change, regarding both economic benefits and biophysical suitability. The economic benefits include direct profits from crop yields as well as benefits from ecosystem services including recreational value, value of biodiversity and erosion control.

The effect on the hydrological cycle of different water demands and the value generated by different land use types under different climate scenarios have been evaluated and compared. This has clearly identified the important role of land use allocation in mitigating the impact of the future water crisis in the region.

Although it is essential to understand the productivity of green water and the impact of land use decisions, it is crucial to transfer and integrate this knowledge into hands-on water management decisions.



**Figure 4.20** Predicted climate change and change in surface runoff (Source: Jung & Kunstmann 2007)

We have therefore expanded the traditional range of water-oriented decision-makers in our science-stakeholder dialogue by stakeholders with expertise in land use. These include Ministries of Agriculture, Ministries of Planning, Ministries of Environment, Nature Reserve Authorities, Friends of the Earth Middle East and other stakeholders and NGOs related to land use planning and nature conservation. GLOWA JR has highlighted the importance of understanding and applying the green-blue water concept and replacing the traditional sectoral approach in water management.

#### 4.9 Volta: Implementation of a Volta Basin Water Allocation System for transboundary water management

Irrigated agriculture is the dominant consumptive use of water in upstream areas of the Volta Basin and competes directly with hydropower generation in the downstream area of southern Ghana (Figure 4.21). While Burkina Faso is expanding its irrigated agriculture by building reservoirs, Ghana is additionally developing its hydropower capacities. With increasing water demands, conflicts arise as a result of competing water uses, and between upstream and downstream countries. In order to improve the understanding of the hydrological cycle on a sound scientific basis, as well as the complex institutional set-up of the Basin's water sector, the GLOWA Volta Project (GVP) has worked closely with water authorities in Ghana and Burkina Faso since the beginning of the project. The formation of the Volta Basin Authority (VBA) in July 2006 is a cornerstone for conflict avoidance, and an important step towards the sustainable management of joint water resources and regional socio-economic integration (Rodgers et al. 2007).

One of the major scientific outcomes of the GVP is the Volta Basin Water Allocation System (VB-WAS). The VB-WAS (Figure 4.22) is a decision support tool that enables the impact of global climate change and projected water demand scenarios on future water resources management and infrastructure to be predicted. One component of the VB-WAS is an integrated model ensemble, which simulates water supply scenarios under recent or predicted future climates and water demand situations, and estimates the water demand by simulating different development and policy scenarios. The model ensemble is composed of a coupled climate-hydrological model (MM5/WaSiM, Figure 4.20, 4.22) and an economic model (M<sup>3</sup>WATER).

These simulated water supply and demand scenarios are stored within a scenario library of the Volta Basin geodatabase. The database also contains physical, economical and sociological data of the Basin, which can be accessed directly for further case study analysis. Within the VB-WAS the river basin management model MIKE BASIN serves as a decision support platform that allows simulations of the impact of competing water uses including irrigation and hydropower. The model can import water supply and demand scenarios from the geodatabase and use them as initial settings for different water resources analyses. Through rapid simulations of water availability and multi-sectoral water demand, the feasibility and impact of proposed developments can be assessed and potential conflicts from competing water uses identified and used as a scientific base for water resources decision makers. Throughout the third project phase (2006–2009), capacity building is being given a high priority to ensure the successful transfer of the project outputs to local stakeholders. Training is provided to experts, who



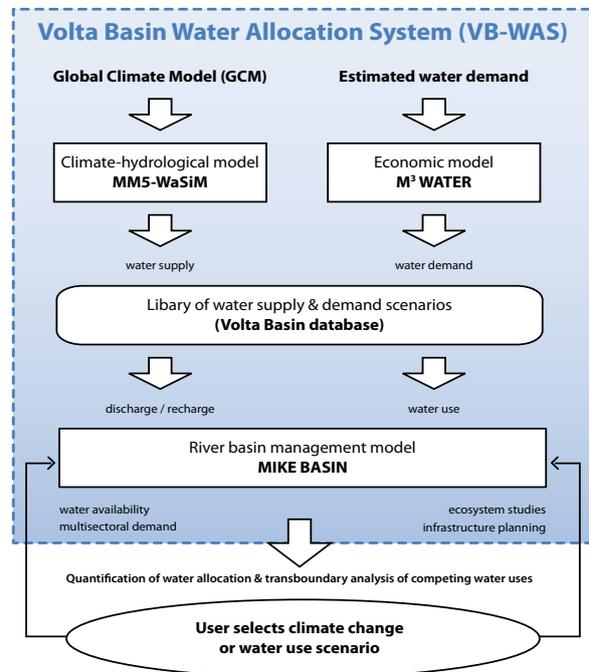
**Figure 4.21** Irrigated agriculture in the upstream regions of the Volta Basin (left) directly competes with hydropower generation at the Akasombo Dam (right) and smaller hydropower plants in the lower parts of the Volta Basin.

will work with and further develop the VB-WAS. This transfer also implies fostering long term and reliable collaboration between the VBA and other organizations with an interest in research based development, e.g. The United Nations University, GTZ and the European Union.

The MIKE BASIN model can be used by water authorities as a decision support tool to analyse the impact of water resources development and climate change, and to identify transnational competing water uses, such as irrigation schemes and hydropower supply under predefined climate change and water use scenarios.

**Box 4.5 Volta Basin Water Allocation System (VB-WAS)**

The GLOWA Volta project has developed a Volta Basin Water Allocation System (VB-WAS), a decision support tool to analyse the impact of infrastructure development, such as the construction of reservoirs for hydropower and irrigation, on the water allocation within the basin. The VB-WAS is also capable of simulating the impact of global climate change on the water resources on a regional and basin scale.



**Figure 4.22** Structure of the Volta Basin Water Allocation System (VB-WAS). A model ensemble of a climate-hydrological (MM5-WaSiM) and an economic model (M<sup>3</sup>WATER) providing scenarios of water supply and demand for the river basin management model (MIKE BASIN).



#### Box 4.6 Predicting the Onset of the Rainy Season (ORS)

Due to a misinterpretation of the ORS, wrong decisions of planting time lead to crop failure and high economic losses within the Volta basin. The meteorology and climate research group of the GVP has developed a scientifically based prediction scheme for the determination of the Onset of the Rainy Season.

The ORS can be predicted spatially for different regions of the Volta basin, which helps the farmers to determine the right time-frame for sowing.

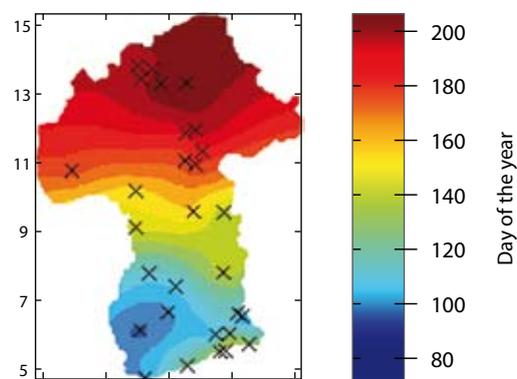
**Figure 4.23** Farmers preparing for the Onset of the Rainy Season. Too early sowing often leads to total crop loss; late sowing is risky due to the short growing season. With increasingly erratic rainfall patterns due to climate change, farmers seek reliable information on the onset of the rainy season to support their decision on the right time to sow.

#### 4.10 Volta: Predicting the Onset of the Rainy Season in the Volta basin

Approximately 70% of the West African inhabitants depend on rainfed agriculture (Figure 4.23). Rainfall is limited to few months per year. As the rainy seasons are short, it is important to sow as early as possible to avoid wasting valuable growth time. The reliable determination of the Onset of the Rainy Season (ORS) is therefore of crucial importance for sustainable food production. In the Volta Basin, the ORS seldom occurs abruptly and is often preceded by short isolated showers with intermittent dry spells of various lengths, which are often misinterpreted as the start of the rains. In addition, farmers reported an increasing variability of the ORS since the 1980s. Due to the very high spatial and temporal variability of rainfall and a high variability in the ORS dates, farmers have problems deciding when to start sowing. Wrong sowing decisions often lead to total crop failure and high economic losses for the farmers. Therefore, their interest in scientifically based prediction methods is increasing (Laux et al. 2008).

The meteorology and climate research group of the GVP has developed schemes to predict the ORS in the Volta Basin and to predict the possible impact of climate change on the ORS. The definition of the ORS is a fundamental prerequisite for all approaches.

The GVP ORS definition accounts for plant physiology and allows for the scheduling of different crop species over the whole Basin. Maps of mean ORS dates have been developed (Figure 4.24) to support agricultural extension workers and farmers in their determination of the correct sowing time. ORS maps can now be produced routinely every year. ORS modelling has also identified a strong trend towards a delayed onset of the rainy season, and has proved to be valuable scientific



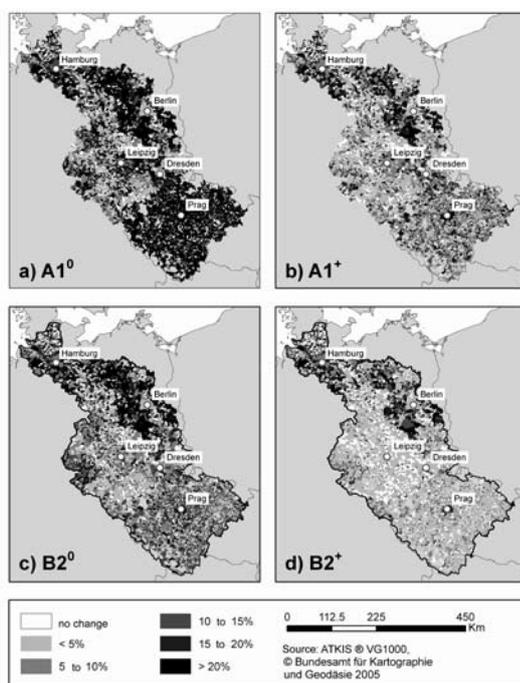
**Figure 4.24** This map describes the spatial and timely distribution of the Mean Onset of the Rainy Season (ORS). The colour scale indicates the day of the year of the ORS for the Volta Basin area of Ghana and Burkina Faso using the approach after Laux et al. (2007).

tool to help prevent crop loss (Laux et al. 2008). A training course in Hydro-Meteorological Decision Support for the Volta Basin was held at the United Nations University Institute for Natural Resources in Africa (UNU-INRA) in Accra, Ghana, and at the Direction Générale des Ressources en Eau (DGRE) in Ouagadougou, Burkina Faso. The transfer of the developed methodologies allows responsible authorities (i.e. the local meteorological services) to predict the ORS within different regions of the Volta Basin. The developed methodology is generic and can be transferred to other regions of the world that are strongly influenced by monsoonal seasons.

#### 4.11 Elbe: Sustainable water use

##### Introduction

In GLOWA-ELBE two major aspects of sustainable water use were explored: first, surface water flows and their regulation for a broad spectrum of demands and users; second, nutrient emissions to the surface water system and their consequences for the river system



**Figure 4.25** Projection for the future change in settlement area in the Elbe basin up to 2020. Four frames of development are considered. These are two regional variants of the IPCC scenarios A1 (a, b) and B2 (c, d) combined with two policies: one without (a, c) and one with stronger (b, d) environmental orientation (Hoymann 2008, personal communication)

itself and the North-Sea estuary. In co-operation with stakeholders methods of conflict analysis were applied to develop policy recommendations and management strategies that would mitigate the impacts of global change.

The conceptual framework consists of two major functional tasks: 1) projecting boundary conditions for the regional water resources 2) optimising supply and demand using priority lists of water customers and water polluters. The core of the projections into the future is the extrapolation of the past developments in climate, in surface water supply and demand and nutrient emissions until 2055. The projections include specific aspects of changes in land use, agricultural production, and technological innovation in the water sector. An example for the land use projections is given in Figure 4.25.

Two major basin wide balances are carried out based on the projections: the balance of surface water demand and supply and the balance of nutrient emissions into the river system with the targets for the good ecological state according to the Water Framework Directive (EC 2000). The balances cover the whole basin area and at the same time address the water conflicts at the regional to local level. Discharge is calculated on a daily basis and then aggregated to balance monthly and yearly discharge and nutrient loads.

##### Basin wide and regional water conflicts

###### 1) Basin wide conflicts

The low flow conditions during summer in the main stream and nutrient surpluses in agriculture are the sources of two major basin wide conflicts addressed in GLOWA-Elbe. Figure 4.26 depicts the possible effects of 100 stochastic realizations of a regional climate change scenario on water discharge in the Elbe mainstream. The low flow conditions during summer are particularly affected. The 25 percentile low flow discharge for the period 2004–2013 is estimated to become the mean flow for the period 2044–2053. Two sectors are very sensitive to this development: river navigation and energy production by thermal power plants. However, the thermal power plants have modified their investment strategy to mitigate the impact of this change by increasing the use of closed circuit cooling. Adaptation measures for shipping are being investigated. Low flow conditions will increase the retention of nutrients in surface waters. However, the ecological state of the main stream will not be improved, for example, because higher temperatures stimulate the growth of phytoplankton.

## 2) Regional conflict in the Spree-Havel basin (Wechsung et al. 2005)

The simulated impacts of the climate change scenario revealed a high vulnerability of water supply security in the Spree-Havel tributary to decreasing precipitation particularly after 2030. Thus, management alternatives to reduce this vulnerability were investigated (Koch et al. 2006). As a result of a stakeholder dialogue process, four relevant strategies for water regulation were suggested to mitigate water scarcity (Messner et al. 2004). Two alternative strategies relating to the flooding regime of open cast coal mining pits (“accelerated flooding” of the pits and “creek drying” near the pits) and two strategies to overcome the water deficit by importing water from the neighbouring Oder river basin (Oder Brb – import via Oder-Malxe canal to the Spreewald in the state of Brandenburg, Oder Bln – import via the Oder-Spree canal to Berlin). The first two strategies have the advantage of low costs for water supply and an earlier availability of a new lake for tourism, but the disadvantage of a reduction in fish pond area and high water treatment costs. The latter variants improve the conditions for local fish farming with lower costs for water treatment, but disadvantages include high water supply costs and delayed use of the lake for tourism.

If in addition the reliability of water supply for ecosystems and industry and the minimum inflow reliability are taken into account, the “accelerated flooding” strategy and the two strategies for using

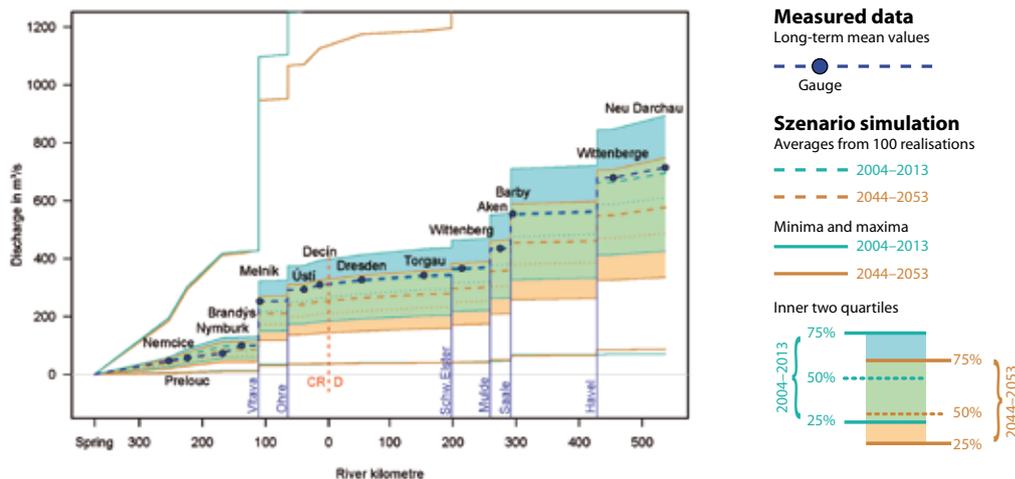
water from the Oder basin (Oder Bln, Oder Spree) generally appear to be more robust with respect to climate change. This is the currently intended baseline strategy. If the possible sensitivity on the Polish site to a water transfer from the Oder River is considered, then the “accelerated flooding” strategy is preferred. However, a sensitivity study for the four economic criteria and two discount rates revealed that the advantage of the “accelerated flooding” strategy decreases with an increasing discount rate (equal to long term growth rates of the gross domestic product) and disappears at a rate of 5%.

### Box 4.7 Impacts of regional warming

Regional warming will decrease surface water availability below critical limits during the low flow period in late summer. The shipping sector is most vulnerable to this development. The thermal power plants are going to adjust. The ecological status will not benefit from a higher nutrient retention under low flow conditions.

### Box 4.8 Reducing vulnerability

The vulnerability of the Spree-Havel Basin to low flow conditions can be decreased by an adequate adjustment of the current water management strategy. The procedure of discounting has a major effect on the economic differences between management alternatives.



**Figure 4.26** GLOWA-Elbe simulations for different river reaches along the main river. The mean yearly discharge is illustrated using the SWIM model (Conradt et al. 2007, Hattermann et al. 2006) to transform the 100 statistical realizations of future climate into river discharge for two scenario periods (2004–2013, 2044–2053) compared with the observed long term mean at the river reach. The climate change scenario postulates a mean temperature increase of 2.1°C between 2004 and 2055. The temperature range across realizations for the trend was 2.21–2.41 °C. The mean precipitation level remained unchanged but summer precipitation decreased and winter precipitation increased. The precipitation range across realizations for the trend was from -48 mm to 0 mm (Conradt 2008, personal communication).

# 5 Lessons for sustainable development

## 5.1 Danube: The significant impact of climate change on low flows in mountainous regions

Climate change in the mountainous Upper Danube will result in a significant decrease in river flows derived from snow and glacial melt and reduced summer rainfall (Figure 5.1). A detailed analysis identified the scale, seasonal and spatial distribution of the impacts on several aspects of water use. For example, seventy percent of Austria’s electric power

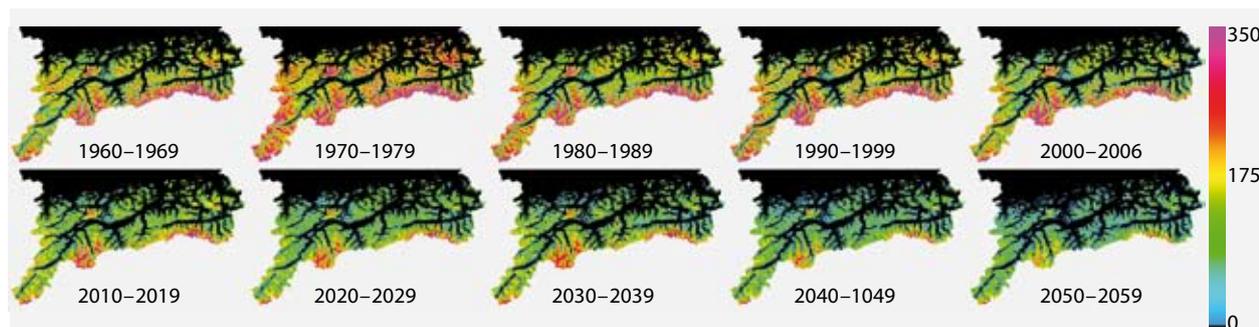
supply depends on hydropower, which is partly produced in the Upper Danube. The predicted change in hydrological regime will strongly influence power infrastructure in the region and the design and operation of hydropower schemes in the Alps. This conclusion stimulated discussion with stakeholders on the efficient future implementation of management tools and long term investments to adapt to the changes in river flow.

**Box 5.1 Summary**

Reduced water storage in snow and summer rainfall together with melting glaciers and increased evapotranspiration will lead to a decreased summer runoff. This will strongly affect the planning and operation of water resource schemes in order to adapt to climate change.

## 5.2 Danube: The complex interaction between climate change and crop production

The reduction in rainfall and increased evapotranspiration will lead to a reduction in soil moisture available for crop production. It can be expected that large areas in the drier parts of the Upper Danube will require irrigation to sustain today’s crop yield. At the same time the wetter areas near the Alps will change their optimum agricultural production.



**Figure 5.1** Scenario simulations of the average annual snow cover in the German and Austrian Alps of the Upper Danube basin. The simulations show the decadal change in the number of days with snow storage of more than 50 mm over the course of one century from 1961 to 2060

**Box 5.2 Summary**

The increased temperature and reduced precipitation in summer will have a strong influence on agriculture. Large areas in the Upper Danube watershed will need irrigation to sustain today’s agricultural yield. Other areas may change from grassland to agriculture.

The present land use of meadows and forest are predicted to change to areas suitable for growing wheat and maize without the need for irrigation. This change of land use potential together with irrigation in the drier regions will increase the demand for groundwater abstraction and reduce summer low flows. As a result the export of water to downstream countries will be considerably reduced.

### 5.3 IMPETUS: Dealing with uncertainties in climate impact modelling

As described in section 3.2, IMPETUS has established an interdisciplinary and holistic approach using innovative research which has highlighted several lessons which are summarised below.

It was found that tropical-extratropical weather interaction accounts for about 50% of the precipitation in large parts of the Drâa valley (cf. Knippertz et al. 2003). This process may explain the out of phase relationship with the long-term rainfall to the northwest of the Atlas Mountains. This questions the climate change projections in the IPCC 4<sup>th</sup> AR report for the region, i.e. a “very likely” drying trend for the entire Maghreb. The additional climate scenario “Process understanding” indicates a moderate increase in precipitation in the Drâa valley due to more frequent and intense tropical-extratropical interactions. However, such empirical climate projections are unsuitable for a variety of applications, for example, in hydrology where gridded meteorological input fields are required.

An additional way to cope with climate model uncertainty is the multi-model approach. IMPETUS was the first project worldwide which carried out ensemble regional climate projections which included realistic transient land use changes in West Africa (Section 3.2). A key conclusion was that the observed and projected drying in tropical West Africa is largely attributable to deforestation. The progress in regional climate modelling is, and will remain, fast and output from multi-model simulations will increasingly be available to the climate impact community. Rainfall generating processes will be captured more realistically in the future. An important contribution to the success of the project was the high priority given to developing well-trained and knowledgeable local users including the academic community who were trained to modify and amend the impact models.

### 5.4 IMPETUS: Sustainability of climate monitoring in the Drâa catchment

In addition to the above conclusions specific lessons were learned. Data for both catchments were very limited especially in the spatially variable subtropical mountainous terrain in the Drâa catchment. To improve this situation, 13 climate monitoring stations were installed to cover the variety of the main temperature, topographical and geological units.

Particularly noteworthy are the cluster of six stations in the Jebel M’Goun region (1900 m to 3850 m a.s.l.) because they are unique in North Africa’s high mountains. The snow depth monitoring at the three uppermost stations are essential for forecasting the spring melt and this was not previously available to regional Moroccan water and agricultural management authorities. As a result there is a strong interest by our Moroccan counterparts to maintain the network for long term environmental monitoring. Technicians have now been trained to run the network including the snow-melt runoff model system, and the monitoring stations, data, systems and tools are all being transferred to the “Agence de Bassin Drâa”.

### 5.5 IMPETUS: Multi-level stakeholder dialogue and the decentralisation process in Benin

The IMPETUS project has established a continuing dialogue with decision makers and provided capacity development at various levels from government administrations to local farmers. During the course of the project, a new opportunity occurred at the *commune* level. Due to the decentralisation process started in 2002 (Box 3.2), a considerable demand for information and training arose from the newly formed *commune* administrations. One key goal of the decentralisation process is the optimisation of water and land use. Due to its extensive knowledge, IMPETUS has been able to support the seven communes in the Upper Ouémé valley. This was done in two commune workshops (Figure 5.2) during which the need for information and training was defined and GIS training provided.



Figure 5.2 Opening ceremony of the IMPETUS commune workshop 2007



**Figure 5.3**  
Moderately grazed area in a semi-arid region. Biodiversity, erosion control, fodder value, recreational value, and water and nutrient cycling are among the many economic services provided by green water in this land use type, which is highly resistant to climate change.

Because the *communes* have limited access to computers, the printed version of the IMPETUS atlas (Judex and Thamm 2008) represents a rich and easy access source of information for these users. The contents of the Atlas were explained to the *commune* representatives and mayors and the process of capacity development has been well received at the *commune* level throughout the region.

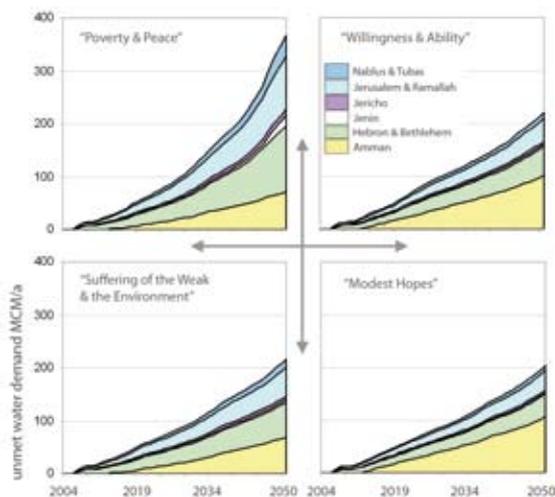
### 5.6 Jordan River: The importance of natural and semi-natural areas for sustainable development

A major lesson from our blue-green water approach is the overwhelming importance of natural and semi-natural areas for sustainable development. Natural ecosystems in arid and semi-arid regions are highly resistant to the impact of climate change, while irrigated agriculture is not. At the same time, water productivity of open spaces may be orders of magnitude larger than the value produced by water in agriculture. The value of natural vegetation varies between economies, but ecosystem services are considerable, even under poor economic conditions (Fleischer & Sternberg 2006). Due to the high resistance of open space to climate change, re-allocation of land from agriculture to natural vegetation may be an efficient and sustainable water management option under global change. However, semi-natural ecosystems are highly vulnerable to changes in land use (grazing

and afforestation) and this must be considered when increasing the area allocated to open space. Our findings are highly innovative because they point to options for sustainable development that have been completely overlooked before. This option is transferable to any water-scarce region in the world with large natural climate variations (Figure 5.3)

### 5.7 Jordan River: Facilitating sustainable resource management through an innovative integrated approach

Basic science, if combined with an efficient stakeholder dialogue, can provide a sound basis for wise decisions in water management. Water resources management under global change must follow an integrated approach that includes management of both water demand and supply in various sectors. GLOWA JR has developed an innovative framework for assessing ‘new’ blue and green water sources (i.e. land management and reallocation options) and conjunctive surface and groundwater management for overcoming the traditionally fragmented approach to sustainable resource management. This approach enables previously independent management options to be traded off. An example of this is the successful implementation of WEAP as a decision support system which allows trade-off analyses between blue and green water management (Figure 5.4).



**Figure 5.4** Decision support through WEAP: computed unmet water demand (in MCM/year) applying the simulated population growth rates of the four SAS scenarios for main cities in the Jordan River region under the impact of climate change

Although WEAP has successfully transferred scientific knowledge from a large variety of disciplines to the end-users, integration can only be realized at the cost of losing detailed information. Therefore, end-users must have access to original scientific findings so they can evaluate the plausibility of local management options. Cross-sectoral co-operation in the region is essential to ensure that complex land-water interaction issues are integrated into the long term planning of sustainable water management. GLOWA JR has been instrumental in that context by, among others, inspiring the formation of inter-ministerial working group for climate adaptation in Israel.

### 5.8 Volta: Constructing data management tools for co-operative transboundary water resources management

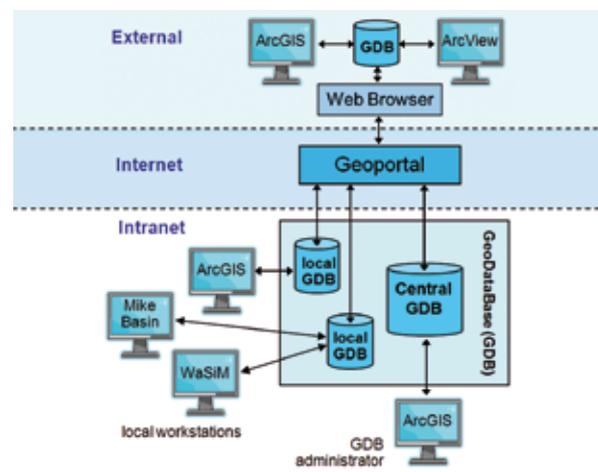
A key lesson learned in the Volta project has been the importance of sharing environmental data and the need for institutional change to manage database development and data dissemination. Climate change affects regions independently of national boundaries, while economic policy and water resources development are decisions of national concern. To prevent transnational conflicts, strategies need to be developed to meet the increasing water demand under limited supply in a larger, basin-wide framework. Transboundary water management, as well as water resources development in individual countries, needs

to be based on good quality physical data for sound decision support. The demand for such data is very high, both on a national and basin-wide level. Access to data, however, and knowledge of its existence, is largely based on personal contacts. To enable the riparian countries to overcome this data scarcity, and engage in transboundary and national water management, the development of a data management framework (Figure 5.5) and sharing platform was essential. (Rodgers et al. 2007)

In GLOWA Volta stakeholder workshops, the participants have identified the need for a user friendly platform to gather, manage, and distribute relevant data. To facilitate this demand, the GVP has developed a geodatabase, which initially archived the data collected and generated in the GVP, and which can be accessed through the Internet. It was essential to provide the initial momentum to actively develop a basin-wide geodatabase, and to implement capacity building activities in the form of well received data management workshops (Figure 5.6). To sustain and expand the database, we sought cooperation with national entities, such as meteorological and hydrological services, and other research institutions.

### 5.9 Volta: Different levels of decision support in a river basin with polycentric water governance

Water management and allocation within the Volta River Basin is characterised by a large number of actors and institutions, as well as the absence of a comprehensive water management framework. Although National Water Administrations underwent crucial reforms beginning in the 1980s it was not until



**Figure 5.5** Infrastructure of the GLOWA Volta Geodatabase



Figure 5.6 Participants of capacity building workshop held in Accra in 2007

2006 that the Volta Basin Authority was established with a mandate for the management of transboundary water resources. Historically, official actors often lacked the resources for the implementation of water management policies. Decentralisation and the (informal) power of local actors contribute to a situation of polycentric water resource governance. Thus, scientific decision support has to target different audiences (Table 5.1) with different demands at different scales. At the basin-scale, the GVP provides an innovative data management system, and the Volta Basin Water Allocation System (VB-WAS) that takes into account climate change. At the national sub-basin scale the GVP has developed data management services and National Water Allocation Systems



Figure 5.7 GLOWA Volta Research Network (selection)

(N-WAS) that can model the impact of climate change and optimise water allocation decisions. At the regional sub-basin scale, the White Volta Water Allocation System (WV-WAS) models the impact of increasing water storage and irrigation development in the White Volta Basin. In order to capture the impact of land use changes, an innovative model projects local socio-economic, ecological, and hydrological impacts of land use and climate change into the future.

These initiatives aim at providing a network for information exchange, as well as capacity building, and knowledge exchange for the large number of stakeholders, institutions and programmes involved (Figure 5.7) (Laube et al. 2005).

Table 5.1 Scientific decision support for distributed water resource management				
	BASIN SCALE (Transboundary)	SUB-BASIN SCALE (National)	SUB-BASIN SCALE (Regional)	CATCHMENT (Local)
ISSUES	Water Allocation	Water Allocation	Storage Development	Land Use Change
	Climate Change Impact	Infrastructure Development	Irrigation Development	
	Data Management	Data Management		
GVP SOLUTIONS	Volta Basin Water Allocation System GVP Geoportal	National Water Allocation System GVP Geoportal	White Volta Water Allocation System GVP Geoportal	Multi-Agent Land and Water Use Model
PARTNERS	Volta Basin Authority	National Water Administrations	Water Resources Commission	Farmers
	National Water Administrations	Government Agencies	Ministry of Food and Agriculture	NGOs
	International Donors	Research Institutes NGOs International Donors		Water Resources Commission Ministry of Food and Agriculture



**Figure 5.8** Left: Aerial view on flooded Elbe sites in 2002.

Right: Sandbanks of the Elbe tributary Mulde during low water period in 2005.

### 5.10 Elbe: The uncertainty in future precipitation trends needs to and can be taken into account in complex regional impact studies for river basins

There is a long tradition in hydrological sciences for addressing uncertainty. The calculation of return periods for extreme hydrological events like floods (Grünwald 2001) and droughts (Figure 5.8) is a prominent example.

Taking the inherent uncertainty in any projection into the future into account, the aim of the project was to quantify the possible range of future changes in water resources in the Elbe river basin using a stochastic approach. The climate group delivered not only one climate scenario projection but a whole set of 100 realizations of the possible future climate (Orlowsky 2007).

Each of them forms one boundary condition for the hydrological scenario analysis in GLOWA-Elbe. This was achieved by applying a statistical downscaling of the climate change signals from the Global Circulation Models. Particularly, the broad range of possible regional precipitation changes related to climate warming could be addressed this way. One important and robust conclusion is that we are able to project that

under further climate warming, current minimum flows in the Elbe main stream will most likely be the mean flow in 2050.

#### Box 5.3 Summary

Statistical realizations of regional climate change scenarios can be used to derive robust conclusions about changes in extreme hydrological events.

### 5.11 Elbe: Rapid changes in global agro-markets determine the projected results

The climate projection for the Elbe region were combined with a whole spectrum of socio-economic projections for the major water relevant sectors, e.g. for agriculture. However, these projections had to be readjusted within the timeframe of GLOWA-Elbe.

The underlying reason was the imbalance between food demand and supply on the global markets. This imbalance and use of arable land for the production of bio-fuel make an intensified use of arable land much more likely in the future (Figure 5.9).



**Figure 5.9** Left: Abandoned agricultural land.

Right: A typical maize field at harvest in the lowland area.

In the first phase of GLOWA-Elbe (Wechsung et al. 2005), the latter was the result of a scenario of liberalization in trade markets in areas with less productive sandy soils (up to 30% of the entire arable land). Changes in projections due to changes in anticipated economic conditions are unavoidable. In order to be able to readjust the impact assessment, the underlying basic assumption and projections need to be clearly stated and recognizable. Furthermore, after concluding the impact study the modelling system and the data base attached to it should be made publically available. GLOWA-Elbe will release the modelling framework in the form of a toolbox at the end of the final project phase in 2010. Institutions within the basin can use the model system for later readjustment of the GLOWA-Elbe assessment and interested users from other basins can use the Elbe basin parameterization as a starting point for new studies.

#### Box 5.4 Summary

The public availability of models and data used in an impact assessment is a major pre-condition for ensuring transparent and reproducible results and to enable results to be revised when the initial projections are no longer valid.

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## Chapter 2

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## Danube

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Source Figure 3.2: Klaus Leibdorf,  
84172 Buch am Erlbach

## Impetus

### Ouémé

Ministère des Mines, de l'Énergie et de l'Hydraulique (MMEH); Ministère de l'Environnement, de l'Habitat et de l'Urbanisme (MEHU); Ministère de l'Agriculture, de l'Élevage et de la Pêche (MAEP); Direction des Forêts et Ressources Naturelles (DFRN/MAEP); Direction de l'Hydraulique (DH/MMEH), Services Départementale de l'Hydraulique (SDH/DH/MMEH) (Parakou, Djougou, Dassa and Bohicon); Direction de la Météorologie Nationale (DMN); Centre National de Télédétection (CENATEL/MAEP); Institut National de Recherche Agricole au Bénin (INRAB/MAEP); Centre d'Action Régionale pour le Développement Rural (CARDER/MAEP); Université d'Abomey-Calavi (UAC); Faculté de Sciences Agronomiques (FSA/UAC); Université de Parakou; CATCH/AMMA (Couplage de l'Atmosphère Tropicale et du Cycle Hydrologique / Analyse Multidisciplinaire de la Mousson ouest Africaine); long-termed component of the project supported by IRD (Institut de Recherche pour le Développement); German Technical Cooperation (GTZ); Projet de Gestion des Terroirs et Ressources Naturelles (PGTRN); Projet

d'Aménagement des Massifs Forestiers du Mont Couffé (PAMF/DFRN/MAEP)

## Drâa

Royaume du Maroc Ministère, de l'Énergie, des Mines, de l'Eau et de l'Environnement, Secrétariat d'Etat auprès du Chargé de l'Eau et de l'Environnement, Rabat; Ministère de l'Aménagement du Territoire, de l'Eau et de l'Environnement (MATEE); Ministère de l'Agriculture et de la Pêche Maritime, Administration du Génie Rural, Haut Commissariat aux Eaux et Forêts et la Lutte contre la Désertification, Rabat; Office Régional de Mise en Valeur Agricole de Ouarzazate (ORMVAO); Direction Régionale de L'Hydraulique (DRH), Agadir: Service Hydraulique Ouarzazate; Office National de l'Eau Potable (ONEP) - Région of Ouarzazate; University of Rabat, Department of Geography, Department of Forestry and Department of Plant Ecology; Institute of Agricultural & Veterinary Science, Rabat; University of Agadir, Department of Geography; University of Cadi Ayyad, Faculty of Sciences and Techniques, Faculté des Sciences Semlalia, Marrakech; Centre National de l'Énergie, des Sciences et des Techniques Nucléaires (CNESTEN), Rabat; Institut de Recherche pour le Développement (IRD), Marrakech; CBTHA (Conservation Project for Biodiversity through Transhumance in the Southern High Atlas); ROSELT, OSS (Observation Network for the Long Term Ecological Surveillance of the Sahara and of the Sahel), Zagora; German Technical Cooperation (GTZ), Zagora, Agadir; Foundation Konrad Adenauer, Rabat

## Jordan River

Al-Quds University, An-Najah National University, Arab Agronomist Association, Arab Technologist for Economical and Environmental Consultations, Arava Institute for Environmental Studies, Bar-Ilan University, Ben-Gurion University, Biodiversity & Environmental Research Center, Forschungszentrum Karlsruhe - IMK-IFU Garmisch-Partenkirchen, Haifa University, Hebrew University of Jerusalem, House of Water and Environment, Israel-Palestine Centre for Research and

Information, Kinneret Limnological Laboratories, Leibniz Centre for Agricultural Landscape Research, Max-Planck-Institute for Colloids and Interfaces, Mekorot, MIGAL – Galilee Technology Centre, Ministry of Agriculture (Israel), Ministry of Agriculture (PA), Ministry of Water and Irrigation, Mu'tah University, Palestinian Academy of Sciences, Palestinian Hydrology Group, Palestinian Water Authority, STAV-GIS, Stockholm Environment Institute, Tahal, Tel Aviv University, Tel-Hai College, University of Bochum, University of Freiburg, University of Hannover, University of Hohenheim, University of Jordan, University of Kassel, University of Potsdam, University of Tübingen, Volcani Center, Weizman Institute

#### **Volta**

Bundesanstalt für Geowissenschaften und Rohstoffe, Center for Development Research (ZEF), Centre de Coopération Internationale en Recherche Agronomique pour le Développement (France, Burkina Faso), Council for Scientific and Industrial Research (Ghana), Delft University of Technology, Direction Général des Ressources en Eau (Burkina Faso), Forschungszentrum Karlsruhe IMK-IFU, German Aerospace Center (DLR)/

University of Würzburg, Ghana India Kofi Annan Centre of Excellence in ICT, Ghana Meteorological Agency, Hydrological Services Department (Ghana), Institute of Statistical, Social and Economic Research (University of Ghana), Institut de l'Environnement et des Recherches Agricoles (Burkina Faso), International Institute for Water and Environmental Engineering (Burkina Faso), International Water Management Institute, Kwame Nkrumah University of Science and Technology (Kumasi, Ghana), New Mexico Tech (USA), Savannah Agricultural Research Institute (Ghana), Small Reservoirs Project, United Nations University – Institute for Environment and Human Security, United Nations University – Institute for Natural Resources in Africa, University of Bonn, University of Ghana, Volta Basin Authority, Water Research Institute (Ghana), Water Resources Commission (Ghana)

#### **Elbe**

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# Abbreviations

## Chapter 1

BMBF	Bundesministerium für Bildung und Forschung
GDP	Gross Domestic Product
GLOWA	Global Change and the Hydrological Cycle
GWSP	Global Water System Project
HELP	Hydrology for Environment, Life and Policy
PA	Palestinian Authority
PT-DLR	Projekträger im Deutschen Zentrum für Luft- und Raumfahrt e.V.
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization

## Chapter 2

AGCM	Atmospheric General Circulation Models
GLOWA	Global Change and the Hydrological Cycle
GCM	Global Circulation Models
RCM	Regional Circulation Models

## Danube

GLOWA	Global Change and the Hydrological Cycle
IPCC	Intergovernmental Panel on Climate Change

## Impetus

CLUE-S	Conversion of Land-Use and its Effects at Small regional extent
DRH	Direction Regional de L'Hydraulique
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
HCEFLCD	Haut Commissariat aux Eaux et Forêts et la Lutte contre la Desertification
HYDRAA	Hydrologic model for the Drâa-catchment
INRAB	Institut National des Recherches agricoles du Bénin
IPCC AR4	Intergovernmental Panel on Climate Change: 4th Assessment Report
IPCC SRES	Intergovernmental Panel on Climate Change: Special Report on Emission Scenarios
IS	Information System
IWEGS	Impact of Water Exploitation on Groundwater and Soil
LMM	Liverpool Malaria Model
MalaRis	Malaria Risk
MATEE	Ministère de l'Aménagement du Territoire, de l'Eau et de l'Environnement

MT	Monitoring Tool
ORMVAO	Office Régional de Mise en Valeur Agricole de Ouarzazate
PESERA	Pan European Soil Erosion Risk Assessment
PRO-RES	Prognosis of snowmelt runoff for the water reservoir
REMO	REgional climate Model
SDSS	Spatial Decision Support System
SEDRAA	Soil Erosion in the Drâa region

### Jordan River

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
DSS	Decision support system
GDP	Gross Domestic Product
GLOWA JR	GLOWA Jordan River project
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resource Management
MODFLOW	MODular three-dimensional finite-difference ground-water FLOW model
SAS	Story and simulation approach
SEI	Stockholm Environment Institute
WEAP	Water Evaluation and Planning

### Volta

DGRE	Direction Générale des Ressources en Eau
GDP	Gross Domestic Product
GTZ	Gesellschaft für Technische Zusammenarbeit
GVP	GLOWA Volta Project
IPCC	Intergovernmental Panel on Climate Change
LUDAS	Land Use Dynamic Simulator
M <sup>3</sup> WATER	Multi-country, Multi-sector, Multi-use (M3) Water Allocation Tech-nology for Efficient Manage-ment of Resources (WATER)
MM5	Mesoscale Meteorology Model 5
NGOs	Nongovernmental Organisations
N-WAS	National Water Allocation System
ORS	Onset of the Rainy Season
UNU-INRA	United Nations University - Institute for Natural Resources in Africa
VBA	Volta Basin Authority
VB-WAS	Volta Basin Allocation System
WaSiM	Water Flow and Balance Simulation Model
WV-WAS	White Volta Water Allocation System

### Elbe

Bln	Berlin
Brb	Brandenburg
GDP	Gross Domestic Product
IPCC	International Panel for Climate Change
SWIM	Soil and Water Integrated Model

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## IMPETUS

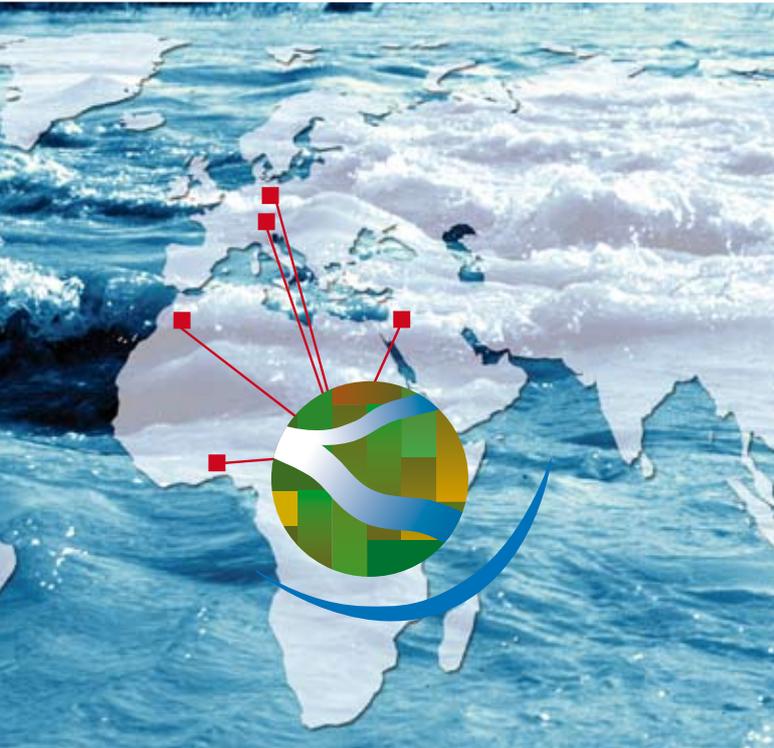
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# Web Sites



## Chapter 1

[www.glowa.org](http://www.glowa.org)

## Danube

[www.glowa-danube.de](http://www.glowa-danube.de)

## IMPETUS

[www.impetus.uni-koeln.de](http://www.impetus.uni-koeln.de)

## Jordan River

[www.glowa-jordan-river.de](http://www.glowa-jordan-river.de) • [www.weap21.org](http://www.weap21.org)

## Volta

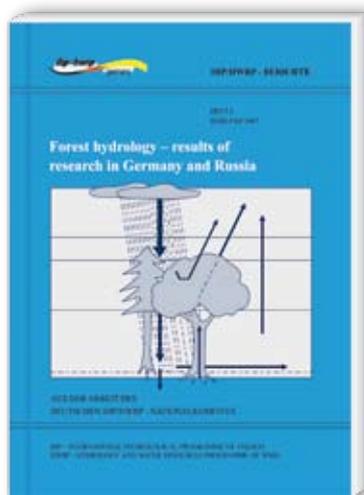
[www.glowa-volta.de](http://www.glowa-volta.de)

## Elbe

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