T869 Climate change: from science to lived experience

The Lived Experience of Climate Change: Water case study on the Nile and Rhine river basins

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Contents

Before you start: aims, learning outcomes and how to study this module

The overall purpose of providing this case study is to familiarise you with one of the fundamentals of life – water – which is being affected by climate change. Water is of such importance, however, that it constitutes a complex subject in its own right, and this is how we present it here. A further important aim, therefore, is to provide a case study which is deliberately not written primarily from a climate change perspective (although it contains sections about the impact of climate change), but to which you can apply the insights you have gained through studying the modules from that perspective. This 'retro-fitting' of a climate change perspective to other, ongoing challenges such as water, is an important generic skill, and helps give you an appreciation of the broader picture. One thing we do not wish to do is present climate change as just another subject or 'discipline' within which you become locked. You should be prepared to conduct dialogues with those whose starting point is different but who also share many of your concerns.

Water and food are the two most important basic human needs. They are strongly affected by climatic variability and trends (IPCC, 2007) and the ensuing effects on water stress and food production. The lived experience of climate change consequently relates strongly to the impacts of changes in precipitation, temperature and evaporation on water systems and agriculture. Given that the impacts on agriculture are primordially related to water availability (in the soil or for irrigation), it becomes clear that the impacts of climate change on water are very important to our societies, and will become more so in the future.

Many experts warn that, in the future, water crises might become much more critical than energy crises or other societal problems. This is not only because of climate change but also population growth, economic growth and related increases in welfare and urbanisation. These changes are in general greatest in developing countries. Water (including its role in developing countries) therefore has been selected as a cross-cutting case study for the three Lived experiences of climate change modules.

Two river basins, the Nile in the global South (developing countries) and the Rhine in the global North (developed countries), are chosen for this case study. These cases will help you understand how people in different countries have adapted to changes in climate in the past and are currently adapting. At the end of the individual river case studies you will find general conclusions with some guidelines on how to study the water case.

Learning outcomes

After studying *The water case study* you should be able to:

- Describe the characteristics of the Nile and Rhine basins and their geographical locations.
- Communicate appropriate insights on water-related problems of the basin from environmental, socio-economic, meteorological, hydrological, institutional, and political points of view.
- Discuss climate and climate impacts in relation to the water sector
- Compare and contrast scientific results on climate change trends in recent years and future projections
- Analyse and discuss how populations in the past were able to adapt to changing climatic conditions in relation to water
- Analyse the general role of water management and technologies in adapting to climate change impacts and the role that dynamic water management strategies will play in the future

- Participate in a learning community of people with a wide range of professional or disciplinary backgrounds, different socio-cultural and physical environments who possess a variety of perspectives and methodological traditions.

Work load

In total the *water case study* will require about 25 hours of study time, if you work through it systematically as a separate module.

Introduction	1 hr
Nile case	11 hrs
Rhine case	11 hrs
Conclusion	2 hrs

Note that for active participation, we have included exercises within the case study, although there is no separate workbook. These exercises are part of the materials to be studied, and are included in the total workload for the case study.

The module workbooks, however, include specific activities which ask you to apply what you are learning to the water case study. The timings for these activities are part of the overall time for the module in which they appear. If you use the workbook activities to ‘lead’ you and you therefore read the water case study on a ‘need to know’ basis, the above study time does not apply as it is incorporated within these activities.

How to study this module

Unlike the teaching modules in this series, *The water case study* consists of a single ‘textbook’ comprising a central narrative about the subject, but within which exercises are embedded in order to foster your active participation (see above). We recommend that you do not neglect these exercises. Your sense of overall satisfaction with the case study is likely to be greater if you engage with them.

How in practice might you combine the *water case study* with your study of the three modules, bearing in mind that a major aim is for you to apply the principles and concepts within the modules to this case study? You should choose the method which best suits your own learning style, but one good way is to:

Read the narrative in the rest of this *water case study* and do the exercises along the way, so that you gain an overall insight into it.

Do the module workbook activities that relate directly to the case study. You may also find that your attempt at other module workbook activities can draw on it.

In other words you first read the case study as a resource in its own right in order to gain an insight into the ‘water’ perspective. Then you apply your study of the climate change modules to it, which is your primary perspective.

1 Introduction

Water is a unique natural resource important to meeting human needs and vital to the existence of life on earth. However, water resources are limited and unevenly distributed in time and space and our globe thus faces many challenges in relation to it. Primarily the demand on water resources is increasing rapidly as population and economic activity expand all over the world. Both the quality and quantity of water represent important challenges. Human activities such as deforestation, agriculture, urbanisation, pollutants in both surface and sub-surface water bodies and so on, all influence the timing and quantities of flows and are having a huge impact on the quality and quantity of freshwater (UNESCO, 2006). In addition, environmental issues, such as climate change and land use change, alter the quantity and quality of the resource. Furthermore, pressure on water resources is aggravated by higher demands for food security and socio-economic well-being by all of society as well as increased competition between different users and different uses to which water is put (UNESCO, 2006).

To obtain a fair, equitable and sustainable distribution of water in a specific basin, water management practices are imperative. These management practices should be able to synchronise the management of water quantity and quality, and life in the water environment. Thus it signifies the importance of implementing Integrated Water Resources Management (IWRM - see Box 1.1) strategies. Nevertheless, there are many influences on IWRM strategies and practices. Some examples are listed below:

- Access to reliable data concerning the quality, quantity and availability of water resources.
- Dynamic ecosystems and impacts of anthropogenic activities on these
- Water conflicts in international river basins concerning water sharing
- Socio-economic conditions of the countries/people who are using the water
- The existence of water resource institutions at basin level and their performance
- Uncertainty of the future in terms of climate change scenarios
- Opportunities for stakeholder participation in management decisions and policy formulation
- Risk and uncertainty

These and other factors can complicate water management practices and imply the need for an interdisciplinary and integrated approach. Climate change, as one of the current challenges facing the management of water resources, needs to be addressed using such an approach. Many aspects of climate have an impact on physical and biological systems. These aspects include temperature and precipitation, and their variability on all timescales, from days to the seasonal cycles to inter-annual variations (IPCC, 2007) and they will in turn have impacts on the environment, ecosystems, water resources and many aspects of human life.

One of the most important and immediate effects of climate change would be changes in local and regional water availability, since the climate system is interactive with the hydrological cycle (see Box 1.2) (Jiang et al., 2007). Such hydrological changes will affect nearly every aspect of human well-being, from agricultural productivity and energy use to flood control, municipal and industrial water supply, and fish and wildlife management (Xu, 1999).

Since the effects of climate change are certain to be felt in several sectors, it is important to formulate adaptation strategies either to live with the changes or to prevent potential damage. According to Smit and Pilifosova, (2001), adaptation is adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions, or activities to climatic change and variability. Adaptation strategies are likely to be river basin-specific according to the type and severity of the problem, and the capacity and sensitivity of the regions.

Even though climate change is real, its impacts are highly uncertain. The uncertainties in climate change emerge primarily from the fact that it is impossible to test the impact experimentally before the facts arise. Climate change projections are therefore based on different assumptions about temperature rise and so forth which then generate possible scenarios (see Module 1 Chapter 2 on climate models). The Intergovernmental Panel on Climate Change (IPCC) has identified a number of possible greenhouse gas emission projections that have led to different scenarios. All these scenarios have been designated as equally valid, with no assigned probabilities of occurrence. Secondly, different parameterization[1] schemes are used in the different climate models. Therefore, the projections we get from these various climate models will not be the same. As a result, our decisions will be challenged in terms of which projected impact we use as a basis for policy formulation. As all scenarios are equally valid, much uncertainty surrounds the results of climate change impact projection and also in the mitigation and adaptation measures that have to be taken.

Additional examples of causes of uncertainty in future climate projections include: possible changes in demography, social and economic status, the future mix of energy sources, the limited physical knowledge on climate and water system responses (climate and impact models) and future greenhouse gas emissions. Considering these and other sources of uncertainties, governments and other responsible institutes need to design/develop new types of management strategies that are flexible (adaptable) and which allow changes to be made (with minimal total cost) depending on the future evolution of our climate.

As mentioned above, the uncertainties in climate change projection are large. However, decision makers should not be deceived by lack of scientific certainty from taking appropriate measures. The question is how to deal with the risks, and how to adapt to uncertain future change. Do we want to take the risk, and adopt a wait-and-see policy? Or should we adopt the 'precautionary principle', meaning that, in cases of threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation?. The precautionary principle thus favours a 'prevention is better than cure' approach. What the preferred approach in water management will be depends on the views of experts and stakeholders on the future risks and uncertainties. One way to deal with this is to involve stakeholders, experts and decision makers in participatory approaches to identify appropriate management strategies.

The argument of this case study is that water resources management should follow a holistic approach to obtain a sustainable result. For this purpose we argue that inclusion of all stakeholders is important in making assessments. A stakeholder is somebody with a 'stake', i.e. an interest, in the water management issue at hand. Stakeholders in the context of water resources management can be defined as all individuals, groups, organisations and governmental agencies that use the particular water resource to meet their needs. For instance, when there is a decision to be made in a locality about the treatment of industrial waste water, different stakeholders – for example industries, municipalities, environmentalists – are involved, with different concerns and interests. In

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[1] Parameterization – in climate change models refers to the method of replacing processes that are too small-scale or complex to be physically represented in the model by a simplified process. See also Module 1 Chapter 2, while Module 3 Chapter 3 (Box 3.3) provides a generalized definition in terms of the ways in which parameterization is a process of constructing boundaries around complex phenomena through what we choose to consider and measure.

the context of climate change adaptation these stakeholders can provide useful information. Generally, the main role of stakeholders in the adaptation process is to share their views, knowledge and resources in order to find reliable solutions and to formulate relevant polices. Finally we argue that development plans or policies are likely to be sustainable if they have involved the capacity and knowledge of a range of stakeholders.

Box 1.1 Integrated Water Resources Management (IWRM)

According to Global Water Partnership (a network established by the World Bank and United Nations Development Programme in 1996), Integrated Water Resources Management (IWRM) is the coordinated development and management of water, land and related resources in order to maximise economic and social welfare without compromising the sustainability of ecosystems and the environment.

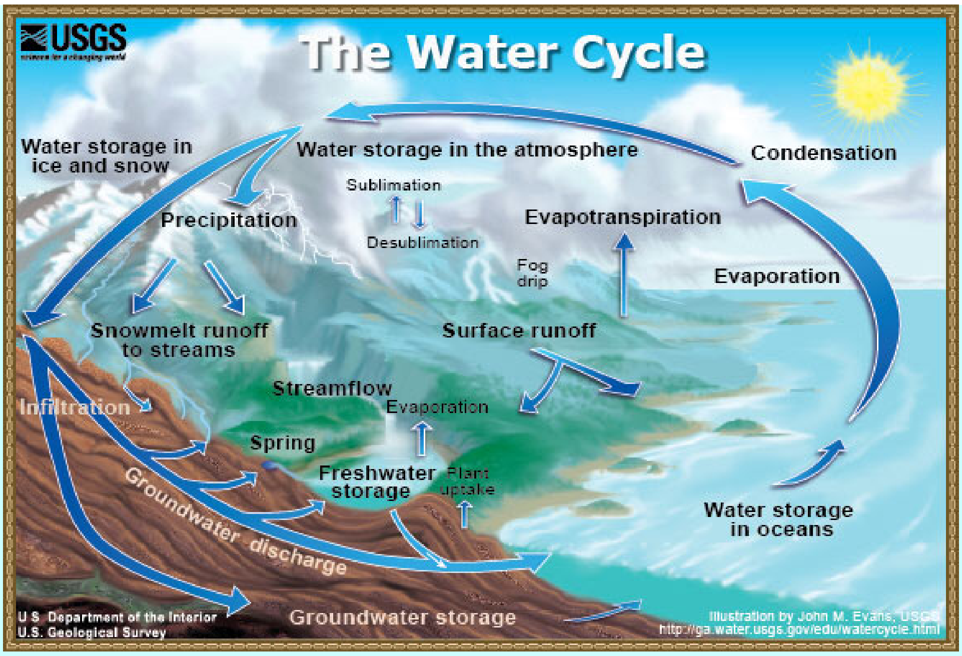
IWRM helps to protect the world's environment, foster economic growth and sustainable agricultural development, promote democratic participation in governance, and improve human health. Worldwide, water policy and management are beginning to reflect the fundamentally interconnected nature of hydrological resources, and IWRM is emerging as an accepted alternative to the sector-by-sector, top-down management style that has dominated in the past.

More information: http://www.gwp.org/The-Challenge/What-is-IWRM/

Box 1. 2 The Hydrological Cycle (The Water Cycle)

The hydrological cycle refers to the continuous movement of water on, in and above the earth in different states, that is from liquid to vapour to solid and back again. This process is driven by the energy from the sun. The hydrological cycle is therefore a continuous process that includes sub-processes where water can be stored in various forms. The figure below illustrates the different components and their interconnections. Some of the terms that appear in the Figure are:

- Evaporation – the transformation of water from a liquid into a gas, a process which humidifies the atmosphere.
- Evapotranspiration – a process that combines two separate processes whereby water is lost from the soil surface by evaporation and from plants by transpiration
- Condensation – the transformation of water from a gas into a liquid
- Precipitation – the transfer of water from the atmosphere to land surface or water bodies, which can be in different forms: rain, hail, snow, and sleet.
- Streamflow – the movement of water in a natural channel, such as in rivers
- Surface runoff – the amount of precipitation that flows over the soil surface and runs into the nearest stream channel
- Infiltration – the downward movement of water from the land surface into soil or porous rock
- Groundwater storage – water existing for long periods below the earth's surface



Source: http://ga.water.usgs.gov/edu/graphics/watercyclesummary.jpg

2 The Nile Basin

2.1 Introduction to the Nile basin

The Nile basin is one of the most important river basins in Africa. It is drained by the longest trans-boundary river[2] in the world, the Nile River. The river is the only source of water for some of the countries it passes through. It is a source of food and has high socio-economic value for the people who are dependent on it.

2.1.1 Where is the Nile?

The Nile is located in the north-east region of Africa. It passes through ten countries (Burundi, Democratic Republic of the Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda). The Nile flows from the south, the farthest point being in Nyungwe forest, Rwanda, to the north, the Mediterranean Sea (Dumont, 2009). Its length is approximately 6,800 km. The Nile has an overall basin area of about 3 million km2 which accounts for one-tenth of the African continent. It lies between the geographical coordinates 4°S and 31°N latitude and from 21° 30´E to 40° 30´E longitude. Figure 2.1 shows the Nile basin and the countries through which it passes.

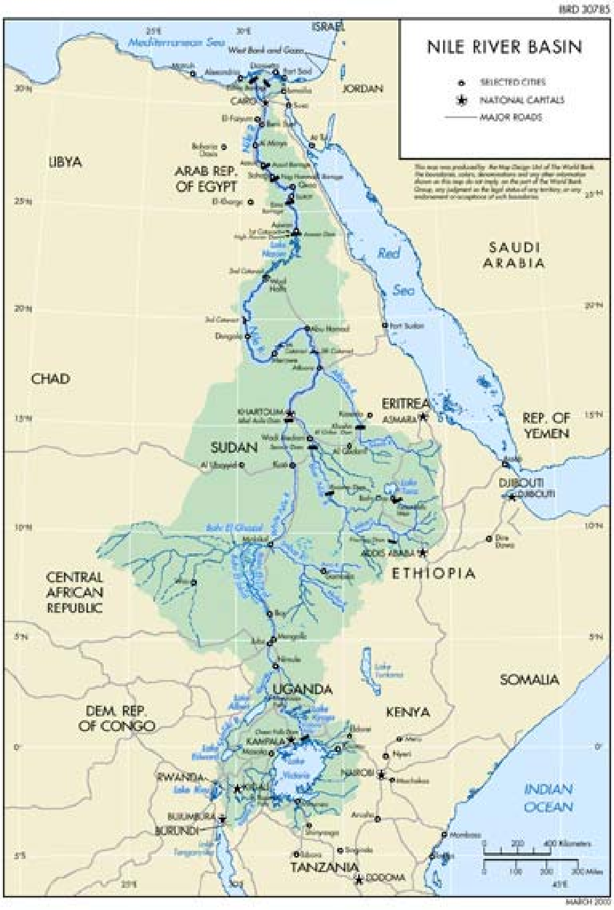


Figure 2.1: The Nile basin

Exercise

Examine Figure 2.1 and distinguish the 10 riparian countries.

Examine the overview of African river basins and identify the Nile river at http://maps.grida.no/go/graphic/major-river-basins-of-africa

2 Trans-boundary River is a river that crosses at least one political border at national or international level.

2.1.2 Characteristics of the Nile basin

In this section you are introduced to the outstanding characteristics of the basin, starting with the major demographic and economic indicators which are summarised in Table 2.1. The Nile basin has a high population which is predicted to double (using 2009 as the base year) by the year 2050 according to the United Nations Population Division (UNPD). The projections are based on the UNPD's medium-variant growth scenario[3]. The economic indicators in Table 2.1 are taken from the World Bank annual report 2008. The Table shows that the Nile River basin is home to a large number of people and that most of the countries are in the category of the poorest nations. Although not shown in the Table, they also have high debt to international organisations.

Table 2.1: Key demographic and economic[4] data of the Nile basin countries

Country	Capital city	Total Population (millions) (2009)	Projected population (millions) (2050)	GNI per Capita US$ 2008	GDP per Capita US$ 2008
Burundi	Bujumbura	8.3	14.8	140	144.04
DR Congo	Kinshasa	66.0	147.5	150	180.49
Egypt,	Cairo	83.0	129.5	1800	1997.1
Eritrea	Asmara	5.1	10.8	300	331.04
Ethiopia	Addis Ababa	82.8	173.8	280	328.16
Kenya	Nairobi	39.8	85.4	770	895.49
Rwanda	Kigali	10.0	22.1	410	458.49
Sudan	Khartoum	42.3	75.9	1130	1413.46
Tanzania	Dar Es Salaam	43.7	109.5	430	482.31
Uganda	Kampala	32.7	91.3	420	458.95

Sources: Population data: United Nations Population Division; Economic data: World Bank

In the Nile basin the major economic activity is agriculture. The Nile is the only significant water resource for Egypt and Sudan (the two most downstream countries). These countries use irrigation to feed their populations while most of the upstream countries depend more on subsistence farming using rainfed agriculture. For example, in Ethiopia some 83% of the population is estimated to live in rural areas (data refers to UNPD revised 2008 report) and are dependent on small scale subsistence farming. In addition to agriculture, fisheries comprise an essential economic activity in the basin, where Lake Victoria takes the greatest share. Industrial activities such as vegetable oil production on plantations, textile factories and tourism are supplementary to the economy of the basin. Hydropower generation and irrigation are supported by dams that are

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3 http://esa.un.org/wpp/unpp/

4 Gross National Income (GNI) is a common measure of a region (or country's) wealth in monetary terms, usually United States dollars (see also Chapter 2 of Module 2). Per capita simply means per head of population. Gross Domestic Product (GDP) is an output measure of what an economy produces (see also Chapter 3 of Module 1). GNI comprises GDP plus income claimed by a country's citizens from abroad (returns on overseas investment, remittances home while working abroad, etc.) minus income claimed by foreigners (repatriated profits, remittances sent home by guest workers, etc.).

constructed along the river. The major dams include the Roseires Dam and Sennar Dam in Sudan, the Aswan High Dam in Egypt, and the Owen Falls Dam in Uganda. The Aswan High Dam is the largest in the basin, and more information is provided in Box 2.1.

Turning to its physical features and climates, the Nile basin is diverse, including different climate zones, geographical and topographical features. The elevation of the basin ranges from about 5000 metres above sea level to 0 metres at the Mediterranean Sea (Figure 2.2). The river passes through complex channels, gorges, plateaus, wetlands, swamps, marshlands, lakes, and desert. The basin is rich in biodiversity and vegetation types.

The climate along the Nile is extremely variable, changing from humid to arid conditions as the river flows downstream. The different climate zones include: mediterranean, arid, semi-arid and humid/semi-humid climates. The sources of the river are located in humid regions while the arid region starts in the desert of the northern third of Sudan, and extends further north to Egypt. This makes the Nile the only river that crosses the entire length (travelling South-North) of the Sahara desert.

The climate zones of the basin correlate strongly with the amount of precipitation received in the different sub basins. As one moves from the source regions to the downstream basins, the amount of precipitation decreases while the potential evapotranspiration (see Box 1.2 above) increases. Thus, the precipitation and the potential evapotranspiration have an inverse relationship. This explains why most of the downstream parts of the basin are more arid.

The strong rainfall variation over the length of the basin is a result of its large latitudinal and altitudinal variation. The source regions receive high amounts of rainfall -- more than 1000 mm/year. The rainfall is bimodal in the southern part of the basin where Uganda, Kenya, Tanzania, Rwanda and Burundi have a March–May rainfall period (referred to as “long rains” corresponding to the main rainy season) and an October–December rainfall period (the so-called “short rains”). In contrast, rainfall is unimodal in the north-eastern part of the basin, in Ethiopia, Eritrea and some parts of Sudan, where the main rainy season concentrates between June and September. The total annual discharge[5] of the Nile is relatively small when compared to other large river basins in the world.

The land use along the basin is as variable as the climate (Figure 2.2). In the desert part of Egypt and Sudan, irrigated agriculture dominates while the rest of the land is left uncultivated. In the highlands of Ethiopia (the eastern part of the basin) and the equatorial lakes region (the southern part of the basin) the land use is dominated by forests and croplands. The northern part of Uganda and southern part of Sudan are covered by savannah land.

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[5] Total annual discharge – is the term that describes the cumulative volumetric flow rate of water that passes through the river’s cross-sectional area per year

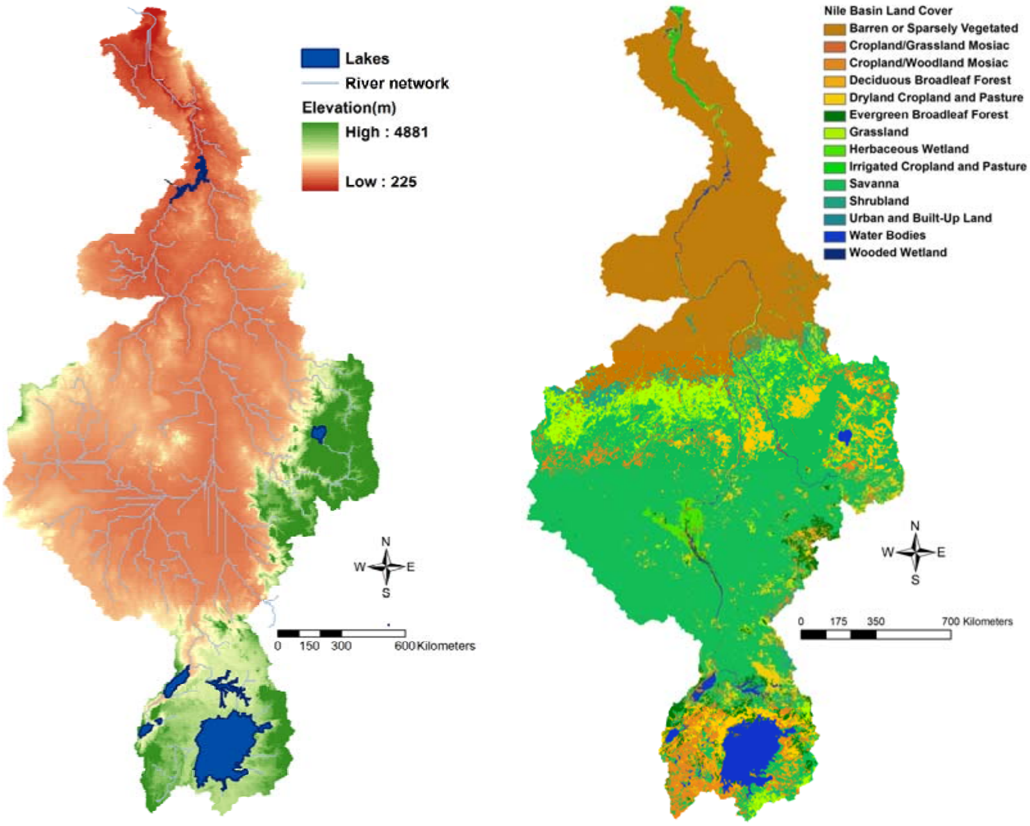

Figure 2.2: Nile basin topography (left) and land cover (right) map

Box 2.1: The Aswan High Dam

The Nile used to flood Egypt once in a year when its catchment area in the highlands of Ethiopia received high rainfall. During the dry seasons, however, drought affects the country as it is located largely in the Sahara Desert. Therefore, with the aim of storing water during the flood seasons the Aswan High Dam was constructed in the 1960s. The dam created a lake named Lake Nasser after Egypt's second president from 1956 to his death in 1970. The dam stores floodwater during rainy seasons and releases the water during times of drought. The dam is also used to generate large amounts of electric power.

Location: Egypt

Purpose: flood control, irrigation, hydropower generation

Width: 980 metres at the base,

40 metres at the crest

Length: 3,830 metres

Height: 111 metres

Reservoir: Lake Nasser

Volume of Lake Nasser: 111 km³

More information:

http://en.wikipedia.org/wiki/Aswan_Dam

2.1.3 Sources of the Nile

The Nile has three main tributaries. It is fed by two main rivers: the White Nile, with its sources on the Equatorial Lakes Plateau, and the Blue Nile, with its sources in the Ethiopian highlands. These two rivers join at Khartoum, Sudan, to make the main Nile River. The third main tributary is the Atbara River, with its source also in the Ethiopian highlands, which joins the main Nile further downstream. Many authors have described the route of the Nile from its sources to the sea (See, for example: Shahin, 1985; Sutcliffe & Parks, 1999; and Dumont, 2009).

Additional tributaries and lakes feed into the Nile. Lake Victoria is the biggest lake in the basin, and is considered to be the source of the White Nile. The lake is located in Uganda, Kenya and Tanzania. However, the lake itself is fed by different rivers from the south, where contributing watersheds are to be found in Rwanda, Burundi, and the Democratic Republic of the Congo. The Victoria Nile, as it is called in this area, leaves Lake Victoria at Uganda's second town, Jinja, and after several kilometres joins the swamp-lake Kyoga. The Nile also receives water from lakes Albert, George, Edward and many small streams as it moves north, becoming the White Nile. As the White Nile crosses Uganda and enters Sudan, its name changes again to Bahr el Jebel. The Bahr el Jebel flows into the Sudd, the great swamps of southern Sudan which are located north of the city of Mongalla. Further north, another tributary known as the Sobat, joins the White Nile from the east, south of Malakal city also in Sudan. The Sobat has its sources in western Ethiopia. From Malakal to the Sudanese capital Khartoum the White Nile flows without additional tributaries.

The Blue Nile starts from the third largest lake in the Nile basin, Lake Tana. The lake is found in the Ethiopian highlands, which is also itself fed by several different rivers. The outflow from the lake runs down the steep gradients of the highlands into Sudan, to join the White Nile at Khartoum. The course from the lake to Khartoum includes waterfalls, deep gorges, and steep slopes. This makes the water highly erosive, taking away the soils of the Ethiopian highlands. The river then flows through relatively gentle gradients after it crosses the border into Sudan. The Blue Nile is the main source of water for the Nile River and contributes more than 60% of the annual flow of main Nile.

Once the White Nile and the Blue Nile join at Khartoum, the river is called the main Nile. The remaining tributary is the Atbara River which joins the main Nile north of Khartoum. The Atbara originates in Ethiopia north of Lake Tana. This river is highly seasonal in nature. During the dry season (January to June), the river flow is very low and may even go dry. However, during the rainy season, the Atbara provides about 20% of the Nile's flow. Due to its torrential nature, the river carries excessive sediment load from the highlands of Ethiopia and Eritrea.

Exercise

Use the mean discharges from the three tributaries given in Table 2.2 below and estimate the total monthly discharge of the Nile. Compare your results with the natural flow estimated at Aswan. Which tributary contributes the most in each month? In which months does the river flood?

Table 2.2: Mean monthly discharges at outlets of tributary rivers of the Nile (flow are in 106*m³/day)

	White Nile at Malakal	Blue Nile at Khartoum	Atbara river at Atbara	Natural flow at Aswan
JAN	80	22	1	126
FEB	62	15	0	106
MAR	56	13	0	84

APR	51	17	0	86
MAY	54	18	0	80
JUN	68	35	2	80
JUL	82	157	51	171
AUG	93	486	171	580
SEP	104	427	110	666
OCT	111	217	25	423
NOV	111	76	5	249
DEC	102	36	2	163

Feedback

From the given mean monthly discharges we can produce a graph as below (Figure 2.3). This graph shows us the cumulative totals from the three tributaries. The first curve is the mean monthly discharge of the White Nile. The second graph is the sum of the White Nile and Blue Nile. The last curve is the sum of the White Nile, Blue Nile and Atbara. The estimated total from the three tributaries is higher than the natural flow at Aswan during the wet season. Losses due to evaporation and transmission while the river travels through the desert could account for the difference. The Blue Nile takes the largest share in the annual flow of the Nile. The months from June to September are the flood periods.

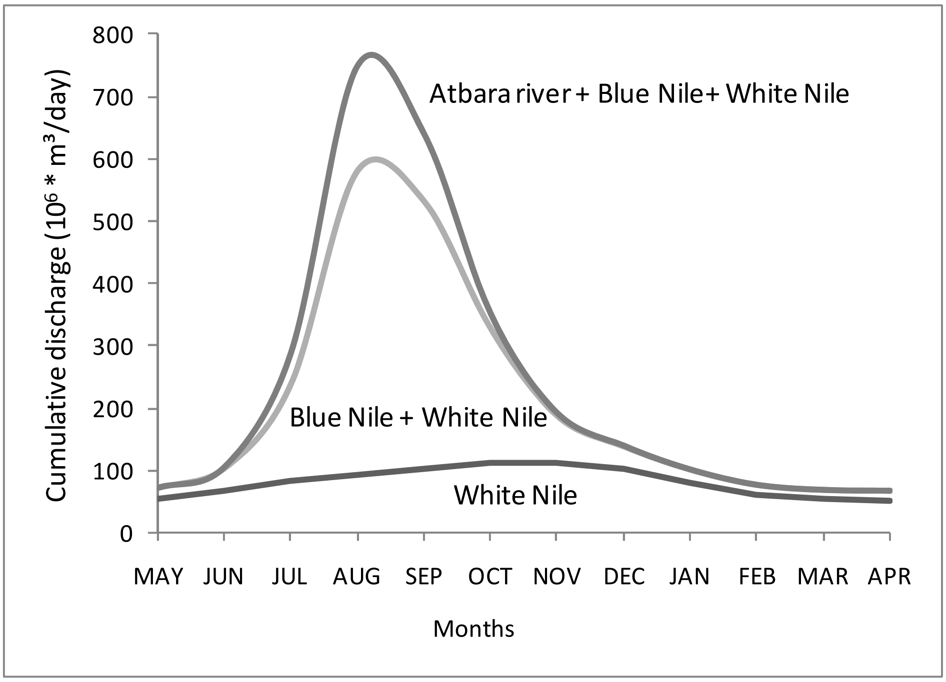

Figure 2.3: Cumulative monthly discharges of the three tributaries to the Nile

2.2 Overview of water related issues in the Nile basin

Having introduced you to the Nile case study area, we now change our focus to the issues in the basin. These issues are diverse, being in relation to the basin's high population growth, deforestation, pollution, social and political conditions and so forth. In this section we try to concentrate on the issues solely concerning water. This is because many experts warn (e.g., Postel, 2010) that, in the future, water crises might become much more important than energy crises or other types of societal problems. Population growth, economic growth and related increases in welfare and urbanisation all contribute to potential crises in many ways. They also can be linked to climate change which is itself a potential source of water crises. Keeping in mind these possibilities for the future, let us examine the current concerns. The following sections will help you understand the issues in the Nile waters from different angles.

2.2.1 Meteorological and hydrological

As noted earlier, the Nile basin is composed of regions receiving extremely variable amounts of precipitation according to the climate zones in which they are situated. Rainfall and river flow records show that the basin has experienced catastrophic droughts and floods in the past. (For those of you who are not familiar with the terms droughts and floods as used by hydrologists, refer to Box 2.2). These natural phenomena impact seriously on the livelihoods of many people and the environment. Floods are causes of damage to settlements, roads and other infrastructure as well as risks to human health and even deaths. Droughts usually affect agriculture and water supply systems. A devastating drought event might cause nationwide poverty, human health risks and death.

To take two well-documented historical examples: in 1961/62 extreme rainfall events occurred in most of the Lake Victoria region causing the lake to rise by approximately 2.3metres (Conway, 2005). There were unusually severe floods in many parts of the basin during this period. Ongwenyi et al. (1993) reported that the Kenyan regions in the Nile basin -- the Kano plains, Yala swamps and other low-lying areas -- were inundated by floods. In contrast, during the 1980s, due to lack of rainfall, extensive drought problems occurred in most of the Blue Nile region. In this period many people starved to death as crops and livestock were destroyed. Ethiopia is well-known for this drought and the situation has been studied and cited by many.

The other meteorological problem in the Nile basin is high evaporation from wetlands, open water and vegetation. The White Nile loses half of its flow through evaporation from the series of lakes in the Lake Victoria region and the Sudd wetlands. Sutcliffe (2009) states that the outflows from the Sudd are on average only about half the inflows, indicating that half the inflow is lost by spill and evaporation. As the Nile passes through the Sahara desert, additional water is lost due to high temperatures. When the river reaches the Aswan Dam in Egypt, which is situated in the middle of desert, a considerable amount of water is lost by evaporation and infiltration every year. The building of this giant dam was originally opposed by British imperial engineers because of major loss of water by the heat of the desert sun. To reduce evaporation loses in the Sudd in Sudan, different methods were proposed. One of these, building a canal that bypasses the wetland, was started and stopped because of civil war in Sudan in 1983 (Sutcliffe, 2009).

Another hydrological problem concerning the reservoirs built along the Nile is sediment load. The Blue Nile and Atbara carry a great deal of sediment from the highlands of Ethiopia and deposit it in the reservoirs. This phenomenon reduces the storage capacity of the reservoirs and also deteriorates the water quality. This has its own consequences on drinking water supply, irrigation water use and ultimately human health.

Box 2.2: Floods and Droughts

Flood – hydrologists define this as the discharge rate of a river that exceeds a certain threshold level, overtops the river banks and flows on the adjacent land known as floodplains.

Drought – this term is defined differently by various sectors. From a hydrologist's perspective it is a complex natural phenomenon which involves long and sustained periods with insufficient precipitation, soil moisture or water resources necessary for a defined region.

For more information:

http://en.wikipedia.org/wiki/Flood http://en.wikipedia.org/wiki/Drought

2.2.2 Environmental

Water pollution is a major current environmental issue for the Nile. The source of this pollution is mainly human activity. While development in agricultural activities, urbanisation and industrial plants in different sections of the basin are progressing, their side effects in polluting the water and hence deteriorating its quality are also increasing. Different types of pollutant emerge from the different sectors. In rural areas as well as in towns, sewage is often dumped into the river directly without being treated. This human waste is composed of nutrients, for example phosphorus and nitrogen among many others. These nutrients are likely to create algal blooms in the river and lead to suffocation of fish. Harmful compounds as well as pathogens (such as Esherichia coli, Klebsiella pneumonia and others - Sabae and Rabeh, 2007) are the other possible pollutants that the river water receives. This has its own consequence on human health as well as aquatic ecosystems.

In the agricultural sector, the use of pesticides and fertilizers is a common practice. Runoff from these agricultural lands pollutes the river. The industrial sector releases untreated waste water to the river. This waste might contain heavy metals that are dangerous for both human health and the aquatic ecosystems. In Egypt alone, the Nile from Aswan to the delta barrage receives wastewater from 124 point sources, of which 67 are agricultural drains. The remainder comprise industrial sources (El-Sheekh, 2009). Vegetable oil production also contributes to deteriorating water quality of the Nile. See El-Sheekh (2009) for more information.

The other historical environmental problem concerning the Nile is the construction of large dams, specifically the Aswan high dam in Egypt. The dam prevented the sediment and silt which are natural fertilisers being carried to arable land. This in turn has been a factor in the increasing use of chemical fertilisers. The chemical fertilisers have dual problems: on one hand the runoff from the cropland pollutes the river downstream, on the other hand the cost of importing the fertiliser is expensive for small scale farmers. Since the construction of the Aswan dam, erosion on the coastal sand belt of the Nile delta has increased. This costal sand belt serves as protection from flooding that can be caused by the Mediterranean Sea. The other problem that has occurred because of damming has been the decrease in the catch of fish.

2.2.3 Socio-economic

Although the Nile basin is rich with natural resources, it is considered as one of the poorest regions of the world (Mohamed and Loulseged, 2008). Since ancient times, people who live along the Nile have used the river for domestic purposes, agriculture and transport. The basin has a population of more than 400 million people with future projection of a high population growth rate. The river is beneficiary directly or indirectly to this large population. More than 70% depends on farming for its income and livelihood (Mohamed and Loulseged, 2008). This makes agriculture the most water-demanding sector in the basin. The increasing water demand is further influenced by population growth among other factors. Hence, water scarcity is a major challenge for this basin, both for domestic use and for productive sectors, especially agriculture. The social welfare of the inhabitants and their food security in particular is threatened by water scarcity.

As the river covers almost the whole length of Egypt and Sudan, the lives of many people in these countries are totally dependent on it. The two countries use the stored water in the dams extensively for irrigation. The irrigation potential in the rest of the basin, however, is not still fully realised by all the basin countries. Most of them depend mainly on rain-fed agriculture for their economy.

Using all the available irrigation potential in the basin might alleviate the problem of food insecurity and poverty. However, this is not simply a technical issue. Interests of particular countries and groups, alongside power relations between and within countries, have an important bearing on who obtains access to what. To give a simple example at an international scale: if upstream countries were to adopt extensive irrigation (and hydropower – see the next paragraph) it would potentially affect the water flow into the Aswan High Dam in the most downstream country. This of course is Egypt, and Egypt would certainly resist having its interests threatened in this way. Similar examples exist at more local scales. See the next sub-section for further discussion on the international political conflicts among the Nile's riparian states.

The constructed dams are also used for hydropower generation extensively in Egypt and Sudan. The source regions, Uganda and Ethiopia, use the Nile for hydropower generation in limited amounts. Hydropower generation is, therefore, an unexploited potential of the basin which could bring economic benefits to the riparian countries. In the basin, hydropower and irrigation projects cannot be implemented to their full extent, however, because most of the countries are poor. They depend on financial assistance from international aid agencies but at present these are unable to assist the upstream countries to a great extent due to political disputes between them and the downstream countries, mentioned above and to which we now turn in more detail.

2.2.4 Trans-boundary, political and institutional

In this section it is important to document the main water agreements made between countries within the Nile basin. To date, two major historical water agreements have guided the river basin management within the Nile. These are:

- In 1929 the first agreement was signed between Egypt and Great Britain.

  This agreement gave Egypt veto power on projects that might be undertaken by the upstream countries. The agreement stated that no works will be undertaken on the Nile, tributaries, lake basins that would impact on the volume of water reaching Egypt. It also gave Egypt the right to inspect and investigate the whole length of the Nile up to the remote sources of its tributaries. In addition, it stated that all riparian countries agree to Egypt's ancient rights to the water. Great Britain was representing Sudan, Tanzania, Kenya and Uganda as they were still colonised states at the time. However, Ethiopia had its own independent government in place, and it was not consulted during the agreement.

- In 1959 the second agreement was signed between Egypt and Sudan.

  This treaty enabled the construction of the Aswan dam in Egypt close to the border of the two countries. The water stored by the dam is shared between Egypt and Sudan under this agreement. In addition, the treaty allowed the entire average annual flow of the Nile to be shared among Sudan and Egypt at 18.5 and 55.5 billion cubic metres, respectively. The construction of a further dam - the Roseires - on the Blue Nile was materialised after this agreement. This helped to develop irrigation and hydroelectric power generation. The treaty also established a Permanent Joint Technical Commission to secure technical cooperation between both countries

According to these agreements the Nile water is divided basically between Egypt and Sudan. All the other riparian countries were not consulted, including Ethiopia, from which more than 60% of the water comes. This has resulted in debate between all riparian countries as to whether the second agreement still holds and if it should be nullified. Efforts have been made since to create cooperation in the Nile basin and to share the water resource between all riparian countries. For example, TECCONILE (Technical Cooperation Committee for the Promotion of the Development and Environmental Protection of the Nile basin) was formed in 1993 and was one of several efforts made around that time. However, most of them were unable to result in a successful cooperation deal across all riparian countries.

In 1999, with nine riparian countries signing (the exception being Eritrea), the Nile basin initiative[6] (NBI) was established. This partnership agreed on a set of policy guidelines to achieve basin-wide cooperation. The NBI envisions development of the Nile basin water resources in a sustainable and equitable way, efficient water management and optimal use. It also aims at poverty eradication and economic growth through cooperation and joint action between the riparian countries. The establishment of the NBI was a success for the Nile basin region as it attracted support from funding organisations in a way that countries acting alone could not have done. Teshome (2008) quotes Baum and Nierenköther (2007) to claim that the Nile basin receives large support from donor countries and organisations because of the NBI.

The NBI has been working to achieve its goals for the past decade. Despite several achievements, Teshome (2008) lists four weaknesses of it as:

1 The lack of overall political leadership

2 The absence of agreement on water allocation among the riparian states that is accepted by all member countries

3 Political problems among some members of the NBI

4 Mutual suspicions and distrust between the “upstream” and “downstream” countries on water resources development

In 2009, ten years after the NBI was launched, the riparian countries drew up the Nile River Cooperative Framework Agreement. This proposed treaty is currently (March 2011) still being negotiated among the nine countries before it can be signed by all and implemented. To date, six of the nine countries have signed the agreement, while the rest are expected to do so within the next year or so.

However, the signs are not good that it will be signed to the satisfaction of every country. Egypt and Sudan have always been against, or at least hard-line negotiators in, agreements such as this, claiming that the upper riparian countries are not entirely dependent on the Nile waters and they receive plenty of rainfall. However, Ethiopia argues that the rainfall over the country is highly variable and not a reliable source. Hence, the country is moving towards other alternatives such as irrigation schemes based on water storage in dams. However, when Ethiopia claims that it has the right to use the water resources from its own country, Egypt uses its much greater political and military power to threaten the implementation of any project on the Blue Nile. According to a news[7] report by McGrath and Inbaraj, (2004), Ethiopia's minister for trade and industry, Ato Girma Birru, accused Egypt of using devious tactics to prevent Ethiopia from developing its water resources. He said, "Egypt has been pressuring international financial institutions to desist from assisting Ethiopia in carrying out development projects in the Nile basin...... It has used its influence to persuade the Arab world not to provide Ethiopia with any loans or grants for Nile water development."

In the same report, Kenya's assistant minister for foreign affairs Moses Wetang'ula stated that his government considers the Nile Basin Treaty invalid and is seeking a new arrangement. He said, "Kenya will not accept any restrictions on its use of Lake Victoria or the River Nile.... It however does not wish to be a lone ranger in deciding how to use the waters, and has consequently sought the involvement of involved countries."

Egypt's minister for water resources Mahmoud Abu Zeid responded to Kenya's statement, saying it amounted to "a declaration of war" against Egypt. In fact, on many instances, Egyptian leaders over recent decades have stated that they are prepared to go to war concerning the use of the Nile. For example, a British Broadcasting Corporation

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[6] http://www.nilebasin.org/

[7] http://www.news24.com/Africa/News/Water-wars-loom-along-Nile-20040116

(BBC[8]) News report by Thomson, (2005) outlines the conflict between Ethiopia and Egypt. This political tension between the countries is a major constraint for the development of basin-wide cooperation. From these accounts, we can argue that the water security problem at international level is the major water related issue in the Nile basin. The current institution in place, the NBI, cannot solve this political conflict and the mistrust among the countries. The NBI's achievements mostly focus on the Lake Victoria region and show less enthusiasm to find multilateral cooperation among the major players, Ethiopia, Egypt and Sudan.

Exercise

Do an internet search to ascertain whether or not the Nile River Cooperative Framework Agreement has now been signed by all nine riparian countries. If not, which countries have not yet signed and why? Do the reasons for delay accord with the discussion above?

2.3 Climate change in the Nile basin

This section is devoted to explaining climate change as a water related problem. Scientific results of past trends and their causes, future projections of climate models and possible impacts are discussed, illustrating the multidimensional consequences of climate change on the Nile waters.

2.3.1 Impacts of climate change in the Nile basin

In addition to the aforementioned issues, climate change threatens the Nile basin and the well being of those who depend on it for their livelihoods. According to the Intergovernmental Panel on Climate Change (IPCC) report 2007, climate factors such as temperature and precipitation, and their variability on all timescales from days to the seasonal cycles to inter-annual variations, influence various characteristics and distributions of physical and biological systems. These climate changes will impact on the physical environment, ecosystems, water resources and many aspects of human life.

Scientific research on the climate of Africa indicates that the temperature is increasing throughout the continent and that it is already significantly warmer than it was 100 years ago (Hulme et al., 2001; Conway, 2009). The countries of the Nile basin have seen a 0.2°C to 0.3° C per decade increase since the 1970s (Camberlin, 2009; Eriksen et al. 2007). See also Figure 2.4.

[8] http://news.bbc.co.uk/2/hi/africa/4232107.stm

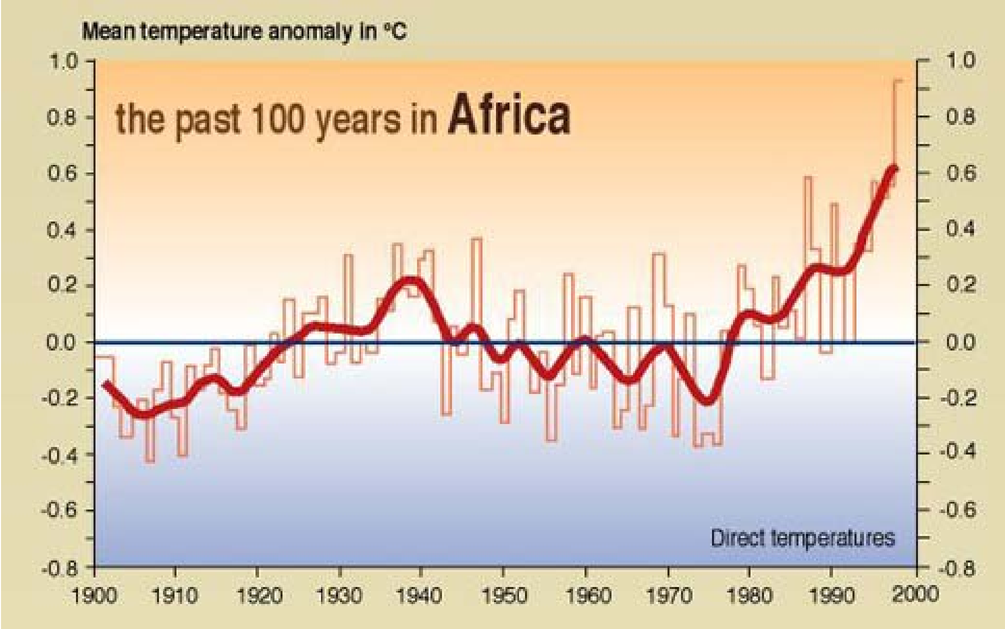

Figure 2.4: Mean Temperature Variation in Africa for the past 100 years. (Source: World Meteorological Organisation (WMO), United Nations Environmental Programme (UNEP), Climate change 2001, Impacts, Adaptation and Vulnerability, and Synthesis report)

Access to water in the Nile basin countries is dependent on runoff from the Ethiopian highlands and the level of Lake Victoria, both of which are sensitive to variations in rainfall (Eriksen et al. 2007). During recent decades, part of the Nile basin has shown a downward rainfall trend. According to Camberlin, 2009, this is observed significantly in northern Sudan (around 50% decrease in rainfall), Darfur (15-50% decrease), central Sudan (10-40% decrease) and south-western Ethiopia (20-35% decrease). There have also been times when the basin has experienced exceptionally wet years, for example 1961, 1951, 1963, 1982 and 1997.

Studies have been conducted by different researchers to discover the causes of rainfall variability in the basin. Most of them concluded that there is a negative correlation between the the ENSO (El Niño-Southern Oscillation – see Box 2.3) event and July-September rainfall in most of the Nile basin regions (Camberlin, 2009; Seleshi & Demarée 1995; Abtew et al., 2009). This rainfall reduction was observed in some El-Nino years which created higher sea surface temperatures (SST) in the eastern equatorial Pacific.

The 2007 IPCC report on the impact of climate variability in Africa indicates that the Nile discharge showed a reduction of 20% between 1972 and 1987, corresponding to a general decrease in precipitation in the tributary basins. The consequence of these changes in climate had significant impacts on the social, environmental, institutional and political aspects of the Nile basin region, including material damage, hunger and death.

Box 2.3: ENSO (El Niño-Southern Oscillation)

ENSO is a climate pattern that occurs across the tropical Pacific Ocean over a period of 3-7 years. It is composed of two components:

1 El Niño refers to the oceanic component of the system. It is characterized by warming or cooling of surface water in the tropical eastern Pacific Ocean. The warm oceanic phase is known as El Niño while the cold phase is known as La Niña.

2. The southern oscillation refers to the atmospheric component of the system. It is characterized by the changes in surface pressure in the tropical western pacific.

ENSO is best-known for its association with floods, droughts and other weather disturbances in many regions of the world, which vary with each event. Developing countries dependent upon agriculture and fishing, particularly those bordering the Pacific Ocean, are the most affected.

These two components are associated with weather disturbances because they interfere with the “normal” ocean-atmosphere system. For example in “normal” conditions the sea surface temperature (SST) of the equatorial Pacific basin is warmer in the western part and cooler in the eastern. This produces higher precipitation on the islands bordering the west Pacific and little rainfall over the eastern Pacific. During typical El Niño conditions, warmer SSTs spread further east, producing warmer ocean surface temperatures. This may cause rainfall and thunderstorm activity to diminish over the western equatorial Pacific, and increased activity over the eastern half of the tropical Pacific (for example, excessive rain on parts of Peru and Ecuador). Even though, ENSO periods are directly linked to the Pacific Basin regions, their impact is noticeable elsewhere in the globe, including in our case, the Rhine basin.

For more information: http://www.esrl.noaa.gov/psd/enso/

Many studies have been conducted in the Nile basin on the effects of climate change. The IPCC reports state that northern and southern Africa are likely to become much hotter and receive less precipitation over the next century. Projections for East Africa are exceptional since the average rainfall is projected to increase in the years to come. See Figure 2.5 which shows past rainfall trends and future climate model projections.

Conway and Hulme (1993) indicated that the combined effects of precipitation and temperature changes have profound effects on the stream flows of the Nile River. If the projection of increased rainfall for East Africa proves correct, the flow might increase, other things being equal. However, temperature increases might raise evaporation rates and consequently decrease the flow. Since most of rainfall projections from climate models for the Nile basin remain uncertain, the future flow of the Nile is tricky to project[9].

Beyond the model predictions of average rainfall changes, extreme climate events, both floods and droughts, might increase in their frequency and intensity and will have far reaching impacts. Floods will damage crops and livestock, and infrastructure such as roads and dams will be destroyed. Floods will also increase the spread of waterborne diseases, including malaria, risking human health. On the other hand droughts might have longer lasting effects as they affect agricultural production, on which most of the Nile basin countries depend.

Finally, climate change projections indicate that sea level rise is inevitable. However, it is uncertain how fast this will be in terms of years and how much the sea level rise will be. The possible catastrophic effects of sea level rise in the Nile basin will impact inevitably on its delta in Egypt, where the river enters the Mediterranean Sea. The delta, which is very fertile land, might be flooded partly and its extent might shrink. This delta supports a large human population that is engaged in agriculture and fishing. As the sea level rises, the salty sea water mixes with the fresh water. This will change the quality of fresh water for the fish. The arable land will be more saline as a result of salt intrusion from the sea and hence less fertile.

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[9] See Chapter 2 of Module 1 for further discussion of the complex feedback loops with which climate models have to deal.

Exercise

a) Review and discuss the major water related issues of the Nile basin. Give special attention to the political conflict among the riparian countries. Search the internet and news broadcasts about past and current political conflicts and indicate how these conflicts are affecting cooperation with in the basin.

b) How has climate in the recent past affected the Nile basin? Search from the internet and make notes on the economic and social damages caused in the 1961/62 flood and the 1983/84 drought

Feedback

a) The political tension between Egypt and Sudan on one hand and Ethiopia on the other hand is one of the major problems within the Nile basin. Ethiopia argues that all riparian countries should benefit from the Nile waters while Egypt and Sudan insist on the treaty signed in 1959 (see above). Thus there is no agreement to date which can allocate water to all the riparian countries. The Ethiopian Prime Minister Meles Zenawi reveals his stand on an interview with Egyptian television. See (http://www.youtube.com/watch?v=2zzXLFKU0HM)

b) The 1961 flood caused extensive flooding in the region with loss of homes and lives and damage to crops, and emergency food had to be flown to marooned villages. Total flood damage costs at the time for Kenya were estimated to have been 6 million Euros (Conway et al, 2005). The 1983/84 drought killed an estimated one million people in Ethiopia. At the time initiatives like Band Aid/Live Aid raised approximately 180 million Euros and saved thousands of lives[10].

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10 http://www.one.org/c/us/issuebrief/3127/

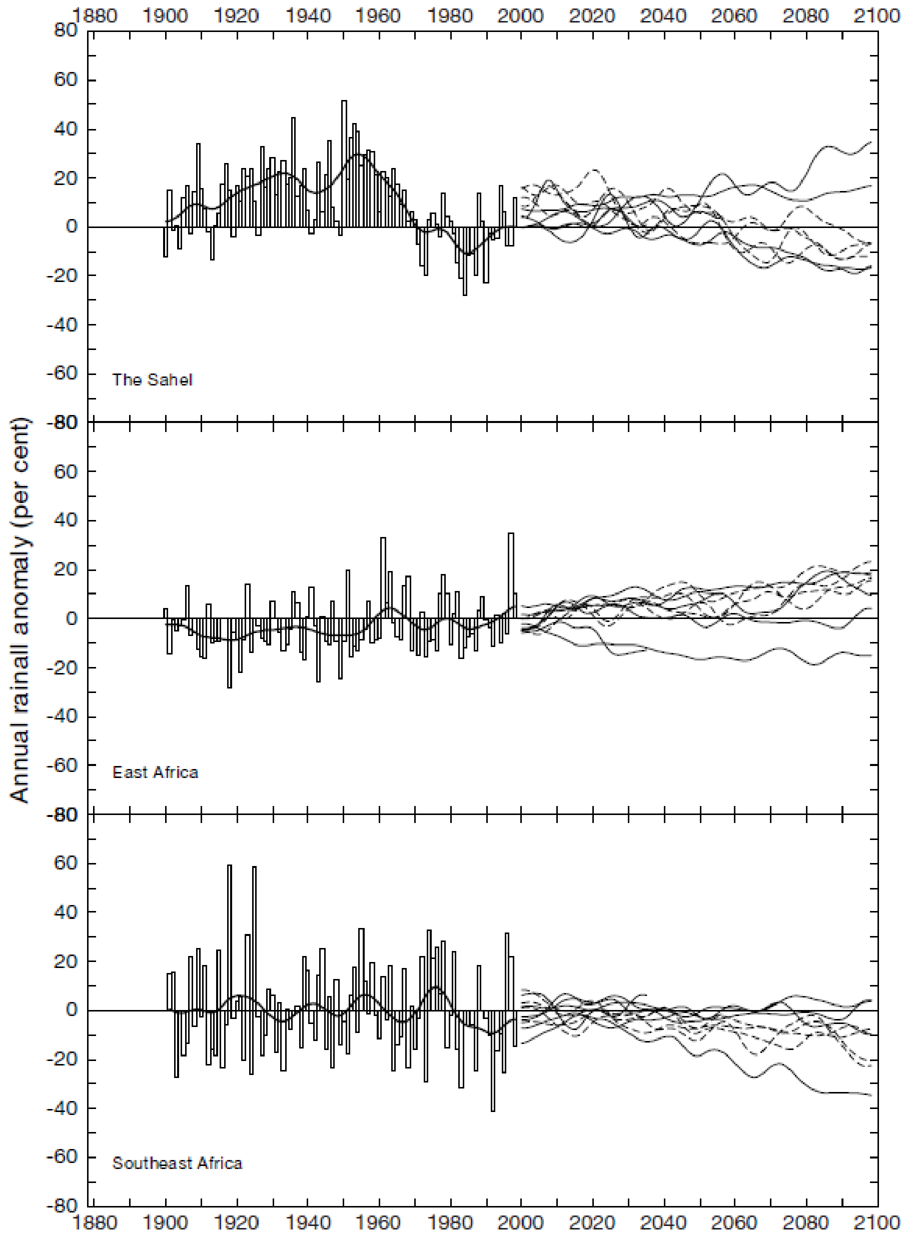

Figure 2.5: Observed annual rainfall anomalies for 3 African regions, (1900–98), and model-simulated anomalies for 2000–2099 (Source: Hulme et at, 2001)

2.3.2 Water stress experiences of recent years

In this sub-section we present some examples of water stress periods in the recent past in the Nile basin countries and other African regions. Water stress indicates a period with a lower amount of available water which cannot meet the demand. The following three examples will provide you with information that will enable you to understand, in the following section, the lived experiences of people in these regions as they have attempted to adapt. The reader, however, needs to be aware that the ensuing impacts of climate variability (e.g. droughts) on human populations are much more complex than that which my analysis allows. . This is because impacts on human populations are very much tied up with prevailing social relations, both at local and national scales. Put crudely, some people do very well out of droughts, floods (and even wars) because they have the means to exploit the situation, while there is no-one, not even governments, able to respond to the needs of the vulnerable who suffer as a result. Further discussions on this issue can be found in Module 3 in this series. For reasons of study load restrictions, however, this water case study analyses the human impacts in terms of their 'natural' causes, hence strongly simplifies the topic. You are invited through your own searches and reflection to elaborate and widen the topic to combine both the physical climate- and social-related issues.

Example 1: The Sahel drought

The Sahel is a region found in the northern part of Africa that demarcates the Sahara desert in the north and the Sudanese savannah in the south. It stretches from west to east between the Atlantic Ocean and the Red Sea respectively (Figure 2.6).

The Sahel experienced a devastating drought in the period 1968 to 1974. In this period thousands of people died due to famine, millions were displaced from the region and suffered from extensive loss of cattle, sheep and goats. The consequence was overwhelming in terms of economic, social and political aspects.

The cause of this extensive drought was believed to be the degradation of the environment over many years. Many believed initially that the expansion of farming decreased the vegetation cover of the area which in turned resulted in lower rainfall (transpiration from vegetation will increase the moisture content of the atmosphere locally) and contributed to soil erosion. However, recent studies show that climate factors instead of human activity caused the regional drought. These studies focus on temperature changes in the global ocean as a cause of the drought.[11]

Recently in 2010 the Sahel also experienced famine due to high temperatures that broke the records of previous years[12]. Crops failed to mature and put many at risk of starvation. The rainfall over this area is highly variable and has a large impact on the livelihoods of the poor and the economies of the countries that still depend on agriculture. Absence of rain for consecutive years has caused water stress and low or non-existent river flows. No rains mean no food and water for these people and their livestock. With repetition of such phenomena famine broke out in the region and claimed the lives of many. Similar disasters have been the story of many African countries. The main reason has been their almost total dependence on rain fed agriculture and limited access to irrigation.

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11 http://news.bbc.co.uk/2/hi/science/nature/3191174.stm

12 http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=1544

Figure 2.6: Map of the Sahel, Source:

http://sahel-energy.org/home/index.php?option=com_content&view=article&id=1&Itemid=4&lang=fr

Example 2: Kenyan drought

Kenya is one of the drought-prone countries of East Africa. Most recently, Kenya faced three serious droughts within a decade (2000-2009). The major cause of the droughts has been consecutive years without rainfall. As the rains fail the rivers become dry and are unable to support the cattle that depend on them for drinking. Rural people are forced to travel longer distances to obtain fresh drinking water while large numbers of cattle face death. The consequence of the recurrent drought is far-reaching for the economy of the country as poverty and food insecurity increases. Social problems are inevitable in different forms, for instance, child abandonment, dropping out of school especially for girls, and family division. Again a major cause of famine and its consequences is water stress. An article[13] by Vidal, (2009) states that as one devastating drought follows another, the future is bleak for millions in East Africa.

Example 3: Ethiopian drought (1983/4)

Ethiopia is also one of the east African countries which has faced repeated drought events. The country and its economy are dependent on rain fed agriculture and water stress causes major problems the economy of the country. In such agricultural systems

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13 http://www.guardian.co.uk/environment/2009/sep/03/climate-change-kenya-10-10

farmers have to live with the highly uncertain rainfall to produce reliable food for their families. In Ethiopia, the 1983/84 drought was one of the most devastating. It took the lives of an estimated one million people, destroyed crops, killed animals, and led to mass starvation. Loss of rain for consecutive years was the major reason for the outbreak of the drought. The drought was further exacerbated by the civil war in the country at that time. Recent studies show that the Ethiopian droughts are linked with ENSO (El Niño-Southern Oscillation – see Box 2.3 above) events (Seleshi & Demarée 1995; Abtew et al., 2009) which resulted in below average rainfall over the area.

2.3.3 How people have adapted to changed climate in the past

The previous sub-section has described three dramatic drought events in Africa and the broad human impacts in terms of livelihoods, health and related issues. The specific impacts on individuals and social groups locally, however, are inevitably more varied and complex. Also, these individuals and groups, whatever limitations they face in terms of their vulnerability to climate impacts, are never completely passive. They experience climate events, they reflect on their impacts and they then adapt according to whatever capabilities they have. This is the basis of what Module 2 in this series elaborates as the 'lived experience of climate change'. Here we examine briefly the lived experiences of people who were caught up in the drought events described above.

The lived experience of climate change: vulnerable Sahelians

The people of the Sahel found it particularly difficult to adapt to the changed climate as the drought from 1968-1974 was a long term event. Most people were forced to migrate from their rural communities to urban centres. This phenomenon caused overcrowding in the urban areas and also increased the spread of malaria. Nevertheless, migration to new regions was a primary means of adaptation for most of the Sahelian people at the time.

Barbier et al. (2009) noted that the famine of the early 1970s caused significant human and animal mortality. A later drought of the mid-1980s had a smaller impact because international food aid was more substantial and arrived on time. Since then, the international community has invested large sums in the region. Numerous programmes and projects have tried many different strategies to lift the population out of poverty. For example, new agricultural techniques have been tested and promoted.

A survey was conducted in northern Burkina Faso (part of the Sahel) by Barbier et al., 2009, to find out the farmers' adaptation strategies. The results confirm that farmers from this community have substantially changed their practices during the last few decades. They have adopted a wide range of techniques that are intended simultaneously to increase crop yield and reduce its variability in the face of a changing climate. Micro-water harvesting techniques have been widely adopted and a majority of fields have been improved with stone lines. Hay and sorghum residues are increasingly stored to feed animals during the dry season, making bull and sheep fattening now a common practice. A majority of the population is also now involved in dry season vegetable production.

The lived experience of climate change: the Kenyan pastoralist

In Kenya, reporter Adam Hart-Davis visited the Masai region and interviewed Practical Action's – an international development NGO -- project manager, Sharon Lorametta[14]. The interview was conducted in 2005 after three consecutive years without rainfall in the Masai (Box 2.4) region. This interview illustrates how the people were responding to the impact of climate change.

Q - "Sharon, when did it last rain here?"

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[14] http://www.climatechoices.org.uk/pages/case1.htm

A - “The last rains that we received in Magadi [a town south-west of Nairobi in southern Kenya], and I would say had an impact on the lives of the people, was about three years ago.”

Q - “Three years?!”

A - “Yes.”

Q - “How often does it normally rain?”

A - “It rains – we have two seasons in a year, that is April, which are the long rains, and October - December, the short rains. But for the last three years we have not had rains at all here in Magadi.

“The people survive by the Grace of God You saw the river where we were, it’s all dry now. They have been fetching water from there the whole of this last year, 2005. It’s been very difficult because the water levels went down. The communities are forced either to drink the saline water, or obtain water from Magadi, or travel to Kiserian, which is about 45 miles [70km] from here. They have to pay for the transport, and they also have to pay for the water.

“It’s really difficult, but all the same, they find that everything is changing. The clouds [skies] are ever blue. They used to have white clouds, grey clouds, but now they are – from here to there the clouds [skies] they are just blue – they are not forming.

“For the last 6 months it’s gotten worse and we are seeing a situation whereby the families are now getting to move out of these small towns to go where there is water.”

Q. People here depend on animals for a living. If their animals die, they have no way of earning money for years into the future.

A - “The animals have moved away from this place. They have been taken to the Mount Kenya region, where we were, and others are in the city of Nairobi. The owners are looking for pasture, they’re looking for water. And by the time the animals come back, most of them will have acquired diseases, so very few animals, compared to what went to Nairobi or to Mount Kenya, will comeback.”

The people who live in the dry lands have been designing strategies to adapt to the region’s climate in different ways. The pastoralists have developed movement strategies for livestock to manage pastures and water resources. They also split their stock among relatives and friends in various places. They increase the number of their herd by adding goats instead of cows. Goats are more resistant to the dry conditions. They also try to earn a living through small trade and handicrafts. In some parts of Kenya, for example Kitui region, sand dams were constructed with the help of a local NGO to reduce the distance to water sources to less than 2 km and make water available for irrigation and other economic activities. In the worst cases the people migrate to urban areas as described above.

Box 2.4: The Masai people

The Masai (also known as Maasai) people of East Africa live in southern Kenya and northern Tanzania along the Great Rift Valley on semi-arid and arid lands. The Masai people are a unique and popular tribe due to their long-preserved culture. They lead a semi-nomadic life style, moving from one place to another rather than settling permanently in one location. Livestock such as cattle, goats and sheep are the primary source of income for the Masai. Thus they are pastoralists who raise herds and move seasonally with their livestock in search of water and fresh pasture. In recent years pasture land and water for their animals is disappearing due to frequent and severe droughts in East Africa. This might force the Masai people to seek out alternative livelihoods.

More information: http://www.maasai-association.org/maasai.html

http://en.wikipedia.org/wiki/Maasai_people

The lived experience of climate change: vulnerable Ethiopians

Similar to the Sahelian people, the adaptation measures used at times of drought in Ethiopia comprise (i) migration to urban areas or even leaving the country, and (ii) depending on food aid. In the BBC news world edition of 11 January, 2003; Martin Plaut wrote of the experience of some Ethiopian highlands people in an article called "Ethiopia's long wait for rain". Follow the link to read about the experience of many vulnerable Ethiopian people and their view:

(http://news.bbc.co.uk/2/hi/programmes/from_our_own_correspondent/2646169.stm)

After experiencing recurrent drought, the farmers found traditional adaptation strategies to utilise and conserve natural resources. A study by Deressa et al. (2009) analysed the factors affecting the choice of adaptation methods to climate change. It was based on cross-sectional survey data collected during the 2004/2005 agricultural production year in the Nile basin of Ethiopia. The surveyed farmers were asked if they had observed any change in temperature and rainfall over the past 20 years. Those who said that they had observed changes over the past 20 years were asked if they have responded to climatic conditions through adaptation. Those who could afford to adapt indicated that they undertake soil conservation, use different crop varieties, plant trees, change planting dates and irrigate their farms to reduce the negative impacts of climate change. Those who did not adapt mentioned lack of information on adaptation methods and financial constraints to using any of the above adaptation methods. This is an example of different entitlements to livelihoods among richer and poorer groups in Ethiopia, explained in the Module 3 workbook.

From these examples we can see that adapting to climate change impacts is hard for many people in developing countries because of their dependence on rain-fed agriculture and their socio-economic positioning in society. Migration appears to be the adaptation measure of last resort. In the future adapting to change might be more difficult as competition for scarce resources becomes exacerbated.

Exercise

What kind of adaptation measures were used in drought stricken areas of the Nile basin? Which methods succeeded? Which ones failed? Search from the internet and discuss with other participants on the online forum if possible.

Feedback

Different adaptation methods were used in the past. A method that succeeds in one area doesn't necessarily succeed in another. Thus adaptation measures are area-specific. In the examples above, migration to urban areas or neighbouring countries is one of the adaptation measures taken by people in drought affected areas. This measure is usually a last resort, but in long run it caused tribal disputes between the resident population and the migrants. You can read the experiences of the Sahelian people from the Barbier et al. (2009) study.

2.4 Adaptation to climate change in the Nile basin today and into the future

The end of the previous section examined briefly the 'lived experiences' of different groups of people who are part of the Nile basin. In all three cases we described their different adaptation strategies as part of that experience. Adaptation, however, is now a common part of the language we use when discussing policy in response to climate change. In this section we cover questions like why do we have this focus on adaptation with respect to water-related issues? What are possible adaptation approaches that are sustainable? What is the contribution of sustainable adaptation measures for the development of the Nile basin?

2.4.1 The imperative for, and barriers to, adaptation to climate change in the Nile basin

According to the scientific consensus, climate change is real and being experienced in our daily lives. The greenhouse gases which lead to global warming, and which have increased their concentrations in the atmosphere primarily through human activity in the past decades, are still being emitted at a considerable scale. This process already is having, and would continue to have even if we were to stop producing greenhouse gases today, significant impact on the environment, human health, the economy, food security and so on. Adaptation to the consequences of climate change is, therefore, an imperative, not an option.

Human populations in the Nile basin are vulnerable to different aspects of water related problems. As we have seen in previous sections, these include long term water security for domestic use and irrigation schemes, extreme events (floods and droughts), and food security. Addressing these is imperative for the basin and provides convincing reasons to implement adaptation measures. According to Adger, et al. (2005), adaptation can involve, (i) building adaptive capacity thereby increasing the ability of individuals, groups, or organisations to adapt to changes, and (ii) implementing adaptation decisions, i.e. transforming capacity into action. Both dimensions of adaptation can be implemented in preparation for, or in response to, impacts generated by a changing climate. They also need to be implemented at different scales. What is done at national (or international) scales affects what is done at local scales and vice versa. Thus adaptation to climate change is a complex issue that involves different sectors of international, national and local institutions[15]. It is the process of adjustment that is required as the climate changes and affects human well-being. It is also a development issue that needs to be addressed by countries at national, regional and local scales.

While implementing adaptation measures, it is important that they also meet sustainable development requirements, otherwise the adaptations are likely themselves to create new problems in the longer term. Sustainable development is a process of using resources in a way that meets human needs of the current generation but without compromising the ability of future generation to meet their own needs. This process involves three overarching, inter-related dimensions: social, environmental and economic (see Chapter 6 of Module 1 in this series). While considering adaptation measures, all three aspects should be met. Adaptation to climate change has the potential to play a major role in reducing the adverse impacts of climate change in a sustainable manner.

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[15] Institutions (see also Chapter 3, Section 3.5.2 and Chapter 4 Box 4.2 of Module 1) are generally defined as the 'rules of the game' which establish values, and ways of working and behaving. Institutions are often embedded in organisations but need not be (an example of the latter being the institution of marriage).

In our water case, sustainable adaptation measures include effective management and technological solutions that may be implemented to reduce the impacts of climate change. Some measures suggested for the Nile basin countries, and already practised to some extent, include: rainwater harvesting, developing irrigation schemes and improving their efficiency, use of new crop varieties that need less water, mixed crop and livestock farming, development of groundwater resources, planting salt tolerant crops when using salty water is the only option, and recycling water.

When we talk about adaptation measures, it is important to raise questions about human capacity to adapt, again at different scales. What influences these human adaptive capacities in positive or negative ways?

According to the IPCC (2007) adaptive capacity is defined as the ability of a system to adjust to climate change (including climate variability and extremes) in order to moderate potential damages, take advantage of opportunities, or cope with the consequences. One of the most important factors shaping the adaptive capacity of individuals, households and communities is their access to and control over natural, human, social, physical and financial resources according to a handbook by the international development NGO, CARE (2009). The handbook lists the following resources as being useful for adaptive capacity:

Human	knowledge of climate risks, conservation of agricultural skills, good health to enable labour
Social	for example, women’s savings and loan groups, farmer-based organisations
Physical	irrigation infrastructure, seed and grain storage facilities
Natural	reliable water sources, productive land
Financial	micro-insurance, diversified income sources.

Using some of these resources, we now examine the adaptive capacity of our study area. From past experience the Nile basin countries have seen the consequences of extreme climate events and they certainly do not want to experience the same problems all over again. This willingness to find adaptive mechanisms and apply what they already know from past experience can be considered a fundamental capacity at local, national and inter-riparian scales.

At local levels small scale farmers often know about selecting drought resistant crops from their past experience. They are also aware of building small scale water harvesting mechanisms and the advantage of using irrigation systems. They have agricultural skills. What is often required, however, is to improve the effectiveness of what they do, but improving effectiveness is a complex matter due to many financial, social and political constraints. For example, Deressa et al., (2009), to whom I referred in sub-section 2.3.3, investigated the factors guiding household choices of climate change adaptation methods in the Blue Nile basin of Ethiopia. In this study, adaptation to climate change is seen as a two-stage process: first, perceiving the change and, second, deciding whether or not to adapt by taking a particular measure. According to this study, lack of information is the major factor which acts as a barrier to adaptation. They also found out that the age of the household head, wealth and social capital (meaning the ability of people to work together) influence farmers’ abilities to appreciate the impact of climate change. Further discussion of this complex area is beyond our scope here, but societal structural constraints on human perceptions and capacity also appear in Modules 2 and 3.

At national level, in principle, governments may engage in adaptation measures which are aimed at rural populations. The reality, however, may also be very different from the principle. Thus, governments can:

- Train and employ extension agents who guide local framers, but in reality the training might be poor, and the extension workers poorly paid and lacking commitment. They also often do not appreciate the local knowledge that already exists among farmers which causes resentment. Moreover, some local farmers are more fundamentally opposed to any form of outside advice or technological input, believing that natural hazards are associated with divine punishment for a perceived wrong-doing.
- Advocate the importance of social resources such as farmer-based organisations and contribute to physical resources such as an irrigation infrastructure. In reality, however, farmer organisations might themselves be hierarchical and exclude some groups (for example, poor farmers and women farmers). Irrigation infrastructure might also be provided only for some groups and not others.
- Engage in land reform and distribute productive land fairly to local people, giving them ownership rights and hence incentives to take care of it and farm sustainably. But yet again, in reality, the land might be more likely to be distributed to certain groups (for example, the Government's supporters) rather than others, or to those who can afford to pay bribes.

At inter-riparian level, meanwhile, all the countries in the basin are aware of the impact of climate change and, again in principle, the need to work together. However, while the latest attempt at coordinated cooperation among these countries -- the Nile River Cooperative Framework Agreement -- is an important development in this regard, as I write not all countries have signed and the historical inter-riparian conflicts have re-surfaced and await solution (see section 2.2.4 above).

2.4.2 Dealing with uncertainties

We have referred earlier to the fact that climate change, including its impact on society and natural resources, is characterised by uncertainty. These uncertainties indeed exist in projected impacts on water systems. Specifically for the Nile basin, the climate models known as general circulation models (GCM – see Chapter 2 Section 2.4.4 of Module 1) provide a wide range of precipitation projections. The projected magnitude of precipitation changes is as variable as the number of GCMs that exist. This makes it hard to give an accurate magnitude of change for the future in terms of water quantity. Also, most records in the basin are not long enough for the kind of analysis that is needed to be performed, for example on extreme events. Thus, on one hand it is important to attempt to know explicitly the uncertainties involved concerning the impact of climate change to avoid blind decisions. On the other hand, decisions have to be taken in the face of uncertainty as the risk associated with the worst-case predictions can be devastating. Thus the adaptive measures/strategies that are required in the Nile basin should be flexible ones that are applicable, easily adjustable and not costly.

2.4.3 Integrated basin management through stakeholder participation

We have discussed adaptation to climate change and how these measures should be sustainable so that they contribute to the development of the Nile basin as a whole. Because of the uncertainties involved, the varied impacts on different groups and the potential for conflict among their competing demands, there is a strong argument for integrated basin management in which the full range of stakeholders make inputs. For the Nile basin, stakeholders include subsistence farmers, those who make a living from fishing, mechanised farmers who use intensive irrigation systems, various productive industries (such as food, textile, pulp and paper, oil and chemical), tourism, agencies that control hydropower generation, and the governments of the riparian countries. Although some of these stakeholders may not be involved in formal decision-making, understanding the interests of all is required to manage the water properly and to satisfy the different parties as much as possible in the process of climate change adaptation.

The main network that exists between the riparian countries is the aforementioned Nile Basin Initiative (NBI). This network is at a governmental level and is unlikely to include the interests of local stakeholders. However, other governmental and nongovernmental organisations, for example, the International Water Management Institute (IWMI), operate by involving stakeholders at community level.

Exercise

What kind of knowledge and resources do different stakeholders provide for adaptation strategies? List the different stakeholders that may be involved in the Nile basin and suggest the different knowledge that they may be able to share.

Feedback

A few examples of stakeholders are mentioned below. Some of them are taken from the Nile Basin Society (NBS[16]) organisation website (http://nilebasin.com/index.html)

Stakeholders	Knowledge and resources
Government officials	Provide insight on the political and economic status of the riparian countries
Community representatives	Present the problems and needs of the community,
Local farmers, people who fish, households	Can share previous practice,
Industries	Can share their future needs and past experience
Funding agencies	Helpful in providing financial assistance
Scientists, hydrologists, engineers	Provide scientific and practical support
Sociologists,	Help in conflict resolution and communication at both community level and higher levels
Environmentalists	Provide knowledge on biodiversity loss, water pollution, etc.
NGOs working in the basin	Provide knowledge associated with practical projects.

2.5 Further reading on the Nile basin

Suggested sources of additional information

- A Wikileaks memo that reveals Egypt's fear over Sudan breaking into two: http://www.bbc.co.uk/news/world-africa-11913940
- An interesting video that explains how climate change is affecting the river Nile and its farming community is: •http://www.guardian.co.uk/environment/video/2010/jan/15/climate-change-nile

  A video on farmer to farmer learning in a changing climate in Ethiopia http://www.climatecentre.org/site/films?pn=3&order=name

16 The Nile Basin Society (NBS) is a Canadian, membership-based, non-profit organization aimed at spreading awareness, access to information and real public participation in development projects through digital means

3 The Rhine Basin

3.1 Introduction to the Rhine basin

The Rhine basin is the largest river basin in Western Europe (Figure 3.1). Large ports and cities of Western Europe are situated along the river, making it economically important. Also ecologically, the river has great value.

Figure 3.1: Map of Europe, indicating the river basin of the Rhine (UNEP, no date)

From its source in Switzerland, the Rhine flows through France and Germany and reaches the North Sea via the Netherlands (Figure 3.2, next page). The total area covered by the basin is 170 000km2, and, in addition to the aforementioned countries, includes (parts of) Italy, Austria, Liechtenstein, Luxembourg and Belgium. The length of the river is 1232km. On average, the discharge of the river is 2000 cubic metres per second (m3/s). The name 'Rhine' originates in the Proto-Indo-European root 'reie-', which means to move, flow, run. The river is fed by snow-melt from the Alps, and rainfall runoff from the basin's hills (http://en.wikipedia.org/wiki/Rhine)

Exercise:

a) Examine the Rhine river basin (Figure 3.2) and identify the 9 riparian countries.

b) Examine the overview of European river basins through the following link and identify the Rhine River:

   http://www.transboundarywaters.orst.edu/publications/register/tables/IRB_europe.html

c) For further information examine the Wikipedia site on the Rhine. It provides information on different areas in the river basin, tributaries, canals, geological history etc. http://en.wikipedia.org/wiki/Rhine. You should always cross reference information from sites like Wikipedia with other sources, as it is an open source, where everybody can contribute something.

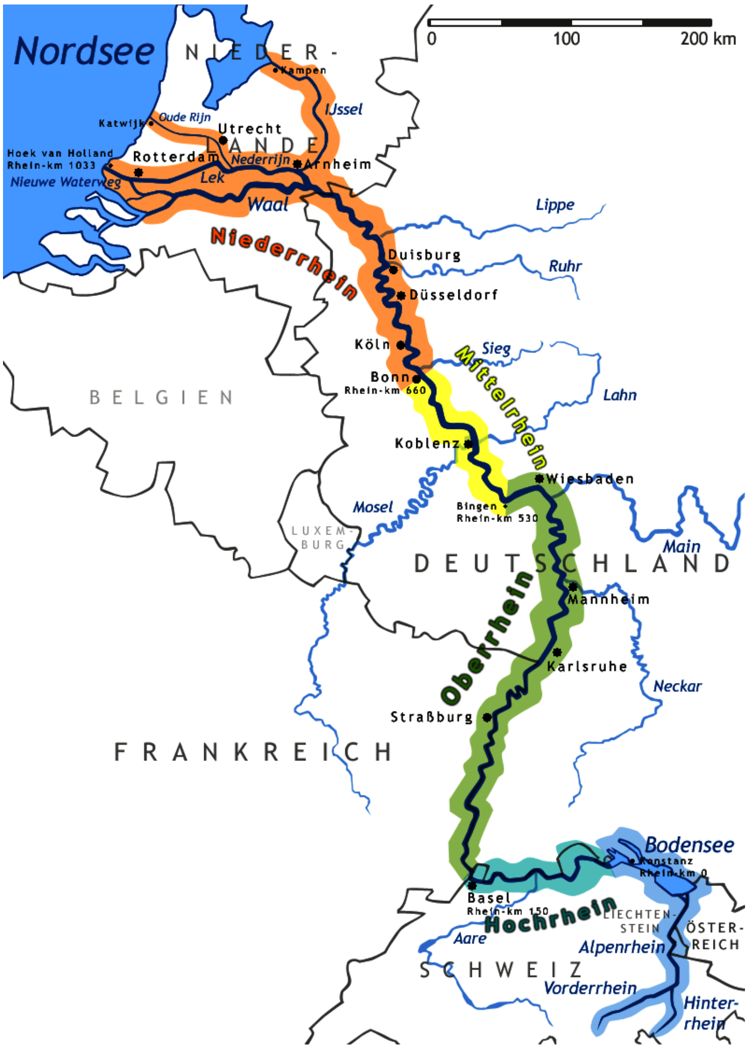

Figure 3.2: Map of Rhine river basin, by Daniel Ullright (source: http://upload.wikimedia.org/wikipedia/commons/4/47/Rhein-Karte.png, accessed 21 March 2012, but you might have to copy and paste the link as ctrl-click does not always work).

3.1.1 Characteristics of the Rhine basin

The Rhine basin has a high population density and a high level of economic activity. The river is navigable from Basel in Switzerland to the North Sea, where Rotterdam, as one of the largest ports in the world, is at the 'mouth' of the river. Its altitude ranges from sea level to 4272 metres.

The climate along the Rhine is variable, although not in an extreme sense. The mountainous areas and the southern part of the basin are warmer in summer and colder in winter than the downstream northern part in the Netherlands, which, due to its proximity to the sea, has a more moderate climate.

Precipitation in the basin is between 500 and 1000 mm annually (Figure 3.3), with most rain falling in the winter season, sometimes as snow. Therefore, the highest discharges of the river Rhine are experienced in spring, due to snowmelt, combined with rainfall.

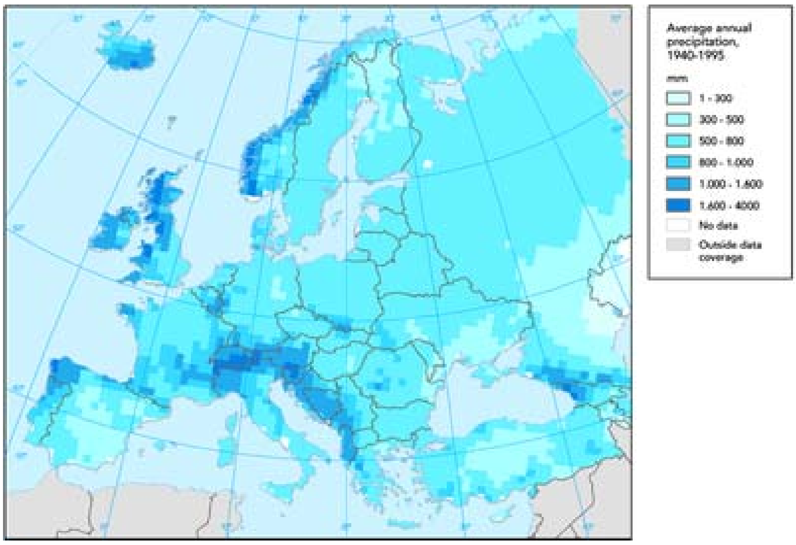

Figure 3.3 Average annual precipitation in Europe (European Environmental Agency, no date)

The land use along the basin varies according to the climate, as well as the suitability of the soil. Agricultural land and forests are present, as well as industrial areas for which the river provides water, either for processing or for cooling, or as a transport mechanism (for example, of construction materials).

The area also has important ecological value, as the basin is home to 18 wetlands that are on the list of wetlands of international importance of the Ramsar Convention on wetlands (UNEP, 2003).

3.1.2 Sources of the Rhine

The Rhine originates at the confluence of the ‘Vorderrhein’ and the ‘Hinterrhein’ near Reichenau in Switzerland. First it is called ‘Alpenrhein’ and constitutes the border between Switzerland and Lichtenstein and later Austria (see also Figure 3.2). The river ‘Aar’ joins in Switzerland and doubles the water discharge to an average of nearly 1,000 m^3/s. From Basel (the Swiss city located where the Swiss, French and German borders meet), it enters into Germany. The Rhine is the longest river in Germany. Major tributaries such as the Neckar, the Main and the Moselle join the river as it flows through Germany, adding an average discharge of more than 300 m^3/s.

Between Bingen and Bonn, the so-called Middle Rhine flows through the Rhine Gorge, a formation created by erosion. This stretch of the river is known for over 40 castles and fortresses from the Middle Ages, many lovely country villages and wine yards. It is a UNESCO World Heritage Site and known as ‘the Romantic Rhine’.

When the river approaches the Dutch border, it has an annual mean discharge of 2,290 m^3/s and an average width of 400 metres (Wikipedia, no date -b).

For the Netherlands, the most downstream country, the Rhine is the largest river, and the country is somewhat dependent on the river’s water management in the upstream riparian countries.

In the Netherlands, the name of the Rhine is no longer used for the major part of the river, being known as the Waal on its journey to the North Sea. In between the cities of Arnhem and Nijmegen, it splits in two: about two thirds of the water continues to flow through the Waal to the West, while one third flows to the North, feeding the “Nederrijn/Lek” and the “IJssel” rivers (Figure 3.4)

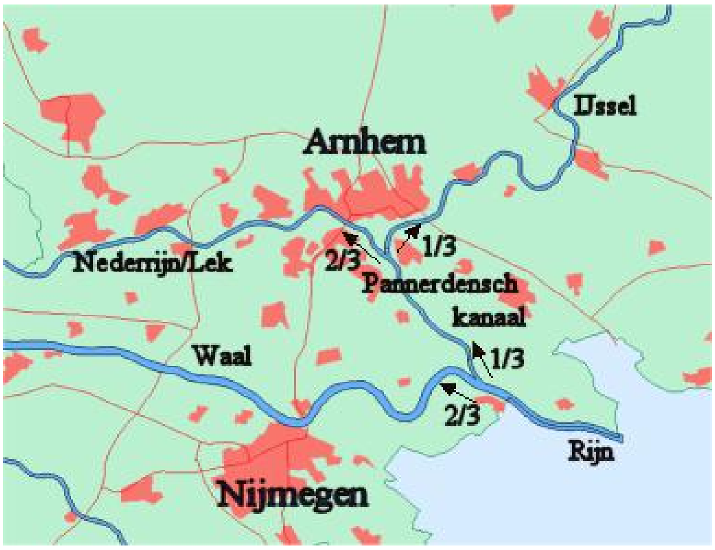

Figure 3.4 Overview of how the Rhine ("Rijn" in Dutch) enters the Netherlands from Germany (light blue in the map). In the Netherlands, the river splits into the "Waal" and the "Pannerdensch Kanaal". Close to Arnhem the Pannerdensch Kanaal splits into the "IJssel" river, and the the "Nederrijn/Lek" (Wikepedia, no date).

3.2 Overview of water related issues in the Rhine basin

The Rhine basin is characterised by diverse problems and opportunities, for example in relation to its high population density (300 inhabitants per square kilometre, compared to 40 inhabitants per square kilometre in the Nile basin), industrialisation and pollution. In this section we concentrate on the issues mainly concerning water. The following subsections help you understand the problems from different angles. We focus on hydrological and environmental issues, as well as on transboundary, political and institutional issues.

3.2.1 Hydrological

There are differences in the discharge characteristics of water, with rapid discharge after precipitation upstream and drainage congestion in the lower reach of the river. This necessitates different water management objectives along the river. For instance, upstream it is important to limit erosion, while downstream it is important to ensure no flooding and to maintain safety as the river is often lower than sea level.

The discharge in the Rhine when entering the Netherlands is 2400 m^3/s on average. At Lobith, where the Rhine enters the country, the discharge is measured continuously. The information on discharges of the river systems at Lobith and throughout the Netherlands can be found at

http://www.rijkswaterstaat.nl/geotool/geotool_afvoer_stroomsnelheid.aspx?cookieload=true (Move your mouse over the map and find 'Lobith' towards the east)

The discharge of a river can be estimated roughly as follows

a) Estimate the width at the surface and the depth of the river; assume a trapezoidal cross-section and estimate the bottom width. Calculate the cross-section area (in m^2) based on your estimations. Note: the area of a trapezoid = (sum of parallel sides) X (Distance between parallel sides)/2.

b) Estimate the flow of the water in the river, for example by focusing for 10 seconds on the water and estimating the speed of the flow. Multiply the cross-section area (in m^2) with the speed of the flow (m/s) to get the discharge (volume per second, in m^3/s).

Example

Suppose we want to estimate the discharge of the Rhine at the entry point of the river in the Netherlands, assuming a surface width of 150 metres, depth of 10 metres, bottom width of 100 metres and an estimated water flow of 2 m/s. As stated in the text, this estimate is rough. Nevertheless, it gives an indication of the average discharge.

On 22 August 2010, the actual discharge for Lobith was 2662 m^3/s. Let us now compare this with a rough calculation.

Example of the calculation

1. Estimated width: 150 metres, estimated depth: 10 metres, estimated bottom width 100 metre

Calculated cross-section area assuming a trapezoidal cross-section = ((150+100)*10)/2 = 1250 m^2.

2. Estimated flow 2 m/s. The discharge is then 1250 x 2 = 2500 m^3/s.

Exercise

Examine Table 3.1 below. Note that ‘afvoer’ is Dutch for ‘discharge’, while ‘tijd’ is Dutch for ‘time’. Examine the highest and lowest discharge. How much is the percentage fluctuation between the lowest and highest discharge?

Table 3.1 Daily discharge of the Rhine at Lobith

Netherlands’ water authority ‘Rijkswaterstaat’ **22-08, 06:30 hrs , Lobith, discharge measured: 2662 m^3/s**	
Time	**Discharge (m^3/s)**
06:00	**2662**
05:00	**2675**
04:00	**2682**
03:00	**2682**
02:00	**2689**
01:00	**2695**
00:00	**2709**
23:00	**2709**
22:00	**2716**
21:00	**2722**
20:00	**2729**
19:00	**2736**
18:00	**2736**
17:00	**2743**
16:00	**2743**
15:00	**2756**
14:00	**2763**
13:00	**2750**
12:00	**2763**
11:00	**2763**
10:00	**2763**
09:00	**2763**
08:00	**2750**
	Source: Rijkswaterstaat, actuele waterdata

Feedback

The lowest discharge is at 0600 and = 2662m^3/s.

The highest discharge is 2763 m^3/s and this occurs at 4 consecutive times the previous day.

Taking the lowest discharge as the baseline, the percentage fluctuation between lowest and highest discharge = 100*(2763-2662)/2662 = 3.8%.

Alternatively, taking the highest discharge as the baseline, the percentage fluctuation between lowest and highest discharge = 100*(2763-2662)/2763 = 3.7%.

Whichever way we calculate it, the fluctuation between the highest and lowest discharge in a day is therefore small.

NB: Note that the discharge on this day is about 2700 m^3/s, which is slightly higher than the average. You may compare this to our example calculation above.

Monitoring the discharge is of course important in order to provide flood warnings.

Discharge characteristics and flooding: safety of people and crops

The discharge of the river Rhine shows a seasonal cycle. Due to snow melt in spring, or due to heavy rainfall, the discharge of the river may increase. This typically happens especially in spring. The river discharge can also be lower than the average. This mainly happens in summer.

In the early 1993 and 1995, high discharges of about 11,000 m^3/s were observed in the Rhine (Engel, 1997). Also the Dutch part of the Rhine faced extreme runoff in those years, with high peak flows (Hurkmans, 2009). This resulted from the coincidence of heavy rainfall with snow melt. Although these events did not result in human casualties, they caused enormous disruption of daily lives and evacuation of in total 250,000 people in the Netherlands. This led in turn to policy action, where more space was allocated for river management (the ‘Room for the River’ programme), and public opinion shifted from a view of ‘all the water out’ towards ‘we need to accept that there is always water, how do we deal with it?’.

For water management, peak flows are more important than average discharges. Currently, the Rhine infrastructure is designed to manage peak flows of 15 000 m^3/s. In the future, peak flows may increase to 16 000 m^3/s or more as a result of climate change. Note that at15 000 m^3/s the discharge is approximately 6 times more than normal. Both the speed of the water flow and the cross-section of the river will increase at such peaks. A peak flow of 15 000 m^3/s may increase the water level by several metres. Increased peak flows as a result of climate change therefore have important consequences for infrastructure design.

There are different ways to manage peak flows. The cross-section of a river in Figure 3.5 illustrates a common strategy. Many large rivers in the Netherlands flow through a ‘summer bed’, a relatively small section, with dikes alongside. These dikes overflow with peak flows, and then the ‘winter bed’ becomes the discharge section of the river, plus the larger dikes alongside it.

As mentioned above, the discharge is a function of the cross-section (depth x width) multiplied by the speed of the water. Note that when the summer bed overflows, with a relatively small level increase, the discharge capacity increases tremendously, as the cross-section equals the width of the overflowing river) and becomes much larger. (See Figure 3.5).

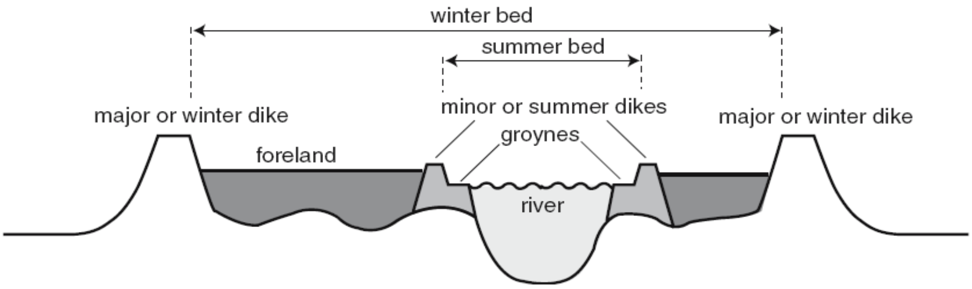

Figure 3.5 Cross-section of the large rivers of the Netherlands (De Vaate et al., 2006)

Drought: navigation and industry

The Rhine basin is a heavily industrialised area. Almost two thirds of the chemical and pharmaceutical companies of the world can be found here. It is also a very busy river with one of the largest seaports of the world (Rotterdam) and the largest inland harbour of the world (Duisburg in Germany). Due to these ports, it has one of the highest water traffic densities in the world. The large economic and industrial value that is concentrated in the basin is very vulnerable to damage by extreme peak flows and low flows occurring in the river. The extreme low stream flow due to drought in 2003 caused problems with inland navigation, and power stations suffered from lack of cooling water due to low discharges and high water temperatures (Hurkmans, 2009).

3.2.2 Environmental

Over the years, the Rhine has severely been affected by pollution, to such an extent that the river was called 'the sewer of Europe' for a long time. At some stage, it was dangerous for human health to swim in the river.

The pollution had different origins. One is direct human pollution, as individuals or municipalities use the river to discharge their domestic waste water (point source pollution). Another type of pollution is from agriculture, as nitrogen from fertilisers and insecticide residues may enter the river. Further, industries cause pollution when they discharge wastewater into the river. Some pollutants build up in the sediments. If this continues over time, such polluted sediments can become sources of pollution themselves. Finally, navigation causes unwanted discharges into the river from time to time (IKSR, no date –a).

The above paragraph has described pollution from everyday activities. Accidents, however, add a further dimension. The most recent, infamous example of an accident on the banks of the Rhine was a fire in a chemical warehouse belonging to the chemicals firm, Sandoz, near the city of Basel in Switzerland on 1 November 1986. Out of the 1,300 tons of chemicals stored there, including 934 tons of pesticide and 12 tons of organic compounds containing mercury, some 30 tons of chemicals including mercury and organo-phosphorus pesticides discharged into the river during the fire-fighting operation. The pollutants included rhodamine, a red dye, which made visible the passage of the pollution down the river. Many intakes for German towns that are dependent on the river for drinking water had to be closed, and water was brought to the cities and villages by trucks (Wikipedia, no date –c).

This accident, also known as the Sandoz accident, was Europe's worst environmental disaster in a decade, and it is estimated that half a million fish were killed and some species totally wiped out. The spill reversed the previous 10 years of cleaning up the river (BBC, no date).

In recent years, mainly due to discussion and collaboration between the member countries (see the next sub-section), the quality of the water in the Rhine and many of its tributaries has distinctly improved. Nowadays, 96% of the population are connected to a waste water treatment plant, while large industries have their own treatment plants, before waste is discharged into the river. As a result, the number of animal and plant species in the river has increased. Currently, there are 63 fish species and since 2006, salmon, sea trout and eel as well as other migratory fish have migrated from the North Sea as far upstream as Strasbourg. (IKSR, no date –b).

3.2.3 Transboundary, Political and Institutional issues

The river Rhine flows through a number of rivers. Like many other large rivers, it is a transboundary river, meaning that it crosses several international borders. Managing transboundary rivers thus requires international cooperation. There are several hundreds of international institutions focussing on the management of issues related to the water quality and water quantity in such rivers. In-depth analysis of these institutions reveals that conflicts over the quality and quantity of water can most of the time be managed peacefully.

In the future, international cooperation in river management may become even more important than it is today because of climate change. Disputes over access to the waters of transboundary rivers have been recognised as possible factors leading to violent conflicts. Public discourse about the impact of climate change frequently emphasises the likelihood of growing violent conflict between riparian states as a consequence of water shortage resulting from climate change. Some authors claim, however, that such a scenario is not inevitable, and that conflict over the use of water could be resolved in international institutions or at least be managed to such an extent that the use of violence can be avoided.(http://www.transboundarywaters.orst.edu/about/wolf.html)

In the following, we present two major water institutions within the Rhine basin as examples of cooperative management of transboundary rivers. These are (a) the International Commission for the Protection of the Rhine (ICPR) and (b) the European Water Framework Directive (EU-WFD).

a) **The International Commission for the Protection of the Rhine (ICPR – www.iksr.org)** was established in Basel on 11 July 1950 as a permanent intergovernmental body to handle general pollution issues along the river. It emerged from several international conventions and protocols which aimed to manage issues related to water quality and quantity. The ICPR co-operates with states, other intergovernmental organisations and nongovernmental organisations. Its main objective at inception was to improve the water quality of the Rhine, at that stage also referred to as 'the sewer of Europe'.

   Focal Tasks of the ICPR were as follows:

Year	Focal Tasks
1970	Improvement of water quality
1987	Remediation of the ecosystem
1990	Flooding
2000	Sustainable development of the Rhine Floodplains.

   Maintain all waters in the watershed in a good state.

   When signing the new Convention on the Protection of the Rhine in Bern on 12 April 1999, the Governments of five countries bordering the Rhine (France, Germany, Luxemburg, the Netherlands, Switzerland), and the representative of the European Community formally confirmed their determination to reinforce their co-operation for continued protection of the valuable character of the Rhine basin, its banks and its flood plains. This Convention replaced the Bern Convention signed in 1963, and entered into force on 1st January 2003.

In addition to the ICPR, there is the International Commission for the Hydrology of the Rhine Basin (CHR). This commission is an organisation where the scientific institutes of the Rhine riparian states formulate joint hydrological measures for sustainable development of the basin. The ICPR and CHR are linked, and coordinate their activities. Representatives of the ICPR attend the CHR meetings and vice versa.

Since 1987, discharges at various points of hazardous substances have decreased by 70 to 100 per cent. Effluents containing dioxins and DDT are no longer found. Discharges of heavy metals such as lead, cadmium, copper and zinc and of pesticides have been substantially reduced. Nitrogen run-off from non-point sources into tributaries, i.e. from agricultural soils, is still a problem (UNEP, 2003).

For many other transboundary rivers, similar commissions exist (e.g., the Danube, Elbe and Oder, Nile, Mekong etc.). These institutions include mechanisms for monitoring, verification, national implementation, compliance, reporting and the settlement of disputes between states. An important question for the future will be how the existing international institutions for the management of transboundary rivers will be able to deal with new issues that result from climate change. Which new issues will arise from climate change in the context of these international institutions? Are these institutions prepared enough to respond to them? The main issues emerging in the coming decades will be climate change-related.

b) **The European Water Framework Directive (WFD)** was adopted in 2000 as an important legislative measure and a central policy of the European Union (EU) to address citizens' and ecosystems' needs for clean water. The European Water Framework Directive is officially referred to as WFD 2000/60/EC, which is the number of the decision made by the European Parliament: (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2000L0060:20090625:EN:PDF).

The policy is oriented towards water quality management issues and aims to provide citizens with an active role in water management. However, its importance is wider than these two issues, because it represents the first occasion that all EU countries have agreed to make water policy and legislation together. River basin management plans in which different institutions and societal groups agree on how to improve water management (in particular in relation to water quality), and participatory processes are key to the EU-WFD.

Overall in Europe, public concern about water quality has contributed to legislation in this area for many years, but the most prominent was the introduction of the WFD, some of which was designed with the Rhine in mind.

Through the WFD, concerted efforts by all the basin countries have contributed to restore the river's health. The return of fish is a clear sign that the water quality has improved. But, although the water quality itself is now good, the natural habitats of the river can still be improved. Passages for migrating fish are needed so that salmon can return in large numbers. There have been tensions between the desire to restore salmon in the river and the planning of hydroelectric power stations (UNEP, no date).

Several environmental problems remain. A major issue concerns the Rhine delta's huge basin in the Netherlands, where toxin-filled mud which is dredged from the port of Rotterdam has been dumped since the 1970s. Contamination levels are falling now, but several old toxins in the river's sediment are only very slowly being removed (UNEP, no date).

Exercise

Read the information from the European Union on the Water Framework Directive at http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm Search for elements of qualitative water management and stakeholder involvement.

Feedback

An important point that emerges from this site is that international collaboration on water quality issues started for the Rhine long before the EU-WFD policy was formulated, rather than the other way around: The collaborations that evolved have provided the model for the river basin management that is described in the EU-WFD.

Although you won't find this on the WFD site that you were asked search, the Coordinating Committee 'Rhine & Water' coordinates the implementation of the EU-WFD with the new ICPR programme 'Rhine 2020' (see Section 3.3.2 below).

3.3 Climate change in the Rhine basin

This section is devoted to explaining climate change as one of water related problems. Scientific results of past trends and their causes, future projections of climate models are discussed. As a result you will learn about the multidimensional consequences of climate change in relation to the Rhine basin.

3.3.1 The impact of climate change in the Rhine basin

Climate change may affect the average discharge of rivers, as well as the peak flows and seasonal trends. This in turn may have implications for flood management and for navigation on rivers. The local effects of climate change along the Rhine and other rivers, however, are relatively uncertain.

The Intergovernmental Panel on Climate Change (IPCC) scenarios provide indications of global effects of climate change (IPCC, 2007). Global climate models have been used to create these scenarios in order to assess future changes in temperature and precipitation at the regional scale. However, these assessments are not detailed enough for projections of climate change in the Rhine basin.

Projections of local climate change in many countries are made available by national institutes that interpret or downscale the large scale global assessments. For instance, the Royal Netherlands Meteorological Institute (KNMI) has published projections for future climate change in The Netherlands, based on the global IPCC SRES scenarios (www.KNMI.nl) and on results from 23 global and regional models. These include important variables such as temperature, precipitation, wind changes, and sea level rise and provide information on the characteristics of the average weather and, very importantly, the chance of weather extremes (see Table 3.2). These scenarios serve as the national standard in adaptation strategies in the Netherlands and are especially used for water management as part of the process of 'climate proofing' the country (Kabat et al., 2005). The scenarios indicate that temperature will continue to rise; on average, winters will become wetter and extreme precipitation will increase; and the intensity of extreme rain showers in summer will increase. However, the number of rainy days in summer will decrease; the calculated change in wind is small compared to the natural fluctuations; and the sea level will continue to rise (KNMI, 2010).

TABLE 3.2 Climate change in the Netherlands projected for around 2050 (top) and 2100 (bottom) compared to the baseline year 1990, according to the four KNMI'06 climate scenarios. The climate in the baseline year 1990 is described using data from the period 1976 to 2005. The seasons are defined as follows: 'winter' stands for December, January and February, and 'summer' stands for June, July and August. KNMI (2010). Note that, except for 'global temperature rise', all data relate to the Netherlands.

2050		G	G+	W	W+
Global temperature rise		+1°C	+1°C	+2°C	+2°C
Change in air circulation patterns		No	yes	No	Yes
Winter	average temperature	+0,9°C	+1,1°C	+1,8°C	+2,3°C
	coldest winter day per year	+1,0°C	+1,5°C	+2,1°C	+2,9°C
	average precipitation amount	+4%	+7%	+7%	+14%
	number of wet days (≥0,1 mm)	0%	+1%	0%	+2%
	10-day precipitation sum exceeded once in 10 years	+4%	+6%	+8%	+12%
	maximum average daily wind speed per year	0%	+2%	-1%	+4%
Summer	average temperature	+0,9°C	+1,4°C	+1,7°C	+2,8°C
	warmest summer day per year	+1,0°C	+1,9°C	+2,1°C	+3,8°C
	average precipitation amount	+3%	-10%	+6%	-19%
	number of wet days (≥0,1 mm)	-2%	-10%	-3%	-19%
	daily precipitation sum exceeded once in 10 years	+13%	+5%	+27%	+10%
	potential evaporation	+3%	+8%	+7%	+15%
Sea level	absolute increase	15-25 cm	15-25 cm	20-35 cm	20-35 cm
2100		G	G+	W	W+
Global temperature rise		+2°C	+2°C	+4°C	+4°C

Change in air circulation patterns		no	yes	no	Yes
Winter	average temperature	+1,8°C	+2,3°C	+3,6°C	+4,6°C
	coldest winter day per year	+2,1°C	+2,9°C	+4,2°C	+5,8°C
	average precipitation amount	+7%	+14%	+14%	+28%
	number of wet days (≥0,1 mm)	0%	+2%	0%	+4%
	10-day precipitation sum exceeded once in 10 years	+8%	+12%	+16%	+24%
	maximum average daily wind speed per year	-1%	+4%	-2%	+8%
Summer	average temperature	+1,7°C	+2,8°C	+3,4°C	+5,6°C
	warmest summer day per year	+2,1°C	+3,8°C	+4,2°C	+7,6°C
	average precipitation amount	+6%	-19%	+12%	-38%
	number of wet days (≥0,1 mm)	-3%	-19%	-6%	-38%
	daily precipitation sum exceeded once in 10 years	+27%	+10%	+54%	+20%
	potential evaporation	+7%	+15%	+14%	+30%
Sea level	absolute increase	35-60 cm	35-60 cm	40-85 cm	40-85 cm

In the Rhine basin the hydrology characteristics are expected to shift from a combined snowmelt and rainfall-driven river to a more rainfall-dominated river. Impact assessments have indicated that this may lead on average to an increase in stream flow of about 30% in winter and spring, and a decrease in discharge of about 30% in summer.

The consequences of climate change for the Rhine have been modelled in several studies. In one of these, regional climate scenarios were used together with a regional climate model (REMO), as input to a macro scale hydrological model (VIC, Variable Infiltration Capacity Model) (Hurkmans et al., 2010; Hurkmans 2009). The climate scenarios were based on a global climate model (in this case ECHAM5-Max Planck Institute Ocean Model, MPI-OM) which in its turn used three IPCC emission scenarios as input (from the Special Report on Emissions Scenarios - SRES). Schematically this is represented in Figure 3.6.

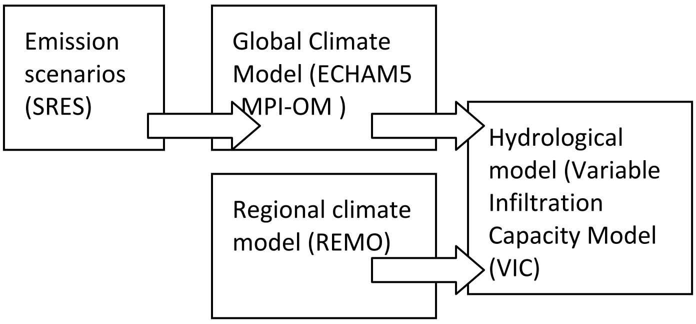

Figure 3.6 Combined use of computational climate and hydrology models (Hurkmans et al., 2010)

The results of the VIC model show an increased precipitation during the first half of the twenty first century, causing an increased stream-flow throughout the year. During the second half of the century the discharge in summer decreases and in winter increases. This is caused by higher temperature and evapotranspiration in the second half of the century, decreasing precipitation in summer and an earlier start of the snowmelt season. Peak flows are expected to increase in magnitude in both the first and the second half of the century, while the droughts (decreased peak flows) increase only in the second half of the century (Hurkmans et al, 2010).

Also, other studies indicate that, in the lowland area of the river Rhine, increased winter precipitation will cause higher winter discharge and winter peak flows. Annual peak flows may increase by 20% (Middelkoop, 2001). During summer, higher evapotranspiration levels are projected to cause a net precipitation deficit, reducing discharge in late summer by about 5% (Middelkoop, 2001). The combined effects of warmer temperatures and reduced mean summer precipitation would enhance the occurrence of heat waves and droughts (Alcamo et al, 2007).

Summarising, climate change may increase annual peak flows in the Rhine while in summer discharges may be reduced. This will have major consequences for flood management and navigation. Anticipating these climate change impacts is one of the challenges of future water management, which involves working with many uncertainties.

3.3.2 Water quality issues

As mentioned above, pollution of the Rhine has been an issue of concern for many decades. In recent years, significant progress has been made in pollution control and ecological restoration. For instance, the “Rhine Action Programme” was introduced by the International Commission for the Protection of the Rhine (ICPR) in 1987 as a comprehensive restoration programme. This was the precursor of the later “Rhine 2020” programme. Rhine 2020 is a programme for the sustainable development of the river. It was adopted in January 2001 by the ministers in charge of the Rhine, and as a follow-up to the “Rhine Action Programme” (1987-2000). In addition, agricultural and environmental policies at the European scale may have a positive effect on the water quality of the river.

Compared to other European rivers, the Rhine carries large amounts of nutrients from land to sea. In particular nitrogen (N) and phosphorus (P) loads are high (Kroeze and Seitzinger, 1998a & b; Seitzinger et al., 2010). This is the result of agricultural inputs of N and P on the land, part of which leaches to surface waters such as the Rhine. The problem of too much N and P in river water is that it can cause eutrophication (overenrichment) of rivers and coastal waters. Eutrophication is an issue in many coastal ecosystems. It may lead to hypoxia (or oxygen depletion) and algal blooms, which are harmful to aquatic life. As such, it may have serious consequences for biodiversity and fisheries.

It is likely that, in the coming decades, N and P loads of the Rhine will be lower than today (Seitzinger et al., 2010). This is the net effect of agricultural and environmental policies leading to reduced N and P inputs to the land (Bouwman et al., 2009), and of changes in hydrology (Fekete et al., 2009). In the future, most world rivers will discharge less water to the sea than today and the Rhine will probably be no exception. This is largely associated with human water consumption and damming of rivers but average annual discharges will alter also as a result of climate change (Fekete et al., 2010). When river discharges are reduced, less N and P is carried by rivers to coastal waters. For the Rhine future discharges may increase in winter and decrease in summer. What the net effect of this is on water pollution is a subject of study.

3.3.3 Water management and climate in the past

Generally speaking, the experience of climate change is perhaps most intense for those who suffer from increased flooding. This may hold in particular for The Netherlands, a country with a long history of 'fighting the water back'. In The Netherlands, the memory of a huge flood in 1953 is still vivid. In this flood of the south western part of the country, over 1800 people died. Afterwards, safety was the first priority in water management. A vigorous plan was developed, therefore, to enhance safety. Known as the 'Deltaplan', it resulted in the 'Deltaworks'.

The Deltaworks are a series of constructions built between 1950 and 1997 in the southwest of the Netherlands to protect a large area of land around the Rhine-Meuse-Scheldt delta from the sea. The works consist of dams, sluices, locks, dikes, and storm surge barriers. The aim of this infrastructure was to shorten the Dutch coastline, thus reducing the number of dikes that had to be raised. While the deltaworks started as measures to ensure safety, eventually also environmental concerns about salt and brackish (i.e. having to contend with salt) ecosystems were taken into account. The Eastern Scheldt storm surge barrier, between the islands Schouwen-Duiveland and Noord-Beveland, which is the largest of the 13 Delta works flood measures, was opened in 1986 by Queen Beatrix of the Netherlands.

Filmpje Deltaworks: http://www.7wonders.org/community/video/netherlands/delta-works/44/156/

Recently, however, there has been a trend away from safety as the only focus of water management in countries like the Netherlands. A general paradigm shift appears to have occurred from 'safety first', 'all water out' or 'discharge all the water as soon as possible', towards 'catch it, store it, and discharge it when required'. This shift holds for water management in the Rhine basin in general, and in water management in the Netherlands in particular. Currently, more attention is given to the environmental aspects of water management and not to quantitative water management in relation to safety only. This has led to a changed approach from 'the river as the discharge channel only' to the 'river as an ecosystem function'.

3.4 Adaptation to climate change in the Rhine basin

3.4.1 The imperative for adaptation to climate change in the Rhine basin

The increased risk of flooding from peak discharges, and lower net discharge levels over certain seasons, make adaptation to climate change on the Rhine a priority.

Flood management may imply two categories of measures: measures between winter dykes, and measures outside winter dykes (see Figure 3.5 above).

Between the winter dykes, measures are taken in the floodplain and the summer bed. These measures are meant to increase the capacity to manage higher peak flows. Lowering of river floodplains or deepening the base-flow course of the river is one of the first choice options in many rivers. Creation of secondary channels is also an option as well as lowering of groynes[17]. In some cases, removal of hydraulic obstacles, like constructions or trees, may help. And, of course, strengthening dykes will be needed.

Measures outside the winter dykes, include dyke relocation, to enlarge the winter bed. Flood bypasses are a way to guide peak flows into areas where inundation will not cause problems. For similar reasons it is possible to create retention areas or to decide to depolder[18] land and make it available for controlled flooding when needed.

Managing changes in navigation time, which is also related to changing discharge, is a different issue. At lower river levels during summer, navigation, as well as industrial use of water, is threatened. For some major ports along the Rhine, the navigability of the river is important. Industrial use, for example power generation plants which use the water for cooling, also is severely limited when water levels are too low. Ensuring water levels that are high enough for navigation in summer seems to be in contradiction with flood management in winter, and combines to make water management of the Rhine a complex issue.

Activities undertaken include the *Room for the River* programme in the Netherlands, where the government is collaborating with stakeholders at all levels to increase the resilience of the water system, for example, by increasing water storage possibilities. It has been decided to design the river such that it can manage peak loads of 16,000 m^3/s, compared to 15,000m^3/s today. (See 'facts and figures' at http://www.ruimtevoorderivier.nl/meta-navigatie/english.aspx. Last accessed on 21 March 2012).

At the level of the European Union, a policy paper on climate change adaptation has been developed and discussed with many stakeholders, resulting in the so-called 'White Paper: Adapting to climate change' (EU, 2009). In this Paper, the need to adjust existing plans and include climate change adaptation was stressed. With regard to water, the Paper indicates that river basin management plans need to be made 'climate proof' (EU, 2010): http://ec.europa.eu/environment/water/adaptation/index_en.htm

3.4.2 Dealing with uncertainties

Planning future river management is generally surrounded by major uncertainties. First of all, the discharge of rivers is unpredictable by nature. Peak loads may occur unexpectedly. In addition to this, the local effects of climate change are uncertain. Given these uncertainties, it is not easy to identify the best management strategy.

Middelkoop et al. (2004) performed an interesting study on uncertainties in future flood management of the Rhine. They present a scenario in which physical modelling has been combined with socio-cultural theory. They argue that decisions on future flood management will depend on peoples' world views, and their perspectives on nature and on climate change. They define perspectives as consistent and coherent visions on how the world functions (worldview) and how management should be carried out accordingly (management style).

In their study, three perspectives or worldviews are considered:

> **Egalitarian** perspective: people with this perspective consider nature to be fragile. Their management style is prevention and they are risk avoiding. They expect radical changes in water functions because of climate change.

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[17] A groyne is a structure built from the shore or river bank into the water, to interrupt water and sediment flows.

[18] Depoldering is the opposite of poldering. A polder is a low-lying area surrounded by dikes so that there are connections with surrounding water. Depoldering implies removing the dikes around a polder.

Hierarchist perspective: people with this perspective consider nature to be tolerant within limits. Their management style is partnership and they are risk accepting. They expect climate change, but call for more research because of all uncertainties.

Individualist perspective: people with this perspective consider nature to be robust. Their management style is adaptation and they are risk seeking. They consider climate as insensitive to human activity and the economy more important than nature.

Middelkoop et al. (2004) illustrate how different world views may lead to different river management styles. In short, the egalitarian management style has the motto "water guides the landscape planning" while the other two styles are characterised by the motto "water follows from landscape planning". The egalitarian style would focus on pro-active sustainable water management with a long time horizon (50 years ahead) and a focus on prevention and adaptation to expected climate change. The individualist style is more reactive, and will use cost benefit analyses and risk assessments to guide water management with a focus on the short term (10 years ahead). The hierarchist style aims for win-win solutions and negotiations between different interests, and prefers a river basin approach at intermediate time scales (10-50 years ahead).

The egalitarian style is more in line with the precautionary principle (see Section 1 above), while the individualist style is more in line with 'no regret' policies. To what extent these management styles will be in line with actual future trends remains to be seen.

In the Netherlands, the Dutch Delta Committee has advised the government on future adaptation to climate change. The advice is summarised in an interview with Professor Cees Veerman, member of this committee and former minister of Agriculture in The Netherlands. http://www.deltacommissie.com/en/film

3.4.3 Stakeholder participation

The course of water in a river basin is influenced by people in order to reach a situation in which the water can be used for a certain function. This may be safety, fisheries, navigation, agriculture, urban development etc. Everybody involved has a certain interest, a 'stake', in the water management issue at hand. These groups or individuals are known as 'stakeholders'. Thus, when a decision has to be made in a municipality about the collection and treatment of wastewater, different stakeholders will inevitably be involved, with different concerns and interests. For example, somebody living near the site of a planned sewage treatment plant may be concerned about the smell, while the owners of local hotels may be concerned that their guests are able to shower and use their bathrooms without problems throughout the holiday season.

The objective of water management is to control the physical system. Water management needs an institutional setting with organisations and legal measures in which this can be applied. For instance in the Netherlands, municipalities make a local water plan, and at sub-national level water boards make water management plans. In an international setting there are other arrangements, such the International Commission for the Protection of the Rhine (ICPR) and the European Water Framework Directive (WFD) as discussed earlier.

Here, however, we focus on the wider stakeholders involved, and try to analyse what happens when water management changes, for example under the influence of climate change. These stakeholders include local residents, farmers, fishermen, administrators, environmentalists, industrials, and so forth (the list of possible stakeholders can be very long). Some argue that also animals or nature are stakeholders. Others consider stakeholders as only those people 'holding a stake'. Whenever there are people who act to defend animal or nature interests, then these people become a stakeholder, who defend the interests of animals or nature.

Local municipalities are of course stakeholders as well. This may apply especially to municipality leaders, such as the mayor who has an interest in the smooth running of the overall day to day business of the municipality. Other stakeholders will be the local water authority as policy maker and implementer with a responsibility to collect and clean the water, and the households as users of the service to have their waste water removed and cleaned in a reliable manner.

But also countries as a whole are stakeholders where transboundary river management is concerned. In the case of the Rhine, for example, industrial activity upstream in one country might cause pollution of the water, and the people living further down the river in another country will be affected. Alternatively, after a heavy rainstorm the water will collect in the river, and the increased discharge might cause flooding downstream. Thus stakeholders in the Rhine basin exist at different scales, from the local to the international.

Integrated Water Resources Management (IWRM; see Box 1.1) strategies typically deal with many different aspects of rivers, and its stakeholders. Many people argue that it is important to involve stakeholders in the identification and implementation of appropriate IWRM strategies.

Exercise

Can you think of a possible argument not to involve stakeholders in IWRM management?

Feedback

Involving stakeholders may complicate the discussions, and delay decision making. In most river basins, stakeholders will be largely affected by the water management. However, different stakeholders have different stakes. Farmers, for instance, will be affected in a different way by flooding than fishermen, while environmental non-governmental organisations (NGOs) that are in favour of creating room for nature will have different preferences than citizens living behind the dikes. As a result, they are likely to disagree about what “appropriate” IWRM strategies are.

The counter-argument to that made in the exercise is, of course, that involving all stakeholders leads to a greater chance of making a decision whose legitimacy everyone at least accepts. Module 2 in this series (The lived experience of climate change) would argue further that it potentially gives rise to a better decision because new knowledge about the issue can be constructed out of the diversity of stakeholders. Nevertheless, a decision does still have to be taken. Serious disruption due to climate change might not wait.

3.5 Further reading on the Rhine case

Suggested sources of additional information on the Rhine are:

- Room for the river programme: http://www.ruimtevoorderivier.nl/meta-navigatie/english.aspx
- 1986: Chemical spill turns Rhine red: http://news.bbc.co.uk/onthisday/hi/dates/stories/november/1/newsid_4679000/4679789.stm
- Pollution along the river Rhine http://www.teachersdomain.org/resource/ess05.sci.ess.watcyc.rhine/
- Rhine pressures http://www.bbc.co.uk/scotland/education/int/geog/eei/rivers/

In the Rhine area much work has been done to involve stakeholders. Also manuals have been written as guidelines for others to use. As this is outside the scope of this case study, we refer to these materials only in the text above. However, if you require further information, see:

EC-HarmoniCOP (2005), Learning together to manage together - Improving participation in water management, EC-funded output of the project "Harmonising Collaborative Planning, ISBN-ISSN-EAN 3-00-016970-9,

http://www.harmonicop.uos.de/HarmoniCOPHandbook.pdf

4 Conclusion

4.1 General conclusions

Exercise

Compare and contrast the water- and climate-related challenges in the Nile and Rhine river basins.

Feedback

What we learn from these two river basins is that water-related issues exist in both developed and developing countries. The difference is the extent and the type of issue. For the Nile basin, the major issue is water scarcity in terms of the amount and the unaccomplished fair distribution among the riparian countries. Thus, most of the water conflicts along the Nile are based on these challenges. On the other hand the major issues for the Rhine basin are water pollution and floodplain management.

The institutional arrangements in the two basins concentrate, therefore, on the respective major challenges that each poses. Thus, the Nile Basin Initiative (NBI) works more on eradication of poverty that can be linked to water scarcity and distribution in the basin, whereas the EU Water Framework Directive (WFD) focuses more on water quality issues in the Rhine river basin.

The difference we see in terms of adaptation to climate change effects is also basin specific. In the Nile basin, most of the climate impacts have been water stress problems that have led to drought conditions. The adaptation measures have been in response to this issue and have focused more on helping farmers to use alternative approaches. For the Rhine basin, the adaptation measures have concerned formulation of legislation such as the EU WFD and 'Rhine 2020' programmes to assist in solving the problems related to the water quality.

4.1.1 The "water system" as integrator, addressing complexity and uncertainty

Water is an essential part of our lives. Studying the water system does not solely concentrate on the natural resource, rather it integrates various aspects of different sectors. The water system brings together environmentalists, hydrologists, engineers, climatologists, water managers, politicians, sociologists, economists, farmers and fishermen, and the list continues. Therefore, water is a system that requires a multidisciplinary approach as it concerns everyone in one way or another. As you investigate the impact of climate change on water systems you are actually studying its impact on facets that are essential to human beings. Complexity is typical for such situations which involve the impact of climate change on society and diverse adaptation options. To understand the complexity of a situation, it is necessary to examine different scales, both spatially and in time, to see how they are interconnected.

While climate and climate models are best studied at a global scale, adaptation options need to address local needs, and be location specific. The water system also can be studied at different scales, from field level to irrigation or drainage system level, to the basin level or at a global level. Therefore, an analysis is required that highlights how the different scales, global, national, sub-national, local are connected. Moreover, time scales range from historical periods to the present, as well as including the more micro-time scales of what happens today, or what happens in a cropping season.

4.2 Guidelines on how to use the water case study

This water case study has been designed to help you appreciate the interdisciplinary, pluralistic and holistic methodological approaches of understanding climate change with respect to water and its inter/multidimensional consequences and experiences.

Some of workbook activities of the modules in this series link directly to this water case study. Generally, after reading the modules you should be able to apply the approach used here to a range of water stress related problems or other existing challenges associated with climate change. Water stress problems directly affecting human basic needs can involve scarcity which limits drinking water supply, irrigation, and food production. Other sectors affected by water scarcity might include industry, hydropower generation, navigation, and recreation. In contrast, receiving excess water might bring problems such as inland river floods, costal floods, urban drainage floods and salt intrusion from sea level rise. These problems, which consequently affect human health, might cause material damage, and deteriorate water quality. Moreover, you should be able to demonstrate lessons learned from past disasters. Finally, you are expected to be able to relate past experiences with future adaptation measures and apply the approach to new cases from either developed or developing countries.

A Masters' thesis or dissertation based on water

When researching water challenges, for instance for a Masters dissertation, you may choose cases from your own country or elsewhere. Along the Nile and Rhine, water stress or flooding events in the past have been mentioned as illustrative examples. Your dissertation could therefore focus on climate change-induced or aggravated problems in parts of the world.

In a dissertation or thesis related to a defined water issue, you might:

- Introduce the place of study (location and characteristics) and the case study (incorporating the issue) you choose to look at.
- Be able to discuss the issue from social, institutional, political, economic and environmental perspectives.
- Give examples of lessons learned from past experiences/disasters and include views of local people and ongoing social debates where applicable
- Explain the current management approaches in place and technologies that have been adopted to alleviate the problem
- Mention plans for the future by local authorities, the government or other interested parties
- Analyse how issues such as the complexity of the situation and the uncertainty for the future are addressed
- Propose your recommendations for sustainable adaptation and justify them from the previous experience

References

Abtew, W, Melesse A. M., and Dessalegne T., (2009). El Niño Southern Oscillation link to the Blue Nile River Basin hydrology, Hydrological Processes 23, no. 26: 3653–3660. doi:10.1002/hyp.7367.

Adger WN, Arnell N, Tompkins E. 2005 Successful adaptation to climate change across scales. Global Environmental Change Part A.;15(2):77-86.

Alcamo, J., J.M. Moreno, B. Nováky, M. Bindi, R. Corobov, R.J.N. Devoy, C. Giannakopoulos, E. Martin, J.E. Olesen, A. Shvidenko, 2007: Europe. Chapter 12 in: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 541-580.

Barbier, B., Yacouba H., Karambiri H., and Zoromé M., (2009). Human vulnerability to climate variability in the Sahel: Farmers' adaptation strategies in northern Burkina Faso. Environmental management 43: 790-803. doi:10.1007/s00267-008-9237-9.

Baum, Ingo and Mijako Nierenköther (Eds). (June 2007): Donor Activity in Tansboundary Water Cooperation in Africa: Results of a G8-Initiated Survey 2004-2007. GTZ. International Water Policy Project. Eschborn:

BBC (no date), BBC on 1 November 1986, retrieved on 21 March 2012 at http://news.bbc.co.uk/onthisday/hi/dates/stories/november/1/newsid_4679000/4679789.stm

BBC (no date), Oceans linked to Sahel drought, retrieved on 21 March 2012 from, http://news.bbc.co.uk/2/hi/science/nature/3191174.stm

Bouwman, A.F., Beusen, A.H.W., Billen, G., 2009. Human alteration of the global nitrogen and phosphorus soil balances for the period 1970-2050. Global Biogeochemical Cycles 23, GB0A04, doi:10.1029/2009GB003576

Camberlin, P., 2009. Nile Basin Climates, In H. J. Dumont (ed.), The Nile: Origin, Environments, Limnology and Human Use, Monographiae Biologicae, Springer, Dordrecht. Vol. 89: 307–333.

Canziani, O. F., Palutikof, J. P., van der Linden, P. J., and Hanson, C. E., Cambridge University Press, Cambridge, UK, pp 1000

CARE, 2009, Climate vulnerability and capacity analysis handbook, CARE International. Used by permission.

Conde, C. and Lonsdale, K., 2005. Engaging stakeholders in the adaptation process. In: B. Lim, E. Spanger-Siegfried, I. Burton, E. Malone and S. Huq (eds.), Adaptation Policy Frameworks for Climate Change, Cambridge University Press, Cambridge, UK, 47-66

Conway D, Allison E, Felstead R, Goulden M. 2005. Rainfall variability in East Africa: implications for natural resources management and livelihoods. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences; 363(1826):49-54.

Conway D., Hulme M., 1993. Recent fluctuations in precipitation and runoff over the Nile subbasins and their impact on main Nile discharge. Climatic Change, 25:127–151.

Conway G., (2009). The Science of Climate Change in Africa: Impacts and Adaptation. Grantham Institute for Climate Change, Discussion paper No 1. Imperial College London.

Conway, D (2005). From headwater tributaries to international river: Observing and adapting to climate variability and change in the Nile basin, Global Environmental Change, 15 (2): 99-114.

Deressa T., Hassan R. M., Alemu T., Yesuf M., and Ringler C., (2008) Analyzing the Determinants of Farmers' Choice of Adaptation Methods and Perceptions of Climate Change in the Nile Basin of Ethiopia, IFPRI Discussion Paper 00798

Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global Environmental Change. 2009;19(2):248-255.

Dumont, H. J., (2009). A Description of the Nile Basin, and a Synopsis of Its History, Ecology, Biogeography, Hydrology, and Natural Resources, In H. J. Dumont (ed.), The Nile: Origin, Environments, Limnology and Human Use, Monographiae Biologicae, Springer. Dordrecht. Vol. 89: 1–21.

Engel, H., 1997. The flood events of 1993/1994 and 1995 in the Rhine River basin, Destructive Water: Water-Caused Natural Disasters, their Abatement and Control (Proceedings of the Conference held at Anaheim, California, June 1996) IAHS, Anaheim, California, pp. 21.

El-Sheekh, M., (2009). River Nile Pollutants and their Effect on Organisms and Water Quality, In H. J. Dumont (ed.), The Nile: Origin, Environments, Limnology and Human Use, Monographiae Biologicae, Springer, Dordrecht, Vol. 89: 395–405.

Eriksen S., K. O'Brien and L. Rosentrater (2007), Climate Change in Eastern and Southern Africa Impacts, Vulnerability and Adaptation Department of Sociology and Human Geography (ISS), University of Oslo, Global Environmental Change and Human security

European Commission (2000), Water Framework Directive, retrieved on 21 March 2012 from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2000L0060:20090625:EN:PDF

European Commission (2009), White paper – Adapting to climate change: towards a European framework for action, retrieved on 21 March 2012 from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0147:FIN:EN:PDF

European Commission, DG Environment (2010), retrieved on 21 March 2012 from http://ec.europa.eu/environment/water/adaptation/index_en.htm

European Environmental Agency, no date, Average annual precipitation in Europe, retrieved on 21 March 2012 from http://www.eea.europa.eu/themes/water/water-resources/hydrological-cycle

Fekete, B.M., Wisser, D., Kroeze, C., Mayorga, E., Bouwman, A.F., Wollheim, W.M., Vörösmarty, C.J., 2010. Millennium Ecosystem Assessment Scenario drivers (1970-2050): Climate and hydrological alterations. Global Biogeochemical Cycles doi:10.1029/2009GB003593.

Hulme M., Doherty R., Ngara T., New M., Lister D., (2001). African climate change: 1900–2100, Climate Research, 17:145 - 168.

Hurkmans, R., W. Terink, R. Uijlenhoet, P. Torfs, D. Jacob, P.A. Troch (2010), Changes in Streamflow Dynamics in the Rhine Basin under Three High-Resolution Regional Climate Scenarios, Journal of Climate, Feb 1, 2010

Hurkmans, R.T.W.L. (2009), Effects of climate variability and land use change on the water budget of large river basins [Ph.D. thesis, Wageningen University, xviii+174 pp.] ISBN 978-90-8585-398-5, retrieved on 21 March 2012 from http://edepot.wur.nl/7187

IKSR (no date -a), International Commission for Protection of the Rhine: Pollution, retrieved on 21 March 2012 from http://www.iksr.org/index.php?id=16&L=3

IKSR (no date -b), International Commission for Protection of the Rhine: History – Balance of the Rhine Action Programme, retrieved on 21 March 2012 from http://www.iksr.org/index.php?id=165&L=3&cHash=455fdab52c&no_cache=1&sword_list[0]=basel

IPCC (2007). Climate Change 2007, In: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), edited by: Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J., and Hanson, C. E., Cambridge University Press, Cambridge, UK, pp 1000

Jiang T., Chen T. D., Xu C.Y., Chen X., Chen Xi, Singh V.P., 2007. Comparison of hydrological impacts of climate change simulated by six hydrological models in the Dongjiang Basin, South China. Journal of Hydrology 336 (3 - 4):316 - 333.

Kabat et al 2005 "Climate proofing the Netherlands", retrieved on 22 March 2012 from http://www.nature.com/nature/journal/v438/n7066/abs/438283a.html

KNMI/Royal Netherlands Meteorological Institute (2010). Retrieved on 21 March 2012 http://www.kmni.nl

Kroeze, C., Seitzinger, S.P., 1998a. The impact of land use on N2O emissions from watersheds draining into the Northeastern Atlantic Ocean and European Seas. Environmental Pollution 102 (1, Supplement 1), 149-158.

Kroeze, C., Seitzinger, S.P., 1998b. Nitrogen inputs to rivers, estuaries and continental shelves and related nitrous oxide emissions in 1990 and 2050: a global model. Nutrient Cycling in Agroecosystems 52 (2), 195-212.

Ansje Lohr and Catharien Terwisscha van Scheltinga, Global Water Systems and Adaptive Water Management, 2010, part of the LEANES project's online course module on climate change. Accessed on 22 March 2012, http://www.environmentportal.eu/files/Leanes_Climate%20Change%20module_%20summary.pdf

Masters J., 2010, NOAA: June 2010 the globe's consecutive warmest month on record, Dr. Jeff Masters' WunderBlog, retrieved on 21 March 2012 from http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=1544

McGrath C. and Inbaraj S., 2004, "Water wars loom along Nile." retrieved on 5 December 2010 from, http://www.news24.com/Africa/News/Water-wars-loom-along-Nile-20040116

Middelkoop (2001), xxxx, retrieved on 21 March 2012 from http://www.waterandclimateinformationcentre.org/resources/8022007_Middelkoop_ClCh.pdf

Middelkoop, H., Van Asselt, M.B.A., Van 't Klooster, S.A., Van Deursen, W.P.A., Kwadijk, J.C.J., Buiteveld, H., 2004. Perspectives on Flood Management in the Rhine and Meuse Rivers. River Res. Applic. 20 (327-342).

Mohamed, Y.A.; Loulseged, M. 2008. The Nile Basin Water Resources: Overview of key research questions pertinent to the Nile Basin Initiative. Colombo, Sri Lanka: International Water Management Institute. 34p. (IWMI Working Paper 127)

NBI, Nile basin Initiative, retrieved 21 March 2012 from, http://www.nilebasin.org/

NBS (no date), Nile Basin Society, retrieved on 21 March 2012 from, http://nilebasin.com/index.html

NOAA (no date), El Niño/Southern Oscillation (ENSO), retrieved on 21 March 2012 from, http://www.esrl.noaa.gov/psd/enso/

ONE (no date), Ethiopian famine 25th anniversary - Questions and Answers, retrieved on 21 March 2012 from, http://www.one.org/c/us/issuebrief/3127/

Ongwenyi, G S; Denga, F G O; Abwao, P (1993). Impacts of floods and drought on the development of water resources of Kenya: case studies of Nyando and Tana catchments, In: Hydrology of Warm Humid Regions, Proceedings of the Yokohama Symposium, IAHS Publ. no. 216, pp. 117-124.

Plaut M., (2003), Ethiopia's long wait for rain, BBC News, retrieved on 21 March 2012 from, http://news.bbc.co.uk/2/hi/programmes/from_our_own_correspondent/2646169.stm

Postel, S., (2010), Water Adapting to a New Normal, In R. Heinberg and D. Lerch (eds), The Post Carbon Reader: Managing the 21st Century's Sustainability Crises, Healdsburg, CA: Watershed Media.

Practical action (no date), Case Study: Drought in Kenya, retrieved on 21 March 2012 from http://www.climatechoices.org.uk/pages/case1.htm

Ross W., 2010. Wikileaks memo reveals Egypt's Nile fears over Sudan, retrieved on 21 March 2012 from http://www.bbc.co.uk/news/world-africa-11913940

Sabae S. Z. and Rabeh S. A. 2007. Evaluation of the microbial quality of the river Nile waters at Damietta branch, Egypt. Egyptian journal of aquatic research, 33: 301–311.

Seleshi Y, Demarée GR. 1995. Rainfall variability in the Ethiopian and Eritrean highlands and its links with the Southern Oscillation Index. Journal of Biogeography 22: 945–952.

Seitzinger, S., Emilio Mayorga, E., Bouwman, A.F., Kroeze, C., Beusen, A.H.W., Billen, G., Van Drecht, G., Dumont, E., Fekete, B.M., Garnier, J., Harrison, J., 2010. Global River Nutrient Export: A Scenario Analysis of Past and Future Trends. Global Biogeochemical Cycles doi:10.1029/2009GB003587.

Shahin, M. 1985. Hydrology of the Nile basin. Elsevier Science Publishing Company, Amsterdam, the Netherlands,

Smit, B. and Pilifosova, O. (2001) Adaptation to climate change in the context of sustainable development and equity, Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment report of the Intergovernmental Panel on Climate Change, WMO/UNEP, 877-912.

Sutcliffe, J.V., and Parks Y.P. 1999. The Hydrology of the Nile. IAHS Special Publication No.5, IAHS Press, Institute of Hydrology, Wallingford, UK.

Terwisscha van Scheltinga and Lohr, 2010, Case study on adaptive water management, SENSE/LEANES project

Teshome W., 2008. Transboundary Water Cooperation in Africa: The Case of the Nile Basin Initiative. Alternatives: Turkish Journal of International Relations;7 (4):34-43.

Thomson M., 2005, Nile restrictions anger Ethiopia, BBC News, retrieved on 21 March 2012, http://news.bbc.co.uk/2/hi/africa/4232107.stm

UNEP (2003), Freshwater in Europe, river Rhine (includes a Map of Europe, indicating the river basin of the Rhine)

UNEP (no date), Major river basins of Africa, retrieved on 21 March 2012 from http://maps.grida.no/go/graphic/major-river-basins-of-africa

UNESCO, 2006, Water a shared responsibility, the United Nations World Water Development Report 2

UNPD (no date), World Population Prospects: The 2008 Revision Population Database, retrieved on 29 August 2010 from http://esa.un.org/wpp/unpp/

Vaate, A. bij de, R. Breukel and G. van der Velde (2006), Long-term developments in ecological rehabilitation of the main distributaries in the Rhine delta: fish and macroinvertebrates, In: R.S.E.W. Leuven, A.M.J. Ragas, A.J.M. Smits & G. van der Velde (eds), Living Rivers: Trends and Challenges in Science and Management, Hydrobiologia 565:229–242, DOI 10.1007/s10750-005-1916-4, Springer

Vidal J., 2009, Climate change is here, it's a reality, retrieved on 21 March 2012 from http://www.guardian.co.uk/environment/2009/sep/03/climate-change-kenya-10-10

Wikipedia (no date - a), River Rhine, retrieved on 21 March 2012 from http://en.wikipedia.org/wiki/Rhine

Wikipedia (no date – b) Rhine river, retrieved on 21 March 2012 from http://en.wikipedia.org/wiki/Rhine#Upper_Rhine

Wikipedia (no date – c), Overview Rhine, Waal and Yssel rivers, including Pannerdensch Kanaal, retreieved on 21 March 2012 from http://upload.wikimedia.org/wikipedia/commons/2/2c/Afvoerverdeling_rijn.jpg

Wikipedia (no date - d), Sandoz chemical spill, retrieved on 21 March 2012 from http://en.wikipedia.org/wiki/Sandoz_chemical_spill#cite_note-0

Wikipedia (no, date), Aswan Dam, retrieved on 21 March 2012 from, http://en.wikipedia.org/wiki/Aswan_Dam

Wikipedia (no, date), Drought, retrieved on 21 March 2012 from, http://en.wikipedia.org/wiki/Drought

Wikipedia (no, date), Flood, retrieved on 21 March 2012 from, http://en.wikipedia.org/wiki/Flood

World Bank (no date), World Development Indicators (WDI), retrieved on 26 March 2012 from http://data.worldbank.org/indicator

YouTube (no date), Prime Minster Meles Zenawi Interview with Egyptian TV on Nile Sharing, retrieved on 21 March 2012 from, http://www.youtube.com/watch?v=2zzXLFKU0HM

Xu C. Y., 1999. From GCMs to river flow: a review of downscaling methods and hydrologic modelling approaches. Progress in Physical Geography 23 (2):229 - 249.