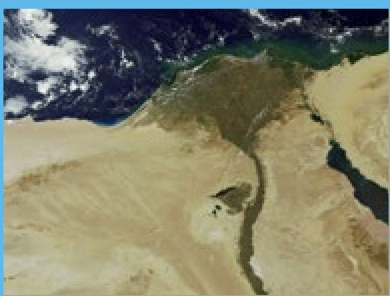
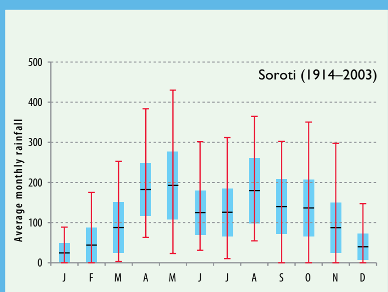
Chapter 2

# The Water Resources of the Nile Basin





# KEY MESSAGES

- The Nile Basin is characterized by high climatic diversity and variability, a low percentage of rainfall reaching the main river, and an uneven distribution of its water resources. Potential evaporation rates in the Nile region are high, making the basin particularly vulnerable to drought.
- White Nile flows only contribute up to 15 per cent of the annual Nile discharge, but are fairly stable throughout the year. The Eastern Nile region supplies up to 90 per cent of annual Nile flows, but its contribution is highly seasonal.
- Extensive regional aquifer systems holding substantial quantities of groundwater underlie the Nile region. Some of the aquifers hold fossil water, but others are recharged from precipitation over the basin, or from irrigation areas and the baseflow of the Nile. Groundwater is the dominant source of domestic water supply in rural communities across the basin.
- The quality of the Nile waters has generally deteriorated because of population growth, intensification of agriculture, and industrial development. Across the basin, environmental sanitation is poor, resulting in bacteriological contamination and nutrient enrichment of the Nile waters. While the quality of large parts of the Nile system – in particular in the sparsely populated areas – remains acceptable, localized high pollution is experienced mainly around urban centres. Groundwater in isolated locations also has naturally occurring high levels of dissolved minerals.
- The headwater regions of the Nile are subject to widespread soil erosion. Sediment yields are particularly high in the Eastern Nile sub-basin, which contributes 97 per cent of the total sediment load. Most sediment is captured in reservoirs in The Sudan and Egypt, which leads to a rapid loss of reservoir storage capacity.
- The finite Nile flows are now fully utilized for agricultural, domestic, industrial, and environmental purposes, while water demand continues to rise steadily due to population growth and economic development.
- Irrigated agriculture in Egypt and The Sudan represents the single most important consumer of the waters of the Nile, but the upper riparians are planning investments that will use the river's renewable discharge and present challenges concerning the equitable appropriation of the Nile water resources amongst the Nile riparian countries.
- Recommended regional-level actions for consideration by the Nile riparian countries include the restoration of degraded water catchments that are critical for sustaining the flow of the major Nile tributaries, restoring badly degraded lands that export large quantities of sediments and cause serious siltation in the Nile tributaries, and establishing a regional hydrometric and environmental monitoring system.

The River Nile, Egypt.

## THE NILE BASIN

The term 'basin' refers to the geographical area drained by a river or lake. The Nile Basin, in the context of this report, refers not only to the physical drainage area of the Nile with its associated biophysical and ecological elements, but also to the people living within the basin and features of their social, cultural, and economic development.

This chapter focuses on the hydrological characteristics of the Nile river system, while the other chapters of the report address the environmental, social, and economic aspects of the basin. The present chapter describes qualitatively and quantitatively the basin's water resources – which comprise rivers, lakes, wetlands, groundwater, and rainfall. It assesses the availability of the water resources in space and time, and their ability, in terms of water quantity and quality, to sustainably support the consumptive and non-consumptive demands for water across the basin. It ends with a discussion on how benefits to the Nile riparians could be optimized through cooperative management and development of the common Nile water resources on a win–win basis.


The Nile, 6,695 kilometres in total length, is, by most accounts, the longest river in the world. Its basin covers an area of 3.18 million square kilometres – some 10 per cent of the African continent – and is shared by 11 countries.

**Below:** The Victoria (White) Nile as it leaves Lake Victoria at Jinja.

## The course of the Nile

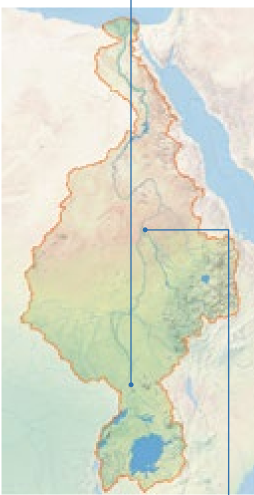
The most distant source of the Nile is the Ruvyironza River, which flows into Lake Victoria through the Ruvubu and Kagera rivers. Other rivers converging into Lake Victoria – the largest of the Nile Equatorial Lakes – include the Simiyu-Duma, Grumati-Rwana, Mara, Gucha-Migori, Sondu, Yala, Nzoia, Sio, Katonga and Ruizi.

From Jinja in Uganda, the White Nile emerges from Lake Victoria as the Victoria Nile, and travels northwards, passing through two other Equatorial Lakes – Kyoga and Albert. Through these two lakes the Nile captures runoff from two mountainous and high-rainfall areas (Mts Rwenzori and Elgon) on the southwestern and southeastern peripheries of the basin.

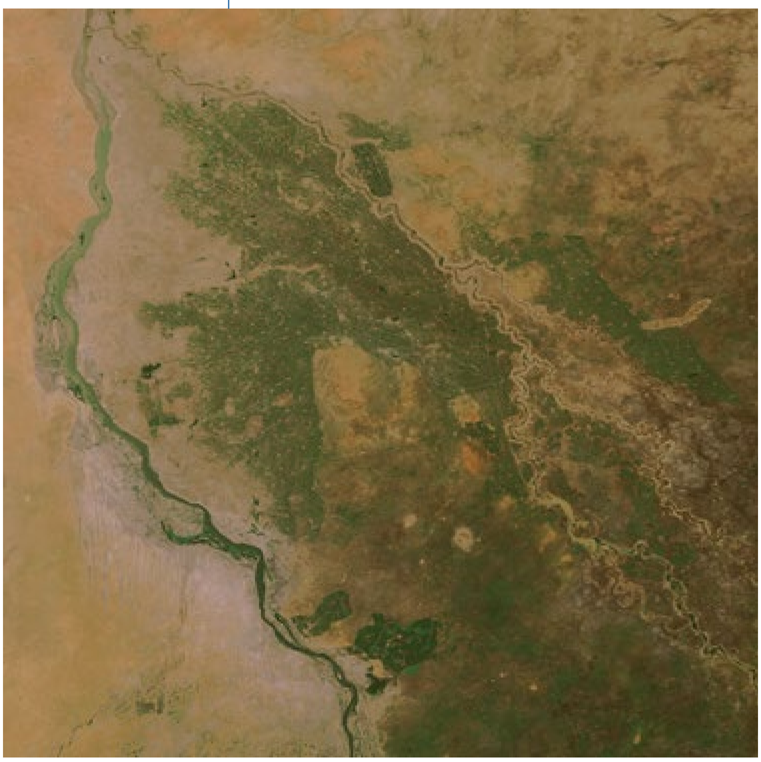
The river re-emerges from Lake Albert as the Albert Nile and journeys northwards to Nimule near the South Sudan–Uganda border. From this point, the river, now known as the Bahr el Jebel (meaning river of the mountains), flows over the Fula rapids and through the Sudd before meeting the Bahr el Ghazal (meaning river of the gazelles) at Lake No. The Bahr el Ghazal drains high rainfall areas of western South Sudan. From Lake No, the river turns eastwards to join with the Sobat River, which carries high, seasonally variable, flows originating in the Ethiopian Highlands. The combined Bahr el Jebel and Sobat rivers form the White Nile, which continues its northward descent and meets with the Blue Nile at Khartoum, The Sudan.

The Blue Nile (also known as the Abbai or Abay) originates in Lake Tana in Ethiopia, and is the second principal stream of the Nile. Before meeting the White Nile, the Blue Nile is joined by a number of rivers, the main ones being the Rahad and Dinder, both originating in the Ethiopian Highlands.

A section of the White Nile, north of Lake Albert. Nimule is at the point where the river narrows considerably and turns northwest, after which it is known as the Bahr el Jebel.



The Blue Nile (Abay), flowing in from the bottom right of the photograph, and being joined by the rivers Dinder and Rahad before meeting the White Nile at the top left of the photograph.



The Nile as it flows through Egypt, providing valuable irrigation water to the agricultural land along its banks and in its delta.

The confluence of the White Nile and Blue Nile (Abay) bottom right, and the stretch of the river up to Lake Nasser/ Nubia and the Aswan Dam.

From Khartoum, the combined rivers of the Nile flow northwards, and are joined by the Atbara (Tekezze), also originating in the Ethiopian Highlands. The Main Nile continues travelling northwards and flows into Lake Nasser/Nubia, a major man-made reservoir on the border between The Sudan and Egypt that provides inter-annual regulation for Egypt. The Nile eventually discharges into the Mediterranean Sea via its delta.

# RAINFALL

## Annual rainfall distribution

Rainfall over the basin is characterized by highly uneven seasonal and spatial distribution. Most of the basin experiences only one rainy season – typically in the summer months. Only the equatorial zone has two distinct rainy periods. The reliability and volume of precipitation generally declines moving northwards, with the arid regions in Egypt and the northern region of The Sudan receiving insignificant annual rainfall. The spatial variability of rainfall is clearly illustrated by the pattern of vegetation and distribution of surface water bodies in the basin.

Large parts of the Nile watershed do not generate runoff. In fact, the main runoff-producing areas are limited to the Ethiopian Highlands and the Equatorial Lakes Plateau, with some contribution from western South Sudan. The relatively small size of the runoff-producing area is central to explaining the very low runoff coefficient of the Nile (3.9%). Total Nile discharge represents a depth of less than 30 mm if spread over the entire watershed.


**TOTAL RAINFALL**
Average annual millimetres
*1960–90*

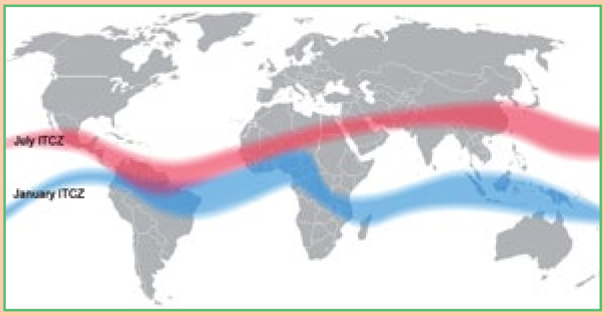
- under 300
- 300 – 600
- 600 – 900
- 900 – 1,200
- 1,200 – 1,500
- 1,500 – 1,800
- 1,800 – 2,100
- over 2,100

(Map prepared by the NBI; source of data: Climatic Research Unit)

## WEATHER PATTERNS IN THE NILE BASIN

The weather patterns over the Nile Basin are influenced by many factors, key among which are the movement of the Intertropical Convergence Zone (ITCZ) and the physiographic features of the basin.

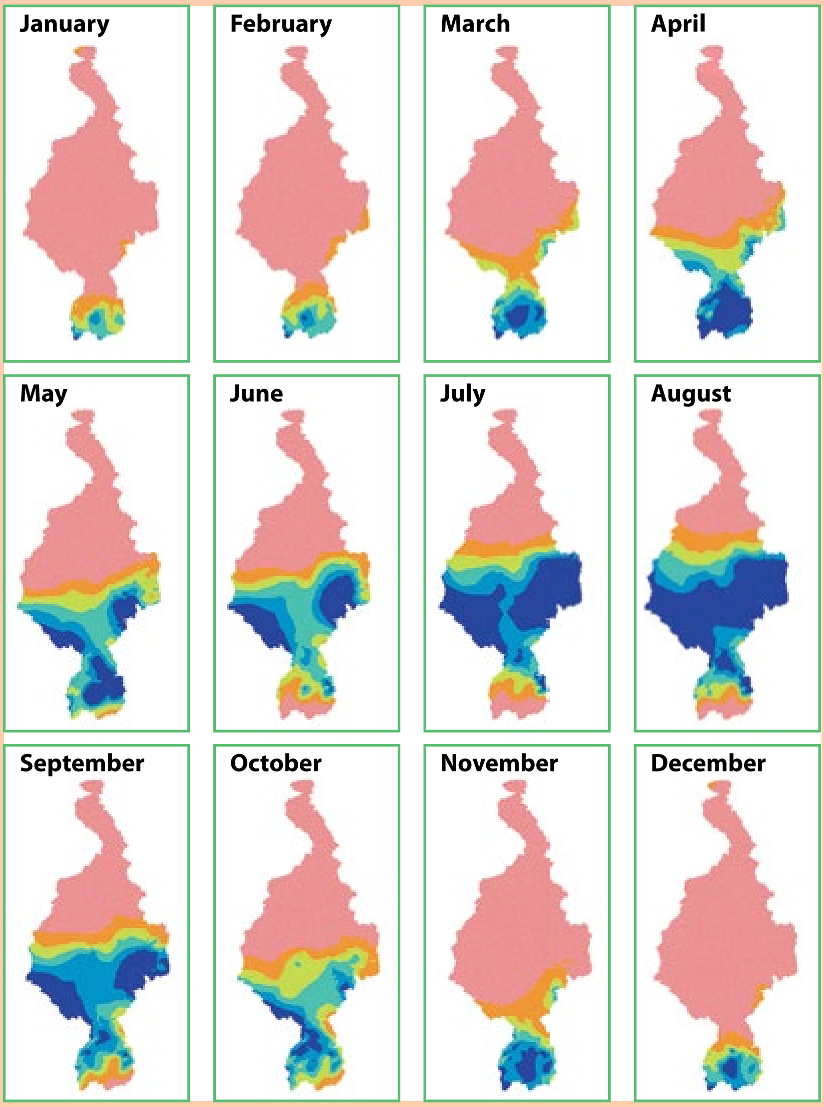
The ITCZ is a belt of low pressure caused by solar heating forcing air to rise through convection, which draws in air from the polar regions. The rising mass of converging air leads to cloud formation and heavy precipitation in the region of the ITCZ. Its location varies throughout the year as it follows the sun's zenith point, producing wet and dry seasons in the tropics. Areas in the Nile Basin located on or near the equator experience two passages of the ITCZ in a year, and have a twin-peaked rainfall distribution pattern, while areas to the north and south, have a single-peaked pattern.




A large part of the Nile Basin is traversed by northeasterly trade winds from the Eurasia landmass. These carry little moisture and generate little rainfall, explaining the low precipitation over much of the basin, and the Nile's very low specific runoff.

The physiographic features of the basin – in particular the mountain chain along the margins of the western arm of the Rift Valley, the broad Equatorial Plateau, the Mt Elgon area, and Ethiopian Highlands – have a marked effect on rainfall distribution. The windward side of the raised land masses receives high rainfall, while the leeward side is typically drier.

Rainfall in Ethiopia, South Sudan, and The Sudan is concentrated in the summer months.




**MONTHLY RAINFALL**
Average millimetres per month
*1960–90*

- 0 – 30
- 30 – 60
- 60 – 90
- 90 – 120
- 120 – 150
- 150 – 180

(Map prepared by the NBI; source of data: Climatic Research Unit)

## Seasonal rainfall distribution

The high temporal variability of rainfall in the basin is demonstrated by the monthly rain records. Broadly speaking, there are three patterns of seasonal rainfall variation:

*A single rain peak June–October,* with little or no rainfall in other months. Found in sub-basins of Eastern Nile and Main Nile. See histograms from Atbara to Wau.

*A fairly evenly distributed rainfall,* with a single peak from April–October. Found in northern Uganda and South Sudan. See histograms for Juba to Eldoret.

*A twin-peaked distribution,* peaking in March–May and September–November, with considerable but lower rain in other months. Found in Nile Equatorial Lakes Plateau. See histograms from Kijura to Mwanza.

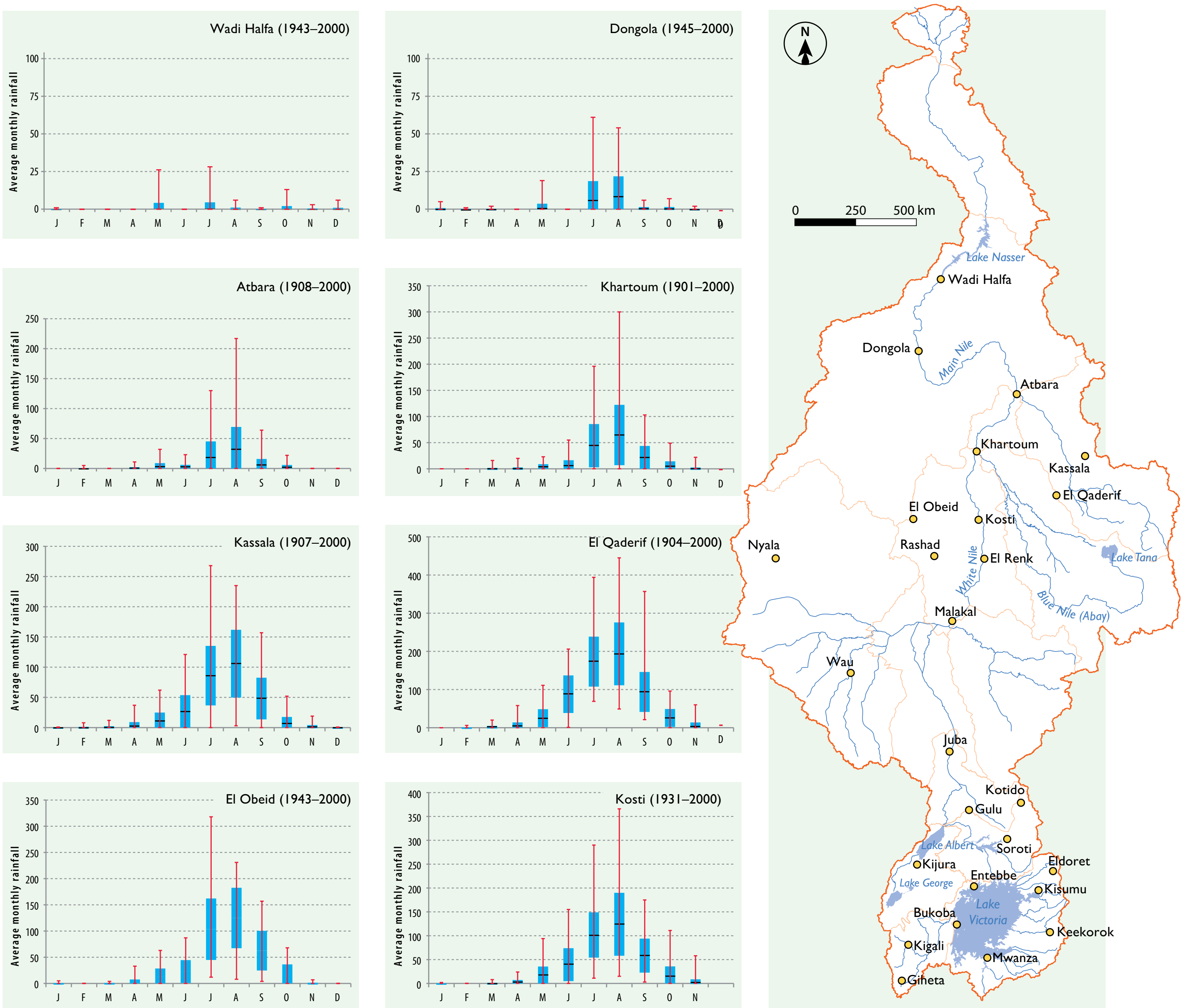
**MONITORING RAINFALL**

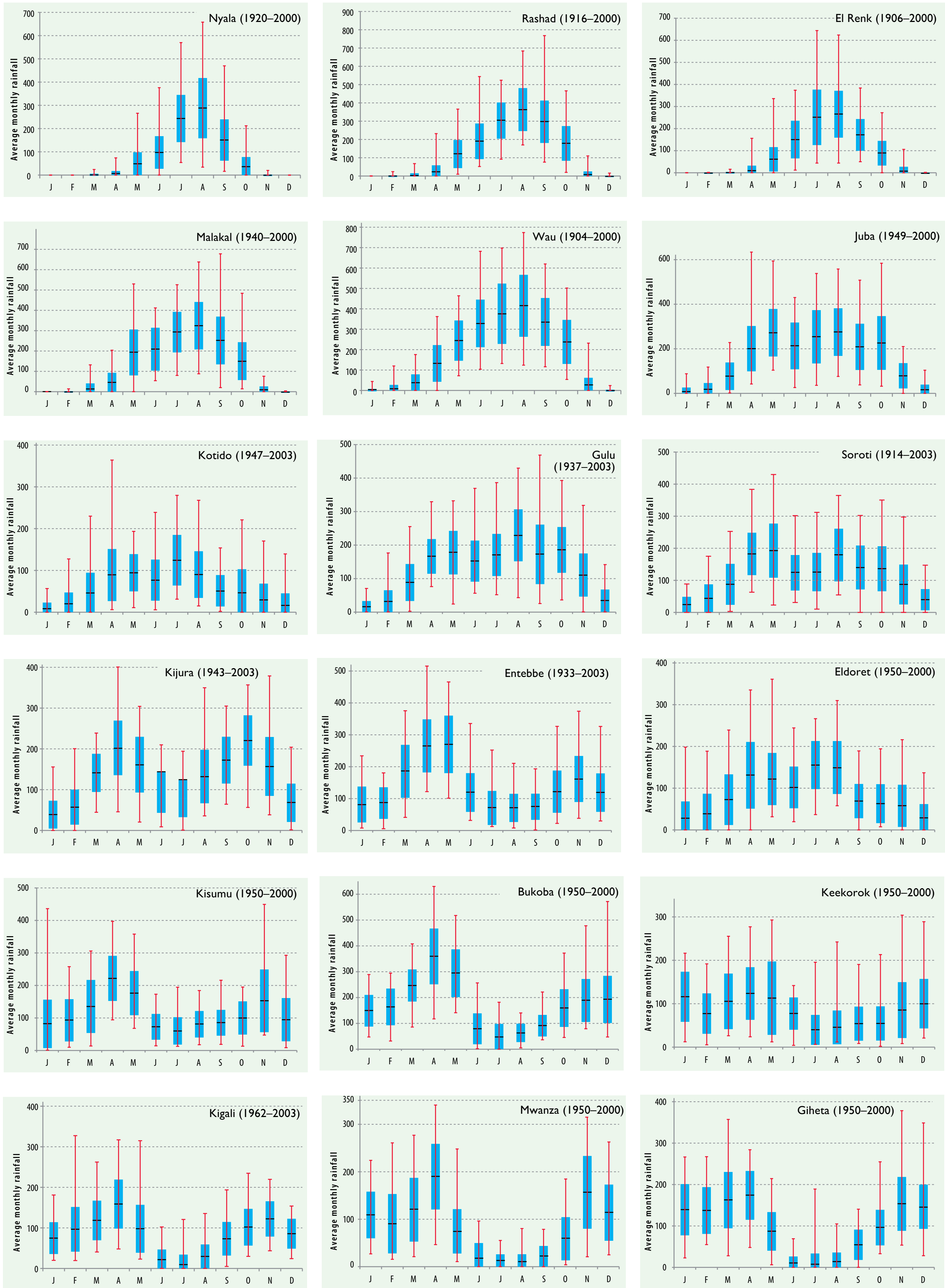
Average monthly rainfall in millimetres

*Varying periods 1914–2003*

- range to one standard deviation
- average monthly rainfall
- highest observation recorded
- lowest observation recorded
- monitoring stations

(Source data: FAO 2009; WRPM 2011)




Nyala (1920–2000)
Rashad (1916–2000)
El Renk (1906–2000)
Malakal (1940–2000)
Wau (1904–2000)
Juba (1949–2000)
Kotido (1947–2003)
Gulu (1937–2003)
Soroti (1914–2003)
Kijura (1943–2003)
Entebbe (1933–2003)
Eldoret (1950–2000)
Kisumu (1950–2000)
Bukoba (1950–2000)
Keekorok (1950–2000)
Kigali (1962–2003)
Mwanza (1950–2000)
Giheta (1950–2000)
Average monthly rainfall
J F M A M J J A S O N D

# EVAPOTRANSPIRATION

## Water loss from the Earth's surface

Evapotranspiration (ET), which is the sum of evaporation and plant transpiration, is an important element of the water cycle. Evaporation accounts for the movement of water from sources such as soil, canopy interception, and open water bodies, to the air, while transpiration accounts for the movement of water within a plant, and its subsequent loss to the atmosphere through plant stomata. Evapotranspiration represents a significant loss of water from drainage basins.

Another important term with regard to water loss from the earth's surface is Potential Evapotranspiration (PET). This is a measure of the amount of water that would be evaporated and transpired if there were sufficient water available. PET is calculated indirectly from other climatic parameters and incorporates the energy available for evaporation as well as the ability of the lower atmosphere to transport evaporated moisture away from the land surface. Actual evapotranspiration (ET) is said to equal potential evapotranspiration (PET) when there is ample water. Actual evapotranspiration in the Nile Basin is generally high compared to other river/lake basins of the world.

The lush vegetation of the upper Blue Nile basin leads to high evapotranspiration, although the region's potential evapotranspiration rate is lower than that of Egypt and The Sudan, where temperatures are much higher.

## Spatial and temporal evapotranspiration trends

Potential evapotranspiration varies considerably across geographical regions and over time. PET is higher in locations and during periods when there are higher levels of solar radiation and higher temperatures (and hence where there is greater energy for evaporation). Accordingly, PET is higher in hot deserts, low-lying lands, and areas near the equator. PET is also higher on less cloudy days and during the dry season (or summer). PET is higher on windy days because evaporated moisture can be quickly transported away from the ground or plant surface, allowing more evaporation to fill its place. Potential evapotranspiration further depends on relative humidity, the surface type (such as open water), percentage soil cover, the soil type (for bare land), and the vegetation type.

Across the Nile region, actual and potential evapotranspiration vary markedly. The arid lands in The Sudan and Egypt have higher potential evapotranspiration rates than the humid headwater regions of the Nile. However, they have much lower actual evapotranspiration rates because there is little available water and vegetation to cause evapotranspiration. Total annual evapotranspiration is highest in the Lake Victoria sub-basin, estimated at about 307 BCM, followed by the Blue Nile sub-basin, estimated at 264 BCM, then by the Sudd sub-basin estimated at 260 BCM. The Main Nile sub-basin downstream of Khartoum has the lowest evapotranspiration rates, estimated at 7 BCM per year. (See page 35 for sub-basin map.)

In terms of components of evapotranspiration, the Blue Nile (Abay) sub-basin has the highest ET losses over land; Lake Victoria sub-basin has the highest evaporation losses over open water; and the Sudd sub-basin has the highest ET losses over wetlands.

Seasonal/monthly variability of evapotranspiration is a function of temperature, wind speed, relative humidity, solar radiation, and biomass production. No significant month-to-month or year-to-year variation is noted in the upper reaches of the Nile as the areas lie in the tropics that are characterized by all-year sunshine and humid conditions.

## A diverse and highly variable climate

The within-year and between-years variability in rainfall over the Nile Basin is high, making over-reliance on rainfed supply or production systems risky. The high potential evaporation values in the Nile region – ranging from some 3,000 mm/year in northern Sudan to 1,400 mm/year in the Ethiopian Highlands, and around 1,100 mm/year in the hills in Rwanda and Burundi – make the basin particularly vulnerable to drought events.

Drought risks are further amplified by the high variability of the rainfall between seasons and years. This is manifested by uncertainty in the onset of rains, occasional cessation of rainfall during the growing season, and consecutive years of below-average rainfall. It has a marked adverse impact on the productivity of rainfed agriculture, and represents a serious constraint to rural development.

The impact of the climatic variability on agricultural production is further aggravated by widespread soil degradation that has led to a reduction in the capacity of soils to hold moisture. Rain deficits, therefore, quickly translate into crop failure.


**POTENTIAL EVAPOTRANSPIRATION**
Average annual millimetres per year
*Average values for 1960–90*

| | | |
|---|---|---|
| under 800 | 1,600 –1,800 | 2,600 –2,800 |
| 800 –1,000 | 1,800 –2,000 | 2,800 –3,000 |
| 1,000 –1,200 | 2,000 –2,200 | over 3,000 |
| 1,200 –1,400 | 2,200 –2,400 | |
| 1,400 –1,600 | 2,400 –2,600 | |

(Map prepared by the NBI; source of data: FAO)

## SUB-SYSTEMS AND SUB-BASINS

### The Nile sub-systems

The Nile Basin comprises three broad sub-systems.

**The Eastern Nile sub-system:** This covers the catchments of the Blue Nile (Abay), Atbara (Tekezze), and Baro, which encompass large parts of the Ethiopian Highlands and the plains of the eastern region of The Sudan. The runoff from this region contributes between 85 and 90 per cent of the annual Nile flows, but the Blue Nile (Abay) can be seen to respond directly to the seasonal rain patterns, exhibiting clear dry and wet spells.

**The Equatorial Nile sub-system:** This covers the entire watershed upstream of the Sobat–White Nile confluence. It includes the Equatorial Lakes region as well as most of South Sudan. The regulating effect of the lakes, combined with extensive wetlands in the White Nile Basin, attenuate river flow. The large swamps are also responsible for high evapotranspiration losses. White Nile flows, therefore, only contribute between 10 and 15 per cent to the annual Nile discharge, but are fairly stable throughout the year.

Cattle grazing on flooded grasslands.

### THE SUDD AND ITS INFLUENCE ON THE NILE HYDROLOGY

The confluence of the main tributaries of the White Nile in South Sudan has vast expanses of tropical freshwater wetlands that exert a considerable influence on the hydrologic regime of the Nile. The wetlands, now known collectively as the Sudd, include the Bahr el Jebel swamps, the Bahr el Ghazal swamps, the wetlands at the Baro–Pibor–Akobo confluence, and the Machar marshes.

Sudd is an Arabic word for 'barrier' or 'blockage'. In its original usage, the Sudd referred to the islands and massive floating mats of vegetation found on the Bahr el Jebel between Malakal and Bor, which occasionally completely sealed off the Nile to navigation.

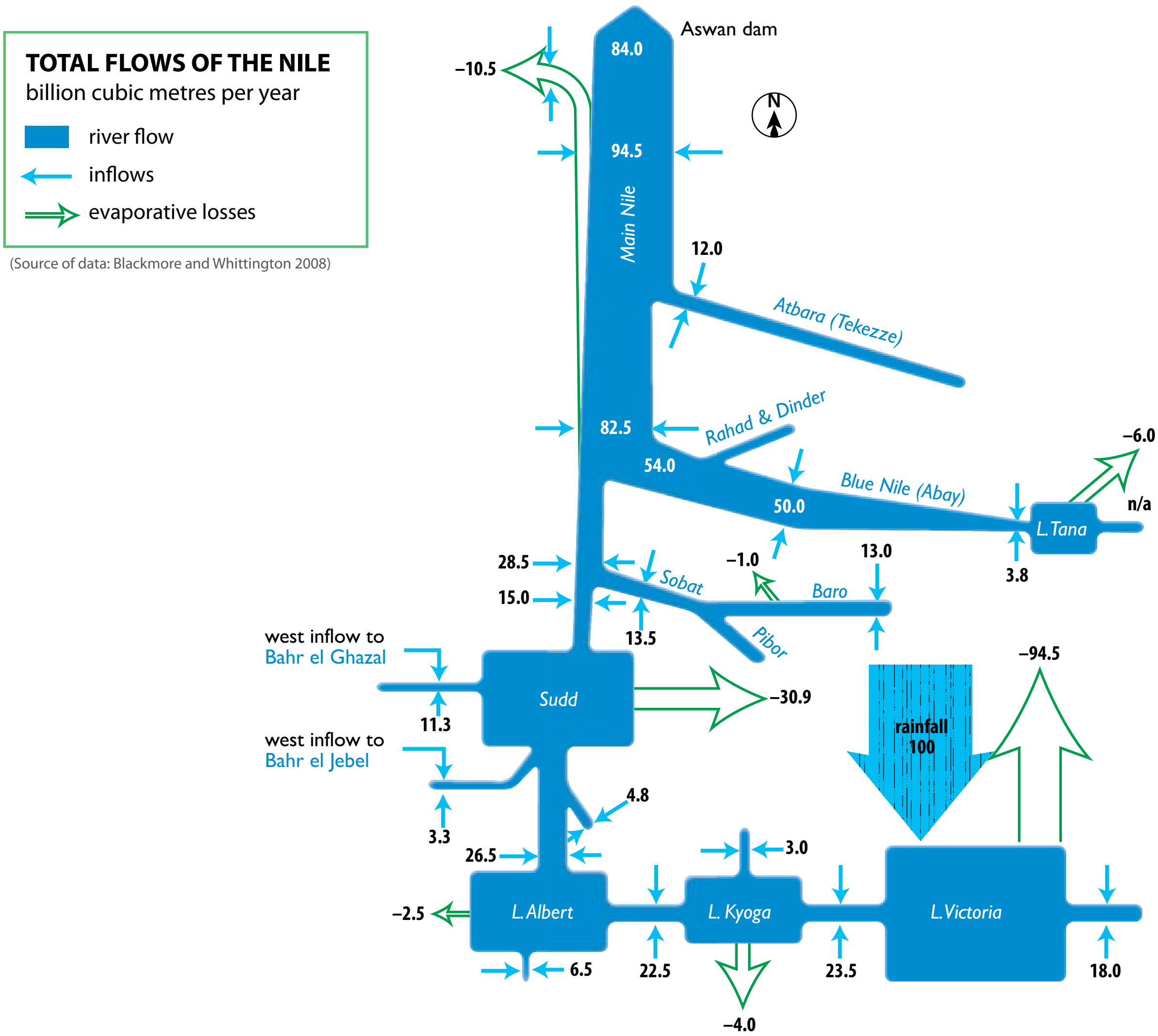
The area at the confluence of the White Nile tributaries is extremely flat, with an average slope of 10 cm per km. Furthermore, river channels at the confluence are very shallow and annually spill large volumes of water into surrounding lands, leading to extensive flooding and wetland formation. The Sudd wetlands have a permanent and seasonal component, the extent of which varies from year to year following local and regional climatic variation, and the flow regime of the Bahr el Jebel and Sobat Rivers.

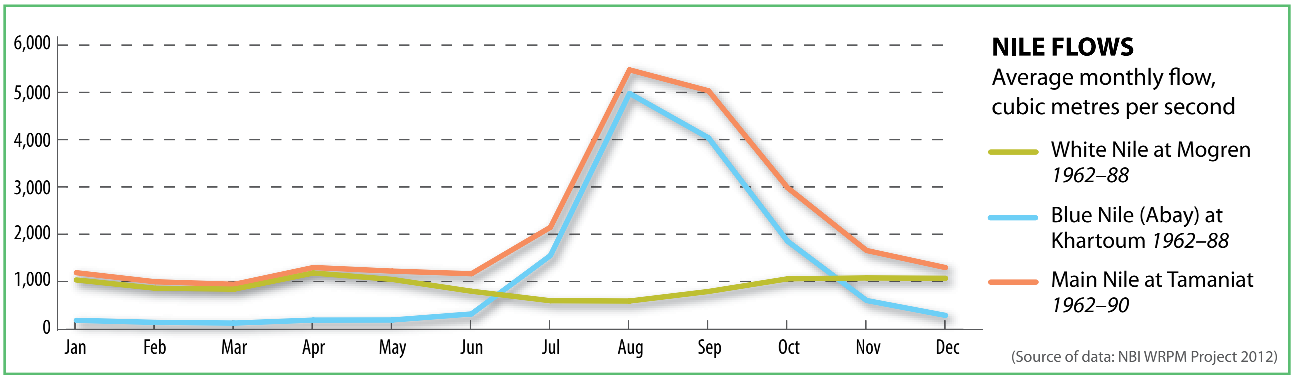
Evaporation from the flooded lands greatly exceeds rainfall, and the wetlands therefore result in a net water loss to the Nile system. While the complexity of the channels and the problems of measuring evaporation from swamp vegetation have meant that the flows in the wetland areas are not well understood, it is estimated that only about half of the inflow to the Sudd emerges as outflow.

Sudd outflows show little seasonal variation, providing a fairly constant contribution to the White Nile throughout the year. By buffering peak flows, the swamps have a regulating effect on the downstream river regime.

The Sudd in flood.

**The Main Nile Zone:** This encompasses the downstream river reach, starting at the Blue–White Nile confluence at Khartoum. This large area generates virtually no runoff, and in-stream evaporation results in a net loss. River flow in the lower reaches is controlled by Lake Nasser, which is subject to significant evaporation losses. Most river flow is diverted to the irrigation schemes in the north of The Sudan and in Egypt, and only drainage and re-used water is discharged into the Mediterranean Sea.



## The Nile sub-basins

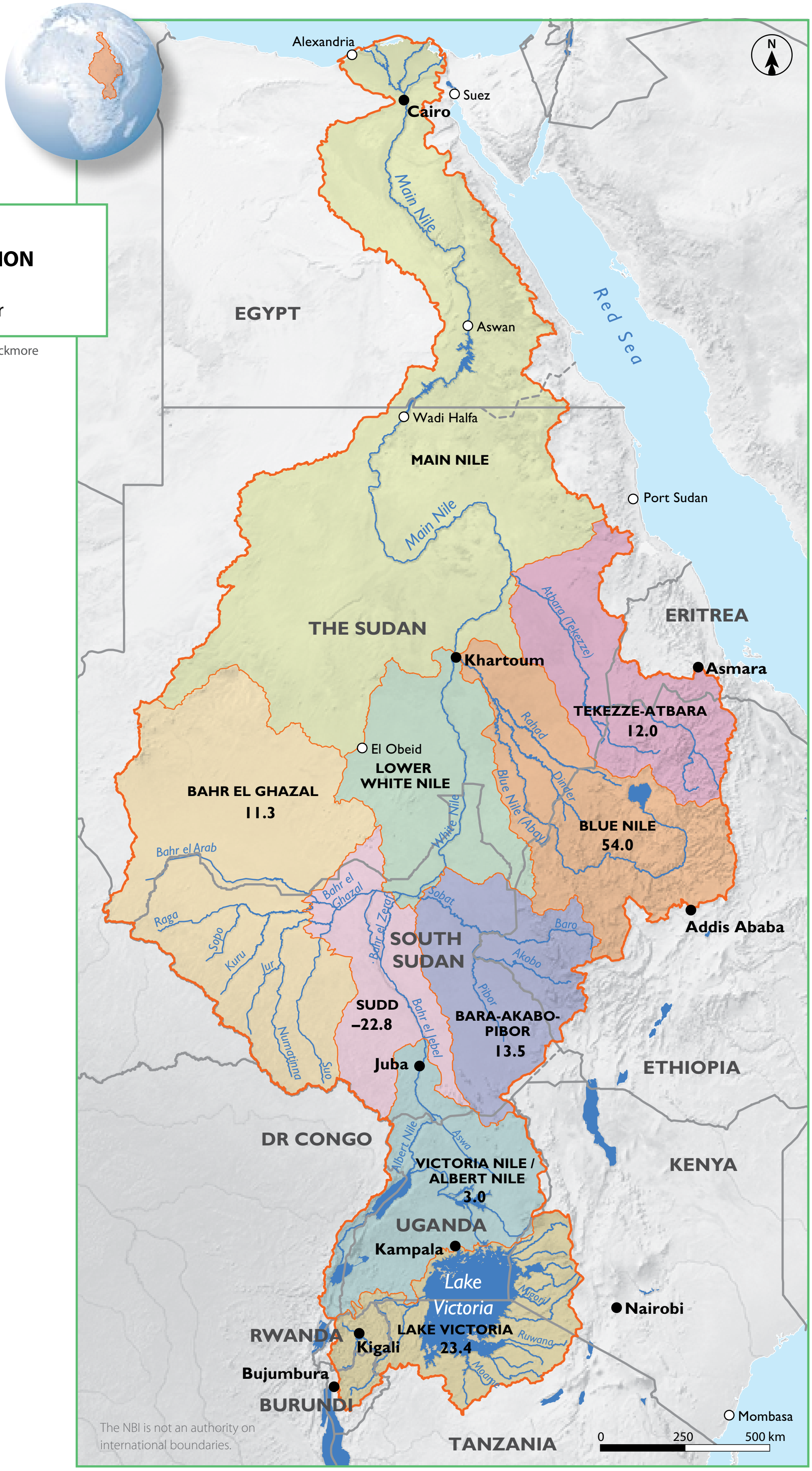
Within the three broad sub-systems, nine distinct catchment areas or sub-basins can be found, namely Lake Victoria, Victoria–Albert Nile, Sudd, Bahr el Ghazal, Baro–Pibor–Sobat, Blue Nile (Abay), Atbara (Tekezze), White Nile, and Main Nile sub-basins. Each one of these has unique hydrological characteristics as summarized below.

## CHARACTERISTICS OF THE NILE SUB-BASINS

| Sub-basin | Area (km²) | Average annual precipitation (mm/yr) | Average annual reference evapo-transpiration (mm/yr) | Specific runoff (mm/ km²/yr) | Runoff coefficient (%) | Specific yield (MCM/ km²/yr) | Comments |
|---|---|---|---|---|---|---|---|
| **Main Nile** | 958,639 | 198 | 2,206 | 0.0 | 0.0% | – | With no surface runoff contribution, in-stream flow losses result in a net loss to the Nile System. |
| **Atbara (Tekezze)** | 232,370 | 733 | 1,778 | 50.4 | 7.3% | 0.054 | All runoff is concentrated in the July to September period. |
| **Blue Nile (Abay)** | 308,157 | 1,099 | 1,765 | 148.9 | 15.9% | 0.175 | Seasonal runoff in July to November, with only base flow in the rest of the year. |
| **White Nile** | 237,391 | 754 | 1,983 | 0.0 | 0.0% | – | |
| **Baro-Pibor-Sobat** | 230,293 | 1,338 | 1,592 | 45.3 | 4.4% | 0.059 | Runoff is attenuated by the large wetland areas in the basin. |
| **Bahr el Ghazal** | 555,428 | 826 | 1,807 | 0.1 | 2.5% | 0.020 | Sub-basin has a low runoff due to high evapotranspiration in the Bahr el Ghazal wetlands. |
| **Sudd (Bahr el Jebel)** | 169,665 | 1,067 | 1,694 | | -12.6% | -0.134 | Because of evaporation in the large wetland areas, there is a net loss of water in the Sudd sub-basin. |
| **Victoria – Albert-Nile** | 243,080 | 1,179 | 1,544 | 37.7 | 1.0% | 0.012 | The low runoff coefficient is caused by net losses due to high evapotranspiration rates in the large lakes and wetland systems. |
| **Lake Victoria** | 241,520 | 1,368 | 1,486 | 107.5 | 7.1% | 0.097 | Over the lake, rainfall and the lake evaporation are the largest components of the water balance of Lake Victoria. The large storage capacity of the lake attenuates seasonal flow variations and leads to relatively stable Victoria Nile flows. |
| **Combined Nile System** | 3,176,543 | 1,046 | 1,972 | 26.4 | 3.9% | 0.030 | |
| Sources: | NBI-GIS Unit | GIS/CRU dataset 1960–90 | GIS/CRU dataset 1960–90 | Sutcliffe & Parks | Computed from JMP Scoping Study figures | Computed from JMP Scoping Study figures | |

## THE MAIN SUB-BASINS AND THEIR CONTRIBUTION TO THE NILE
billion cubic metres per year

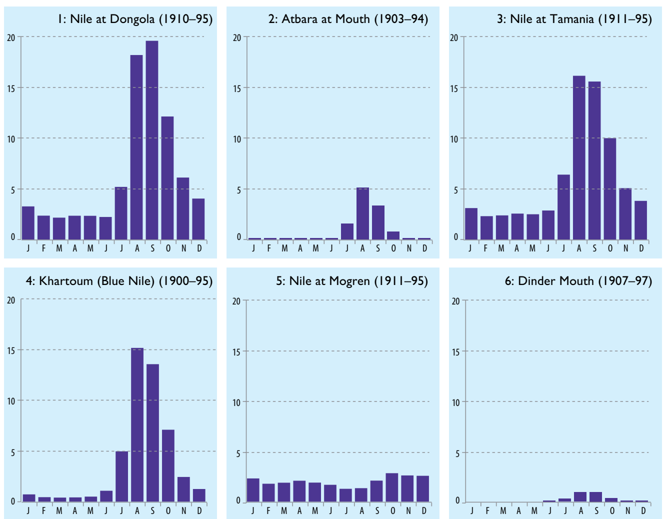
(Map prepared by the NBI; source of data: Blackmore and Whittington 2008)



## RECORDING RIVER FLOW

Since the early years of the last century, records have been kept of the monthly discharge at key sections of the Nile and its main tributaries. Because these were calculated from flow data with different periods they cannot be compared directly, but they do provide a good picture of the seasonal variation, and of the relative contribution of the respective tributaries to the total Nile flow.

Hydrometric activities have declined in recent years, and data gaps now exist for important sections of the Nile system (see Chapter 8). This prevents proper water resources planning and management, and makes it difficult to validate climate models.

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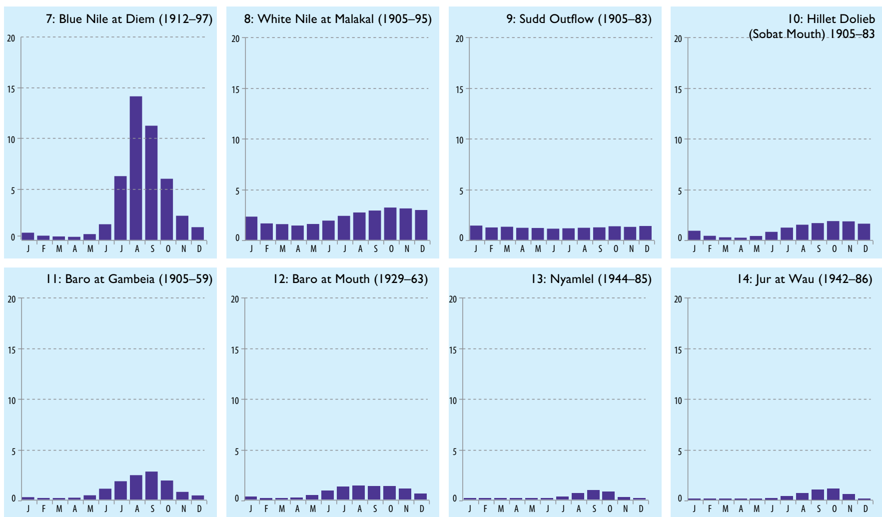
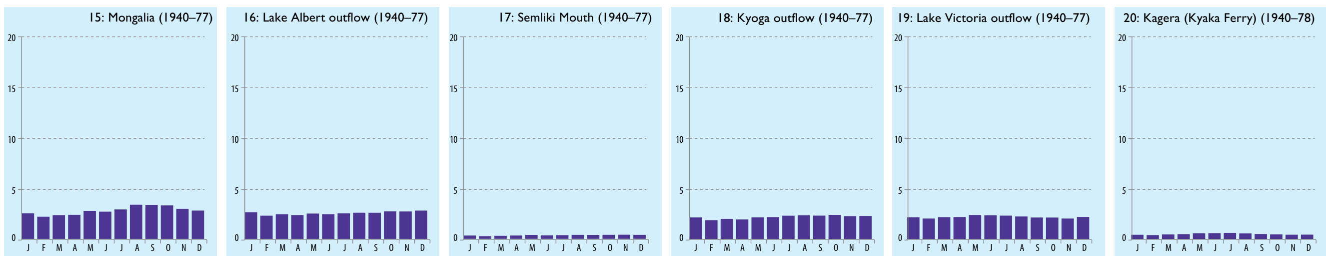
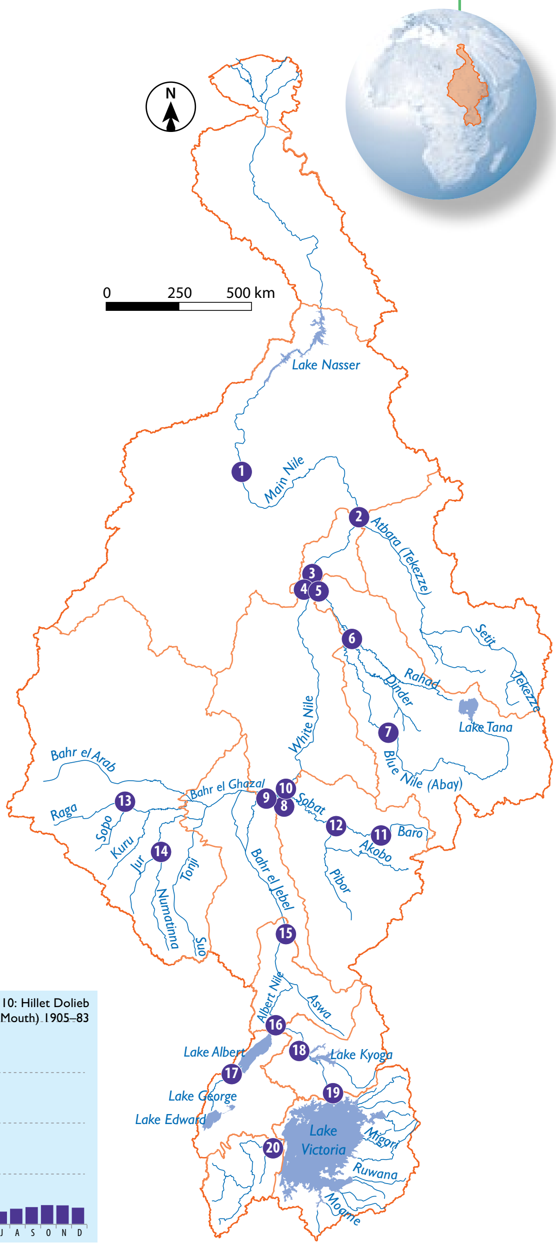



**MEASURING RIVER FLOW**
Average monthly runoff in billion cubic metres
*Varying periods 1900–95*

(Map prepared by the NBI; source of data: Sutcliffe & Parks)

## GROUNDWATER

### Where groundwater occurs

As well as surface waters, the Nile Basin countries have considerable groundwater resources occurring in localized and regional basins. Groundwater is an important resource, supporting the social and economic development of the Nile riparian countries and making an important contribution to water and food security in the region. The degree to which it is relied upon varies from country to country, but commonly it is the most important source of drinking water for rural communities in the basin.

Groundwater in the Nile Basin mainly occurs in four rock systems or hydrogeological environments: Precambrian crystalline/ metamorphic basement rocks, volcanic rocks, unconsolidated sediments, and consolidated sedimentary rocks. Water in these four rock types occurs in confined and unconfined conditions.

### Main aquifers

**Victoria artesian aquifer:** This occupies an area underlain by Precambrian basement rocks and is distinguished by abundant precipitation, a well-developed surface drainage system, and complex geomorphology and structure produced by neotectonic movements. The aquifer is extremely abundant in surface water, which is present in numerous swamps, rivers, and lakes. It also has many mineral springs, some of which issue warm water.

**Congo hydrogeological artesian aquifer:** This occupies an area of more than 3.2 million square kilometres of Equatorial Africa. The geologic section of the basin consists of Archean, Proterozoic, Paleozoic, Mesozoic, and Cenozoic deposits. The characteristics of the aquifer have not been adequately studied due to the abundance of surface water.

### MAIN HYDROGEOLOGICAL ENVIRONMENTS IN THE NILE REGION

**Crystalline igneous and metamorphic rocks:** These rocks, dating from the Precambrian period, underlie large parts of the basin but are most extensive in the Nile Equatorial Lakes Plateau, the southern and southwestern parts of South Sudan, southern parts of The Sudan, and parts of the Ethiopian Highlands. The parent rock is essentially impermeable, and productive aquifers occur in the weathered overburden (regolith) or where there is extensive fracturing of the parent rock. Generally, the latter are the more productive crystalline basement aquifers.

**Volcanic rocks:** Volcanic rocks are mainly found in the highlands of Ethiopia, where they form variable but highly productive aquifers. Volcanic rock aquifers occur at deeper depth and typically have higher yields than the crystalline basement aquifers. They are widely used for urban and rural water supply in the Ethiopian Highlands.

**Consolidated sedimentary rocks:** This group has highly variable rock types that vary from low-permeability mudstones and shale to more permeable sandstones and limestones. They occur mostly in The Sudan and Egypt, and form vast, regionally extensive, productive aquifers. The Nubian sandstone aquifer system is the largest of the consolidated sedimentary rock aquifers, and one of the largest and most productive aquifers in the world.

**Unconsolidated sedimentary rocks:** These are distributed throughout the basin, occurring mainly along the courses of the main rivers. In Ethiopia they occur in the Blue Nile (Abay), Atbara (Tekezze), and Baro sub-basins. In The Sudan, there are several unconsolidated alluvium khors and wadis, the most notable being the El Gash basin. In Egypt there are two main unconsolidated aquifers, namely the Nile Valley and Nile Delta aquifers.

**Upper Nile artesian aquifer:** This lies in the extreme southern part of Bahr el Ghazal, White Nile, and Sobat plains. These plains constitute an internal recharge and accumulation area for the aquifer, while surrounding mountains (which are composed of metamorphic rocks, Precambrian granites, and Quaternary sediments), serve as an external recharge area. The northern parts of the basin are underlain by rocks of the Nubian series and have water occurring at depths of 25 to 100 metres, with sufficiently high artesian yields. In the Precambrian varieties, groundwater is encountered at depths varying from 3 to 60 metres. In spite of the limited reserves of water accumulating in the weathering crust; they are widely used for water supply. The alluvial deposits of the external recharge area of the basin contain fresh and brackish pheriatic waters occurring at depths of 6 to 10 metres.

Water is the most precious resource in the drier regions. Goats, camels, and cattle all use this crowded water point in Southern Kordofan.

**Volcanic rock aquifers:** These occur mainly in the Ethiopian Highlands and cover large parts of the Gambela plains, the Lake Tana area, the Shinile plain, the Rift Valley areas, and grabens filled with alluvial sediments at the foothill of the rift-bounding escarpments. The aquifer comprises of shallow to very shallow and loose sediments. Yields of the metamorphic rocks are variable, depending mainly on the degree of weathering.

**Nubian sandstone aquifer system:** This covers an area of approximately 2 million square kilometres spanning parts of The Sudan, Egypt, Libya, and Chad. The aquifer holds fossil (non-renewable) water originating from the Pleistocene period when more humid conditions prevailed in the region. It varies in thickness from 200 to 600 metres, is highly porous and has high transmissivity (up to 4,000 $m^3$/day). Other notable consolidated sedimentary aquifers in the region include the Umm Ruwaba, Gezira, and Al Atshan aquifers in The Sudan; the Moghra Aquifer found between the Nile Delta and the Qattara Depression in the Western Desert in Egypt; and fissured and karsified carbonate aquifers in the Wadi Araba areas in the Eastern Desert in Egypt.

**Nile Valley aquifer:** This consists of fluvial and reworked sands, silts, and clays ranging in thickness from a few metres to over 300 metres. This high storage capacity combined with high transmissivity and active replenishment from the Nile River and irrigation canals makes the aquifer a highly valued resource.

**Nile Delta aquifer:** Like the Nile Valley aquifer, this consists of sand and gravel with intercalated clay lenses. The aquifer, which is up to 1,000 metres thick in some areas and has high transmissivity (up to 25,000 $m^3$/day) is an equally valuable resource.

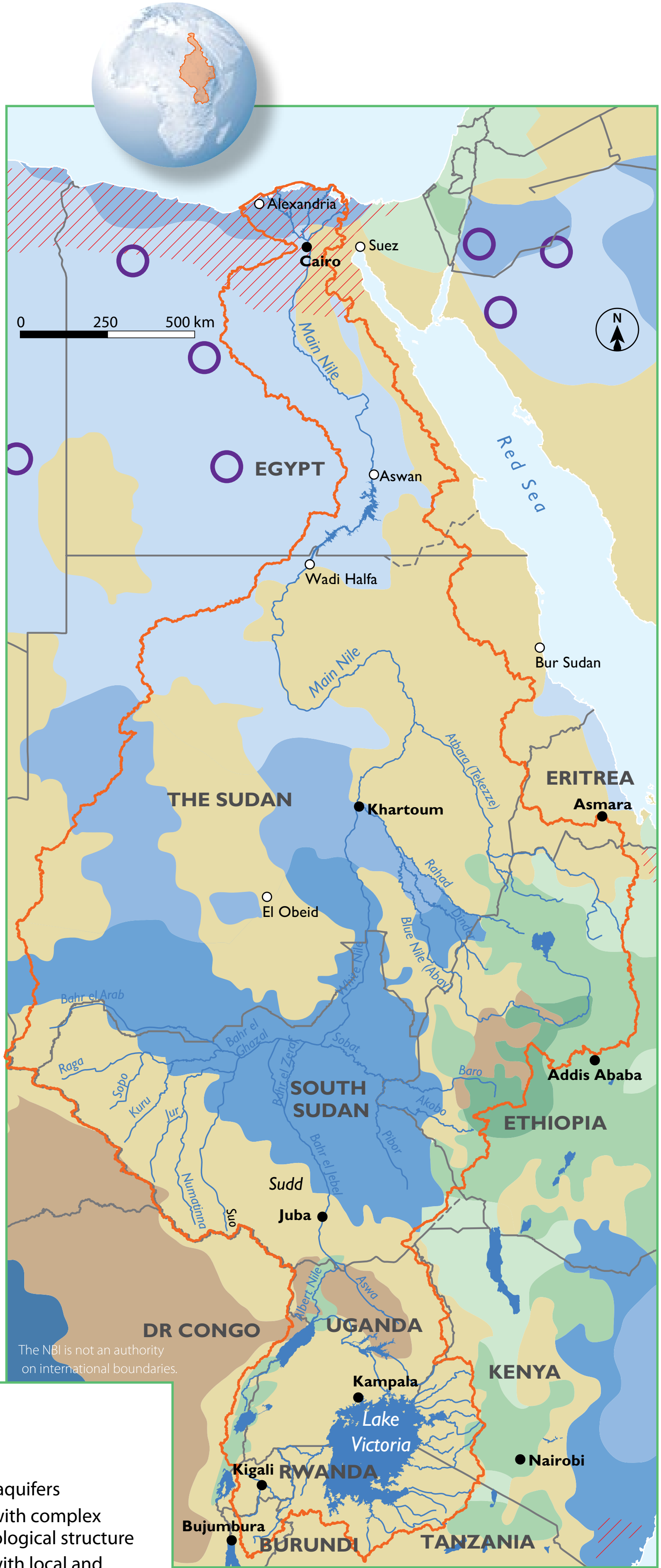
### Groundwater recharge

There is high variability in recharge in the groundwater systems in the Nile region, with rates ranging from a few millimetres to over 400 millimetres per year. This high variability is due to differences in the distribution and amount of rainfall across the basin, contrasting geomorphology, varying rock permeability, and uneven distribution of large surface water bodies that recharge groundwater.

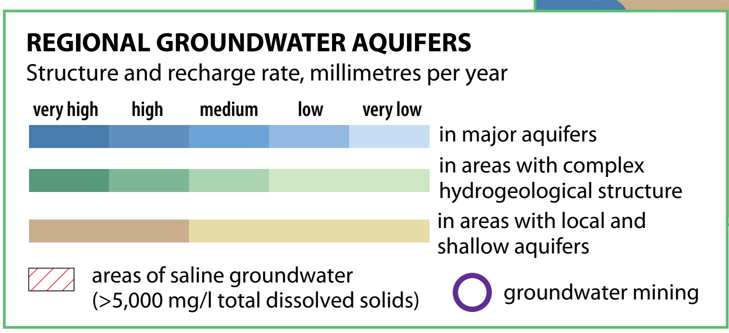
Recharge in the crystalline basement rock aquifers ranges from 6 mm/yr close to the shores of Lake Victoria to 200 mm/yr in the Kyoga sub-basin in central Uganda. In the Ethiopian Highlands, where there is an extremely complex hydrogeological setting, and intricate interaction between recharge and discharge occurring at local, sub-regional, and regional scales, recharge ranges from below 50 mm/yr in Precambrian basement rock aquifers to well over 300 mm/yr in the highly permeable volcanic sedimentary aquifers.

The Nubian sandstone aquifer system has fossil water and very low modern-day recharge rates, partly due to the long travel time to reach the deep aquifer. The aquifer is recharged by Nile water seepage in a few areas, by precipitation in some mountain regions, and by groundwater influx from the Blue Nile/Main Nile Rift system. Groundwater infiltration by the above mechanisms is small compared to the natural groundwater flow in the aquifer (estimated to be in the order of 109 m³ per year) that results from discharge in depressions, evaporation in areas where the groundwater table is close to the earth's surface, and leakage into confining beds.

The Moghra aquifer in Egypt has a mixture of fossil and renewable water: recharge of the aquifer occurs by upward leakage from the underlying Nubian sandstone aquifer and some rainfall input. The unconsolidated sedimentary aquifers in the proximity of the Nile River and Delta in Egypt receive high recharge in excess of 400 mm/yr from the base of the river and irrigation seepage.




(Based on map by BGR / UNESCO.)



### Groundwater use

Groundwater is widely used across the basin for domestic water supply (for drinking and other domestic uses) for both rural and urban communities. With the exception of Egypt, groundwater from dug wells, springs, and boreholes is the main source of drinking water for rural communities in the basin. In the Nile Equatorial Lakes Plateau and the Ethiopian Highlands, about 70 per cent of the rural population is dependent on groundwater. This proportion rises to about 80 per cent in The Sudan and close to 100 per cent in South Sudan. In Egypt, groundwater accounts for only about 13 per cent of total annual water requirements. The proportion of the population dependent on groundwater for domestic use in Egypt is not so high because most houses in urban areas and new settlements are connected to conventional piped water supplies based on surface water. The population in small rural settlements in Egypt largely uses water from small waterways to meet domestic water needs.

In addition to domestic use, groundwater in the Nile region is also used for agricultural irrigation, livestock watering, and industrial processing. Groundwater use for agricultural irrigation is most widespread in the lower parts of the basin (The Sudan and Egypt), and low in the headwater regions of the basin due to sufficient rainfall and availability of large surface-water bodies. Conjunctive use of surface and groundwater is widely practised in the Nile Valley and Nile Delta, where farmers abstract water from shallow, unconsolidated aquifers during periods of peak irrigation demand and in lands located on the margins of the irrigation command areas. Groundwater use for industrial processing is most intensive in Egypt, particularly in Cairo and the Nile Delta.

### GROUNDWATER POTENTIAL OF NILE BASIN COUNTRIES

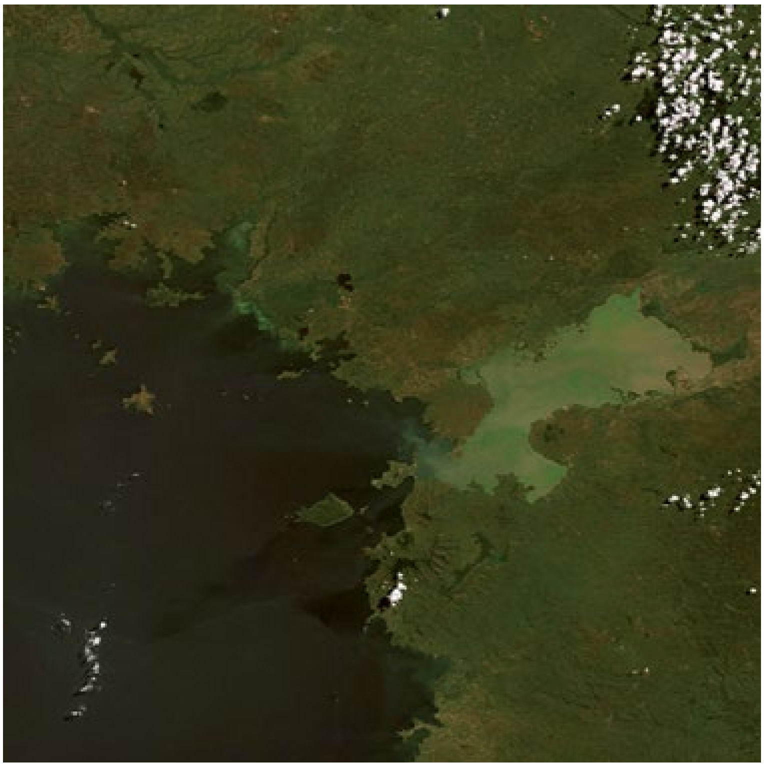
| **Country** | **Groundwater** $km^3$/year | **Renewable groundwater** $km^3$/year | **Non-renewable groundwater** $km^3$/year | **Groundwater annual extraction** $km^3$/year |
|---|---|---|---|---|
| Burundi | 0.40 | 0.18 | 0.22 | 0.03 |
| D R Congo | 51.9 | 46.75 | 5.15 | 0.21 |
| Egypt | 4.00 | 0.09 | 3.91 | 0.90 |
| Ethiopia | 7.23 | 5.50 | 1.73 | 0.40 |
| Kenya | 2.34 | 1.01 | 1.33 | 0.42 |
| Rwanda | 0.40 | 0.32 | 0.09 | 0.04 |
| Sudan | 6.40 | 1.75 | 4.65 | 0.50 |
| Tanzania | 5.23 | 4.00 | 1.23 | 0.38 |
| Uganda | 2.12 | 1.95 | 0.17 | 0.18 |

(Source of data: Hassan, Attia & El-Attfy 2004)

# WATER QUALITY

## Surface water

The quality of surface waters in the Nile Basin is influenced by both natural and human factors, with human influences having far greater impact. Although the chemical quality of the water is good, its physical and bacteriological quality is generally poor.



The Winam Gulf, northeastern Lake Victoria, showing a greenish tinge indicative of the presence of algae.

The headwater regions of the basin are densely populated and intensively used for rainfed agriculture. During the rainy season, the combination of hilly terrain, torrential rains, human-induced land-use change, and poor agricultural practices produce widespread soil erosion, leading to the problems of colour, turbidity, and suspended solids in the headwater rivers. Concentrations of suspended solids range from 1 to 1,500 mg/L in the Equatorial Lakes region, with the heaviest silt loads being carried by the Kagera river, and the rivers in western Kenya such as the Yala and Nzoia. The Eastern Nile sub-basin rivers have much higher sediment loads, sometimes approaching 5,800 mg/L in the rainy season. The dry season in the headwater regions is associated with low-flow conditions and clearer waters.

Colour ranges from 20 to 1,250 TCU in the Equatorial Lakes region and 0 to 350 TCU in the Eastern Nile headwater rivers. The Equatorial Lakes region has areas of dense forest and large tropical swamps that add a brown hue to the Nile waters from decomposing vegetable matter. However, the specific dissolved organic carbon output of the Nile, estimated at 0.089 t/km$^2$/yr, is the lowest of all major world rivers. This is due, in part, to the low carbon content of soils in the basin and a large area of desert within the basin with little or no biomass production.

Across the basin, environmental sanitation is poor, resulting in bacteriological contamination and nutrient enrichment of the Nile waters. Because of this poor bacteriological quality, most Nile waters are not fit for consumption in the raw form. Concentrations of faecal coliform bacteria are above 50 cfu/100 mL in nearly all surface waters in the basin. During the rainy season, this value may rise to above 1,000 cfu/100 mL. Total coliform concentrations are much higher, averaging 500 cfu/100 mL in most upstream rivers, and reaching levels of 150,000 cfu/100 mL in heavily polluted sections such as the Rosetta branch of the Nile Delta.

The Equatorial Lakes are categorized as eutrophic to hypereutrophic systems, and experience frequent algal blooms and widespread water

hyacinth infestation. The presence of algae gives the headwater rivers and lakes their characteristic greenish tinge. Water hyacinth mats aggravate water quality problems and are a major nuisance to water transport as discussed in Chapter 3 and Chapter 7.

Dissolved oxygen concentrations are high in most headwater rivers, ranging from 6 to 9.5 mg $O_2$/L. Concentrations below 5 mg $O_2$ /L are encountered downstream of major cities and in the Nile Delta, and are attributed to pollution. Biochemical oxygen demand (BOD) does not show a clear distribution pattern in the basin but tends to be high (above 100 mg $O_2$/L) immediately downstream of major urban areas, pointing to pollution from domestic and industrial sources.

The water chemistry of the Nile River is mainly determined by rock weathering. Bicarbonates strongly dominate the anion content of Nile waters and are strongly and positively correlated with electrical conductivity. The other major ions are chlorides and sulphates.

Away from major pollution spots, surface waters in the upstream parts of the basin have good chemical quality and are generally fresh (low mineral levels). This is because much of the basin is underlain by very old and highly weathered rocks that contribute only small amounts of solute to the water. However, there are isolated areas, such as parts of the Atbara (Tekezze) sub-basin, where water is more mineralized, and may contain harmful concentrations of substances such as fluoride. Also, within Egypt, there are some enclosed water bodies derived from the Nile that are relatively more mineralized, such as the Khor Toshka, Lake Qarun, and Wadi Natrun.

### Upstream–downstream trends

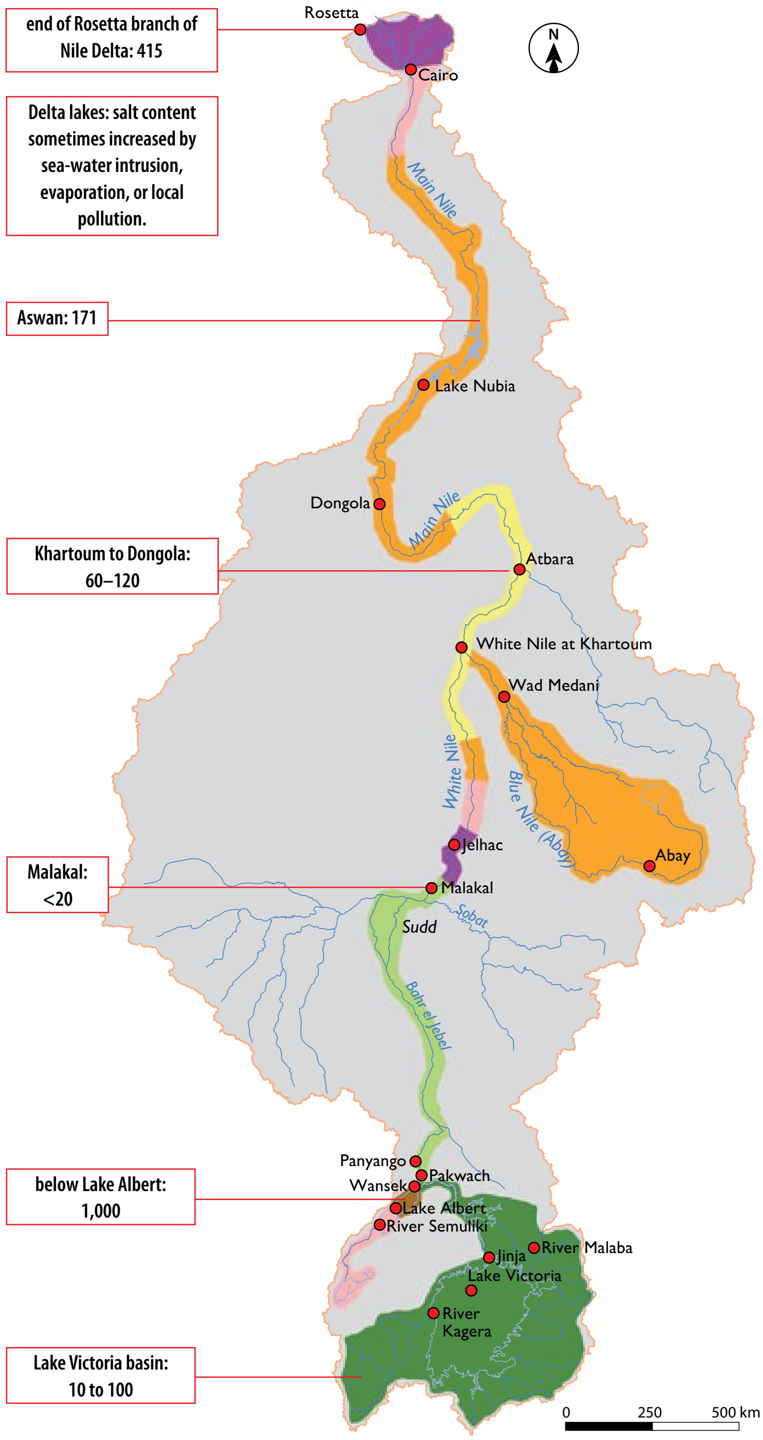
Changes in water quality, moving from upstream to downstream parts of the basin, do not occur in a linear fashion, owing to the influence of the Equatorial Lakes, the Sudd, and the reservoirs in The Sudan and Egypt. The Equatorial Lakes play an important role in homogenizing contributions from various headwater sub-basins, dampening seasonal variability in flow and water quality of the White Nile, and trapping sediments. The extensive wetlands of the Sudd impact water quality by bringing about a reduction in suspended solid load, decreasing dissolved oxygen concentrations, increasing acidity, increasing dissolved carbon dioxide concentrations, reducing sulphate concentrations, and increasing total dissolved solids concentrations.

From high turbidity and silt loads in headwater areas, the White Nile just before Malakal has a relatively low suspended sediment concentration due to the sediment-retention property of the Equatorial Lakes, and the Sudd and Machar marshes.

An over-stretched sewerage capacity resulting in raw sewage flowing into the Nile, Khartoum 2007.

The series of dams constructed on the Blue and Main Nile act as sediment traps in a similar manner to that of the Equatorial Lakes, and have a combined trap efficiency close to 100 per cent. Suspended sediment concentrations downstream of Aswan are in the low range of 20 to 50 mg/L all year.

Chloride concentrations are very low in the Equatorial Lakes headwater areas, and only increase in the White Nile downstream of Lake Albert. Downstream of the Sudd, the contributions of the Sobat and Blue Nile (Abay) help to bring down chloride concentrations. Sulphate is present in low concentrations in all headwater areas. In the White Nile, sulphate concentrations increase from the contributions of the western rift system, but drop again after passage of the White Nile through the Sudd. With respect to cations, calcium ($Ca^{2+}$), and magnesium ($Mg^{2+}$) are dominant in the Ethiopian and Eritrean headwater areas, while sodium ($Na^{+}$) and potassium ($K^{+}$) are dominant in the Equatorial Lakes headwater areas.




**ELECTRICAL CONDUCTIVITY**

Variation in average annual electrical conductivity which reflects the total amount of solids dissolved in water and is a good indicator of salinity

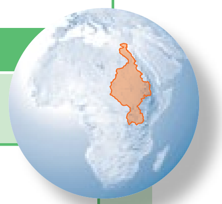
*2005*

µS/cm

- more than 420
- 361 – 420
- 301 – 360
- 241 – 300
- 181 – 240
- 121 – 180
- 60 – 120
- less than 60
- water quality sampling point
- average total dissolved solid concentrations, mg/L

(Map prepared by the NBI; source of data: NTEAP Regional Water Quality Monitoring Baseline Report, 2005)

## EROSION, SEDIMENT TRANSPORT, AND RESERVOIR SEDIMENTATION



From analysis of sediment accumulation in Sudanese reservoirs, the total load of sediment in the Nile is estimated to be about 230 million t/yr. Only about 2 per cent of this is bedload, while the rest is suspended load. The contribution from the different parts of the basin to the total load is not even, but is strongly focused towards the Ethiopian Highlands. The largest sediment contribution (61%) comes from the Blue Nile (Abay) catchment, followed by a considerable contribution (36%) from the Atbara (Tekezze), and an insignificant (3.5%) input from the rest of the Nile catchment – mainly the Equatorial Lakes plateau, the Sudd area and hyper-arid Red Sea Hills region.

The bulk (98%) of the annual suspended sediment load is transported during the summer floods in the Blue Nile (Abay) and Atbara (Tekezze) catchments. Owing to the relatively small area actively contributing to sediment production and export, the suspended solid load of the Nile is modest, when compared with its basin area and with other large rivers of the world.

The disproportionately large contribution of sediments from the Ethiopian Highlands is due to a multiplicity of factors which include the deeply incised topography of the region, unstable and easily erodible slopes, high runoff concentrated in a single July–August peak, sparse vegetation cover, and intensive land use. The exceptionally high sediment yields from the Ethiopian Highlands

The Blue Nile (Tis Issat) Falls, Ethiopia, orange with sediment.

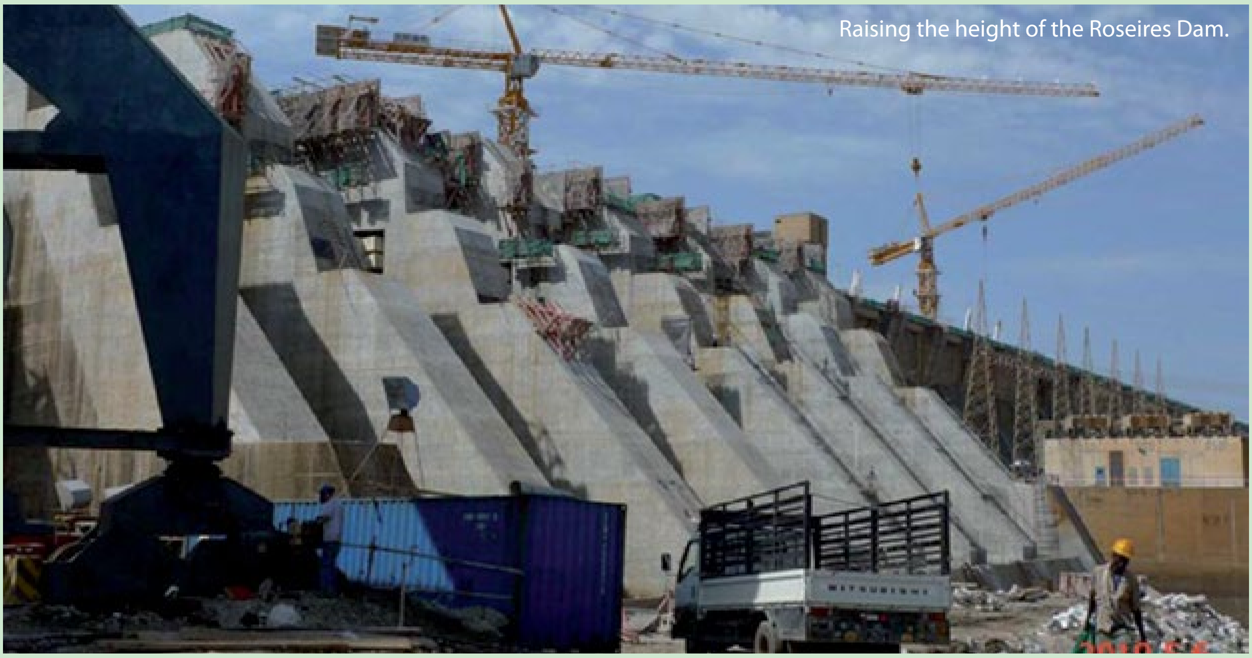
partly reflect accelerated soil erosion caused by land-use changes over several centuries.

Erosion and land degradation are also occurring in the Equatorial Lakes Plateau, but the specific yield of the sub-basin is low because it is underlain by resistant, less-erodible rocks. The Equatorial Lakes region also has a more effective cover of protective vegetation, flatter (plateau) topography, more evenly distributed rainfall over the year (twin peaks in March–May and September–October), and stronger chemical weathering. Furthermore, a major proportion of the sediment produced in the White Nile headwaters is trapped in the Equatorial Lakes, retained in the Sudd marshes, or deposited along the river course downstream of the Sudd, where the Nile flows sluggishly over a low-gradient course.

For thousands of years, and until the closure of the Aswan High Dam in 1964, the fertile volcanic muds carried by the summer floods of the Nile were a critical feature of the farming system in Egypt, and brought prosperity to ancient Egyptian dynasties. Sands and mud of Nile provenance have been identified in the Nile cone and along the margins of Israel, while finer-grained clays have been traced as far north as Turkey. Over the last 100 years, dams have been built in Egypt and The Sudan for flood regulation, water supply, and hydropower generation. These dams have virtually halted the transport of sediment to the sea, and caused a dramatic shift in sediment dynamics and geomorphological processes in the Egyptian Nile. Fluvial erosion of the river channel and direct inputs of aeolian dust are today the main sources of suspended sediments downstream of Aswan. Rather than accumulating within the Nile Delta and fan, huge volumes of sediment now accumulate in reservoirs, resulting in rapid loss of storage capacity on one side, and ravaging erosion of the deltaic cusps on the other.

The dams constructed in the basin to deal with the problem of seasonal and interannual flow variability in the Nile include the Aswan High Dam and Merowe Dam on the Main Nile, the Jebel Aulia on the White Nile, the Roseires Dam on the Blue Nile (Abay), and the Khasm el Girba on the Atbara (Tekezze). These dams provided essential storage to serve the ever-growing and year-round irrigation demands in Egypt and The Sudan. However, the rapid sedimentation in the reservoirs has affected their effectiveness and shortened their lifespan. The storage capacity of the Roseires and Khasm el Girba reservoirs, for example, are estimated to have fallen by 60 per cent and 40 per cent respectively over the first 30 years of operation. Desilting of these dams is not economically viable, although raising their height may be a short-term option.

The lasting solution to reservoir sedimentation will have to come from introducing watershed management measures in the upland parts of the basin to reduce sediment production. This is already being done, as discussed under Chapter 3.



Raising the height of the Roseires Dam.

## Groundwater quality

The quality of groundwater in the Nile region is highly variable, and depends on numerous factors such as the type of rock, type of water source, the residence time of water, and level of anthropogenic influence. There are a number of features common to all the aquifer systems, but also differences between them.

In general, the groundwaters across the region are fresh and fit for human consumption with respect to physico-chemical quality. There are some localized cases of high salinity and naturally elevated levels of iron and manganese in the groundwater. There are also isolated cases where the physico-chemical quality is potentially harmful to human health.

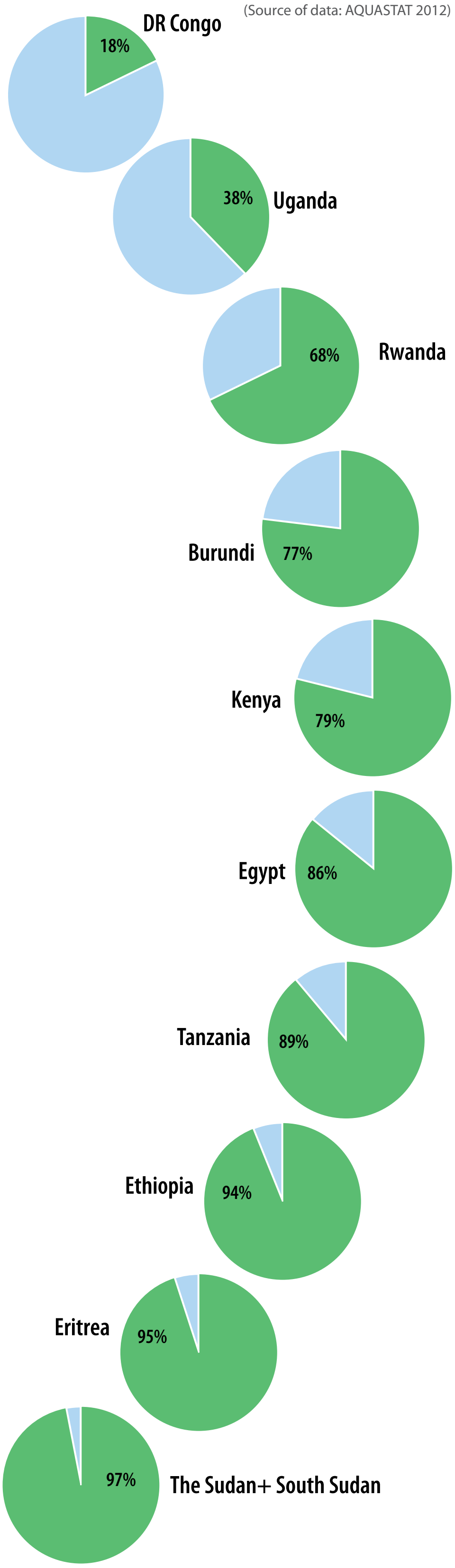
With respect to bacteriological quality, the picture is mixed, with some sources being contaminated with bacteria of faecal origin and others being totally free of contamination. Bacterial contamination does not occur naturally but as a result of anthropogenic influence. Across the basin, elevated levels of nitrates occasionally occur from poor domestic waste disposal and agriculture (farm animals and fertilizers). This is most severe near large urban areas located close to shallow aquifers and is most common in the downstream parts of the basin.

In the Precambrian basement rock systems in the Nile Equatorial Lakes region, groundwater is mainly of calcium-magnesium sulphate and calcium-magnesium bicarbonate type. It is mostly fresh and suitable for human consumption except for areas where there are high levels of iron and manganese. Water in the Ethiopian Highlands is also fresh and naturally good for human consumption. There are some localized exceptions where there are high levels of mineralization (from more reactive rock types), high salinity, and high levels of sulphides, arsenic, fluoride, and iodine. The waters are calcium-magnesium bicarbonates, calcium-magnesium sulphates, and calcium chlorides types.

Water in the Nubian sandstone aquifer system is mainly of sodium bicarbonate type, with calcium and magnesium bicarbonate types near recharge zones. The waters are largely fit for human consumption except where water is highly mineralized. The Umm Ruwaba is the second most important groundwater aquifer in The Sudan following the Nubian sandstone aquifer. The aquifer is mostly fit for consumption but there are areas where salinity may exceed 5,000 mg/L. In Egypt, as in the other parts of the basin, groundwater is mostly fit for human consumption: total dissolved solids are mostly below 1,500 mg/L. However, there are areas where salinity tends to be much higher, such as at the eastern and western margins of the Nile Valley and Nile Delta aquifers. Groundwater in the northern peripheries of the Nile Delta has elevated salinity levels due to an additional factor: salt-water intrusion from the sea.

**AGRICULTURAL WATER WITHDRAWALS**
As percentage of total water withdrawal
*latest data 2000–10*

(Source of data: AQUASTAT 2012)



## TOWARDS INCREASING WATER STRESS

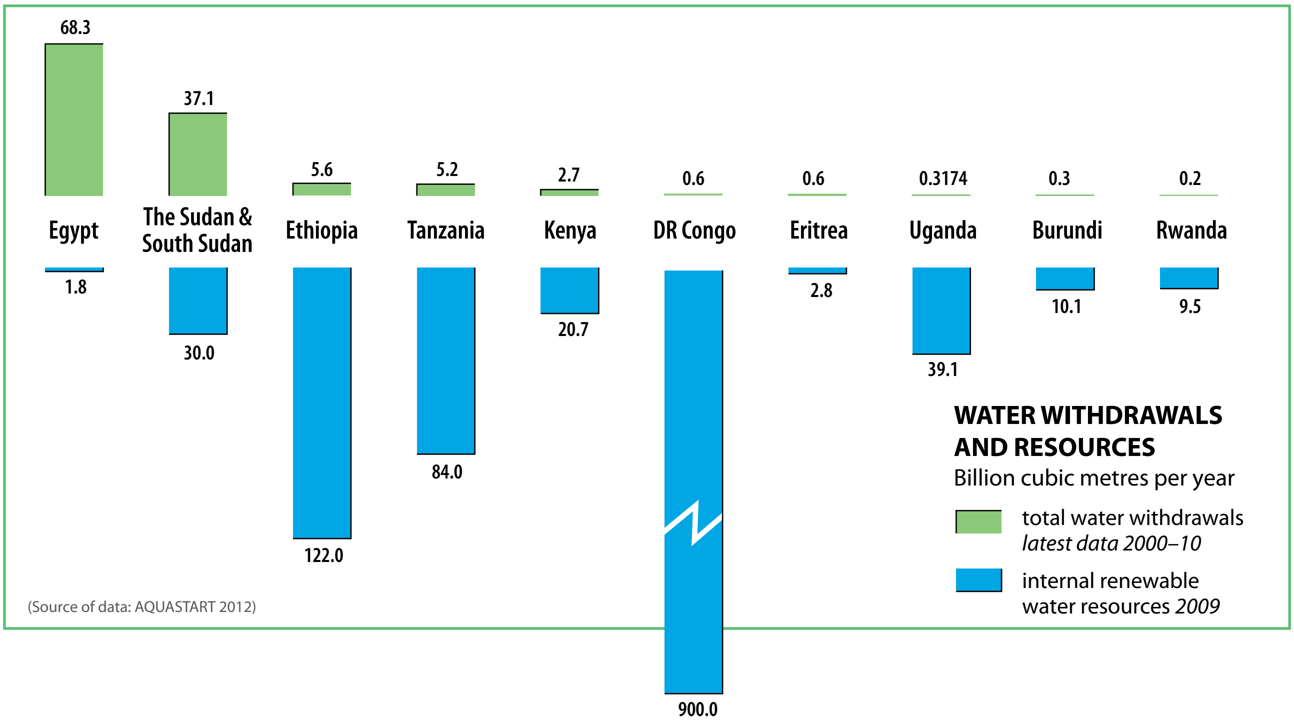
The renewable Nile waters are now almost fully used for various productive purposes, although water utilization differs greatly among countries and sectors. Currently, the dominant use of Nile runoff is by the downstream riparians, with little of the river flows in the upstream reaches used.

Irrigated agriculture in Egypt and The Sudan represents the single most important water consumer. Extensive irrigation systems with a combined acreage well exceeding 4.5 million hectares exist in the Nile Delta, along the Nile Valley in Egypt and northern Sudan, and around the confluence of the Blue and White Nile near Khartoum. Formal irrigation in the other riparians is very limited and is estimated at less than 50,000 hectares.

A number of hydropower facilities have been established, although total installed capacity is still well below its potential. Hydropower is considered a non-consumptive water user; although it alters the downstream flow regime, it does not reduce flow volume. However, the loss of water through evaporation from the various reservoirs in the Nile system (such as lakes Nasser, Merowe, Jebel Aulia, Kashm el Girba, and Roseires) is very significant.

Water use for domestic and industrial purposes is relatively small. In spite of an estimated 232 million people living within the Nile catchment, water for domestic and industrial use is estimated at some 2.0 billion cubic metres (BCM) per year.

A number of concurrent developments point to increasing water stress in the Nile Basin. First, the demand curve is continuing its steady rise due to ongoing population growth and economic development. Secondly, the upper riparians – up to now barely using Nile waters –



are planning investments in the water sector, which will involve using some of the river's renewable discharge, thereby reducing downstream flows. Lastly, while some potential exists to increase renewable water resources by draining wetlands, increasing abstractions upstream of the White Nile floodplains, or by reducing reservoir evaporation, the scope and feasibility of such projects is limited by the serious environmental and socio-political consequences associated with their implementation. Hence, for all practical purposes, the Nile water supply will remain more or less constant.

In view of the finite nature of the water resources in the basin, reconciling the diverging interests among the various riparian countries and stakeholders is a critical task for Nile managers.

## WATER-RELATED NATURAL DISASTERS AND CONFLICTS IN SOUTH SUDAN

Competition for grazing lands and water, especially during the dry season is a regular source of conflict in South Sudan.

The extensive floodplains (toic) of South Sudan are subject to periodic water logging and intensive drying. In drought years, most water-holding features in the floodplains dry up. Given the small number of boreholes and lack of water-storage facilities in the area, a large number of people, livestock, and wildlife are left to depend on a few perennial rivers, lakes, pools, and marshes.

Fierce tribal fights frequently erupt over the limited water resources and the rights to fishing grounds, essential to the livelihoods of the floodplains communities. These conflicts lead occasionally to loss of life and internal displacement of people.

Apart from the problem of frequent droughts, the floodplains experience occasional flooding that results in widespread crop failure, livestock deaths, loss of cropland, and loss of pasture. Thus, even in the absence of conflicts, communities in the floodplain are periodically displaced and forced to migrate beyond their territories, including into neighbouring countries, by natural disasters.

Water infrastructure is urgently needed in the floodplains area for harnessing the water resources and facilitating their use for socio-economic activities. The needed infrastructure includes boreholes, valley tanks, small dams, river training works, and a variety of water-harvesting structures such as haffirs and dykes.

Source of information: Ministry of Water Resources and Irrigation, Republic of South Sudan.

# TOWARDS IMPROVED WATER USE EFFICIENCY

### Challenges related to surface water management

There are several challenges related to surface water management in the Nile Basin, the main ones being inadequate water infrastructure, weak surface-water monitoring networks, weak human capacity, and weak control of pollution activities. Egypt is an exception to the general picture painted above. Egypt has a diversity of water infrastructure, small and large, a dense and fully functional network of surface-water monitoring stations, a large force of water professionals, and a strong regulatory service. Institutional mechanisms for cooperative management of the common Nile water resources by riparian countries are still under development under the NBI.

### Challenges related to groundwater management

The cross-cutting challenge in the region with respect to groundwater management is weak institutional and human capacity. With the exception of Egypt, and to a lesser extent The Sudan, information on groundwater is scanty, and monitoring networks are hardly in place. Groundwater abstraction is not properly controlled, which in some cases leads to unsustainable exploitation of groundwater. The most serious case of unsustainable use relates to the heavy mining of the Nubian sandstone aquifer by the countries that share the resource. Much remains to be done with respect to improving the understanding of the occurrence and distribution of groundwater, including surface water–groundwater interactions.

The major aquifers of the Nile region do not follow national boundaries but there is as yet no clear mechanism for co-riparian states to cooperate in joint monitoring, development, and management of the shared aquifers.

### What NBI is doing

The NBI has initiated a number of projects to strengthen regional water resources planning and management, and to increase the efficient use of the water resources in the basin.

The Water Resources Planning and Management (WRPM) project has developed the Nile Decision Support System (Nile DSS), which is a computer-based platform for planning and information management. The tool enables the riparian states to assess the trade-offs and consequences of alternative basin-wide water-resources development options. The Nile DSS further provides a framework for data and knowledge sharing amongst the Nile riparians.

The Eastern Nile Technical Regional Office (ENTRO) located in Addis Ababa is implementing the Eastern Nile Flood Preparedness and Early Warning Project. This project aims to improve the regional and national capacity in Ethiopia, South Sudan, and The Sudan to forecast floods in the Eastern Nile basin and mitigate possible flood damage. The project also serves to strengthen flood-risk management

The NBI has initiated projects to strengthen management and improve efficient use of water resources.

and emergency preparedness. Under the project, flood-warning advisories are regularly issued to the communities in flood-risk zones of the Eastern Nile.

Monographs have been prepared for the rivers Kagera, Mara, Sio-Malaba-Malakisi, and lakes Edward and Albert. These documents have compiled and organized all existing information on the water-resource-related sectors in the basins, and thus provide a factual basis for integrated water resources management, and the formulation of investment plans – currently in progress.

Other notable interventions by the NBI include broad support to institutional- and human-capacity building in the Nile riparian countries, and promoting Integrated Water Resources Management (IWRM) approaches in the region.

### What broader cooperation could achieve

The Nile Basin contains untapped potential for hydropower generation, irrigation, and navigation. A number of possible multi-lateral projects have been identified where – if sufficient inter-basin cooperation can be achieved – the total benefits to the Nile system will amply exceed losses to individual stakeholders. Examples of these so called win–win projects include:

- Construction of dams to increase over-year water storage for hydropower production, irrigation, and flood protection. Location of the dams in high-altitude upstream areas could result in substantial reductions in evaporation losses. Cooperation will be needed to minimize downstream impacts during construction and operation.
- Construction of a dam on the Baro could reduce overbank spillage into the Machar marshes and wetlands around the Baro–Akobo confluence. The wetlands are of unique environmental value, and such a development needs to be accompanied by a sound environmental impact assessment.
- Coordinated reservoir operation would maximize the benefits from the whole system, but require high levels of cooperation and clear mechanisms for benefit sharing.
- Regulation of outflows from Lake Victoria or Lake Albert, possibly in conjunction with increased abstractions upstream of the Sudd to minimize water losses from the Nile system.

Chapters 5, 6, and 8 of this report examine the above options in greater detail. The bottom line for all of them is greater levels of cooperation, and pursuing sustainable development approaches.

## SUMMARY AND CONCLUSIONS

The Nile has a total length of 6,695 km, making it the world's longest river. Its drainage area, at 3.1 million square kilometres, is one of the largest on the African continent. The Nile hydrology is characterized by uneven distribution of water resources and high climatic variability in space and time.

Despite the long length of the river and its expansive basin area, the flow in the Nile is a small fraction of the flow in other large rivers of the world, such as the Congo, Amazon, and Yangtze. This is partially explained by the low runoff coefficient of the Nile (below 5%) and the fact that about two-fifths of the basin area contributes little or no runoff as it is comprised of arid and hyper-arid drylands.

The Nile countries have substantial groundwater resources that occur in extensive regional aquifer systems. The aquifers have varying properties, with some, such as the Nubian sandstone aquifer system and Nile Valley sedimentary aquifer, having high yields.

The surface resources of the Nile are now almost all used up. Withdrawal of water from surface and groundwater resources is variable, with upstream riparian countries having lower withdrawals than downstream riparians. A high proportion of annual water withdrawals go to support agricultural use in the region. Rising population, increasing demand for food, and expanding urban areas, among other factors, are expected to escalate the strain on the Nile water resources.

There is need to increase capacity building interventions across the region that target the strengthening of the human resource base and institutional framework for integrated water resources management. Increased cooperation is needed amongst Nile riparian countries to, *inter alia*, jointly operate water-resource monitoring networks and decision-support tools that facilitate rational management and development of the common Nile surface and groundwater resources. The Nile riparian countries also need to consider a number of possible multi-purpose projects through which they could collaboratively increase efficiency of water use, and optimize and equitably share the benefits of the cooperative development of the Nile water resources.