Information Products for Nile Basin Water Resources Management

Synthesis Report

COOPERAZIONE ITALIANA
NILE BASIN INITIATIVE
Initiative du Bassin du Nil
FIAT PANIS

Information Products for Nile Basin Water Resources Management

Synthesis Report

FAO-Nile Basin Project
GCP/INT/945/ITA
2004 to 2009

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2011

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AFRICOVER	FAO programme
ADCP	Acoustic Doppler Current Profiler
AWP	Agricultural water productivity
DB	Double Burden
DEM	Digital Elevation Models
ENSAP	Eastern Nile Subsidiary Action Program
ENTRO	Eastern Nile Technical Regional Office
ETa	Actual evapotranspiration
ETo	Reference evapotranspiration
F4T	Food for Thought
GIS	Geographic Information System
GWRI	Georgia Water Resources Institute, USA
ITCZ	Inter-Tropical Convergence Zone
IUCN	the International Union for Conservation of Nature
JE	Joint Effort
Kc	Crop-specific coefficient
Ma	Million years before present
NASA	National Aeronautics and Space Administration
NBI	Nile Basin Initiative
NELSAP	Nile Equatorial Lakes Subsidiary Action Programme
Nile Com	Nile Council of Ministers for Water Affairs
Nile DST	Nile Decision Support Tool
Nile TAC	Nile Technical Advisory Committee
Nile SEC	Nile Secretariat
NO	Nile on its Own
ORNL	Oak Ridge National Laboratory
PSC	Project Steering Committee
R	Recharge term
RO	Runoff term
RS-RO module	River Simulation and Reservoir Operations
SLM	Sustainable Land Management
SRTM-DEM	Shuttle Radar Topography Mission Digital Elevation Model
SVP	Shared Vision Programme
UC	Unintended consequences
UNDESA	United Nations Department of Economic and Social Affairs
WRPM	Water Resources Planning and Management Project

Acknowledgements

This report was compiled by FAO Chief Technical Advisor for the project, Bart Hilhorst, with inputs from Jacob Burke, Jippe Hoogeveen, Karen Frenken, Jean-Marc Faurès and Dorit Gross. The authors are grateful for the dedicated input from project staff based in Entebbe and the consultants and Focal Point Institutions in all ten countries involved in the project. Overall design of the reports and information products was managed by Nicoletta Forlano, James Morgan and Gabriele Zanolli.

1. Introduction

This report summarizes the activities and outputs of the FAO project "Information Products for Nile Basin Water Resources Management". In addition to this report, the results are presented in a set of companion reports and related data products:

- Farming systems report (FAO, 2009b);
- Food for Thought (F4T) report (FAO, 2009c);
- Agricultural water use and productivity projections report and accompanying user manual and spreadsheet model (FAO, 2009d);
- ten thematic posters and underlying data;
- Nile Decision Support Tool (Nile-DST) package;
- hydrometric data.

All reports and related data are contained in an accompanying DVD. Taken together, these information products provide an account of project activities, information and data to inform water resource management in the Nile Basin. Particular attention has been paid to the preparation of Geographic Information System (GIS) information used to prepare the project posters. These are made available in current ArcView/Arc Reader formats and can be used in standard Arc GIS packages.

The purpose of this synthesis report is to pull together the current natural resource and agricultural water use information across the basin. Much of the data have been derived from detailed national reports prepared under the project and provide evidence of the dedication of all the national Focal Point Institutions and consultants involved in the project.

2. Background and development objectives

Background

The Government of Italy started its basin-wide support to the Nile process in 1996 with project "Operational Water Resources Management and Information System in the Nile Basin Countries". The project was implemented by the national Focal Point Institutions (FPIs) in the participating Nile riparians. FAO provided technical and operational support. The project had a budget of USD5.5 million and ended in 1999.Its achievements include:

- improved communication facilities;
- establishment of GIS units at the FPIs;
- upgraded satellite remote sensing equipment;
- capacity building in technical, environmental, legal and institutional aspects of the shared Nile river basin.

A follow-up project "Capacity Building for Nile Basin Water Resources Management" was approved for funding by the Government of Italy in December 1999. Total budget amounted to USD5.5 million. The project completed its activities in November 2004. The main accomplishments include:

- establishment of a transboundary hydro-meteorological monitoring network comprising more than 100 stations;
- establishment of geo-referenced databases at the national FPIs;
- development of the Nile Decision Support Tool (Nile-DST);
- training in legal and institutional aspects of water resources management issues.

Project "Information Products for Nile Basin Water Resources Management" became operational in December 2004. It was carried out under the umbrella of the Nile Basin Initiative (NBI). The project was implemented by the ten Nile riparians with technical and operational assistance from FAO and a budget of USD5 million. This brought the Government of Italy's total contribution since 1996 to the Nile process to more than USD16 million.

The project was intended to strengthen the ability of the governments of the ten Nile countries to take informed decisions with regard to water resources policy and management in the Nile Basin. A thorough understanding of the state of the Nile resource, and the current use and productivity of its waters, will enable decision-makers to assess the trade-offs and implications of co-operative management better.

Development objectives

Overall development objectives

The first overall project objective was to contribute to the establishment of a common knowledge base at the Nile Basin level.

Water resources management resembles a political process in the sense that it determines who gets what and when. In this context, cooperation and dispute are two sides of the same coin and can occur simultaneously. Dispute management emphasizes process: how to deal with the inevitable differences efficiently, peacefully, and at minimum cost. The obvious answer is to engage in negotiations. A common knowledge base is considered an essential prerequisite for a successful negotiation process. Prospects for a negotiated solution improve if parties have a common understanding of the physical characteristics of the resource, and of the consequences and trade-offs of various allocation proposals and development options. The project made several contributions to this common knowledge base in the Nile Basin. It established a set of shared databases at the Nile Basin level – with meteorological data, hydrological data, and agricultural production data. It also established common models, notably Nile-DST. Through its scenario work and negotiation skills training, it also introduced common concepts and a shared analysis of rural development issues in the Nile Basin.

The second overall project objective was concerned with strengthening government capacity at the national level. While the regional context is important, most government resources are employed at the national level to manage scarce water resources and deal with competing demands from different societal sectors. Various observers have noted that most water conflicts occur at the sub-national rather than the international level. Local conflicts occur when livelihoods of stakeholders are directly threatened because their access to water resources is limited through competition with others.

To strengthen government capacity, the project undertook a major capacity building exercise in which more than 600 trainees took part in 56 training events.

Specific development objectives

More specific project objectives included the following.

1. Building capacity for developing information products that integrate technical water resources data with socio-economic and environmental information: The aim was to present and illustrate general issues and trends concerned with the availability allocation, use and development potential of the shared Nile resources as cartographic products. This builds on the Geographic Information System (GIS) technology already established in the region by the project.

2. Providing stakeholders and decision-makers in the Nile Basin with a sound assessment of the linkage between agriculture and water in the basin: Within this context, a basin-wide survey was conducted to assess current and potential water use and water productivity in rainfed and irrigated agriculture. A further case study was concerned with the analysis and improvement of water productivity. To estimate future agricultural water use, scenarios were developed for demand of agricultural produce in the Nile Basin in 2030.

3. Distributing information and project results to a wide spectrum of decision-makers, civil society and other stakeholders: A communication strategy was developed to increase awareness among government officials, local stakeholders and the public about the use of the Nile system as a shared resource.

Consolidating the achievements of the previous project "Capacity Building for Nile Basin Water Resources Management": Limited activities were implemented to extend the transboundary hydro-meteorological monitoring network, and to finalize the database quality control exercise. The project also consolidated Nile-DST, developed in the previous project, through the implementation of a limited training programme.

The Nile Basin

The Nile system

The Nile Basin covers an area of 3.17 million km^2, which represents some 10 percent of the African continent. Ten countries share the river: Burundi, the Democratic Republic of the Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, the Sudan, the United Republic of Tanzania and Uganda. The geographic location of the basin is presented in the poster Nile Sub-Basin Delineation on page 19. Five of these countries are among the poorest in the world. The Nile Basin is home to approximately 200 million people, while some 370 million live within the ten riparian States. The Nile region is characterized by high population growth and significant development challenges.

At 6 825 km, the Nile is the longest river in the world. It has two main tributaries: 1) the White Nile, originating from the Equatorial Plateau of East Africa, and 2) the Blue Nile, with its source in the Ethiopian highlands. Other significant tributaries are the Atbara and the Sobat, both originating in the Ethiopian highlands. All tributaries begin their journeys in relatively humid areas, with an annual rainfall of 1 200 to 1 500 mm. The downstream stretch of the river, by contrast, flows northwards to the Mediterranean through the Sahara Desert. While the Blue Nile flows are highly seasonal, the White Nile waters have a steady flow but contribute only 10 to 20 percent of the total Nile runoff. Lake Nasser, a major reservoir on the Sudan-Egypt border, provides inter-annual regulation for Egypt.

The Nile waters play a vital role in the socio-economic development of the Nile Basin States. Agriculture is the dominant economic sector in most Nile riparians, and reliable access to water remains key to increasing agricultural productivity, providing employment, and raising the standards of living of the people residing in the basin. The Nile also represents a vast resource for hydropower generation.

The Nile region is plagued by environmental degradation, armed strife, drought and famine. Weak institutions, low financial capacity and inadequate infrastructure conspire to perpetuate poverty. The Nile waters are seen to have great potential as a lever for social and economic development. Collaborative and sustainable development of the shared water resources can attract investment and assist in alleviating poverty. High demographic growth rates and accelerating environmental degradation narrow the window of opportunity for reversing the negative trends in the region.

The Nile hydro-political scene

Physical and socio-political factors set the overall hydro-political scene, which conditions the evolution of water policy across the basin.

The Nile flow is small in relation to its area. From a hydrologic point of view, this is among the most characteristic features of the Nile. In spite of the size of its basin, which measures more than 3 million km^2, the mean annual flow of 80 km^3 equals that of the Rhine. If this total yearly volume of runoff were spread over the entire watershed, it would represent a layer of not more than 30 mm.

The Nile is the only significant source of water for the downstream riparians. Egypt and northern Sudan are situated in a hot and arid region with only sparse and insignificant rainfall. Close to 80 million people in the downstream stretch of the river depend exclusively on the Nile for their water supply. They effectively have no alternative. Since their societies have used the Nile waters for more than 4 millennia, they have developed a sense of entitlement and have adopted the principle of "prior utilization", which gives right of use to the first user.

The upstream riparians have large rural populations that depend on subsistence agriculture. For instance in Ethiopia, of a total population of about 79 million in 2005, some 84 percent are estimated to live in rural areas. Similar percentages are seen in the other upstream countries. Most rural people depend on smallholder subsistence farming for their livelihood. Farming is their only means of income generation and food security. Alternative employment opportunities are virtually non-existent. The region has a history of food insecurity, mainly during

Box 1: The swamps in southern Sudan

The Sudd, the Bahr el Ghazal swamps and the Machar marshes represent vast wetland areas in southern Sudan. Evaporation from the flooded lands exceeds rainfall. The wetlands have a permanent and a seasonal component. The extent of the swamps fluctuates over the years, following local and regional climatic trends. The Sudd area is determined by the regime of the Bahr el Jebel and has increased in size since the 1960s. By contrast, the extent of the Bahr el Ghazal swamps has tended to decrease in this period. The complexity of the channels and the challenge of measuring evaporation from swamp vegetation have meant that the flows in the wetland areas are not well understood.

Below Mongalla, the high flows of the Bahr el Jebel spill over the riverbanks into seasonal and permanent swamps. This is the Sudd area. It is estimated that the outflow from the Sudd is about half the inflow. Sudd outflows also show little seasonal variation, providing a fairly constant contribution to the White Nile flows. In the period from 1905 to 1961, the size of the permanent and seasonal flooded areas was estimated at 6 700 and 6 200 km^2 respectively. The wetlands area increased significantly in the period from 1961 to 1980, reflecting above average rainfall in the Lake Victoria area. Permanent swamps were estimated at 17 900 km^2, while the seasonal component reached 11 000 km^2.

The Bahr el Ghazal basin is relatively large and has the highest rainfall of any basin within the Sudan. However, the flows of the various tributaries spill into seasonal and permanent swamps, and virtually no runoff reaches the White Nile. Satellite imagery shows that each tributary feeds a separate swamp of relatively limited size, and that no extensive continuous wetland area exists.

Downstream of Gambeila, the Baro spills into the adjacent Machar marches during the high flow periods. This is a remote area that is little understood. Only in exceptional wet years does flow from the Machar marches reach the White Nile.

Source: Sutcliffe and Parks, 1999.

periodic drought years. By and large, people in rural areas do not have the financial means to procure food from international markets. They eat what they grow, or buy from local markets. Small farm size combined with low levels of inputs – such as fertilizer or improved seeds – result in low agricultural productivity and inefficient water use. The persistent key role of agriculture – and lack of alternatives – accentuates the importance of water.

Ongoing population growth puts unprecedented pressure on natural resources. Family-based survival systems lead to higher population growth rates. According to the low-variant prospect developed by the United Nations Population Division (UNDESA), the total population in the Nile Basin is expected to increase by 61 percent by 2030. The high-variant prospect sees a growth of 82 percent. No effective policies are in place to cope with the unprecedented pressure on infrastructure (such as schools and hospitals) and natural resources, but there is a clear perception that the Nile waters are essential in providing food security and rural development.

The Nile stream flow is fully allocated. The limited Nile flows are now fully used for industrial, domestic and agricultural water supply, almost exclusively by Egypt and the Sudan. Each year, less than 10 km^3 reaches the Mediterranean, which is considered the minimum requirement for environmental purposes. The potential for increasing this supply – for instance by draining wetland areas or reducing evaporation in the various reservoirs – is limited. As a consequence, Nile water allocation has become a near zero-sum game.

Rainfall is abundant but variable in large parts of the upstream riparians. The (sometimes extreme) temporal variability of rainfall in most of the upstream riparians has a marked adverse impact on the productivity of rainfed agriculture. Farmers opt for drought-resistant but low-yielding varieties, and are hesitant to invest in inputs as they can lose their entire investment in a drought. Some upstream countries, notably Ethiopia, have prioritized investments in (large-scale) hydraulic infrastructure and storage capacity, to mitigate the effects of weather uncertainties. In their analysis, hydrologic variability is among the key constraints to development. The current discussion on climate change is strengthening this perception.

There are limited direct links between upstream and downstream riparians. Owing to geography and history, economic and social ties between the upstream and downstream regions of the basin are very limited. Without effective north-south road or rail connections, inter-basin trade volumes are small. Apart from the river, there is little that links all ten States. Hence, direct common interests among the Nile riparians are conditioned by relative isolation from global and regional markets.

There is a history of tense relations among the upstream and downstream Nile riparians. It is only in the last decade that a thaw and a strong concerted effort to improve relations have been witnessed.

These eight features broadly define the shape of the Nile water policy context. Other issues, for instance hydropower development or environmental protection, are currently not considered as key obstacles to progress.

The Nile Basin Initiative

Recognizing the development challenges in the Nile region, the Nile Council of Ministers launched the NBI in 1999 in Arusha, United Republic of Tanzania. The NBI is a partnership of the Nile riparian States: Burundi, the Democratic Republic of the Congo, Egypt, Ethiopia, Kenya, Rwanda, the Sudan, the United Republic of Tanzania and Uganda, with Eritrea currently participating as observer. The NBI comprises the Nile Council of Ministers for Water Affairs (Nile COM), the Nile Technical Advisory Committee (Nile TAC), and the Secretariat (Nile SEC), which is based in Entebbe, Uganda. Through dialogue and negotiations at the highest level, the riparian States of the Nile Basin agreed on a shared vision "to achieve sustainable socio-economic development through equitable utilization of, and benefits from, the common Nile Basin water resources".

To support this vision, they developed the Shared Vision Programme (SVP) of basin-wide projects, and the Subsidiary Action Programmes (SAPs), consisting of investment programmes at a sub-basin level. The main objective of these programmes is to build capacity, trust, and confidence among the riparian States, to develop the river in a cooperative manner, share socio-economic benefits, and promote regional peace and security.

Eight basin-wide projects have been implemented under SVP:

1. Nile Transboundary Environmental Action: to provide a strategic framework for environmentally sustainable development of the Nile River Basin;
2. Nile Basin Regional Power Trade: to establish the institutional means to coordinate the development of regional power markets among the Nile Basin countries;
3. Efficient Water Use for Agricultural Production: to provide a conceptual and practical basis for increasing water availability and efficient water use for agricultural production;
4. Water Resources Planning and Management: to enhance the analytical capacity for a basin-wide perspective that supports the development, management and protection of Nile Basin waters;
5. Confidence-Building and Stakeholder Involvement: to develop confidence in regional cooperation under the NBI and ensure full stakeholder involvement in the NBI and its projects;
6. Applied Training: to strengthen institutional capacity in selected subject areas of water resources planning and management in public and private sectors and community groups;
7. Socio-Economic Development and Benefit Sharing: to strengthen Nile River Basin-wide cooperation;
8. SVP Coordination: to coordinate the above projects and capture synergies.

The SVP projects build on each other to form a coordinated programme. They aim to apply an integrated and comprehensive approach to water resources development and management, and to ensure that this serves as a catalyst for broader socio-economic development and regional cooperation. The SVP projects have been designed to pave the way for investments on the ground through the SAPs.

Through two groups of Nile countries – one in the Eastern Nile and the other in the Nile Equatorial Lakes Region – joint and mutually beneficial investment opportunities have been identified. These projects will be implemented through the SAPs.

Integration and coordination with the Nile Basin Initiative

Project design was characterized by extensive consultations with the NBI Secretariat with the aim of capturing synergies and avoiding duplication. As a result, FAO Nile sat squarely under the NBI umbrella. It reported to the annual Nile TAC and Nile COM meetings, and participated in the periodic SVP coordination meetings. A representative from the Nile Secretariat participated in the annual Project Steering Committee (PSC) meetings as observer. Frequent informal coordination took place among individual SVP projects.

At the national level, members of the PSC reported project activities and progress to the national TAC members. In line with NBI operational policies, project staff were recruited mostly from the Nile countries. Only the Chief Technical Advisor and a number of specialist consultants came from outside the Nile Basin.

Several events were organized jointly with SVP and SAPs, notably:

- First Regional Negotiation Skills Training in Bujumbura, Burundi, in February 2006; 42 participants including members of Nile TAC, organized jointly with the SVP Coordination Project;
- two-week Nile DST Training Workshop in Addis Ababa, Ethiopia, in September 2006; 24 participants, organized jointly with the SVP Water Resources Management Project;
- training workshop in modern hydro-meteorological monitoring equipment in Kisumu, Kenya, in September 2007; 16 participants, organized jointly with the Nile Equatorial Lakes (NELSAP);
- Advanced Regional Negotiation Skills Training in Nairobi, Kenya, in December 2007; 45 participants including members of Nile TAC, organized jointly with the SVP Coordination Project.

Project management

Project implementation was directed and supervised by the PSC, which comprised two members nominated by each participating country, two representatives from the donor, and two representatives from FAO.

The PSC had the following mandate:

- Direct project implementation, review and endorse project work plans, and monitor project progress. The PSC also provided regular advice and recommendations to FAO, as the executing agency, on project implementation and all project-related matters.
- Take responsibility for ensuring that appropriate mechanisms are in place to ensure close cooperation, coordination and exchange of project results with other related activities of the NBI programme, and vice versa.
- Report regularly to Nile COM through Nile TAC on all project matters, including progress, outputs and coordination issues.
- Liaise, through national PSC members, with line ministries and relevant national programmes to ensure that potential synergies are captured.

3. Outputs

Overview of products

Hydro-meteorological monitoring network

The Nile is among the most studied rivers in the world. with records dating back for more than a thousand years (Said, 1993). However, hydro-meteorological monitoring has been declining in recent years. Budgetary constraints and political circumstances have conspired gradually to reduce the extent of the network. The resulting data gaps may hamper the future capacity for informed decision-making regarding the common Nile resource.

The project made an in-depth analysis of the major constraints in hydro-meteorological data acquisition. Vandalism and high operating costs were among the leading causes for declining monitoring activities in the Nile Basin. By introducing modern electronic hydrometric instruments, operating costs were reduced to within the budgetary means of the respective water departments.

Limited funds were made available for extension of the network and the emphasis was on capacity building. A substantial training programme accompanied the introduction of modern monitoring technology. Hands-on national and regional workshops created a core group of trained professionals who are now fully conversant in the installation, operation and maintenance of the new instruments. This core group is small but training was mostly implemented by regional experts thereby building capacity within the basin.

An example was the Acoustic Doppler Current Profiler (ADCP) workshop organized in Jinja, Uganda, in January 2006 where specialists from the Directorate of Water Resources Management in Uganda trained their colleagues from Rwanda in river flow measurement. The workshop illustrated the project policy of training trainers and building on expertise in the Nile countries. This approach was cost-effective and reduced the need for outside support.

Hydrometric monitoring is experiencing fundamental changes because of rapid advances in computer, battery and cellular communication technology. New electronic hydrometric instruments have large internal memories, are small in size, and have low power consumption. Data loggers now routinely include enough memory to store a full year of recordings.

These innovations have a profound impact on monitoring practices. Operating expenses are drastically reduced because monthly field visits – to set a clock or change a chart – are no longer necessary. Electronic data transfer has greatly simplified data processing and quality control. Vandalism is reduced because instruments are portable or can be hidden in stilling wells, owing to their small size. Using the mobile phone network, data can be transferred to the central database on a daily basis.

The project has capitalized on these developments by introducing a carefully selected set of modern electronic hydro-meteorological instruments in all Nile countries. These include:

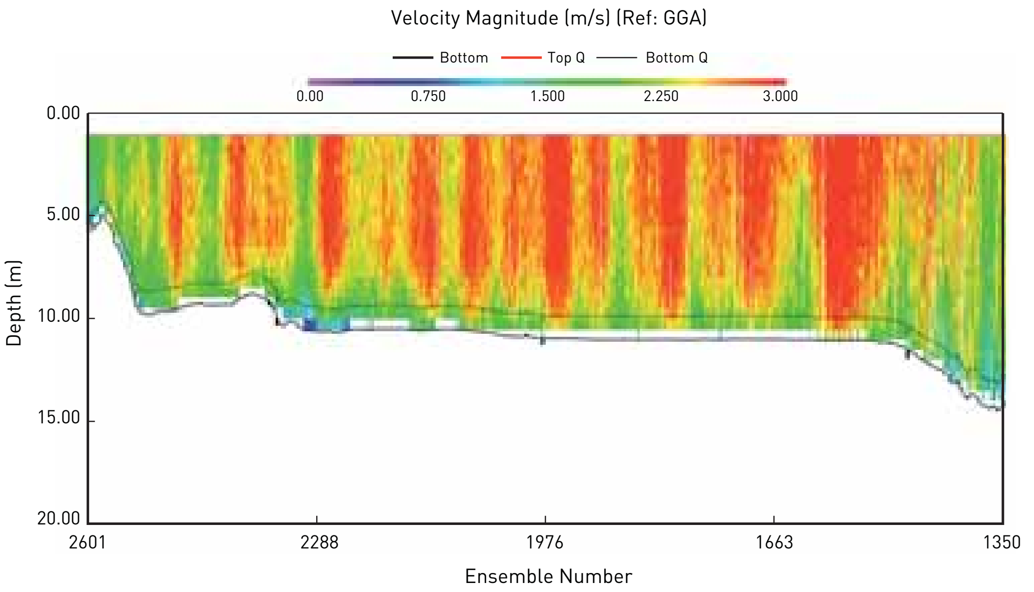
Box 2: ADCP measurement on the Blue Nile in the Sudan during peak flows

The high sediment load in the Blue Nile during the flood season has complicated discharge measurements with the Acoustic Doppler Current Profiler (ADCP). This instrument applies the Doppler effect to measure flow velocities, and automatically calculates total discharge.

ADCP technology has proven effective on the Blue Nile. However, during the annual flood peaks in August and September, sediment concentrations have reached levels that made ADCP operation unreliable.

A methodology was developed and tested to conduct ADCP measurements under high sediment conditions. It recommended a 600 KHz ADCP with a number of peripheral devices, notably a Global Positioning System (GPS) unit, a depth sounder, and a gyrocompass if steel boats are used. Counterpart staff were trained in applying the methodology.

The following figure shows the velocity profile of Blue Nile measurement at Sennar, the Sudan on 10 September 2007. Total flow was 6 900 m^3 per second.



- Acoustic Doppler Current Profiler (ADCP) for river flow measurement (see Box 2);
- Thalimedes shaft-operated water level recorders;
- pressure transducers for water level recording in volatile rivers;
- automatic weather stations;
- automatic evaporation measurement stations on buoys in Lake Nasser.

The experience in the field so far is generally positive, with the vast majority of stations established fully operational. Risks are by and large concerned with staff turn-over and the insufficient computer skills of hydrometric technicians.

Database development

Technical water resources data and socio-economic and environmental information are needed to support informed decision- and policy-making regarding the scarce Nile water resources, and to serve as input into simulation models such as Nile-DST developed under the previous project. Data can be divided into two categories: geo-referenced and non-geo-referenced.

Hydro-meteorological and other water resources data in the Nile countries are of varying quality, stored in different formats, and hosted by a diverse set of national organizations.

The project developed a standard database structure for time-series data, to ensure data consistency and facilitate data exchange. A large set of hydrologic and meteorological data was transferred into electronic format and subjected to systematic quality control.

This was a challenging undertaking. Each Nile country has its own measurement procedures, data format, and policies for quality control. Compiling basin-wide data sets involved reclassifying legends, reinterpreting information, changing units and making assumptions regarding the inevitable data gaps. Historical data were stored in MS Access in a separate file for each country. MS Access is part of the MS Office suite that is available on most PCs. Trained operators are widely available. This off-sets the limitations of MS Access with regard to the upper limit of records it can store. The project made a deliberate choice not to opt for proprietary systems such as HYDATA or more complex software such as MS SQL or ORACLE. The database is designed to be easily expandable in terms of adding both new records or entirely new stations.

At present, there is no information exchange agreement among the Nile riparians, and data remain the property of the respective Nile countries. While FAO Nile has compiled a number of basin-wide data sets, it has not distributed any information to third parties. The project's data requests were referred to the respective national coordinators.

Developing spatial layers is not the prime responsibility of the ministries responsible for water affairs in the Nile Basin. The project therefore focused some attention on digitizing maps and preparing spatial layers (see Box 3). The main thrust was on identifying and collecting existing information from national and international institutions, and assessing its application for informed decision-making. A metadata catalogue was prepared to list web-based data sources useful for water resources planning and management in the Nile Basin. It is available on the attached CD. The inventory documents and describes the attributes and contents of various web-based data sets, along with information on how to obtain the data and the format in which they are presented. It concerns both public domain and proprietary data. The main categories are topographic, climatic and socio-economic.

Common data sets are an important part of the common knowledge base, which is considered an essential prerequisite for a successful negotiation process. This is particularly the case for hydro-meteorological information, which is subject to inherent spatial and temporal variability. Dry spells

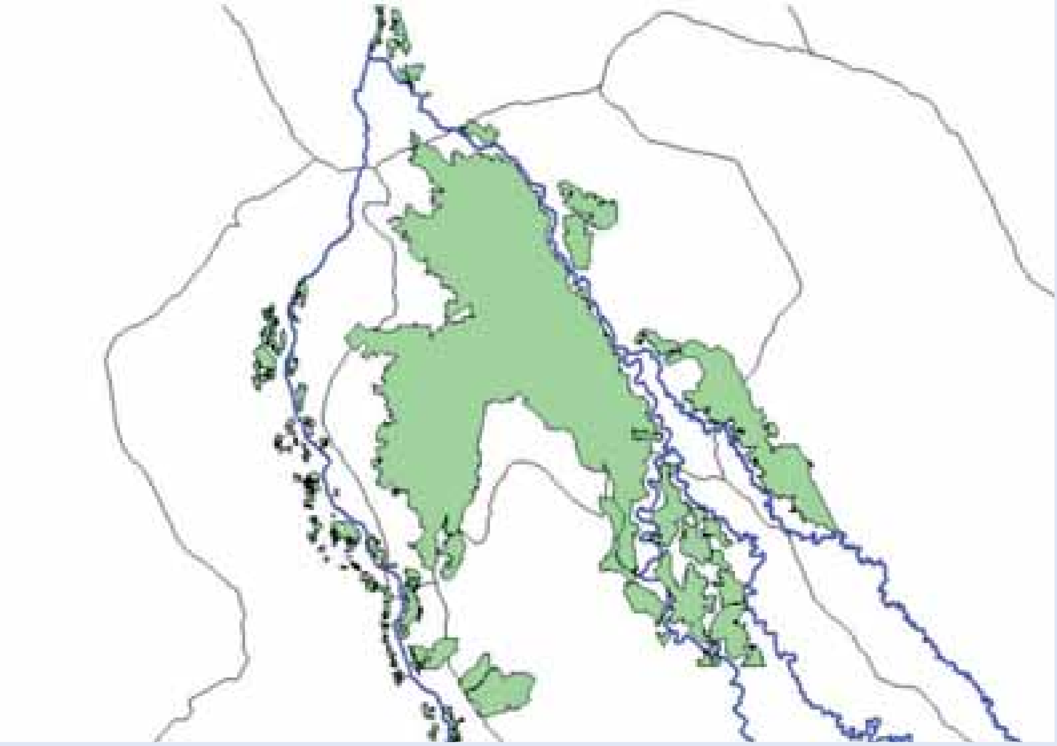
Box 3: Nile Basin irrigation layer

In view of the importance of irrigation in the Nile water balance, special attention was given to the development and validation of a detailed irrigation map. The layer includes the actual geographic locations of the irrigated areas, as well as a set of basic descriptors for each irrigation scheme. These include crop, type of water control, area equipped for irrigation, and area effectively irrigated.

National databases were compared with international datasets and satellite imagery. The latter included FAO–Frankfurt Global Map of Irrigated Areas, AFRICOVER and Landsat. A number of field visits were organized to verify unclear situations.

The map represents the most detailed irrigation layer available in the Nile Basin so far. But it remains work in progress, and the quality of the data sets varies by country. For instance, detailed information for Burundi and the Democratic Republic of the Congo could not be obtained.

The following figure presents part of the irrigation layer for the Sudan. It shows the Gezira and Rahad gravity schemes, the Blue Nile pumping schemes, the White Nile pumping schemes, and the public-private schemes close to Khartoum.



are followed by wet ones. Calculating average river flow for a specific station for different time spans yields different results. As a consequence, modelling a river basin with data sets of different length inevitably leads to different model parameters, and subsequent inconsistencies in trade-off analysis.

The project's database development activity has made a major contribution to establishing shared information sets in the Nile countries. The information also serves to support water resources assessment, planning and management at the national and Nile Basin levels.

Nile Decision Support Tool

Nile-DST is a prototype software that models the entire Nile system and serves to assess the trade-offs and consequences of alternative basin-wide development scenarios. It was developed by the Georgia Water Resources Institute (GWRI) under a contract with FAO during the previous project, and released by Nile COM in February 2003.

Nile-DST consists of three main components: database, interface, and application modules. The latter include the following:

- Nile-DST data analysis tool: This allows the user to build specific algorithms based on the large data set included in the system. Examples are mean-area precipitation, potential evapotranspiration and inflow sequences of particular sub-basins. The results can serve as inputs for the other application modules.
- Nile-DST hydrology module: This uses rainfall and evapotranspiration as inputs to estimate the basin soil moisture index and generate inflow forecasts. The forecasted inflows are used as input in the planning and operational modules. The hydrological models are calibrated for each sub-basin in Nile-DST.
- Nile-DST river simulation – reservoir operation module: Also called the River Basin Management Module, this examines the impact of the Nile system under various operation and development scenarios.
- Nile-DST agricultural planning module: This incorporates crop models and enables the user to develop planting schemes that maximize the utility of normally available precipitation and minimize the use of irrigation to produce crops.
- Nile-DST remote sensing module: This provides access to a large database of remotely sensed infrared, visible and water vapour radiation recorded by METEOSAT. It includes several models for estimating the rate and volume of precipitation falling on the basin from remote sensing data.

The Nile-DST River Simulation and Reservoir Operation (RS-RO) module was updated and the following additional facilities were incorporated in the tool (see Box 4):

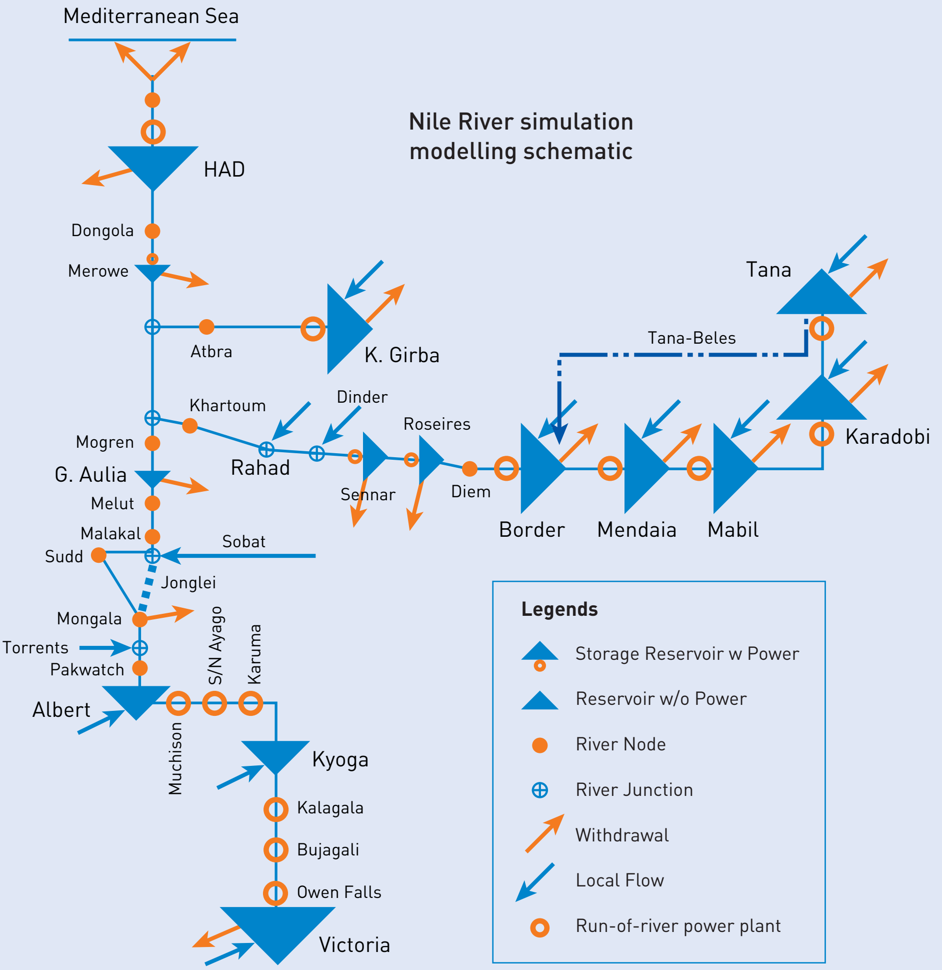
- six potential hydropower facilities in Uganda: Bujagali, Karuma, Kalangala, South Ayago, North Ayago and Murchison Falls;
- Merowe Dam on the main Nile in the Sudan;
- Roseires on the Blue Nile in the Sudan;
- Tana-Beles hydropower facility.

A detailed technical report and user manual were produced for the consolidated RS-RO module. Another report was prepared that documents the Nile-DST system structure. All documents are available on the project CD.

Box 4: Nile-DST RS-RO module

The River Simulation and Reservoir Operation (RS-RO) module is a planning tool for water resources management. It simulates the system responses under different development configurations, regulation policies and hydrologic regimes. The module includes a long-term inflow forecasting model for major tributaries, river routing models and reservoir operation models. It is designed for quick impact assessment of various factors such as water allocation plans, reservoir regulation policies, physical constraints, climate changes, etc.

It includes 14 existing or planned reservoirs, 20 existing or planned hydropower plants, 13 inflow nodes, 16 river nodes, and 15 demand nodes.



A comprehensive capacity building programme accompanied the introduction of the system. It aimed to transfer DST expertise to the Nile countries. The project formulation mission identified a need to internalize and consolidate Nile-DST further.

A Nile-DST training workshop was held in September 2006. It was organized jointly with the SVP Water Resources Planning and Management Project (WRPM) and took place at its office in Addis Ababa, Ethiopia. Participants at the event included counterpart staff from all Nile countries, as well as officers from WRPM, NELSAP and the Eastern Nile Technical Regional Office (ENTRO).

The training focused on using the updated RS-RO module and transferring DST technology to the Nile countries. Prior to the event, a three-week Internet-based training was implemented in which trainees were introduced to basic operation of the different Nile-DST modules. It aimed to prepare the participants for the more rigorous training workshop and create a more level knowledge base.

As a follow-up activity, national Nile-DST workshops were organized in a number of Nile riparians. These events were facilitated by the workshop participants and aimed to expand the user base and encourage widespread use of the tool in relevant agencies. This aimed to address the high turn-over of national Nile-DST experts being experienced in some of the counterpart government agencies.

These activities concluded the project's involvement in Nile-DST. As agreed with the NBI Secretariat, further development of decision support technology in the Nile Basin is being implemented by the SVP WRPM. All Nile-DST activities were handed over to this project.

Project posters

The Nile is among the most studied rivers in the world. A large collection of books, papers, technical reports, tabular data sets and maps resides in libraries across the ten Nile countries or is available on the Internet. But this wealth of information is not easily accessible, if only because of its sheer volume or the way it is presented. Unused data and information are of limited value. To support the public policy process, better means are required to communicate the complex – but existing – information on the dynamics of the Nile system and the factors that drive water demand, to decision-makers and Nile stakeholders alike.

The project opted for a set of posters. Maps and pictures carry very high volumes of data and can be presented on a single page. An appropriate arrangement of images, words and numbers can provide a visual explanation of the Nile hydrology, demographic trends and other relevant aspects of Nile water demand or management. The aim is to make it easier for stakeholders to participate – informed and knowledgeable – in discussion of how to achieve the "shared vision: sustainable socio-economic development through equitable utilization of, and benefits from, the common Nile Basin water resources".

This endeavour builds on powerful GIS software combined with the increasing availability of spatial data sets – many in the public domain and obtained through remote sensing – for the African continent. A GIS integrates, stores, analyses and displays geographically referenced information, together with associated statistics.

The cartographic products combine information from various sources. Typically, they present average information derived from regional and global data sources. Remote sensing is now the prime source of geo-referenced information for traditionally data-scarce regions, such as the Nile Basin. Examples are MODIS and AFRICOVER. When combined with field measurements or local expert knowledge, the information content of maps can increase significantly.

The development of the GIS products built directly on the GIS capacity in the Nile countries established by the project.

The following posters were prepared:

1. Basin and sub-basin delineation in the Nile Basin. This poster sets out the geographic location of the Nile Basin and its sub-basins, as determined by interpretation of available Digital Elevation Models (DEMs). The poster explains the technical issues associated with defining a strict topographic divide in low-lying parts of the basin. It gives updated areas for each of the major sub-basins.

2. Hydrologic regime in the Nile Basin. This poster visualizes the hydrology of the Nile River and shows the relative contributions of the various tributaries to annual Nile flows. The map uses a hill-shaded DEM as background to show the relief of the terrain. Graphs of mean monthly flow at key river sections exhibit the seasonal variability of runoff over the basin. All data presented are obtained from public domain sources.

Similar posters were developed by counterpart staff for relevant sub-basins in their respective national Nile areas. This exercise served several purposes: 1) to quality control hydro-meteorological data sets and identify systematic errors – such as missing months or erroneous units; 2) to train counterpart staff in using GIS for visual explanation; and 3) to provide effective means of explaining the hydrology of the sub-basins to national stakeholders and decision-makers.

3. Water infrastructure in the Nile Basin. This poster shows the location of the main dams, weirs and irrigation systems in the Nile Basin, together with associated information. The poster also presents a selection of planned dams and canals, as proposed by the respective national FPIs.

4. Water balance in the Nile Basin. This poster shows the results of a distributed water balance model used by FAO to assess the impact of irrigated agriculture on river basin flows. Based on a 5 arc minute cell size (approximately 10 km^2 at the Equator), daily rainfall and evapotranspiration data are used to generate outflows at both the country and sub-basin levels. The resulting water balances for each sub-basin are calibrated on mean flows reported by Sutcliffe and Parks (1999). Full details of the model results are given in the FAO Nile Information Products Synthesis Report.

5. Observed biomass production in the Nile Basin. This poster serves to visualize the spatial and temporal variability of vegetation cover and associated rainfall over the Nile region. It also relates annual biomass production to the irrigation volumes withdrawn from the Nile and to total annual rainfall. Biomass production is calculated monthly using the Normalized Difference Vegetation Index (NDVI). The base data are obtained from the orbiting MODIS Terra satellite sensor for the period 2000 to 2004. For all Nile countries annual rain volumes and biomass production are calculated and represented by proportional circles, which are drawn to the scale of the map. The green area represents total vegetation growth under rainfall while the blue area is the amount of biomass from stream flow. As can be observed, large parts of Egypt and the Sudan (the Sahara Desert) have no vegetation at all. On the other hand, the Lake Victoria region is covered with vegetation throughout the year, so is the Sudd in southern Sudan. This poster clearly indicates where water is the main constraint to vegetation growth. It should be noted, however, that it does not consider the quality of the vegetation.

6. Population prospects in the Nile Basin. This poster presents two images of human population distribution in the Nile countries: an estimate for 2005, and a projection for 2030. Landscan 2004 provided the geo-referenced base layer. It was combined with the medium demographic growth variant for 2030, obtained for each Nile country from UNDESA. The poster shows the high population densities in the Lake Victoria region, the Nile delta and valley, the Ethiopian highlands, and around Khartoum. Outside the Nile valley, large areas of the Democratic Republic of the Congo, Eritrea, Kenya, the Sudan and the United Republic of Tanzania are sparsely populated. This poster shows that the settlement pattern in the lower riparians follows the Nile, while in the upper riparians it tends to follow – broadly – rainfall distribution.

7. Farming systems in the Nile Basin. A set of farming systems have been derived from an interpretation of land cover classes from Global Land Cover 2000 project (http://bioval.jrc.ec.europa.eu/products/glc2000/products.php) and the typology prepared by FAO and World Bank (2001) Farming Systems and Poverty. Rome and Washington DC 412pp. The resulting map supplements a Synthesis Report prepared on the basis of individual country farming systems prepared by each country in the basin. Across the basin, the influence of altitude and decreasing rainfall away from the equator determine the progression of agro-ecological 'opportunity', conditioned by geological and geomorphological influence on soil types. Superimposed upon this physical potential is the practice of agriculture which range from deeply traditional hunter-gatherer systems in equatorial forest and agro-pastoral cultures in central Suday to precision irrigation in the Nile Delta. The clustering of rural population in Lake Victoria basin and the Ethiopian highlands is associated with very mixed farming systems. Away from the highlands in the eastern Nile, population and farming systems follow the water . Some of these systems are becoming progressively adapted with technological change. Access to groundwater in the traditional livestock trekking routes in the central basin has expanded and sustained cattle production. Mechanised rainfed farming in central Sudan have also seen the impacts on yields – when rainfall permits.

8. Agricultural trade in the Nile countries. This poster shows the balance of trade for agricultural commodities in the ten Nile riparians, expressed in monetary values. Total exports and imports per country have been averaged over the period 2000 to 2004, with the objective of attenuating annual price and production swings caused by weather and market conditions. The values were obtained from FAOSTAT and represent the entire countries – not only the Nile Basin parts. All riparians except Kenya, the United Republic of Tanzania and Uganda have trade deficits. The poster should provide a first indication of market opportunities for agricultural commodities in the Nile Basin. Also presented are figures on trade flow. These show that inter-basin trade of agricultural produce is very limited.

9. Agricultural outcomes in the Nile Basin. This poster visualizes the extent of the Food for Thought (F4T) scenario set. To maximize the spread of a scenario set – to capture a wider range of the future – stories are developed at the extreme corners of a two-dimensional scenario space. F4T is based on two polar axes: 1) international trade regime; and 2) quality of governance. These represent the factors that were classified by the scenario team as both "most influential" and "most uncertain". The stories –presented in abbreviated versions – describe how the world may move from the current situation to arrive at very different, but plausible, futures. The scenario names describe the main dynamics. An influence diagram accompanies each story to illustrate the system dynamics. It is important to note that the four scenarios should be used as a set, with none considered more likely than the others.

10. Nutritional requirements in the Nile Basin for 2030. This poster presents a realistic range of food supply requirements in the Nile Basin for 2030. The approach combines information from three main sources: 1) demographic prospects by UNDESA; 2) nutrition trends and statistics reported by FAO; and 3) the F4T scenario set, which concerns a systematic and participatory analysis of key drivers and influencers regarding the agricultural demand function in the Nile Basin. The posters show baseline figures for 2030, the assumptions of the key state variables for each scenario, and the annual calorie requirements for 2030, by country.

Rwenzori poster series. The year 2006 marked the centenary anniversary of the climbing of the Rwenzori by a scientific expedition headed by Luigi di Savoia, the Duke of Abruzzi. The Embassy of the Republic of Italy in Uganda organized a scientific conference and other festivities to commemorate this event. The project prepared four posters for the conference and celebrations, illustrating:

- geography and geology of the Rwenzori mountain range;
- land cover of the Rwenzori mountains and surroundings, derived from AFRICOVER;
- glacier retreat in the period 1906 to 2005;
- various satellite images of the Rwenzori mountains.

Using a Shuttle Radar Topography Mission (SRTM)-DEM data set laid over satellite images, the project also prepared a brief fly-over video showing the topography of the Rwenzori mountains and the Rift Valley.

BASIN AND SUB-BASIN DELINEATION IN THE NILE BASIN

Nile basin and sub-basin delineation by digital elevation models

About this poster

[illegible]

Figure 1: Different Nile basin delineations

[illegible]

[illegible]

[illegible]

Table 1: Principal Nile sub-basin areas

[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
TOTAL			[illegible]

Information Products for Nile Basin Water Resources Management GCP/INT/945/ITA

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[illegible]

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HYDROLOGIC REGIME IN THE NILE BASIN

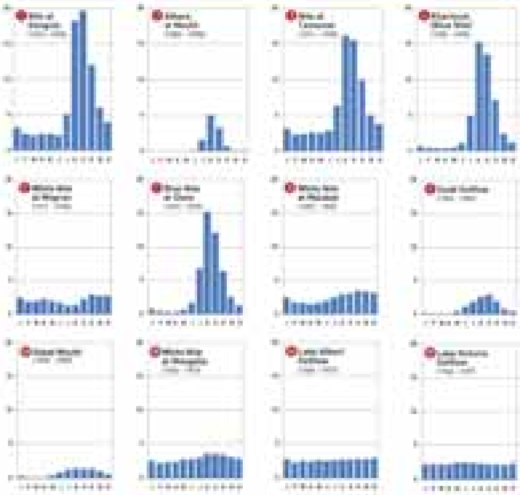
Mean annual flow of the Nile and main tributaries upstream of Lake Nasser

About this poster

This poster presents the average annual flow of the Nile and its main tributaries upstream of Lake Nasser. Downstream of this point, no new tributaries join the Nile system after Atbara, and Lake Nasser outflow is fully regulated. All data presented on this poster has been obtained from Sutcliffe and Parks (1999) "The hydrology of the Nile". When comparing the relative contributions of the various Nile components, it should be remembered that average annual discharge at key sections was calculated from flow records of different length and periods. Full details of the basin hydrology are given in the project 'Synthesis Report'.

It should also be noted that the 1959 Nile agreement apportions 55.5 km³ to Egypt and 18.5 km³ to Sudan. ... This was calculated in proportion to population at the time and based on a mean annual flow of 84 km³ at Dongola/Aswan inflow less 10 km³ of reservoir evaporation.

Mean monthly flow in cubic kilometers (km³) at key stations (numbers indicated on map)



Mean annual flow in cubic kilometers (km³) at key stations (numbers indicated on map)

N°	River and Station Name	Data Period	Avg Ann Flow (km³)
1	**Main Nile at Dongola**	1890 - 1990	86.1
2	**Atbara at mouth**	1903 - 1996	11.1
3	**Main Nile at Tamaniat**	1911 - 1995	72.7
4	**Blue Nile at Khartoum**	1900 - 1995	48.3
5	**White Nile at Mogren**	1911 - 1995	26.0
6	Dinder at mouth	1907 - 1997	2.8
7	**Blue Nile at Diem**	1912 - 1997	48.7
8	**White Nile at Malakal**	1905 - 1997	29.7
9	**Sudd Outflow**	1905 - 1983	16.1
10	**Sobat at Hillet Doleib**	1905 - 1983	13.5
11	Baro at Gambela	1905 - 1959	12.2
12	Baro at mouth	1929 - 1963	9.5
13	Lol at Nyamlel	1944 - 1985	3.2
14	Jur at Wau	1942 - 1986	4.5
15	**Bahr el Jebel at Mongalla**	1905 - 1977	36.0
16	**Lake Albert outflow**	1940 - 1977	32.8
17	Semliki at mouth	1940 - 1977	4.4
18	Lake Kyoga outflow	1940 - 1977	29.5
19	**Lake Victoria outflow**	1940 - 1977	28.6
20	Kagera at Ruska Ferry	1940 - 1978	6.5
21	Setit at Kunbur	-	7.0
22	Atbara at Wad el Hilaiw	-	4.9
23	Rahad at mouth	1908 - 1997	1.1
24	Akobo (incl. Gila & Mokwai)	-	2.8
25	Pibor	-	1.8
26	Bahr el Ghazal R. [illegible]	1937 - 1966	0.3
27	Bahr el Arab	-	0.2
28	Pongo	-	0.6
29	Tonj	1944 - 1980	1.6
30	[illegible]	1940 - 1977	0.5

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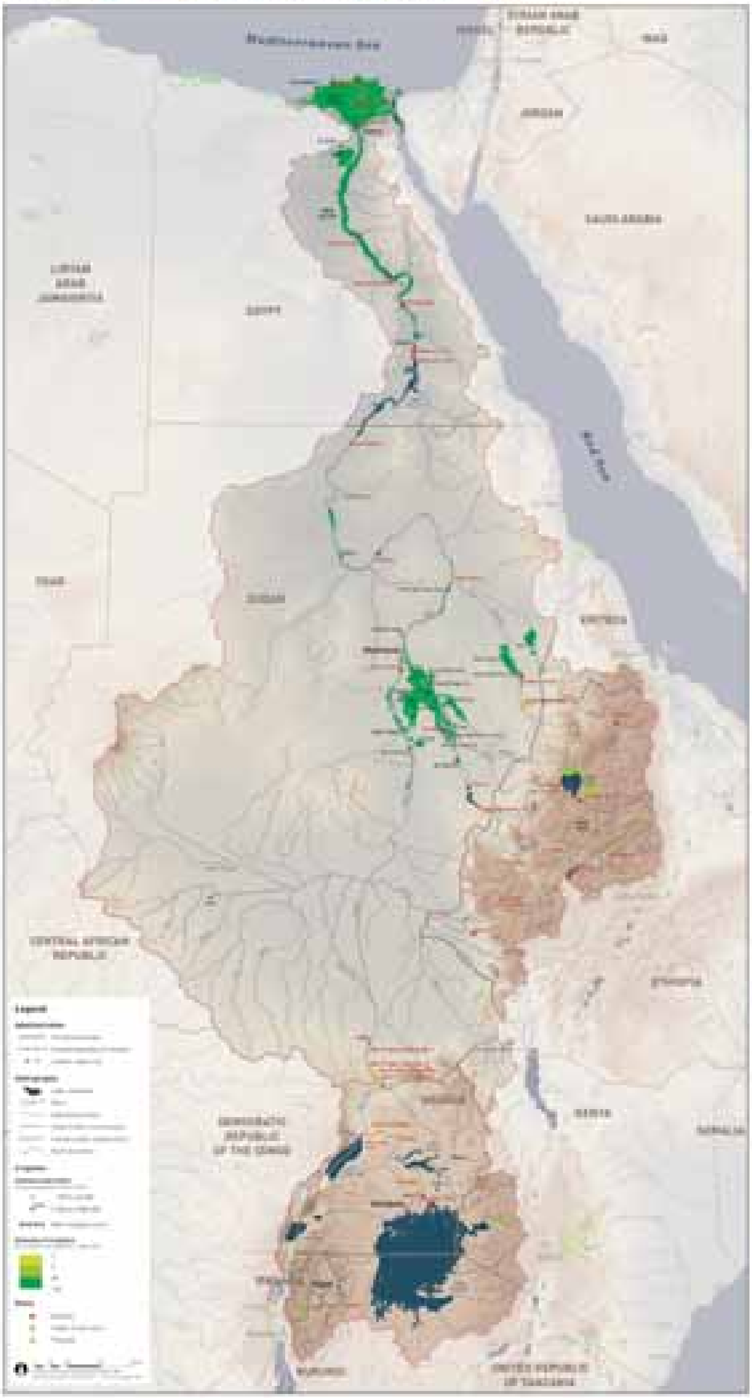
WATER INFRASTRUCTURE IN THE NILE BASIN

Existing dams and main irrigation areas



About this poster

[illegible]

Existing dams in the Nile basin

Dam name	Country	Crest Height (m)	Reservoir Capacity (km³)	Purpose	Operational since
Assiut barrage	Egypt	14	NA	irrigation, navigation	1902
Esna barrage	Egypt	14	NA	irrigation, navigation	1902
High Aswan Dam	Egypt	111	162	irrigation, flood control, hydropower	1970
Nag Hammadi barrage	Egypt	14	NA	irrigation, navigation	1930
Old Aswan dam	Egypt	53	5	irrigation, hydropower	1902
[illegible]	Ethiopia	56	[illegible]	irrigation	1995
Fincha'a	Ethiopia	20	0.65	irrigation	1973
Tana Beles	Ethiopia	run of river	-	hydropower	2010
Tekeze	Ethiopia	188	9	hydropower	2009
Tis Abay I + II	Ethiopia	run of river	[illegible]	hydropower	1953/2001
Jebel Aulia	Sudan	22	3.5	irrigation, hydropower	1937
Khashm El Girba	Sudan	70	1.3	irrigation, hydropower	1964
Merowe	Sudan	67	12.5	irrigation, hydropower	2009
Roseires	Sudan	68	3	irrigation, hydropower	1966
Sennar	Sudan	40	0.93	irrigation, hydropower	1925
Bujagali	Uganda	30	[illegible]	hydropower	2011
Owen Falls	Uganda	30	204*	irrigation, hydropower	1954

* additional capacity on lake Victoria

Equipped Irrigation Areas (ha)

Burundi	[illegible]
Dem. Rep. of the Congo	0
Egypt	[illegible]
Eritrea	[illegible]
Ethiopia	[illegible]
Kenya	[illegible]
Rwanda	[illegible]
Sudan	[illegible]
Tanzania	[illegible]
Uganda	[illegible]
Total	**[illegible]**

Proposed dams in the Nile basin

Dam name	Country
Baro multi-purpose dam	Ethiopia
Grand Millenium	Ethiopia
Karadobi	Ethiopia
Mabil	Ethiopia
Mendaia	Ethiopia
Rusumo	Rwanda
Bahr El Jebel - Bedden Dam	Sudan
Bahr El Jebel - Lakki Dam	Sudan
Bahr El Jebel - Shukoli Dam	Sudan
Bahr El Jebel - Fula Dam	Sudan
Fifth Cataract - Shereiq Dam	Sudan
Second cataract - Dal Dam	Sudan
Third cataract - Kajbar Dam	Sudan
Kalagala	Uganda
Karuma	Uganda
Murchison Falls	Uganda
South-North Ayago	Uganda

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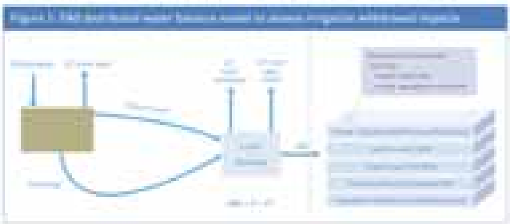
WATER BALANCE IN THE NILE BASIN

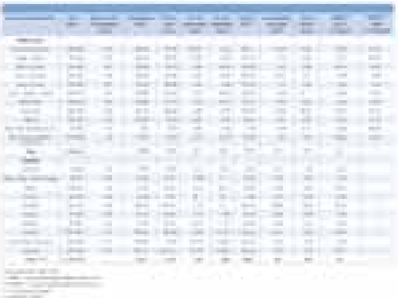
Components of Natural and Actual Water Balances by Sub-Basin and Country

About this poster

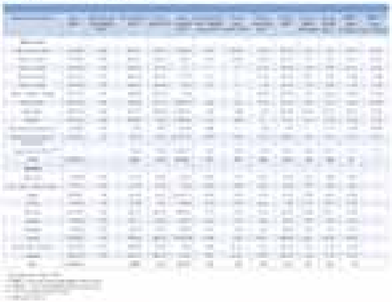
This poster shows the results of a distributed water balance model used by FAO to assess the impact of irrigated agriculture on river basin flows. Based on a 5 arc minute cell size (approximately 10 km² at the equator), daily rainfall and evapotranspiration data are used to generate outflows at both country and sub-basin level. The resulting water balances for each sub-basin are calibrated on mean flows reported by Sutcliffe and Parks (1999) "The Hydrology of the Nile". Full details of the model results are given in the FAO Nile Information Products Synthesis Report.



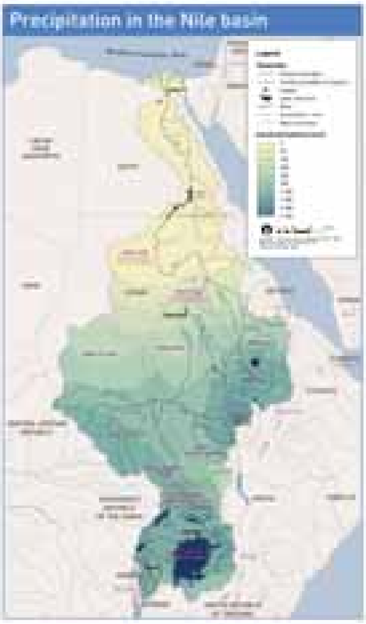
Natural Water Balance



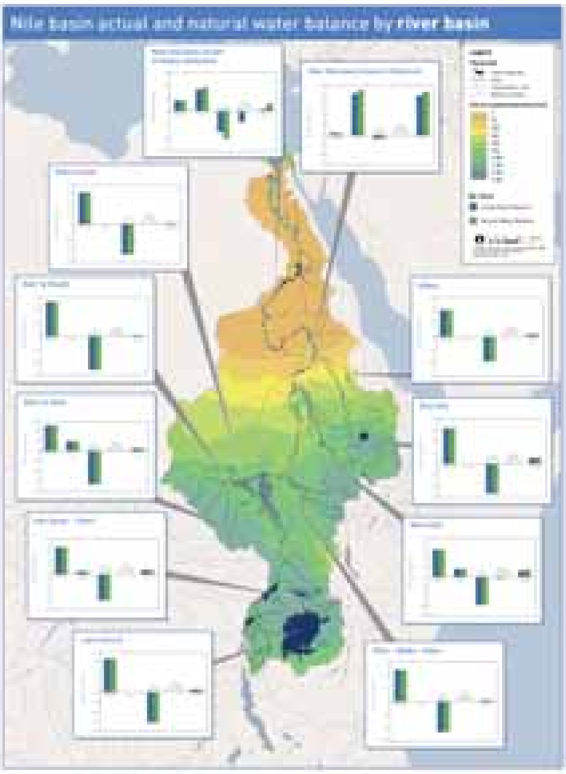
Actual Water Balance



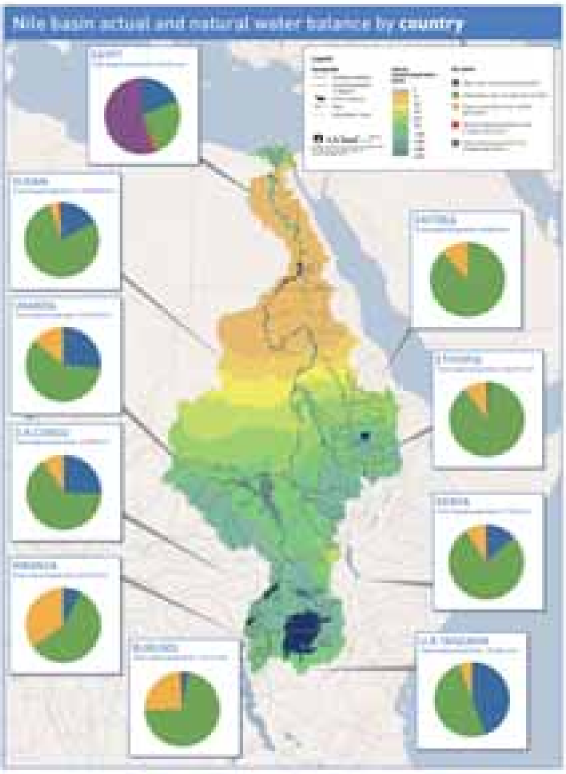
Precipitation in the Nile basin



Nile basin actual and natural water balance by **river basin**



Nile basin actual and natural water balance by **country**



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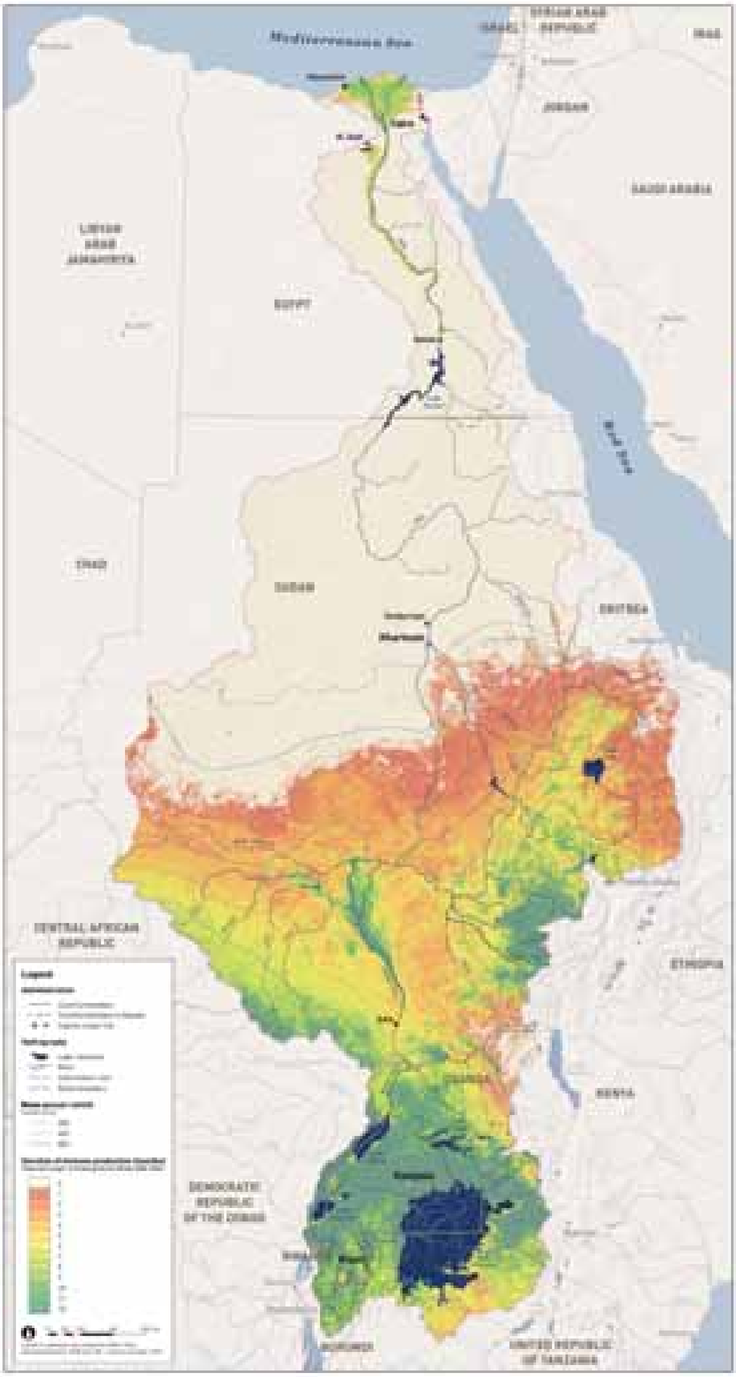
OBSERVED BIOMASS PRODUCTION IN THE NILE BASIN

Spatial relationship between precipitation and biomass (2000 - 2004)



About this poster

This poster shows the spatial distribution of observed biomass production in the Nile Basin.

Biomass production is obtained through photosynthesis, a process in which water is extracted from the soil by plant roots and 'evapo-transpired' into the atmosphere. In most cases, soil water is derived from direct precipitation falling to the ground and stored in the rootzone. In other cases, soil water is derived from natural inflows, either through diversion of streamflow for irrigation or through natural seepage processes, such as in the case of swamps and wetlands.

Biomass production has been calculated using satellite remote sensing data from MODIS Terra over the period 2000-2004, using the Normalized Difference Vegetation Index (NDVI). NDVI is a simple numerical indicator that can be used to analyze remote sensing measurements and assess to what extent the target area being observed contains live green vegetation. The NDVI was calculated on a monthly basis and subsequently expressed as cumulative green area per year. A typical NDVI threshold was applied to distinguish between healthy growing vegetation and other conditions.

Monthly progression of rainfall and biomass production across the Nile Basin

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POPULATION PROSPECTS IN THE NILE BASIN

2005 Estimates

[illegible]

2030 Projections

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Country	2005 ('000)	Nile Basin 2005 ('000)	Nile Basin 2030 ('000)
Burundi	[illegible]	[illegible]	[illegible]
DRCongo	[illegible]	[illegible]	[illegible]
Egypt	[illegible]	[illegible]	[illegible]
Eritrea	[illegible]	[illegible]	[illegible]
Ethiopia	[illegible]	[illegible]	[illegible]
Kenya	[illegible]	[illegible]	[illegible]
Rwanda	[illegible]	[illegible]	[illegible]
Sudan	[illegible]	[illegible]	[illegible]
Tanzania	[illegible]	[illegible]	[illegible]
Uganda	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]

[illegible]

Country	2030 Low Variant ('000)	2030 Medium Variant ('000)	2030 High Variant ('000)
Burundi	[illegible]	[illegible]	[illegible]
DRCongo	[illegible]	[illegible]	[illegible]
Egypt	[illegible]	[illegible]	[illegible]
Eritrea	[illegible]	[illegible]	[illegible]
Ethiopia	[illegible]	[illegible]	[illegible]
Kenya	[illegible]	[illegible]	[illegible]
Rwanda	[illegible]	[illegible]	[illegible]
Sudan	[illegible]	[illegible]	[illegible]
Tanzania	[illegible]	[illegible]	[illegible]
Uganda	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]

[illegible]

Country	2005 Urban ('000)	2030 Urban ('000)	2030 Rural %
Burundi	[illegible]	[illegible]	[illegible]
DRCongo	[illegible]	[illegible]	[illegible]
Egypt	[illegible]	[illegible]	[illegible]
Eritrea	[illegible]	[illegible]	[illegible]
Ethiopia	[illegible]	[illegible]	[illegible]
Kenya	[illegible]	[illegible]	[illegible]
Rwanda	[illegible]	[illegible]	[illegible]
Sudan	[illegible]	[illegible]	[illegible]
Tanzania	[illegible]	[illegible]	[illegible]
Uganda	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	

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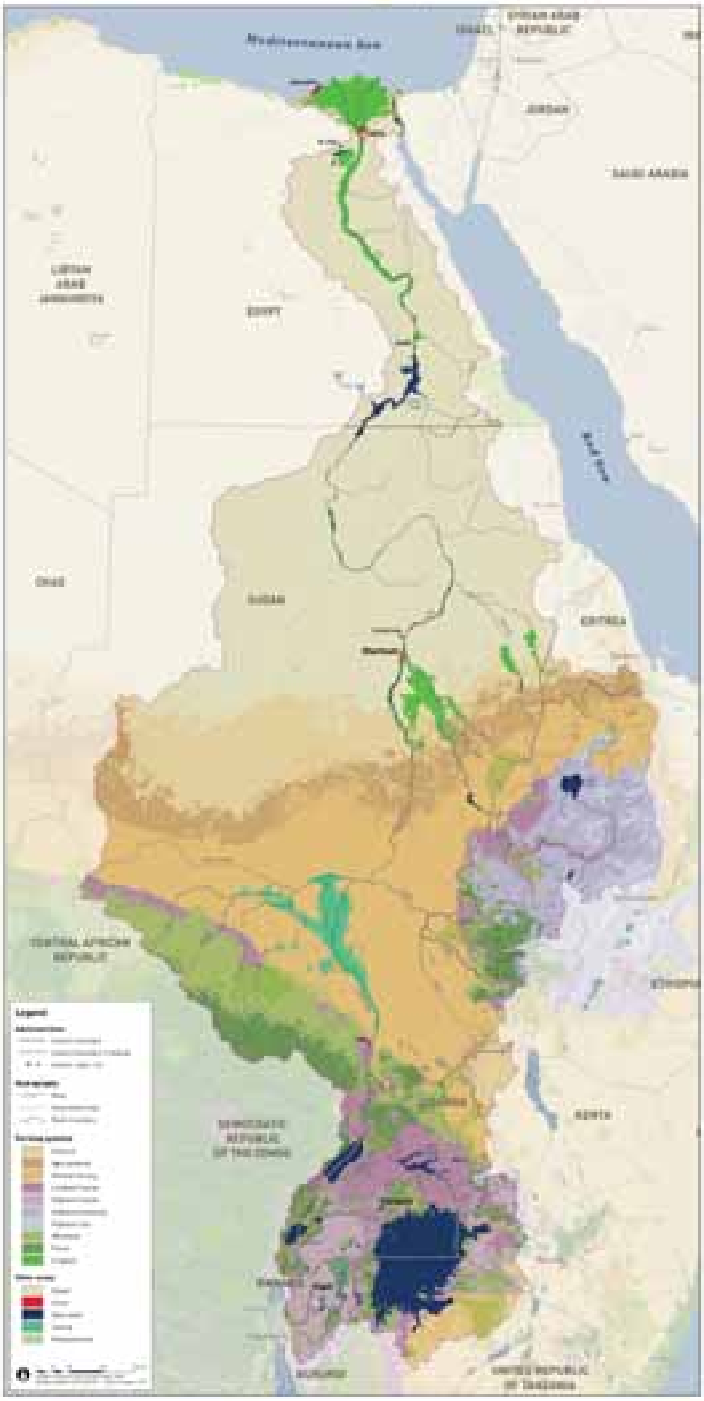
FARMING SYSTEMS IN THE NILE BASIN

Areal distribution of farming systems



About this poster

[illegible]

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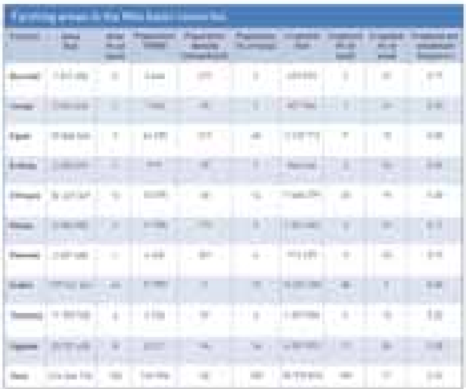

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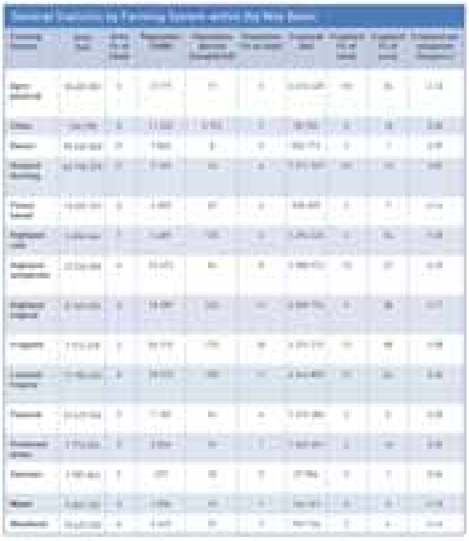

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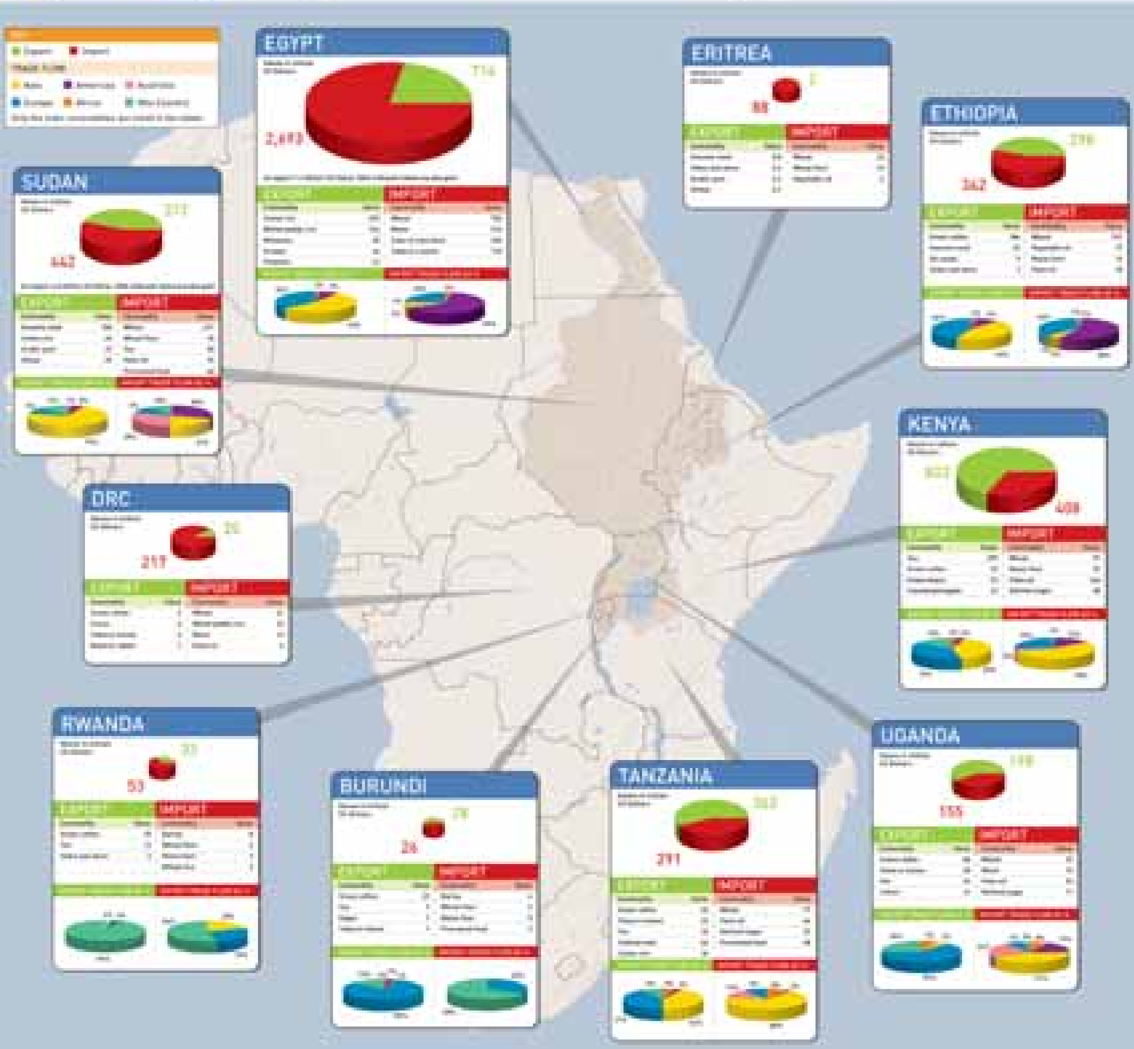
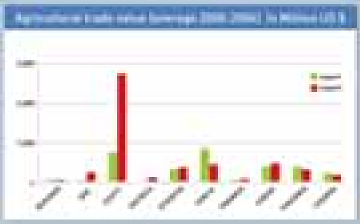
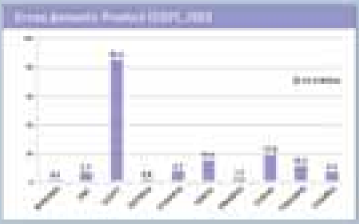
AGRICULTURAL TRADE IN THE NILE COUNTRIES

Export and Import of Agricultural Commodities (Average 2000-2004)




Agricultural trade value (average 2000-2004) in Million US $


Gross Domestic Product (GDP) 2003


Composition of GDP 2003

Information Products for Nile Basin Water Resources Management GCP/INT/945/ITA

burundi d.r.congo egypt eritrea ethiopia kenya rwanda sudan u.r.tanzania uganda

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A project sponsored by the Government of Italy

AGRICULTURAL OUTCOMES IN THE NILE BASIN FOR 2030

Four Scenarios Based on the "TRADE - GOVERNANCE" Framework

About this poster

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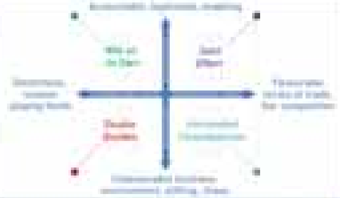


① Nile on its Own

Regional trade grows owing to improved Nile governance and limited international agricultural trade prospects

INFLUENCE DIAGRAM

PRESENT DAY

2030

[illegible]

② Joint Effort

Robust governance and improved international agricultural market opportunities propel Nile countries into the middle class

INFLUENCE DIAGRAM

PRESENT DAY

2030

[illegible]

ACCOUNTABLE, LEGITIMATE, ENABLING

DISTORTIONS, UNEVEN PLAYING FIELDS

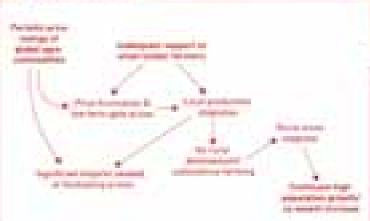
FAVOURABLE TERMS OF TRADE, FAIR COMPETITION

UNFAVOURABLE BUSINESS ENVIRONMENT, STIFLING, CHAOS

③ Double Burden

Ineffective governance and unfavourable international trade conditions conspire to impede agricultural development and keep Nile countries in poverty

INFLUENCE DIAGRAM



PRESENT DAY

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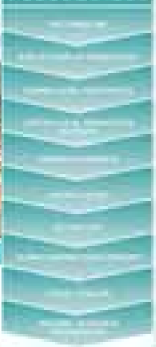
④ Unintended Consequences

Nile countries suffer high food prices when they fail to increase their agricultural output after OECD countries end surplus production

INFLUENCE DIAGRAM

PRESENT DAY



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Information Products for Nile Basin Water Resources Management GCP/INT/945/ITA

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NUTRITIONAL REQUIREMENTS IN THE NILE BASIN FOR 2030

Four Scenarios Based on the "TRADE - GOVERNANCE" Frame

About this poster

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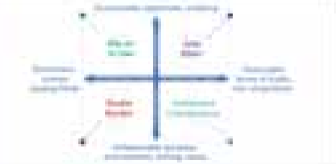
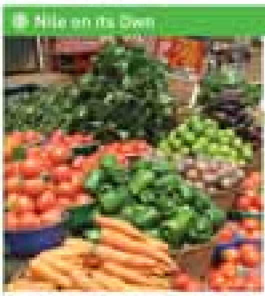


① Nile on its Own



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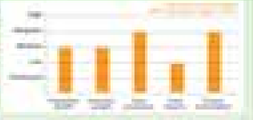

END STATE

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Food requirements for the Nile basin area in 2030

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② Joint Effort

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END STATE

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Food requirements for the Nile basin area in 2030

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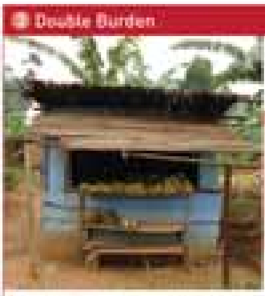
ACCOUNTABLE, LEGITIMATE, ENABLING

DISTORTIONS, UNEVEN PLAYING FIELDS

FAVOURABLE TERMS OF TRADE, FAIR COMPETITION

UNFAVOURABLE BUSINESS ENVIRONMENT, STIFLING, CHAOS

③ Double Burden



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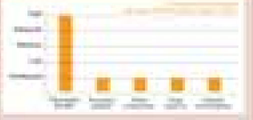

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Food requirements for the Nile basin area in 2030

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④ Unintended Consequences

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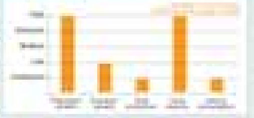

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Food requirements for the Nile basin area in 2030

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Information Products for Nile Basin Water Resources Management GCP/INT/945/ITA

burundi d.r.congo egypt eritrea ethiopia kenya rwanda sudan u.r.tanzania uganda

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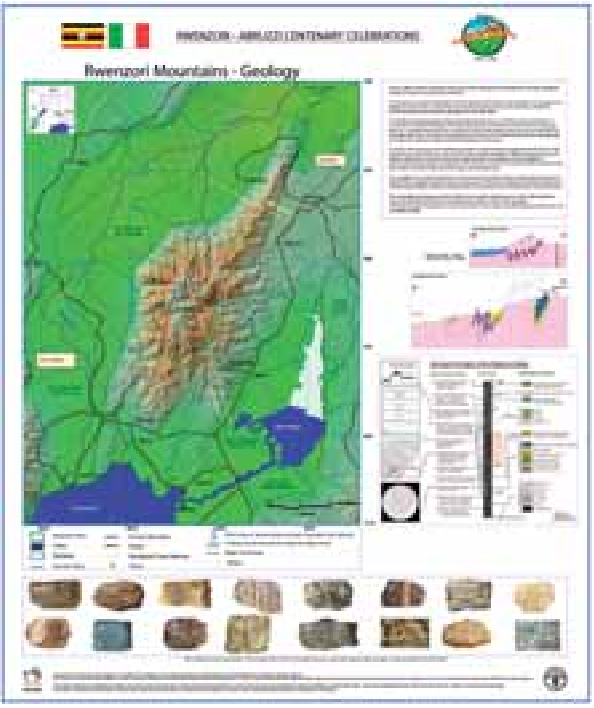
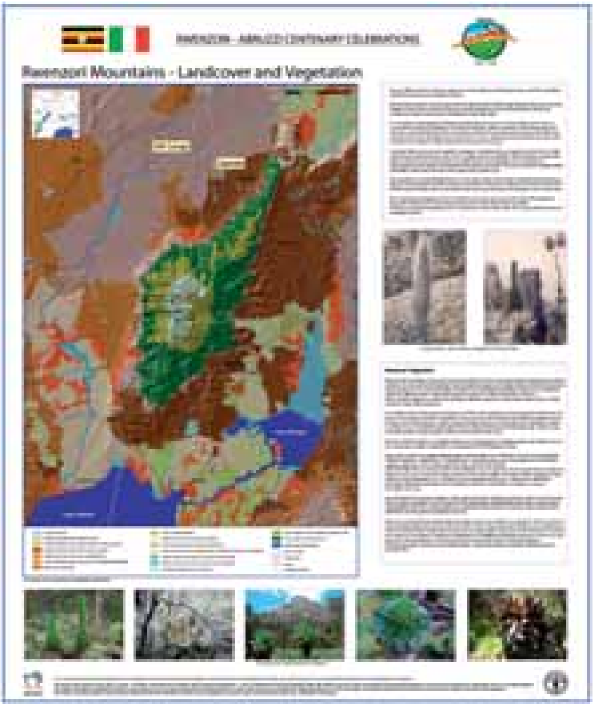


RWENZORI - ABRUZZI CENTENARY CELEBRATIONS

Rwenzori Mountains - Geology



RWENZORI - ABRUZZI CENTENARY CELEBRATIONS

Rwenzori Mountains - Landcover and Vegetation

RWENZORI - ABRUZZI CENTENARY CELEBRATIONS

Rwenzori Mountains - Glacier Retreat 1906-2005

RWENZORI - ABRUZZI CENTENARY CELEBRATIONS

Rwenzori Mountains - Satellite Images

Agricultural production database and water productivity analysis

The twin objectives of food security and rural development are high on the agenda in the Nile countries. Although Kenya, the United Republic of Tanzania and Uganda are net exporters, all Nile countries import very large quantities of food, almost exclusively from outside the region. Hence vast sums of money are leaving the basin instead of supporting the rural economy. This seems contradictory to national policies to foster rural development. A regional food economy could create new links among the Nile countries, to expand the common ground, and would make it easier to reach a negotiated solution of Nile issues.

The first question that arises concerns the scope for increasing production. Has the ceiling been reached? If so, is this because of biophysical constraints? Is there still room for expansion?

A baseline survey aimed to determine the current state of agriculture in the Nile Basin. Data on cultivated areas, yield and production for the most important crops were collected at the district level by teams of national consultants. Cropping calendars were added to enable an assessment of evapotranspiration. Data obtained vary in quality, reflecting the differences in data acquisition and accessibility among the riparians. However, the resulting agricultural production data set is among the most comprehensive currently available in the basin.

As previously discussed, special attention was given to the development and validation of a detailed irrigation map. The layer includes the actual geographic locations of the irrigated areas, as well as a set of basic descriptors for qualifying the irrigation schemes. In particular, a substantial digitizing effort produced a comprehensive irrigation layer for the Sudan, which has the largest area equipped for irrigation in the Nile Basin excluding Egypt.

Combining the agricultural statistics with information on rainfall and potential evapotranspiration, an analysis was made of water productivity in agriculture in the basin and presented in the companion Projections Report (FAO, 2009d).

Farming system survey

A farming system survey was initiated to identify the full set of constraints to agricultural production in the Nile Basin.

Farmers in the basin operate in a diverse environment (biophysical, social and institutional), which makes analysis very complex. A concept of typology is used to cope with this diversity. Criteria for identifying similar farms are based on observations and/or secondary information. Farms are then grouped into similar types. Farms in each typology (recommendation domain) are assumed to face similar environments and to benefit from the same interventions.

Typical farming systems in Nile Basin States are identified and mapped, and their predominant features presented. Agricultural statistics are then collected and analysed for each distinct farming system.

To implement the survey, teams of national consultants undertook the following tasks:

- studying the objectives and resources of the farmers: the biophysical (i.e., technical) and socio-economic (i.e., human) environments in which farm households operate;
- identifying the constraints that limit

farm productivity and production and hinder the welfare of farm households;
- identifying possible solutions to these constraints;
- estimating expected gains in productivity and number of potential beneficiaries if proposed solutions (policy and/or technology) are implemented.

A wealth of information is held at the project office, taken from the national reports received. Work is ongoing to synthesize the results and summarize measures for increasing agricultural productivity.

Food for Thought (F4T) scenario set

Within the context of high demographic growth rates and increasing pressure on land and water resources, food security is a critical concern for policy-makers in the Nile Basin. The region has dominant rural populations, many of whom are engaged in agricultural activities. A high proportion of the rural population in the upstream riparians depends on rainfed subsistence farming for its livelihood. Because of their poverty, these people are effectively cut off from access to international food markets.

Within this setting, and taking into account that agriculture uses more than 80 percent of the renewable water resources in the basin, Nile decision-makers have to base water resources and agricultural development policies on a plausible assessment of future demand for agricultural produce.

FAO Nile engaged in a scenario building exercise to examine the agricultural demand function in the Nile Basin for the horizon year 2030. By adopting a scenario approach, it explicitly acknowledged the inherent uncertainties associated with the future. Four alternative but plausible scenarios were produced and the associated food requirements quantified.

The F4T scenario exercise concerned a highly interactive process. Built by a core group of some 25 participants from all Nile countries, it evolved into a tool for a systematic and multi-stakeholder analysis of the complex rural development question in the Nile Basin.

Scenario thinking aims to engage decision-makers in systematic thinking through of the implications and options for the future. By asking the "what if" question from multiple perspectives, a set of options for the future are obtained for each scenario, but also – collectively – across all the scenarios. This will give a feel for robust options, risky options, "tickets to ride", what to avoid, what to do together, timing, etc.

F4T was well received. Over time, confidence grew that the group's scenarios – as a set – were both highly plausible and highly relevant. It provided fresh insights regarding the dynamics and underlying structure of the subject matter, notably rural development.

The F4T scenario exercise is discussed in more detail in the chapter on Prospects for the future and detailed results are presented in the companion F4T Report.

Land cover to land use

Land cover is the physical material at the surface of the earth. It includes grass, asphalt, trees, bare ground, water, etc.

Land cover is distinct from land use. Land use is a description of how people utilize the land and for which social-economic activities. Typical high-level land-use classes are urban or agricultural uses. Agriculture comprises a wide variety of land-use classes, ranging from – for instance – small plots with mixed maize and beans to large-scale commercial irrigated sugar cane.

For an accurate estimation of crop evapotranspiration, it is not sufficient to know which areas are used for agricultural activities. Information on crop types, cropping patterns and calendars is also required. This level of detail is generally not available, certainly not at the Nile Basin scale.

The FAO AFRICOVER project has produced a land cover layer – with associated database – for nine out of ten Nile countries at 1:200 000 scale (1:100 000 for Burundi, Eritrea and Rwanda). Only Ethiopia did not participate in AFRICOVER. The land cover database indicates lands used for agricultural activities but does not specify which crops. However, it can be observed that agricultural practices in areas with similar environmental and socio-economic characteristics are quite uniform. Hence, by combining sub-national agricultural statistics with the AFRICOVER layer, it is usually possible to acquire appropriate land-use information that leads to a better estimation of agricultural water use.

The project developed a comprehensive methodology to convert land cover to land use. It integrates expert knowledge on cropping activities with district statistics and the AFRICOVER database. It also incorporates information on vegetation dynamics derived from the MODIS TERRA satellite. The methodology identifies all probable areas of cultivation, their topographic and physiological limitations, and subsequently disaggregates lumped crop statistics – in an iterative process – into the relevant land cover polygons. Anomalies may occur owing to inaccurate or incomplete data. However, this process results in a spatially and temporally distributed grid that represents the average land use of the area.

Land-use layers with a 90 x 90 m resolution were prepared for Ethiopia, the Sudan and Uganda.

Multimedia products

Three multimedia products were developed. Multimedia products combine various information formats and let the user access increasingly detailed information. For instance, when moving the cursor over an illustration, explanatory text can emerge. Users can also determine their own paths through the information ensemble. Multimedia products have proven effective in education and information dissemination.

F4T scenario logics: These describe the causal system that determines the agricultural demand function in the Nile Basin. The scenario logics were used as backdrop to examine pertinent policy questions at the series of F4T workshops. However, communicating the scenario logics to a new audience proved time-consuming and laborious. A better tool was needed. A multimedia F4T product was developed that guides users through the scenario set and provides detailed information for the various elements of the diagram. Users can now study the scenario set and logic in advance, and arrive better prepared at the workshops.

Temporal and spatial variation of biomass in the Nile Basin: This presents a sequence of 12 successive monthly images of vegetation cover in the Nile Basin, as observed by MODIS TERRA. For each month, the average was calculated for the 2000 to 2004 time frame.

The user can observe how the vegetation patterns expand and contract through the seasons, which areas have perennial vegetation cover, and which are permanently barren. A similar product was made to show average monthly rainfall.

From producer to consumer – some constraints in agricultural production and trade: This photo series follows agricultural produce from the field around Mbale, eastern Uganda, to the markets in Kampala. It aims to illustrate some of the non-biophysical constraints to agricultural production.

All multimedia products were produced in Macromedia Flash and are available on the project Web site.

Training manuals, publications and reports

A total of 19 manuals were developed and are available on the project CD. They are listed in Table 1.

Three articles were prepared:

1. Supporting the Nile Basin Shared Vision with Food for Thought: Jointly Discovering the Contours of Common Ground;
2. Quantifying Nutrition Requirements in the Nile Basin for 2030 Using a Scenario Approach;
3. Sustainable Hydro-meteorological Data Acquisition in the Nile Basin through the Introduction of State-of-the-Art Monitoring Technology.

Table 1: Training manuals, publications and reports

No.	Title	Description
	Hydrometric monitoring	
1	*Campbell Scientific Automatic Weather Station*	Detailed guidelines on installing, operating and maintaining Campbell Scientific Automatic Weather Stations introduced by the project in a number of Nile countries
2	*Evaporation measurement buoy station*	Detailed instructions on how to install, operate and maintain the buoy stations on Lake Nasser, which are equipped to measure evaporation. The instrument set was procured from Campbell Scientific
3	*Campbell Scientific Automatic Water Level Recorder*	Detailed guidelines on how to install, operate and maintain Campbell Scientific Automatic Water Level Recorders introduced by the project in a number of Nile countries
4	*Data retrieval and storage for Campbell Scientific monitoring equipment*	Step-by-step instructions for data retrieval, processing and storage for automatic monitoring equipment procured from Campbell Scientific
5	*Thalimedes AWLR*	Guidelines on how to install and operate the Thalimedes automatic water level recorder; it also covers data retrieval, processing and quality control
6	Tipping bucket rain gage	Instructions on how to install and operate a Texas electronic tipping bucket rain gauge coupled to a HOBO data logger

(Continued)

Table 1: *(Continued)*

No.	Title	Description
7	*ADCP measurement under high-sediment conditions*	Guidelines on performing discharge measurements during extreme sediment conditions using the Teledyne RDI Acoustic Doppler Current Profiler; it also provides information on required peripheral devices
	Database development	
8	*Data quality control guidelines in MS Access*	A set of queries for systematic quality control of time series databases in MS Access
9	*Workbook: Blue Water Poster for Nile Sub-Basin*	Detailed instructions to explain visually the hydrologic regime of a river. It presents a poster showing a hill shaded image of the watershed
10	*Workbook: Geo-referencing of scanned spatial data sources*	Step-by-step instructions on how to reference a scanned image in ArcView
11	*Workbook: satellite imagery Processing for agro-meteorological assessments*	Instructions for analysing MODIS vegetation time series in IDRISI GIS software
12	*Introduction on image analysis in ArcView 3 – land cover changes in the Rwenzori mountains 1973-2005*	Guidelines on using Arc View Image Analysis. Includes training material for a case study of the Rwenzori mountains
13	*Projections*	Instructions for using the Arc View projections utility
14	*Hydro Tools: Watershed Delineator*	Instructions for using the Arc View watershed delineator utility
15	*Nile-DST*	Detailed write-up of Nile-DST
16	*Nile-DST Technical Report (volumes 1 and 2 Nile-DST RSRM User Manual)*	Instructions for using the Nile-DST river simulation-reservoir operation module
17	*Nile-DST RRSM Exercise*	A set of exercises for the Nile-DST river simulation-reservoir operation module
18	*Miscellaneous*	Comprehensive package for training in negotiation skills, conflict resolution and law, focused on the context of international river basins
19	*FAO Training Manual: Law, Negotiation, Conflict Resolution Nile Google*	Manual on operating the Nile Google spatial text library

Four reports were prepared:

1. Food for Thought, demand for agricultural produce in the Nile Basin for 2030: four scenarios;
2. a synthesis report;
3. a farming systems report;
4. a projections report.

Overview of supporting processes

Capacity building component

The second overall project objective was concerned with strengthening government capacity at the national level to manage scarce water resources and deal with competing demands from different sectors in society. To this effect, a substantial capacity building component was implemented. It was geared towards developing relevant technical skills and competence of individuals at the respective technical water agencies. Although the main thrust was on information technology (IT)

Box 5: Hydrometric training in Mwanza, United Republic of Tanzania

To strengthen the skills of counterpart staff in the United Republic of Tanzania in operating electronic hydro-meteorological monitoring equipment, the project organized a one-week workshop in Mwanza, on the shores of Lake Victoria, from 13 to 18 November 2006.

Mr Felix Sangale from Kenya and Mr Jetty Masongole from Uganda facilitated the event, illustrating the project's policy of drawing on human resources from the Nile region.

The project invited seven hydrometric technicians from Bukoba, Dar-es-Salaam, Musoma and Mwanza.

Theoretical sessions alternated with field exercises. The trainees practised discharge measurement with the high-tech Acoustic Doppler Current Profiler (ADCP) on Mbaragethi River. They also studied electronic data acquisition systems, built an automatic weather station, and got hands-on practice in trouble-shooting.

skills and knowledge of hydro-meteorological monitoring practices, the programme covered a broad scope, ranging from negotiation skills training to courses in the English language. A total of 60 events were organized, benefiting 562 trainees. The training contributed to establishing a level playing field in the Nile Basin: an equal level of technical expertise and institutional capacity at the respective water ministries.

A variety of training methods were employed. Where possible, the project contracted qualified national training institutes, particularly in the IT domain. For the hydrometric programme (see Box 5), it employed consultants from the Nile region to train counterparts in other riparian States. On one occasion, staff members from a national water agency trained their colleagues from a neighbouring State. For large regional workshops, international experts were recruited.

Joint regional workshops contributed to building the common knowledge base.

In line with NBI operational policies, project staff were recruited mostly from the Nile Basin countries, to ensure that valuable skills, experience and knowledge of the Nile system were retained in the region. Of the 16 professionals who worked at the project office – some for a few months, others for the entire duration of the project – 14 were Nile Basin nationals.

Institutional strengthening

There is broad consensus that sustained Nile Basin cooperation requires a permanent institution, and agreement on the core legal principles for management of transboundary waters. Two international conventions are concerned with freshwater:

- The Helsinki Convention on the Protection and Use of Transboundary Watercourses and International Lakes (1992);
- The United Nations Convention on the Non-navigational Uses of International Water Courses (1997).

The international water law embodied in these conventions includes a list of considerations and criteria for managing international waters jointly by the riparians. However, these provide only a framework, and the specifics have to be worked out for each case by the parties.

The Nile riparians have engaged in negotiations on a comprehensive cooperative framework. Negotiators require good understanding of negotiation techniques combined with knowledge of the legal aspects of managing a shared water resource and, in particular, the role of international water law.

The project organized two large institutional strengthening events and integrated negotiation skills training with international water law and policy education. It was based on the core elements of the principled negotiation approach developed by the Harvard Negotiation Project and used in the F4T scenario set developed by the project as a case study in a number of advanced simulation exercises. The principled negotiation approach aims to shift the focus of discussions from positions to interests. The workshops also discussed the role of facilitation and mediation. A side objective was to build capacity in translating agreements into clear legal texts that reflect the outcome of negotiations. The events were organized jointly with the SVP Coordination Project. Participants included members of the PSC and Nile TAC, and a number of legal advisers to the respective water ministries.

Based on the experience of the two events, a training package was developed: *FAO training manual for international water courses/river basins including law, negotiation, conflict resolution and simulation exercises*. This 124-page document (plus annexes) incorporates the recommendations and feedback of trainees and evaluations of the workshops. It is accompanied by a 60-page teacher's manual.

Information dissemination

A public policy process characterized by participative decision-making requires well-informed stakeholders that understand the essence of the subject under discussion. In the Nile Basin, this starts with a shared understanding of the physical characteristics of the Nile system, followed by consensus regarding the development problems and agenda, and the principal trade-offs and consequences of major development options. This common knowledge base is seen as a prerequisite for a negotiated solution. FAO Nile considered creating and disseminating this common knowledge base as one of its main tasks. Confidence building efforts are strengthened when informed and knowledgeable stakeholders feel comfortable about taking part in the discussions of Nile water development that essentially determine their future.

The poster series – discussed previously – forms the principal communication tool. Most project data products were translated into poster format. Graphic illustrations are far more accessible than written text. Taken together, the posters tell a large part of the story of the Nile Basin: where the water originates and how it travels to the Mediterranean, where people live, how rural smallholders make their living, where water is the principal constraint to agricultural production, what the difficulties for producing for domestic markets are, what the agricultural trade flows and market opportunities are, etc. So far, the posters have been distributed in only limited numbers, but whenever presented, they have quickly become the centre of lively and informative discussions among Nile stakeholders, decision-makers and experts: exactly the aim of the exercise.

Scenario setting is the other key component of the public communication effort. Scenarios are plausible and logical stories about the future, presented as easily accessible narratives. They provide a context that makes it possible to combine disparate information from multiple disciplines and sectors. Story telling comes naturally. Facts – presented in reports, spreadsheets or PowerPoint bullet points – are boring and not easily retained. With a logical plot and facts put into a context with emotions, stories engage and are much more easily remembered. They become "memories of the future". Story telling has proven efficient in communicating information, and F4T has capitalized on this experience.

A comprehensive project Web site was maintained to inform stakeholders and partners on project activities and achievements, and to disseminate digital copies of project products.

One additional communication effort deserves mention. FAO Nile was the subject of four television specials:

- a 20-minute news story by RAI International, the global wing of the Italian national broadcaster, on water management in relation to World Water Day;
- two six-minute specials on the Nile by EURONEWS;
- a five-minute story by NTV – EAST AFRICA.

Searching for common ground

With some exceptions, prevalent thinking on Nile cooperation is still mainly concentrated on hydrologic issues. This reflects the historic context, in which the Nile is the main cause that brings the ten riparians together. The riparian interests are generally tuned towards river flow or the trade-offs of alternative allocation regimes. This is a difficult subject as compromise may require painful adjustments to national economies and affects perceived water security.

The multi-stakeholder F4T scenario exercise contributed to broadening the scope of the Nile dialogue. It was deliberately designed to incorporate a wide range of views and encourage a multi-disciplinary perspective. By broadening the discussion, possible new areas of common ground emerged.

With rural populations predominating across the basin, the shape of future water demand is determined by the state of the rural economy. F4T moved the discourse towards economic and social constraints to agricultural production, demographic dynamics and rural-urban migration, and rural development. Alignment grew among the F4T participants on new shared interests, particularly those related to the agricultural trade regime. Crucially, these are not directly related to river flow and therefore could offer alternative pathways for negotiated solutions.

The key factor here is not the refocusing itself. The insights obtained are not new. The relevance of F4T lies in the joint discovery of these insights by a group of Nile experts and decision-makers from all riparian countries. The strong communality of views that emerged in the scenario group is seen as an important outcome of the exercise.

4. Water and agriculture in the Nile Basin

Introduction and objective

This chapter presents the basic water resource and water use information collected and analysed over the course of the project. The emphasis is on agricultural water use across the basin to establish a relevant baseline for the scenario work elaborated in the following chapter. The information presented in this chapter comprises:

- an account of observed flows;
- river sub-basin hydrological and hydrogeological summaries;
- a basin-wide water balance using a distributed model;
- national water balances for the ten riparian countries of the basin;
- summary results of agricultural water use and farming system studies using field data to establish a 2005 water use baseline.

The hydrological summary includes the inflow components rainfall and transboundary river inflow, as well as the various water use components, notably agriculture. It distinguishes between water used for rainfed agriculture, irrigated agriculture, range lands, forest and shrub lands, and water resources allocated to sustain permanent or seasonal wetland areas. The methodology is based on data sets for precipitation hydrometric data and known land use.

Other methods of deriving basin water balances – the use of GRACE satellite data (Bonsor *et al.*, 2009) or the SEBAL method (Mohamed *et al.*, 2005) are now being deployed to help explain hydrological observations, but these independent methods need to be calibrated and validated rigorously if they are to have any predictive, operational utility.

The anticipated impacts of climate change on the Nile Basin have not been included in the overall water resource analysis for the project. Not only were these impacts not specified in the project document, but also the level of uncertainty in the rainfall projections for the basin as a whole risks generating more hydrological 'noise' than trends (Conway, 2000; 2005; IPCC, 2007). When enough control data can be assembled and statistical downscaling can be acieved with an acceptable level of precision, these impacts will need to be evaluated. However, at the scale of the Nile Basin, the exercise is beyond the scope of the current project.

The results of the computations serve to inform decision-makers about the total volume of the water resources available in their part of the Nile Basin, how the waters are currently used, and what percentage is available as stream flow. It provides a framework for appreciating the relative importance and productivity of the different water use sectors, both within the country and in the Nile Basin context.

The study builds on the information contained in the FAO AFRICOVER (http://www.africover.org/) land cover layer and database. One of its principal shortcomings is the absence of matching periods of record among the various data sources. For instance, rainfall and potential evaporation originate from a global data set for 1961 to 1990, while runoff is estimated for any period for which consistent record sets were available. It was not always possible to find discharge time series for the entire 1960 to 1991 time frame, particularly for the smaller Nile tributaries. A similar situation was encountered with regard to land-use statistics. For instance, agricultural statistics were obtained for the period 2001 to 2004, while AFRICOVER is based on satellite remote sensing imageries from 1996 to 2000.

The analysis therefore provides an indication of the main components of the basin and national Nile water budgets with respect to agricultural use, but not exact figures. This is considered adequate for informing policy-making at the regional or even the national level. Furthermore, water accounting is not static. Dynamic factors such as population growth, rural-urban transitions and climatic variability may lead to quite fundamental changes over time. Hence, the improved accuracy of more detailed water accounting – representing some point in the past – is not always useful or needed. Before embarking on a more detailed study, it is worth considering the extent to which more accurate figures will lead to better decisions and policy-making.

This chapter focuses on agricultural water use and presents a more hydrologically detailed account of agricultural water use in the Nile Basin than accounts based on data collected in the pre-digital era (FAO, 2000 for example). It is important to note, however, that although water is a principal input in many production processes, there are typically other constraining factors as well. For instance, with regard to agricultural production, non-biophysical factors related to the agricultural trade regime, pricing policies, socio-political circumstances or other factors are in some instances more constraining and challenging.

Basin overview

It is not possible to base the assessment of tributary runoff on a comprehensive set of discharge time series of sufficient length. Such a set does not exist for the Nile Basin. The main reference for the project is Sutcliffe and Parks, 1999, which is complemented by information from diverse sources, including national hydro-meteorological databases, master plans, monographs and others. The general picture of the Nile hydrology is now well established. Consistent discharge time series exist at key sites of the main Nile and of its tributaries the White Nile and the Blue Nile, but not for many smaller tributaries. In particular measurement of transboundary flows of smaller rivers is typically absent. Here the cross-border volumes are estimated based on available flow records at stations close to the border, complemented with runoff estimates for the ungauged areas. As flow records may represent different time periods, the estimates are not always based on common periods of record. For the purpose of the analysis – to establish a basic water balance for each national Nile area – this approach is acceptable.

However, the basin areas contributing to measured flows are not always clear. Basin area estimates have changed over time as digital elevation models and satellite imagery have improved. A number of different Nile Basin delineations exist, including: 1) Hydro 1k (orange line); 2) FAO Nile 1998 (blue line); 3) SRTM (red line); and 4) FAO Nile 2007 (purple line), as presented in Figure 2. The FAO 2007 delineation was carried out on the basis of the STRM Digital Elevation Model (DEM) and Landsat imagery. For locations where the water divide was unclear, the drainage direction was determined by "manual interpretation", i.e., checking the direction of the closest water courses using Landsat ETM+ Mosaics or Landsat TM images made available by the Global Land Cover Facility (http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp). A large number of small corrections were made relative to the previous delineations. Two controversial areas stand out: 1) Wadi Howar in northern Sudan; and 2) Lotikipi plain in northeast Kenya. Both areas are very flat and a difference of 1 to 2 m in the SRTM DEM can make a relatively large change in basin delineation. It was concluded that Wadi Howar no longer contributed to the Nile Basin owing to sand dunes that have blocked the original wadi, transferring Wadi Howar into a dormant or fossil sub-basin. By contrast, the Lotikipi (30 769 km^2) in northeast Kenya most likely does contribute to the Nile flows in very wet years, and thus technically belongs to the Nile. The discrepancies between the basin delineations are illustrated in Figure 1. As a result of the evolution of digital mapping, Figure 2 shows the principal sub-basins adopted for the FAO Nile project The sub-basins for which the balance was carried out were identified from Hydroshed (http://hydrosheds.cr.usgs.gov/) 15-second data and comprise the 11 principal basins listed in Table 2. This group of sub-basins is used subsequently to run a basin water balance.

Table 2: Nile principal sub-basin areas

NBI Grouping	Countries	Sub-basin	Area (km^2)
Equatorial Lakes	Burundi Kenya Rwanda United Rep.Tanzania Uganda	Lake Victoria	264 985
	Dem. Rep. of the Congo Uganda	Lake Kyoga - Lake Albert - Aswa	197 253
	Sudan	Bahr el Jebel – Sudd	136 400
	Sudan	Bahr el Ghazal	236 330
	Sudan	Bahr el Arab	370 098
Eastern Nile	Kenya Ethiopia Sudan	Sobat	246 779
	Sudan	White Nile	260 943
	Ethiopia Sudan	Blue Nile	308 198
	Ethiopia Eritrea Sudan	Atbara	237 044
	Sudan	Main Nile downstream of Khartoum confluence (to Atbara)	34 523
	Egypt Sudan	Main Nile downstream of Atbara confluence	877 866
Total			**3 170 419**

The more detailed hydrological analysis is centred around groupings of sub-basins and catchments, the Kagera, Lake Victoria, the Semlike, Ugandan catchment contributions, basins in the Ethiopian highlands, Nile flows in the Sudan and Nile flows in Egypt.

Rainfall

Rain data were obtained from the CRU CL 2.0 global climate data set. This comprises a raster of monthly precipitation estimates with a spatial resolution of 10 arc minutes. It

Figure 1: Nile Basin delineations

Figure 2: Principal Nile sub-basins

is based on a large volume of rain statistics from 1961 to 1990, and has been cross-validated and compared with other data sets. The raster data are published by the University of East Anglia, United Kingdom, and the International Water Management Institute (IWMI), and date from 2000.

Rainfall is the key driver of the hydrologic cycle and among the principal inputs for agricultural activities. Because CRU CL 2.0 – as a global data set derived from 30 years of records – has been subjected to some level of averaging, it is important to appreciate the accuracy of the rain values, and to know if and to what extent the loss of detail affects the analysis. To this end, annual rainfall over a number of key basins was calculated and compared with figures from the literature (Sutcliffe and Parks, 1999). The results are presented in Table 3.

Table 3 shows an acceptable fit for land areas. The two data sets have no common period of record, and the stochastic nature of rainfall should explain the small differences encountered. In some instances – e.g., the main Nile – the original delineation of the sub-basin could not be verified. A new Nile Basin delineation presented by FAO Nile in 2007 has somewhat changed the shape of the catchment, adding some land mass to the southern part. This receives most rainfall and thus affects the average of this watershed. In conclusion, for land areas, CRU CL 2.0 yields acceptable results and can be used for the analysis.

By contrast, the CRU CL 2.0 rainfall over Lake Victoria differs substantially from the figures presented by Sutcliffe and Parks. This is in line with the accompanying documentation, which states that the data set has been developed for land areas. Hence, the use of CRU CL 2.0 is limited to land areas only. ArcGIS spatial statistics are used to calculate the average annual rainfall for the respective national Nile areas. A correction is required to account for the

Table 3: Average annual rainfall over key catchments in the Nile Basin

	Sutcliffe & Parks (mm/year)	CRU CL 2.0 (mm/year)
Period	**Up to 1972***	**1960-1991**
Land area		
Lake Victoria Basin (excluding the lake)	1 186	1 196
Lake Kyoga Basin	1 276	1 224
Lake Albert Basin	1 214	1 175
Lake Albert to Mongalla	1 180	1 154
Mongalla to Lake No	871	961
Bahr el Ghazal Basin	1 169	1 105
River Baro Basin	1 503	1 555
Ethiopian Nile catchment	1 227	1 184
Main Nile downstream of Atbara confluence	36	46
Water body		
Lake Victoria	1 650 – 1 858	1 326

* *Rainfall averages up to 1972 for the stations available; the periods of record vary.*

decreasing width of grid cells with increasing latitude. The latitude range in the Nile Basin – from south 6 to north 32 – does not permit the assumption of a constant grid cell surface. To this effect, a raster was prepared with relative width of grid cells as a function of latitude. For each country, the correction factor was set to 1 at the true centroid of the respective national Nile area. The correction factors for cells below and above this point were adjusted accordingly, keeping the average correction per country at 1. For each country, the ten-minute rainfall values were multiplied with the respective correction factors and averaged for the national Nile area.

As noted, FAO Nile prepared a new delineation of the Nile Basin. This is based on the 90-m DEM produced by the National Aeronautics and Space Administration (NASA) Shuttle Radar Topology Mission. For a number of areas – where the delineation was not clear – the watershed boundary was checked with Landsat imageries. Only minor changes were made for the Lake Victoria, Bahr el Ghazal, Atbara, Blue Nile

Table 4: Average annual rainfall for national Nile areas

Country	Rainfall (mm/year)	Area (km^2)	Volume (km^3)
Burundi	1 202	13 250	16.1
Dem. Rep. of the Congo	1 146	20 191	23.0
Egypt	19	303 084	5.8
Eritrea	435	24 578	10.8
Ethiopia	1 184	364 925	431.8
Kenya, Lake Victoria Basin excl. lake area	1449	45 845	66.4
Kenya, Lake Victoria area		4 063	
Kenya, northern part	463	20 340	9.4
Total Kenya		**70 248**	
Rwanda	1 137	20 823	23.4
Sudan	487	1 993 079	966.3
United Republic of Tanzania, excl. Lake Victoria area	1 043	85 180	87.7
United Republic of Tanzania, Lake Victoria area		35 588	
Total United Republic of Tanzania		**120 768**	
Uganda, excl. Lake Victoria area	1 193	210 277	250.4
Uganda, Lake Victoria area		29 191	
Total Uganda		239 468	
Total Nile area		**3 170 418**	

and Baro sub-basins. A number of changes were made in the Bahr el Arab basin, and a substantial area in northern Kenya was added to the Pibor-Akabo basin. This watershed, however, only spills into the Nile Basin in exceptionally wet years and its contribution to Nile flows is negligible. With very scarce population, its economic value for Kenya is currently limited. It is represented in Table 3 as "Kenya, northern part". The calculations ignore the water balance of Lake Victoria, as accurate information on over-lake rainfall and evaporation is not available. Rain volume is obtained by multiplying average rainfall with the respective area. The results are presented in Table 4.

It should be noted that Table 4 presents average annual values. No information is provided on the temporal variability of rainfall – both within a growing season and over several years. In addition, not all precipitation is of value for agricultural production or other economic activities. In particular in arid regions – e.g., Egypt and northern Sudan – small rain volumes on bare lands quickly evaporate, contributing little to runoff, groundwater replenishment or agricultural production. Hence, for these parts of the Nile Basin, only rainfall that falls directly on agricultural land is included in the national Nile water balance.

To appreciate the importance of the Nile area with regard to the national water budget, Table 5 compares average rainfall over the entire country with that over the national Nile area. Here it is apparent that for Ethiopia, Eritrea and Kenya, the rainfall over the national Nile area exceeds the national average. The opposite is the case for the Democratic Republic of the Congo.

Observed flows

At the outset, it is important to establish the observed flows in the Nile Basin. Table 6 gives an account of observed flows as reported by Sutcliffe and Parks (1999) with the location of

Table 5: Country versus Nile Basin rainfall

Country	Average country rainfall (mm/year)	Average Nile rainfall (mm/year)
Burundi	1 245	1 202
Dem. Rep. of the Congo	1 541	1 146
Egypt	24	19
Eritrea	278	435
Ethiopia	845	1 184
Kenya	722	1 449*
Rwanda	1 208	1 137
Sudan	419	487
United Republic of Tanzania	1 007	1 043**
Uganda	1 229	1 193**

* *for the Kenyan land area of the Lake Victoria Basin.*

** *excluding the Lake Victoria surface area.*

the gauging points presented in Figure 3. This data are elaborated in the hydrologic regime in the Nile Basin poster. As these flows integrate all surface water and groundwater contributions after evapotranspiration losses and replenishment of aquifers has occurred, it is important to appreciate that very few millimetres of rainfall over the basin appear in the main watercourse. This reflects not just the spatial extent of the basin, but the high proportion of lowland areas that are saturated for several months of the year and that evaporate freely. These losses are acknowledged and provide the rationale for schemes such as the Jonglei Canal, but they could also be recognized as a widely distributed environmental and agricultural opportunity. This opportunity is reflected in

Table 6: Principal hydrometric stations in the Nile Basin

FAO Station No.	Principal hydrometric station	Area (km^2)	MAR (km^3/yr)	mm equivalent	Estimated mean baseflow (km^3/yr)	mm equivalent
	Aswan inflow (1869-1995)	2 637 976	88.1	33		
1	Dongola	2 575 418	84.1	33		
2	Atbara	205 099	11.1	54		
-	Main Nile at Hassanab (1909-1995)	2 046 553	72.3	35		
3	Main Nile at Tamaniat	1 980 733	72.7	32		
4	Blue Nile at Khartoum	308 195	48.3	157		
5	White Nile at Mogren	1 670 850	26	16		
23	Rahad	36 624	1.1	26		
6	Dinder	176 317	2.8	77		
7	Blue Nile at Rosieres/ el Diem	1 412 571	48.7	275	2.5	14.2
8	While Nile at Malakal	1 189 961	29.6	21	12.0	8.5
9	Sudd outflow	214 882	16.1	13		
10	Sobat at Dolieb Hill	23 586	13.5	63	1.5	6
12	Baro at Gambeila	38 731	13.2	432		
14	Jur at Wau	52 368	4.5	85		
15	Bahr el Jebel at Mongalla	33 338	36	74		
18	Kyoga Nile at Kamdini	483 601	30.5	94		
19	Lake Victoria outflow at Jinja	409 412	28.6	108		
17	Semliki at mouth (1940-1978)	33 877	4.6	134		
20	Kagera at Kyaka Ferry (1940-1978)	323 494	6.3	116	2.8	52.2

the account of the International Union for Conservation of Nature (IUCN) conservation category areas (Tables 17 and 18), but could also be realized for the many local recession systems where land access and markets coincide.

This set of flow measurements indicates the mean annual flow volumes and the overall system limits. The difficulty of measuring hydrological inputs to the Sudd is all too apparent, and clearly the use of remote sensing techniques will prove

Figure 3: Location of hydrometric stations

essential because they can be calibrated sufficiently well to estimate inflows where hydrometric data are missing, for instance from the Bahr el Arab and Bahr el Gazal.

The Kagera

The Kagera is the largest river in the Lake Victoria basin, contributing roughly 32 percent of the total catchment runoff. The basin is shared by Burundi, Rwanda, the United Republic of Tanzania and Uganda. Its major tributaries are the Nyabarongo, the Akanyaru and the Ruvuvu. The former rises in the western Rwandan mountains at 2 750 m altitude. Slopes are steep in the upper reaches but, particularly after the Akanyaru confluence, the river passes through large areas of swamps and several lakes, which have a distinct effect on the hydrologic regime.

The Ruvuvu originates in Burundi at an elevation of 2 400 m. It has a more gradual slope than the Nyabarongo and its catchment does not include extensive wetland areas. The Ruvuvu joins the Kagera 2 km upstream of Rusumu falls, at the border between the United Republic of Tanzania and Rwanda. Downstream of Rusumu, the Kagera enters flat country characterized by several lakes and large papyrus and reed swamps. After the Katigumba confluence, the river once more enters an area with moderate slopes, but from point 118.1 km (the proposed Kakono dam site) the Kagera flows through flat land with a slope of 0.09 m/km. Two more tributaries (the Mwisa and the Ngono) join the river at 133.6 and 58.0 km respectively. Extensive wetlands areas exist at the mouth of the river.

Good information, based on consistent flow records at four key stations, is available for the three upper catchments: the Ruvuvu, the Akanyaru and the Nyabarongo. Net basin flows for these tributaries can be assessed with an acceptable degree of accuracy. This is not the case for the middle reaches of the Kagera. Available data are limited and scattered, and not sufficient to arrive at a proper understanding of the hydrology of these sections. The existence of extensive wetland areas and lakes further complicates net runoff calculations. Only for Kyaka ferry – some 100 km from the river mouth – does a consistent long-term runoff record exist. Hence, in particular for the middle reaches, a number of assumptions have been made. Fortunately, most of the transboundary Kagera flows – just over 90 percent – originate

Table 7: Available flow data in the Kagera basin

River	Station name	Avg. flow (km^3/yr)	Period	Source
Ruvuvu	Muyinga	2.77	1975-1985 (1984 missing)	Project database
Nyabarongo	Kigali-Butare bridge	2.52	1972-1985	Project database
Nyabarongo	Kazenze	3.93	1972-1985	Project database
Kagera	Rusumo falls	6.79	1972-1985	Project database
Kagera	Kyaka Ferry	7.26	1972-1985	Project database
Kagera	River mouth	7.42	1956-1978	Sutcliffe & Parks
Katigumba	At confluence	0.3	Not known	Monograph
Ngono	Ngono bridge	0.7	Not known	Monograph

in the upper catchments. The estimates therefore affect only about 10 percent of the transboundary flows, limiting the possible errors in any hydrological balance. Table 7 presents the available discharge data.

Table 8 presents the assessment of national hydrological balance for the Kagera. This is anchored on the observed average annual discharge figures presented previously. Net contributions of those sections with extensive wetlands and lakes were set at zero. Flows originating from transboundary catchments were attributed to the respective countries in proportion to the surface area of the national sub-basin.

Lake Victoria basin

Lake Victoria is the largest freshwater lake in the eastern hemisphere. It is shared by Kenya, the United Republic of Tanzania and Uganda, and provides the origin of the Victoria Nile at Owen Falls. Information from two studies was combined, but the studies cover different periods of record. Sutcliffe and Parks (1999) is used as the principal reference, and the Hydromet Survey Biennial Review (1967 to 1969) is used for assessing tributary inflow. Sutcliffe and Parks (1999) estimate total catchment inflow at 22.98 km^3/year for the period 1956 to 1978. They do not differentiate among sub-basins, apart from the Kagera, which they calculate to be 7.42 km^3/year. Table 9 presents the average annual discharge of the various tributaries and ungauged areas as estimated by the Hydromet Survey in 1970 indicating a total inflow of 12.24 Km^3/year.

From Table 9, the runoff percentages were established for Kenya, the United Republic of Tanzania and Uganda as 61.8, 36.1 and 2.1 percent respectively. Applying these figures to the 1956 to 1978 time frame, the annual runoff from the Lake Victoria land area – excluding the Kagera – for the national catchments of Kenya, the United Republic of Tanzania and Uganda is estimated at 9.62, 5.62 and 0.34 km^3/year respectively. It should be noted that these figures relate to the lateral inflow into Lake Victoria only. Rainfall over the lake itself is not included.

Table 8: Country contribution to Kagera flow at mouth

Sub-basin	Avg P (mm/yr)	Average national contribution (km^3/yr)				
		BUR	RWA	TAN	UGA	Subtotal
Ruvuvu	1 186	2.81		0.05		2.86
Nyabarongo	1 257		2.52			2.52
Akanyaru	1 153	0.56	0.85			1.41
To Rusumo	1 006					-
Wetlands zone	977					-
Katigumba	1 043		0.10		0.20	0.30
To Kyaka Ferry	1 205			0.17		0.17
Miswa	1 094					-
Ngono	1 654			0.16		0.16
To river mouth	1 652					-
Total		**3.37**	**3.47**	**0.38**	**0.20**	**7.42**

Table 9: Tributary inflow Lake Victoria (excl. Kagera) 1967 to 1969

River	Country	Catchment (km^2)	Avg. P (mm/year)	Avg. Q (km^3/year)	Runoff co. (%)
Sio	KEN/UGA	1 450	1 370	0.6	33.6
Nzoia	KEN	12 400	1 410	1.92	15.6
Yala	KEN	3 500	1 640	0.97	20.7
Kibos	KEN	included in 'other streams'			
Nyando	KEN	3 600	1 370	0.5	10.2
Sondu	KEN	3 600	1 590	1.24	21.4
Awach Kabound	KEN	included in 'other streams'			
Gucha Migori	KEN	6 600	1 530	0.87	8.5
Mara	KEN	8 700	880	0.4	6
Shore and other streams	KEN	5 500	1 480	0.8	10.1
Mara	TAN	14 250*	930	1.33*	10
Mori	TAN	1 590	1 170	0.15	8
Suguti	TAN	1 140	1 060	0.10	8
Grumeti-Rwana	TAN	10 260	850	0.70	8
Mbarageti	TAN	3 300	825	0.22	8
Simiyu-Duma	TAN	11 000	825	0.84	8
Magogo-Moame	TAN	3 600	765	0.17	6
Isanga	TAN	4 840	860	0.17	4
Shore and other streams	TAN	17 000		1	6
Ruizi	UGA	8 960	900	0.09	1
Katonga	UGA	15 800	800	0.12	1
Shore and other streams	UGA	4 580	1 100	0.05	1
Total				12.24	

** including Kenyan part of Mara watershed*

Semlike sub-basin

The Semlike is shared by the Democratic Republic of the Congo and Uganda. The river drains into Lake Albert. The sub-basin includes both sides of the Rwenzori mountains as well as lakes Edward and George and covers 38 065 km^2, of which 41 percent lies in the Democratic Republic of the Congo and 59 percent in Uganda. In the 1930s, Hurst and Phillips estimated the Semlike's outflow at 5.74 km^3/year, comprising two components: 1) annual outflow from Lake Edward, of 3.69 km^3/year; and 2) runoff downstream of Lake Edward, estimated at 2.05 km^3/year. However, subsequent measurements at Bweramule for the 1940 to 1978 period reported annual flows of 4.58 km^3/year. The Hydromet Survey estimated an additional contribution of 0.25 km^3/year from the ungauged area downstream of this station, bringing the Semlike inflow to Lake Albert to 4.83 km^3/year.

In the absence of measurements of Lake Edward outflow, it is not possible to calculate with precision the respective contributions of the Democratic Republic of the Congo and Uganda. It is assumed that the relative proportions of the two components are maintained. The respective runoff per component is approximated in proportion to the relative national share of the catchment. This results in 2.19 km^3/year of Semlike flows originating in the Democratic Republic of the Congo and 2.64 km^3/year in Uganda.

Transboundary flows on the Ugandan land area

As already discussed, this hydrological analysis ignores the vertical water balance on Lake Victoria because accurate over-lake rainfall and evaporation data are lacking.

For the Ugandan land area, inflow components include:

- the Victoria Nile at Jinja;
- the Semlike – net Democratic Republic of the Congo contribution;
- the Malaba-Malakisi;
- the Lake Albert inflow – net Democratic Republic of the Congo contribution.

Outflow components include:

- the Kagera;
- the inflow into Lake Victoria (excluding the Kagera);
- the Bahr el Jebel at Nimule;
- the Ugandan share of the torrents between Lake Albert and Mongalla;
- the contribution to Akabo-Pibor flow from Karamoja.

The Nile is the principal component of the river flow balance of the Ugandan land area. It starts its journey at the outlet of Lake Victoria at Jinja, and leaves Uganda as the Bahr el Jebel just upstream of Nimule. Nile inflow and outflow are in the same order of magnitude, but river regime is modified by the passage through Lake Kyoga and Lake Albert. From the outlet of Lake Albert at Pakwatch, to Nimule the river flows through flat lands fringed by wetlands on both sides. It enters a single channel after the rapids at Nimule. Table 10 presents the available discharge data.

Bahr el Jebel flows are not measured at the border, but at Mongalla some 180 km

Table 10: Average annual flow at key stations in Uganda

Station	Flow (km^3/yr)	Period	Data source
Lake Victoria outflow	28.6	1940-1977	Sutcliffe & Parks
Kyoga Nile at Masindi Port	28.6	1940-1977	Sutcliffe & Parks
Kyoga Nile at Kamdini	29.4	1940-1977	Sutcliffe & Parks
Semliki mouth	4.83	1940-1977	
Lake Albert outflow	32.8	1940-1977	Sutcliffe & Parks
Torrents (between Lake Albert and Mongalla, including Aswa)	4.69	1940-1977	Sutcliffe & Parks
Bahr el Jebel at Mongalla	36.0	1940-1977	Sutcliffe & Parks

downstream of the Uganda-Sudan border. Table 11 presents the components of the flow accounting and shows that the total flow generated over the Ugandan land area is rather limited. Particularly noteworthy is the very limited surplus of the Nile catchment. The balance of Nile inflows and outflows (the Victoria Nile at Jinja, the Bahr el Jebel at Nimule and the Semlike Democratic Republic of the Congo contribution) shows that just 0.54 km^3/year is added to the Nile flows.

Flows originating in the Ethiopian highlands

Three major rivers (the Baro, Blue Nile and Atbara) and a number of minor streams (the Rahad, Setit and Akabo) originate in the Ethiopian highlands. The climate – as in all mountainous countries – varies with altitude, latitude and slope. It is determined by the migration of the Inter-Tropical Convergence Zone (ITCZ), producing a marked rainy season from June to September. A short rainy period – known as *Belg* or small rains – occurs in March to April, affecting particularly the southwestern part of the basin. The rest of the year is mostly dry. As a result, the Ethiopian Nile tributaries are highly seasonal with most flows occurring from July to October.

The Baro originates in the southwestern Ethiopian highlands. The upper Baro, above Gambeila, collects streams from a mountainous and wet area. Below Gambeila,

Table 11: River flow accounting for the Ugandan land area for 1940 to 1977

River	Net flow (km^3/yr)	Remarks
Inflow components		
Victoria Nile at Jinja	28.6	
Semliki – net DRC contribution	2.19	See 3.4.4
Malaba-Malakisi	0	Very small catchment in Kenya; set to zero for lack of available info
Lake Albert – net DRC contribution	0	Not known, but it is assumed that rainfall broadly matches evaporation
Outflow components		
Kagera	0.20	See 3.4.2
Catchment flow to Lake Victoria (excl. Kagera)	0.34	See 3.4.3
Bahr el Jebel at Nimule	31.31	Bahr el Jebel at Mongalla minus Torrents between Lake Albert and Mongalla: 36.0 – 4.69 = 31.31 Ignores instream losses from Nimule to Mongalla
Ugandan share of Torrents	3.75	80% of 4.69; torrent flows appropriated in proportion to the relative national catchment areas
Karamoja contribution to Akabo-Pibor	0	No information available; small catchment area in semi-arid zone

it enters the eastern margin of the Jonglei plain before joining the Sobat in the Sudan. During high flows, the river is liable to overflow its banks and inundate large areas in the plain. Its overspill constitutes the main inflow into the Machar marshes – a large wetland area in southeastern Sudan. Although it straddles the border with the Sudan for a short stretch near its mouth, Baro watershed lies almost entirely on Ethiopian territory.

Although the Akabo watershed is of considerable size, its contribution to the Nile flows is quite limited because of the extensive wetlands near its mouth. In these swamp lands, various interconnected streams emerge. The hydrology is little known owing to the complex pattern of spilling and return flows.

The Blue Nile is the largest tributary of the main Nile. It is known as the Abay in Ethiopia. Its basin is characterized by mountainous topography and drains a large portion of the central and southwestern Ethiopian highlands. The river has cut a deep canyon through the highlands; in some places the gorge is 1 300 m deep. After crossing into the Sudan, it enters a vast plain. Although the river starts at Lake Tana – at 1 800 m altitude – most flow originates from a large number of downstream tributaries, of which the most important are the Didessa and Dabus. The Blue Nile outflow from Ethiopia is measured at Border/Roseires.

The Rahad and Dinder are highly seasonal, but unlike the Blue Nile, dry up completely in the dry season, except for some perennial flow supported by groundwater flows. During flood events, however, there are considerable streams.

The Atbara is the most northern tributary of the main Nile. It drains an area of some 106 350 km^2 in the Sudan, 24 900 km^2 in Eritrea and 88 000 km^2 in Ethiopia. It is a large muddy river in flood, reducing to a small stream in the dry season. Its main tributaries are the Setit (called the Tekezze in Ethiopia) and the Atbara (or Bahr el Salaam), which is the smaller of the two. While the catchment in Ethiopia is rough and uneven, the lower basin in the Sudan is flat and eroded. The Atbara sub-basin contributes some 10 to 15 percent of Nile flows. A reservoir at Khashm el Girba supplies the new Halfa irrigation scheme. Table 12 presents the key flow measurement stations and the periods of record for main water courses flowing out of the Ethiopian highlands.

The challenge now is twofold: 1) in the absence of transboundary measurements, estimate the national contributions to the various rivers; and 2) reconcile the different periods of record.

For the Atbara, Rahad and Dinder, a simple monthly water budget is used to approximate the total annual flow into the respective national sub-basins. For each month, surplus rainfall (average monthly rainfall minus average monthly potential evaporation) is calculated using CRU CL 2.0 records. It is assumed that the first 25 mm of surplus does not contribute to runoff, but instead is stored in various terrain depressions. This arbitrary assumption works quite well in closing the water balance. The total annual flow is then distributed to the respective national catchments in proportion to the sum of the surplus rainfall for each country.

The calculations are presented in Table 13. Although this approach is basic in nature, the results obtained correspond to the literature and anecdotal evidence.

The hydrology of the Baro-Akabo is complex because of the bank spills, evaporation

Table 12: Available discharge records for the Nile flows originating in Ethiopia

River	Station	Period	Avg. flow (km^3/yr)	Remarks
Baro	Gambeila	1905-1959	13.18	Major overbank spillage and evaporation losses downstream of Gambeila
Blue Nile	Border/ Roseires	1961-1997	46.41	All flows originate in Ethiopia
Rahad	At mouth	1961-1997	1.04	Basin in Ethiopia and Sudan In-stream losses neglected
Dinder	At mouth	1961-1997	2.37	Basin in Ethiopia and Sudan In-stream losses neglected
Atbara	At mouth	1961-1994	8.62	Flows include Khashm el Girba canal abstractions Basin in Eritrea, Ethiopia, and Sudan In-stream losses neglected

Table 13: Basic water balance for Ethiopian highland basins

River	Area (km^2)	Rain surplus (P – ETo) (mm/month)				Rain surplus (P – ETo) – 25 mm (mm/month)				Share* (%)	Flow 1961-1997 (km^3/yr)
		JUN	JUL	AUG	SEP	JUN	JUL	AUG	SEP		
Dinder											2.37
ETH	13 500	16.3	128	136	27.7	0	103	111	2.7	90	2.14
SUD	14 300	0	23	55.6	0.1	0	0	30.6	0	10	0.23
Rahad											1.04
ETH	9 600	7.8	132.5	132.9	9.1	0	107.5	107.9	0	85	0.89
SUD	24 600	0	23.7	56.4	0	0	0	31.4	0	15	0.15
Atbara											8.62
ERI	24 900	0	7.1	5.8	0	0	0	0	0	0	0
ETH	88 000	3	91	91.7	0	0	66	66.7	0	100	8.62
SUD	106 300	0	2.6	3.6	0	0	0	0	0	0	0

**Figures have been rounded*

losses in seasonal and permanent wetlands, and return flows. The analysis of El-Hemry and Eagelson (1980) presented in Sutcliffe and Parks (1999) is used. The respective contributions of the various rivers and streams are presented in Table 14.

The period of record for the Atbara, Blue Nile, Dinder and Rahad flows corresponds reasonably well with the CRU CL 2.0 time period for 1961 to 1990. However, this is clearly not the case for the Baro-Akabo system. Table 15 presents the flow accounting for Ethiopia.

Table 14: Mean annual Baro-Akobo flows originating in Ethiopia

River / stream	Flow (km^3/yr)	Remarks
Akabo	0.37	1929-1944
Gila	1.12	1929-1947
Mokwai	1.30	Period unknown
Baro at mouth	9.53	1929-1963
Spills to Machar marshes	2.82	As estimated by El-Hemry and Eagleson, including 0.86 through Khor Machar
SUM	15.14	

Table 15: River flow accounting for Ethiopia

River	Net Flow (km^3/yr)	Remarks
Atbara	8.62	1961-1994; ignoring in-stream losses
Dinder	2.14	1961-1997;
Rahad	0.89	1961-1997;
Blue Nile	46.20	1961-1997
Baro-Akabo-Pibor	15.14	diverse record sets 1929-1963
Total	**72.99**	

Nile flows in the Sudan

Combining Tables 11 and 15, the flow balance for the Sudan is presented in Table 16. This overall negative flow for the Sudan illustrates how the basin loses downstream from the Sudd, even accounting for substantial inflows from the Ethiopian highland tributaries. While the long-term (1890 to 1995) flow series for Dongola would indicate a mean annual flow of 84 km^3, the more recent series for 1961 to

Table 16: River flow accounting for the Sudan

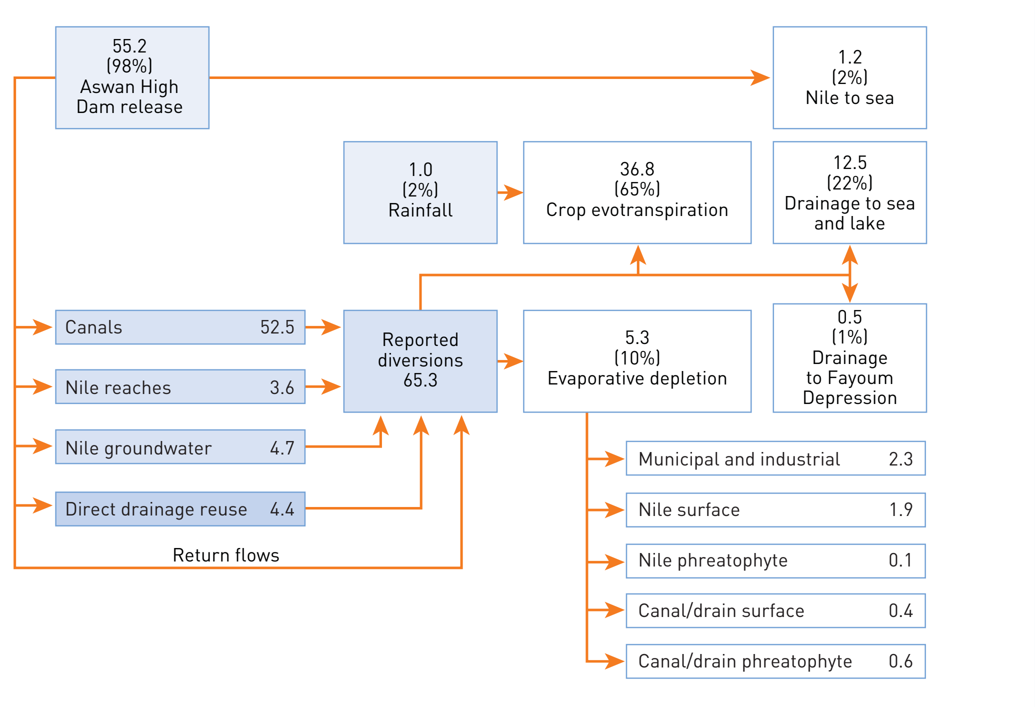
River	Net Flow (km^3/yr)	Remarks
Inflow		
Bahr el Jebel at Nimule	31.31	1940-1977
Ugandan share of Torrents	3.75	1940-1977
Rahad and Dinder	3.03	1961-1997
Blue Nile	46.20	1961-1997
Atbara	8.62	1961-1994
Baro-Akabo	15.14	Diverse record sets 1929-1963
SUM INFLOW	108.05	
Outflow		
Main Nile at Dongola	73.09	1961-1995
Balance	**-34.96**	

1995 has a mean annual flow of only 73 km^3. Again, it is important to stress that different periods of reliable records can generate very different hydrological balances.

Nile flows in Egypt

Once the Nile enters the Aswan High Dam backwater near the once-gauged site at Wadi Halfah, flows are regulated to the Mediterranean. Apart from spills into the Toshka depression since 1998 (the saddle 183 m above sea level) and evaporation losses on Lake Aswan itself (estimated at 10 km^3/year), remaining flows of at least 55.5 km^3/year enter the Egyptian water economy at Aswan. Irrigation withdrawals, drainage return flows, channel dredging, and industrial and municipal water withdrawals all influence a complex but low-gradient cascade to the Nile delta and ultimately the Mediterranean Sea. As with the irrigation schemes on the Blue Nile, a heavily regulated flow regime and sediment build-up become complicating factors, making flow measurement in the main Nile redundant. While irrigation withdrawals to main canals are measured with a high degree of precision, near real-time monitoring of the system as a whole is not possible. Flows in the Nile mainstream to Cairo and the distributaries of the delta can only be estimated on the basis of modelled water balances. Faures *et al.* (2007) compiled a water balance for the Nile in Egypt for 1993 to 1994, using a range of published sources (Figure 4). This balance assumes final outflow of 14.2 km^2/year. In this case, only some 13.7 km^3 is estimated to reach the front of the Nile delta.

Figure 4: Nile water balance in Egypt, 1993 to 1994 (km^3 year)



Note: Values may not sum to totals because of rounding.

Source: Faures *et al.* (2007).

Hydrological summary, by country

Table 17 synthesizes the information from the previous paragraphs and presents a runoff balance for the Nile countries.

As discussed before, among the main shortcomings of the analysis are:

1. the absence of a common period of record;
2. in many occasions, the absence of hydrometric stations at border crossings;
3. the lack of calibrated rainfall runoff models for ungauged areas;
4. the lack of accurate information on over-lake rainfall and evaporation for large water bodies such as Lake Victoria;
5. the short time series of discharge measurements for smaller tributaries; available records may not fully represent the historic temporal variability.

Hence, the figures obtained have only indicative value.

Table 17: National runoff balances

Country	National runoff (km^3/year)	Sum (km^3/year)	Period of record
Burundi	3.37[1]	3.37	1972 -1985
Dem. Rep. of the Congo	2.19[2]	2.19	1940 -1978
Egypt	0	0	
Eritrea	0.6	0.6	
Ethiopia	72.99	72.99	1961 -1994[6] 1961 -1997[7] 1929 -1963[8]
Kenya (land area Lake Victoria basin)	9.62[3]	9.62	1956 -1978
Kenya (northern part)	-	-	
Rwanda	3.47[1]	3.47	1972 -1985
Sudan	73.09[9] – 108.05[10]	-34.96	1940 -1977[4&5] 1961 -1994[6] 1961 -1997[7] 1929 -1963[8]
United Rep.Tanzania (excl. lake area Lake Victoria)	0.38[1] + 5.62[3]	6.00	1972 -1985[1] 1956 -1978[3]
Uganda (excl. lake area Lake Victoria)	0.20[1] + 0.34[3] + 0.54[4] + 3.75[5]	4.83	1972 -1985[1] 1956 -1978[3]

[1] *Kagera*
[2] *Semlike*
[3] *Lake Victoria land area (excl. Kagera)*
[4] *Net Nile (Bahr El Jebel at Nimule – Lake Victoria inflow – Semlike Democratic Republic of the Congo)*
[5] *Ugandan share of the Torrents between Lake Albert and Mongalla*
[6] *Atbara*
[7] *Rahad, Dinder and Blue Nile*
[8] *Baro-Akabo*
[9] *Total outflow the Sudan*
[10] *Total inflow the Sudan*

The hydrological significance of wetland areas in the Nile Basin

Wetlands are characterized by permanently wet or periodically flooded lands with diverse fauna. Their hydrology is complex because of the heterogeneity of the vegetation, the seasonal variation of the inundated areas, and the often unstable nature of the many small channels in the floodplains. Wetlands are considered the most biologically diverse of all ecosystems. When they depend on surface inflow in addition to direct rainfall, sufficient water resources need to be committed to maintaining their ecosystem services.

It has proved difficult to measure the evaporation from a wetland. The classic assumption is that actual evaporation from a wetland with emerging vegetation resembles open-water evaporation. Later research has questioned this and Mohamed *et al.* (2008) point out that wetland evaporation is site-specific and difficult to extrapolate to a regional level.

Wetlands matter for the Nile hydrology. The basin holds a diverse and large collection of swamps and marshes. The largest include the Sudd and Machar marshes in the Sudan, the middle reaches of the Kagera in Rwanda and the United Republic of Tanzania, and the areas around Lake Kyoga and Lake Victoria in Uganda. Their number, extent and diversity make it unpractical to engage in a detailed assessment of evaporation that takes into account the specific conditions at each site. For instance, AFRICOVER differentiates 58 wetland types in the Sudanese Nile area alone. The equivalent figures for the United Republic of Tanzania and Uganda stand at 55 and 32 respectively.

Therefore, the assumption that evaporation from a permanent wetland approximates open-water evaporation may be reasonable for the basin level, but for lakes, the energy balance of the water body drives the evaporation process, and each lake is different. For instance, a deep lake evaporates less than a shallow one. The literature indicates that open-water evaporation is slightly lower than reference evapotranspiration, but in later modelling exercises, simply getting rid of the positive water balance has required some adjustment. After calibration, open-water evapotranspiration is assumed to be 130 percent of reference evapotranspiration, while evapotranspiration over swamps and wetlands is assumed to be 60 percent of reference evapotranspiration when potential evaporation is greater than precipitation. This range of estimates based on limited field observations and modelled water balances points to the need for detailed

Table 18: IUCN conservation area classes in the Nile Basin

IUCN Category	Description	Agricultural activities
Ia	strict nature reserve	None
II	protected area managed mainly for ecosystem protection	None
IV	protected area managed mainly for conservation through management intervention	Pastoralist & small-scale agriculture
VI	protected area managed mainly for the sustainable use of natural ecosystems	Rangelands, pastoralist & small-scale agriculture

Table 19: Rain volumes on protected areas in IUCN categories Ia and II in the Nile Basin

Name	Country	Area in Nile Basin (km^2)	Avg. annual precipitation (mm/yr)	Total annual rain volume (km^3)
Virunga	DRC	5 554	1 166	6.48
Qarun Lake	EGY	1 146	19	0.02
Wadi el Rayan	EGY	1 756	14	0.02
Elba	EGY	1 649	36.5	0.06
Wadi el Assuity	EGY	35	0	0.00
Simien Mountains	ETH	450	1 017	0.46
Gambella	ETH	5 774	1 074	6.20
Omo	ETH	91	1 185	0.11
Mount Elgon	KEN	84	1 177	0.10
Kakamega	KEN	48	1 874	0.09
Ruma	KEN	125	1 305	0.16
Masai Mara	KEN	1 763	1 244	2.19
Akagera	RWA	1 020	935	0.95
Volcans	RWA	412	1 419	0.59
Dinder	SDN	8 400	759	6.38
Southern	SDN	14 680	1 160	17.03
Shambe	SDN	1 749	892	1.56
Rubondo	TZA	202	1 211	0.25
Serengeti National Park	TZA	12 449	902	11.23
Ngorongoro Conservation Area	TZA	278	751	0.21
Lake Mburo	UGA	837	1 117	0.93
Queen Elizabeth	UGA	2 072	947	1.96
Rwenzori Mountians National Park	UGA	602	1 672	1.01
Bwindi Impenetrable National Park	UGA	295	1 291	0.38
Murchison Falls	UGA	3 822	1 127	4.31
Kidepo Valley	UGA	1 447	813	1.18

sub-basin assessments and field measurements over the extensive wetland areas in the Sudd. Advected energy across the extensive wetlands in the mid-Nile is expected to have a significant role in raising open water evaporation.

The hydrological significance of protected areas in the Nile Basin

Table 18 lists the IUCN classes Ia and II protected areas by country, together with their areas, average annual precipitation and total rain volumes. River discharge generated on protected areas is based on the average runoff coefficient for the respective riparian.

Agricultural activities may be limited or completely barred in conservation areas. It appears that the conventions for naming conservation areas, and the associated levels of protection, differ among Nile countries, so names do not provide a clear indication of the level of existing agricultural activities. The analysis therefore uses the IUCN category definition, which has clear rules with regard to the type of human activities allowed. Table 18 lists the conservation classes in the Nile Basin.

It is assumed that no agricultural activities take place in classes Ia and II, while IV and VI include "pastoralist" zones.

Groundwater circulation in the Nile Basin

Introduction

The hydrological regime of the Nile Basin is influenced to various degrees by surface-groundwater interactions. These are clearly evident in the extensive wetlands of the Sudd, where shallow groundwater circulation from the adjacent plains is expected to sustain areas of open water throughout the annual water cycle. An unpublished report commissioned by FAO from Mr. M.J. Jones provides the basin for this account.

Geological framework

Sutcliffe and Parks (1999) provide an outline of the geomorphological development of the basin since about 6 million years before the present (Ma), which concentrates on the major elevation changes in the basin morphology. Although this outline is sufficiently succinct and valid for hydrological purposes, a groundwater study requires considerably more regional and local detail if the geometry and distribution of the aquifers are to be fully appraised. In particular, tectonic and climatic events since 6 million years (Ma) have significantly modified the emplacement and circulation of local groundwater occurrences across the basin. In turn, the styles of direct and indirect recharge processes and the location of groundwater discharge points into the Nile watercourse and associated wetlands are partially responsible for the natural hydrological signature of the basin. The basic geological framework of the Nile Basin is given in Figure 5.

Following Said (1993), the overall relationship of the Nile hydrology to the broad geological structure of the Nile is presented in Figure 6.

Apart from the clear demonstration of losses and gains along the course of the Nile, observations prompted by this figure are as follows.

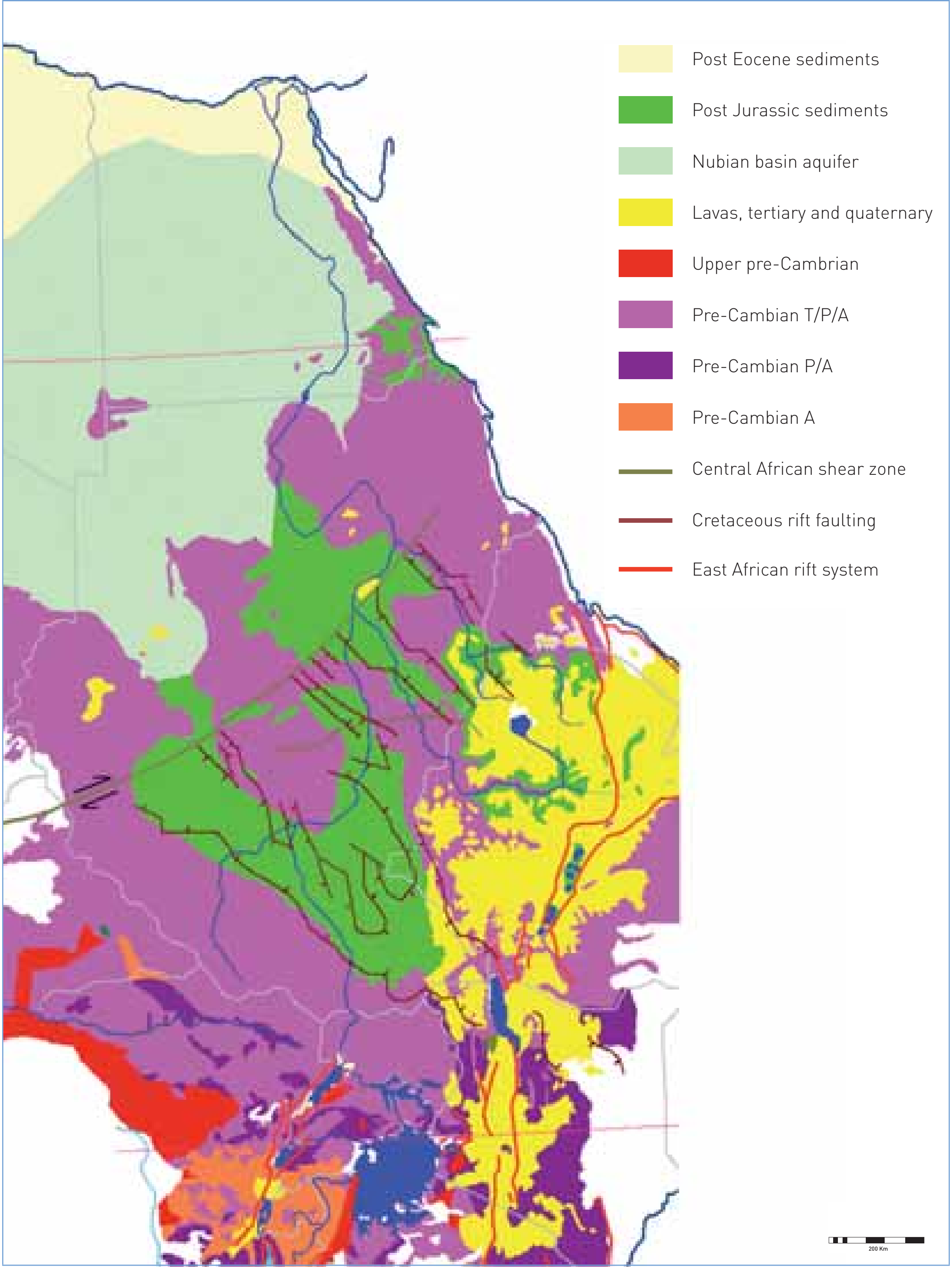
Victoria Nile

- Although crystalline basement rocks dominate the Victoria Nile catchment area, these have been subjected to considerable recent tectonic movement in Uganda, Rwanda, Burundi and the Democratic Republic of the Congo.
- Precipitation of the open water surface of Lake Victoria makes the largest contribution to the river flow and is similarly augmented by the other lakes within the catchment.

Sudanese Nile

- The crystalline basement upper and middle catchment watercourses collectively considered as making up

Figure 5: Generalized geological framework for the Nile Basin



the Bahr el Ghazal system are isolated groundwater occurrences and make no contribution to the baseflow of the Sudanese Nile mainstream.

- The Muglad cretaceous rift basin underlies the very subdued topography of the Sudd and the lower reaches of the Bahr el Ghazal. The indications are that the area may still be subsiding, possibly exacerbated by the compaction of unconsolidated sediments.
- Likewise the Melut rift basin strongly controls the surface water flows in the lower Sobat catchment and the tributaries that drain northern Uganda and southwestern Ethiopia. The impeded drainage and evaporation losses to the Sobat flow reaching the main Nile are probably in the order of 40 percent. Although this compares favourably with the almost total losses of the Bahr el Ghazal, the losses are more seasonal and are less likely to support ecosystems of environmental or economic importance.

Blue Nile and main Nile to Hassanab

- The extensive outwash plains deposited by the Blue Nile and Atbara between the highlands and the modern course of the Nile may provide significant groundwater storage and support regional underflow.
- The rifted basin under the lower course of the Atbara may also have hydrogeological significance.

Cataract Nile

- Potential exists for groundwater and runoff flow to the Cataract Nile along the alignment of the Wadi Howar (el Melik) that drains the northern flanks of the Jebel Marra. This wadi catchment is frequently included as part of the recharge area for the Nubian Aquifer System (NAS).
- The estimated 8.8 km^2 decline in flow between Dongola and the Aswan discharge is attributed to evaporation losses and takes no account of diversion to the Toshka depression or possible influent losses to the surrounding NAS or the overlying Eocene limestones.
- Under present climatic conditions, surface and groundwater inflows from the west to the Nile below Malakal are rare and limited to rare storm floods and recharge events.

Egyptian Nile

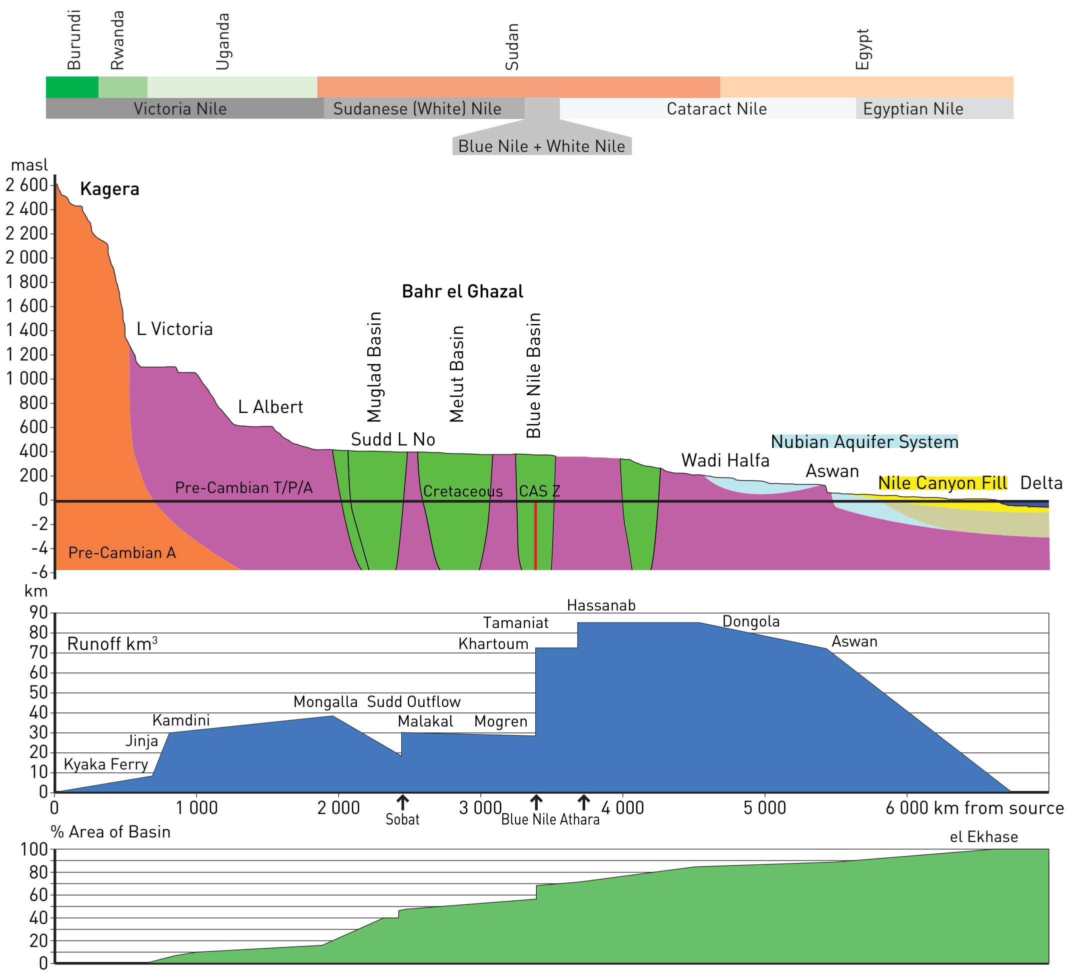
- The post-6 Ma entrenchment of the Eonile canyon during the Messinian salinity crisis and subsequent late Tertiary and Pleistocene sedimentary infill dominates the configuration of the groundwater occurrences of the modern Egyptian Nile Valley.
- The bulk of the basal gulf phase infill deposits in the Eonile canyon are marine clays that effectively seal the later Egyptian Nile valley aquifer zones of the Palaeonile and Neonile sediments from the underlying Nubian sandstone aquifer.
- Below Aswan, figures for consumptive water use are incomplete, but report that only 1.2 km^3 currently flows into the Mediterranean (Faurès *et al.*, 2007).

This cross-sectional view supports the suggested broad division of the main Nile, together with the major eastern Sobat, Blue Nile and Atbara basins and the Bahr el Ghazal river system. Within these broad divisions, groundwater resources can be assigned to specific climatic zones and hydrogeological provinces.

Hydrogeological provinces and groundwater resources

Two aspects require brief clarification before examining the Nile Basin in detail. These are

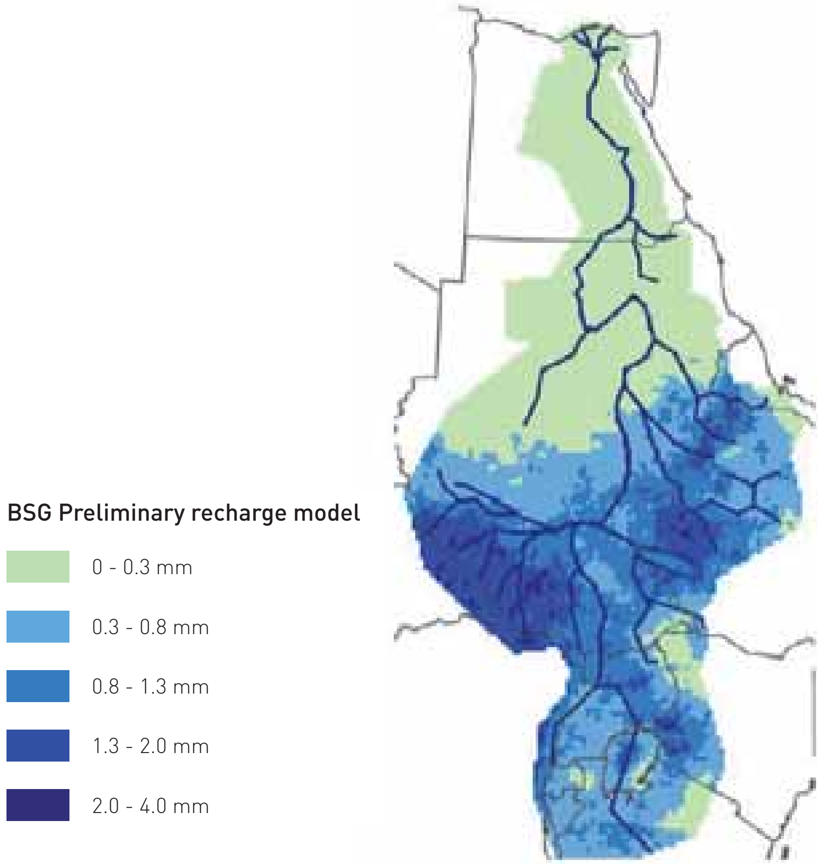
Figure 6: Long profile of main Nile showing main basin sub-divisions, key geological features, mean annual river flows and percentage growth in catchment area



the scope and nature of the aquifer recharge, and the water-bearing properties of the crystalline rock aquifers. Given the prevailing arid and semi-arid climate across much of the Nile Basin and that many rainfall events are of relatively short duration and highly localized, it is inherently difficult to quantify any hydrological response when the analysis is based on mean daily, monthly or annual data, particularly when trying to establish aquifer recharge. Based on mean annual values in the tropics, the cut-off value for significant direct recharge is 600 mm. Below this mean value, direct recharge is erratic and unpredictable. Above 600 mm, recharge can be expected to rise exponentially and become predictable. At and above about 1 200 mm, the available aquifer storage can become a factor in whether recharge is accepted or rejected.

Figure 7 shows a preliminary distribution of aquifer recharge mechanisms and the potential for recharge events to occur. Although based on a subjective (but detailed) estimation of numerous worldwide recharge assessments, it provides a good starting guideline for groundwater resource assessments. For comparison, the British Geological Survey (BGS) recharge model (Bonsor *et al.*, 2009) is shown as an insert. This was prepared to provide a baseline for interpretation of the Gravity Recovery and Climate Experiment (GRACE) satellite dataset. The BGS model recharge output values refer to the groundwater baseflow contribution to the main Nile River. The GRACE programme specifically aims at monitoring changes in the water mass by remotely measuring seasonal microgravity variations directly. These variations have been interpreted and the divisions between soil moisture and surface and groundwater changes assigned for the High Plains aquifer system in the United States of America (Strassberg, Scanlon and Chambers, 2009). With more reliable field data,

Figure 7: Preliminary distribution of potential aquifer recharge in the Nile Basin based on subjective consideration of mean annual precipitation (No allowance is made for influent seepage from the main rivers)



Source: H. C. Bonsor *et al.*, 2009.

the application of GRACE measurements will prove a valuable monitoring tool, but care will be needed, as seasonal soil moisture changes form a major component of the water balance, particularly in crystalline basement areas with thick weathered saprolite and regolith profiles.

Outside the Equatorial zone, rainfall is generally limited to a few months, and the year can be divided into clearly defined wet and dry seasons. As the climate becomes drier, rainfall in the wet seasons tends to become more variable in both quantity and distribution. In the Nile Basin, this pattern of rainfall is characteristic of semi-arid and sub-humid zones with annual rainfall of less than 600 mm. The main differences in rainy seasons are their duration and the number of days with rain. Direct annual recharge under these conditions mirrors the rainfall pattern and is very variable. It ranges from zero, to a few percent of rainfall in wetter years. In the semi-arid areas, rainfall is limited to three to five storms a year, each lasting only a few hours. Indirect infiltration of runoff is the dominant recharge mechanism in such semi-arid and arid regions, and it has been recognized that 5 percent of the storms cause over 50 percent of the stream flows, while approximately 15 percent of the floods produce 90 percent of the total stream flows.

Six broad hydrogeological divisions can be made:

1. **Victoria Nile:** The Equatorial zone of the Victoria Nile, including Kyoga plateau to the border with the Sudan above the Sudd, is characterized by Pre-Cambrian basement in which the generally shallow and discontinuous aquifers are fully recharged during the wet seasons and then drain to the main watercourses. Baseflow separation on the Kagera, for instance, indicates 40 to 45 percent of mean annual flow of 6.3 km3/year (116 mm over the sub-basin). This level of groundwater contribution to flows entering Lake Victoria is also apparent in the Nzoia sub-basin, for example, and indicates groundwater baseflow contribution in the order of 50 mm, from an annual rainfall of approximately 1 200 mm. Before the Kyoga drains into Lake Albert, baseflow separation suggests that this order of groundwater contribution from the weathered zone aquifers is maintained.

2. **Sudanese Nile:** The Sudd represents the hydrological and hydrogeological "hinge" for the basin. As the main Nile and the upper-mid Bahr el Ghazal catchments drain a crystalline basement complex through extensive colluvial outwash flats, surface and shallow groundwater circulation flows into an extensive set of seasonal wetlands. Although the outwash flats that transition between the upstream basement complex and wetlands of the Sudd complex may have groundwater potential, the hydrometric record from the Bahr el Ghazal is limited to one station on the Jur at Wau. These hydrographs indicate very little baseflow contribution. With rainfall amounts still about 1 100 mm, but declining towards the north, it is estimated that much of the shallow groundwater circulation is lost to evaporation. By contrast, the baseflow contribution in the Sobat can be estimated at approximately 10 percent of mean annual flow (13.5 km^3/year). This amounts to some 6 mm over the Sobat sub-basin, although the overall contribution may be masked by a strong interflow component typical of low-gradient plains and marshland. The upper catchment flows are generated on basement, but the extensive mid- and lower sub-basin reaches

lie in a broad structural depression filled by post-Cretaceous alluvial fill, in which seasonal groundwater storage and release are significant. It is suspected that some of the Sobat flow drains to the north into the Machar plain.

3. **Downstream of the Sudd:** when all White Nile flows are integrated, the baseflow component at Malakal is still notable, at approximately 12 km^3/year from a mean annual flow of 30 km^3. Over the upstream catchment area, this order of baseflow represents 8.5 mm. Downstream of Malakal towards the Blue Nile confluence, structural controls on groundwater flow in faulted depressions filled with Jurassic and Cretaceous deposits become more apparent. However, comparison of hydrographs at Malakal and Mogren (just upstream of the Blue Nile confluence) indicate that interflow and baseflow components are maintained along this long reach of the White Nile, rising from 12 km^3/year at Malakal to approximately 15 km^3/year at Mogren. The hydrogeology of the series of rift basins across the southern and central Sudan is characterized by relatively deep aquifers in Umm Rawaba, and Nubian deposits to the west of the Nile. Lateral inflow between the Sobat and Blue Nile is limited by flat plains extending to the Ethiopian highlands in the east and the Nuba Mountains to the west. This is owing to the steadily decreasing rainfall of 400 to 450 mm/year. The prospects for direct recharge are limited, and recharge events are limited to seasonal spate flows; the hydrochemistry indicates active modern recharge in superficial deposits, with occasional spills into the Nile.

4. **Blue Nile and main Nile to Hassanab:** The transition from the Ethiopian highlands to the semi-arid setting of the Atbara basin is marked by generally low rates of recharge. The local groundwater contributions to Lake Tana, however, are estimated at 15 to 17 percent of inflows. Recharge becomes progressively more limited as the isoheyts decline to the north, to the point where annual rainfall over the upper Atbara, even with estimates of recharge based on precise hydrochemical and isotope analysis, can be considered negligible. The net result is apparent in the Blue Nile hydrograph at Roseires dam. With a mean annual flow of 48.7 km^3/year, baseflow is only about 2 to 2.5 km^3/year. The rapid fall in the baseflow recession curve points to a combination of limited groundwater storage and high evapotranspiration losses in the lower part of the Blue Nile gorge. Equally, the contributions from the intermittent flow of the Dinder and Rahad are lost to extensive floodplains and irrigation schemes. At the confluence of the two Niles, more hydrogeological information becomes available, but all indications are that the watercourses are effluent to local aquifers.

5. **Cataract Nile:** Below the Atbara confluence, the Nile becomes progressively de-coupled from the thickening Nubian aquifer whose flow systems are driven north and west under paleo-gradients, to appear as discharge in the Libyan and western Egypt oases. Downstream of Dongola, the Nile crosses on to the basement complex of the Nubian swell before flowing over the western margin of the Nubian aquifer, but there is little or no hydraulic connection between the aquifer and the Nile.

6. **Egyptian Nile:** At Aswan, the Nile becomes entrenched in the Nile canyon fill and eventually dispersed across the distributaries of the Nile delta. Irrespective of the tectonic controls on the course of the Nile, the river is clearly in hydraulic continuity with the Pleistocene and Holocene alluvial aquifers of the Eonile canyon fill, and the side wadi draining the Red Sea hills contribute intermittent but significant indirect recharge to the alluvial aquifers.

Overall groundwater connection with the Nile

In broad terms, upstream of the Sudd, saturation of adjacent wetlands and related aquifers sustains perennial baseflow contributions to the main Nile watercourses. Downstream of the Sudd, the lower rates of recharge, damped circulation and structural controls inhibit effluent flow from the pre-Pleistocene aquifers. Locally, however, lateral inflow from Quaternary/Holocene aquifers (mainly outwash fans) contributes sporadic inflows to the White Nile, Blue Nile and Atbara systems. Hence, with the exception of a few highly transmissive outwash aquifers in the Blue Nile sub-basin, the connection to the Nile beyond the Sudd is limited and subject to strong structural controls that set the boundary conditions for a set of paleo-hydraulic gradients. The localized alluvial aquifer connection is strong in the Nile canyon fill below Aswan, and supports conjunctive use in the "old lands" of the valley and the Nile delta. It is not apparent that the Nile serves as a major linear source of recharge to the underlying Nubian aquifer system.

A basin and country water balance

Given the physical state of the basin, its length and breadth, and the lack of hydrometric data for calibrating and validating model runs, the application of high-input distributed modelling and hydraulic routing for the whole basin is not possible at this stage. Attempts to refine a basin-wide rainfall-runoff mode will be made as part of the decision support system anticipated by the NBI, but in this project, a distributed basin water balance model is used to determine the impact of irrigated agriculture on the Nile Basin. Out of practical necessity, this Nile Basin water balance is based on a number of assumptions and approximations, but is designed to calculate the upper limit of evapotranspiration given a distributed set of cultivated areas (rainfed and irrigated) across the basin. The balance therefore calculates the maximum evapotranspiration limit from cultivated areas. The additional evapotranspiration losses from canals and irrigation drainage sinks is not accounted for, nor are any gains from groundwater. However, these irrigated crop water use requirements have to be multiplied by the assumed water use requirement ratios to obtain actual withdrawals for irrigation. These assumptions are considered to be valid for most of the basin, given the small percentage of equipped irrigated area (60 000 km^2) over the whole basin (3 170 419 km^2) and, with the exception of Egypt, the low level of groundwater mobilization for irrigation.

Basin balance methodology

The results of the water balance calculations consist of monthly values by grid cell (pixels) for actual evapotranspiration, runoff, groundwater recharge and water stored as soil moisture. The model assumes that land is either rainfed or irrigated, from which an upper level for actual evapotranspiration is calculated on the basis of reference evapotranspiration factored for available soil moisture.

Hence, the cultivated areas under rainfed conditions and the equipped irrigated areas are taken as the main distributed variables and are derived from FAOSTAT (http://faostat.fao.org) and GMIA (http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm) distributions. These assumptions made for the modelling should be distinguished from the detailed district-level data compiled for the project's water use surveys, where areas are distributed by district not pixels.

The water balance for the Nile is calculated in two steps. First a soil water balance is calculated, and this is corrected for the water balance for open water and swamps at a later stage. Both water balances have spatially distributed input and output layers. Input layers for the soil water balance consist of monthly precipitation, number of wet days per month, monthly reference evapotranspiration, maximum soil moisture storage capacity (taken from the Harmonized Soil Map of the World – www.iiasa.ac.at/research/luc/external-world-soil-database/html/index.html), maximum percolation flux (FAO estimates) and irrigated areas (GMIA).

The basic water balance equation for this model is as follows:

$$P = ETa + R + RO + \Delta S$$

where:

P = precipitation in mm;
ETa = actual evapotranspiration in mm;
R = groundwater recharge in mm;
RO = direct runoff and interflow runoff in mm;
ΔS = changes in soil moisture storage in mm.

The computation of water balance is carried out by a model with a 5 arc minute spatial resolution of grid cells (approximately 9.3 km at the Equator) and in daily time steps. The monthly precipitation is divided by the number of wet days to obtain daily precipitation. It is assumed that all precipitation falls in equal amounts in the first days of the month.

The groundwater recharge term (R) and the runoff term (RO) comprise the drainage over the whole basin. This drainage is then assumed to be lost to ETa in open water and swamps before translating to measured outflows at each of the sub-basins. In this sense the model is calibrated on long-term mean annual runoff.

Rainfed areas

Actual evapotranspiration (ETa) over rainfed areas is assumed to be equal to the reference evapotranspiration (ETo) when there is enough water stored in the soil to allow ETa to be equal to reference evapotranspiration as calculated on a monthly basis with the FAO Penman-Monteith method (FAO, 1998). In drier periods, when the available soil moisture is reduced below a certain level, lack of water reduces actual evapotranspiration to an extent proportional to the available soil moisture.

In equations:

$$ETa(t) = ETo(t) \text{ for } Smax \geq S(t) \geq 0.5 * Smax)$$
$$ETa(t) = ETo(t) * S(t-1) / (0.5*Smax) \text{ for } S(t-1) < 0.5 * Smax$$

where:

t = time step in days;
ETa(t) = actual evapotranspiration on t in mm;
ETo(t) = reference evapotranspiration on t in mm;

S(t-1) = available soil moisture on t-1 in mm;
Smax = maximum soil moisture storage capacity in mm.

Groundwater recharge is assumed to occur only when there is enough water available in the soil to percolate. The percolation rate is assumed to be proportional to the available soil moisture.

In equations:

$R(t) = Rmax * (S(t-1) - 0.5 * Smax) / (0.5 * Smax)$ for $Smax \geq S(t) \geq 0.5 * Smax)$
$R(t) = 0$ for $S(t-1) < 0.5 * Smax$

where:
R(t) = percolation flux on t in mm
Rmax = maximum percolation flux in mm

The available soil moisture is calculated per day by adding ingoing to and subtracting outgoing fluxes from the available soil moisture of the day before. Runoff occurs when the balance of the in- and outgoing fluxes exceeds the maximum soil moisture storage capacity.

In equations:

$$B(t) = S(t-1) + P(t) - ETa(t) - R(t)$$

if $B(t) < Smax$ then:
$S(t) = B(t)$
$RO(t) = 0$

if $B(t) \geq Smax$ then:
$S(t) = Smax$
$RO(t) = B(t) - Smax$
where:
B(t) = balance on t in mm.

Irrigated areas

The evapotranspiration of a crop under irrigation is obtained by multiplying the reference evapotranspiration (ETo) with a crop-specific coefficient (Kc). This coefficient has been derived for four different growing stages: the initial phase (just after sowing), the development phase, the mid-phase, and the late phase (when the crop is ripening to be harvested). In general, these coefficients are low during the initial phase, after which they increase during the development phase to reach high values in the mid-phase before declining again in the late phase. It is assumed that the initial, development and late phases each take one month for any crop, while the duration of the mid-phase varies according to the type of crop. For example, the growing season for cotton in the Sudan starts in April and ends in October, as follows: initial phase April (Kc = 0.35); development phase, May (Kc = 0.8); mid-phase, June to September (Kc = 1.2); and late phase, October (Kc = 0.6).

The rate of evapotranspiration coming from the irrigated area per month and per grid cell is calculated by multiplying the area equipped for irrigation with cropping intensity and crop evapotranspiration for each crop:

$$ETc(t) = IA * \Sigma c(CIc * Kc * ETo(t))$$

where:
ETc(t) = actual evapotranspiration of an irrigated grid cell in mm;
IA = irrigated area in percentage of cell area for the given grid cell;
c = crop under irrigation;
Σc = sum over the different crops;
CIc = cropping intensity for crop c;
Kc = crop coefficient, varying for each each crop and each growth stage.

The difference between the reference evapotranspiration of the irrigated area (ETo) and actual evapotranspiration under non-irrigated conditions (ETa) is equal to the consumptive use of water in irrigated agriculture in the grid cell, i.e., the net irrigation water requirement. In the case of paddy rice, an additional amount of water is needed for flooding. In this study this amount has been computed by multiplying the area under irrigated rice by a water layer of 20 cm.

Although this assumption overestimates ETa in any one month or year, it sets the maximum ETa limit that can be expected for the given area and cropping calendar with related cropping coefficients (Kc).

Soil water balance

The spatial soil water balance is calibrated by changing maximum soil storage capacity values and maximum infiltration fluxes. The input layers with climatic information remain untouched. The spatial soil water balance is corrected for evaporation over open water and swamps, derived from GLC 2000 data. It is assumed that natural cover has a Kc of 1, i.e., the maximum evapotranspiration of natural land cover is assumed to be equal to reference evapotranspiration. Actual evapotranspiration is then a function of the soil moisture deficit. As indicated in Figure 8, when natural land cover (including forests) has a soil moisture content between field capacity and the reduction point, maximum evapotranspiration is assumed to occur. After

Figure 8: Assumed relationship between actual evapotranspiration and soil moisture

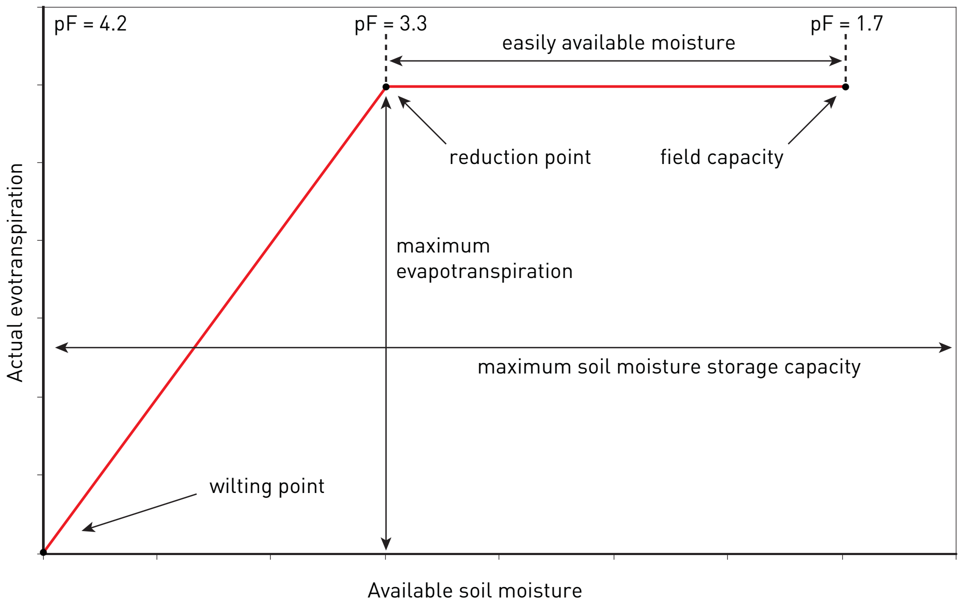


Table 20: Comparison of sub-basin balance outflows – natural and actual

Sub-basin name	Area (km^2)	Outflow at sub-basin - natural (km^3)	mm equivalent	Outflow at sub-basin – actual (km^3)	Irrigated crop water use requirement (km^3)
Lake Victoria basin	264 985	27.563	44	27.507	0.056
Kyoga - Albert	197 253	40.690	35	40.628	0.062
Bahr el Jebel	136 400	16.236	26	16.16	0.076
Bahr el Ghazal	236 330	5.891	39	5.885	0.006
Bahr el Arab	370 098	4.396	16	4.388	0.008
Pibor - Akabo - Sobat	246 779	15.829	61	15.828	0.001
White Nile	260 943	31.621	20	26.485	5.136
Blue Nile	308 198	57.324	129	55.236	2.088
Atbara	237 044	10.115	28	8.443	1.672
Main Nile d/s of Khartoum	34 523	85.647	3	78.374	7.273
Main Nile d/s of Atbara	877 866	42.616	1	14.959	27.658
	3 170 419				**44.036**

Table 21: Natural water balance components

Natural water balance	Area (km^2)	Mean annual Precipitation (mm)*	Precipitation (km^3)	ET over land (km^3)	ET over open water (km^3)	ET over wetlands (km^3)	Total ET (Km^3)	Groundwater drainage (km^3)	Direct Runoff (km^3)	IRWR ** (km^3) P-Total ET	TRWR *** (km^3) I+P-Total ET
Basin name											
Lake Victoria basin	264 985	1 264	334.96	191.21	103.57	12.62	307.4	14.47	11.56	27.56	27.56
Kyoga - Albert	197 253	1 190	234.74	189.91	16.82	14.89	221.62	7.92	6.98	13.13	40.69
Bahr el Jebel	136 400	941	128.34	96.13	0	66.94	163.08	4.62	3.58	-34.74	16.24
Bahr el Ghazal	236 330	1 124	265.65	227.93	0	31.83	259.75	15.01	9.20	5.89	5.89
Bahr el Arab	370 098	537	198.76	189.88	0	4.48	194.36	1.14	5.95	4.40	4.40
Pibor - Akabo - Sobat	246 779	971	239.58	201.2	0	22.55	223.75	6.99	15	15.83	15.83
White Nile	260 943	533	138.98	119.11	0.16	20.15	139.42	3.57	5.34	-0.44	31.62
Blue Nile	308 198	1 042	321.27	248.28	4.88	10.78	263.95	24.8	39.76	57.32	57.32
Atbara	237 044	433	102.55	91.59	0.85	0	92.44	4.21	6.57	10.12	10.12
Main Nile d/s Khartoum	34 523	114	3.92	3.57	0	3.65	7.22	0	0.11	-3.30	85.65
Main Nile d/s Atbara confluence	877 866	45	39.10	36.76	13.42	42.57	92.76	0.04	1.09	-53.66	42.62
Total	**3 170 419**	**--**	**2008**	**1596**	**140**	**230**	**1966**	**83**	**105**	**42**	**--**

(Continued)

** CRU data sets 1960-1990*
*** IRWR = Internal Renewable Water Resources*
**** TRWR = Total Renewable Water Resources*
I = upstream inflow

Table 21: *(Continued)*

Natural water balance	Area (km^2)	Mean annual Precipitation (mm)*	Precipitation (km^3)	ET over land (km^3)	ET over open water (km^3)	ET over wetlands (km^3)	Total ET (Km^3)	Groundwater drainage (km^3)	Direct Runoff (km^3)	IRWR ** (km^3) P-Total ET	TRWR *** (km^3) I+P-Total ET
Country											
Burundi	13 250	1 190	15.76	12.00	0.11	0.21	12.32	2.13	1.28	3.44	--
Dem. Rep. of the Congo	20 191	1 165	23.52	16.99	5.88	0.00	22.86	1.37	0.87	0.66	--
Egypt	303 084	80	24.10	22.46	10.15	30.21	62.82	0.00	0.63	-38.73	--
Eritrea	24 578	439	10.78	9.96	0.00	0.00	9.96	0.16	0.66	0.82	--
Ethiopia	364 925	1 186	432.73	337.60	4.73	0.00	342.33	35.88	55.21	90.40	--
Kenya	70 248	1 159	81.41	65.65	7.10	1.88	74.63	5.39	3.92	6.78	--
Rwanda	20 823	1 163	24.22	19.03	0.43	1.23	20.69	2.25	1.61	3.53	--
Sudan	1 993 082	491	978.46	852.56	4.36	171.59	1 028.51	24.41	30.32	-50.05	--
United Rep. Tanzania	120 768	1 147	138.58	73.87	52.18	6.26	132.30	3.51	3.79	6.28	--
Uganda	239 468	1 237	296.19	202.90	54.70	19.08	276.68	7.65	7.36	19.51	--
Total****	**3 170 419**	--	2021	1613	140	230	1983	83	106	43	--

** CRU data sets 1960-1990*

*** IRWR = Internal Renewable Water Resources*

**** TRWR = Total Renewable Water Resources*

***** including all Egypt*

I = upstream inflow

Table 22: Actual water balance components

Actual water balance	Area (km^2)	Mean Annual Preciptiation (mm)*	Precipitation (km^3)	ET over land (km^3)	Area irrigated (km^2)	Incremental ET over irrigated areas (km^3)	ET over open water (km^3)	ET over wetlands (km^3)	Total ET (km^3)	Ground water drainage (km^3)	Direct Runoff (km^3)	IRWR ** (km^3) P-Total ET	TRWR *** (km^3) I+P-Total ET
Basin name													
Lake Victoria basin	264 985	1 264	334.96	191.21	283.34	0.06	103.57	12.62	307.46	14.47	11.56	27.51	27.51
Kyoga - Albert	197 253	1 190	234.74	189.91	72.61	0.01	16.82	14.89	221.62	7.92	6.98	13.12	40.63
Bahr el Jebel	136 400	94	128.34	96.13	0.00	0.00	0.00	66.94	163.08	4.62	3.58	-34.74	16.16
Bahr el Ghazal	236 330	1 124	265.65	227.93	21.00	0.01	0.00	31.83	259.76	15.01	9.20	5.88	5.88
Bahr el Arab	370 098	537	198.76	189.88	19.42	0.01	0.00	4.48	194.37	1.14	5.95	4.39	4.39
Pibor - Akabo - Sobat	246 779	971	239.58	201.20	17.06	0.00	0.00	22.55	223.75	6.99	15.00	15.83	15.83
White Nile	260 943	533	138.98	119.11	9 068.72	5.50	0.16	19.72	144.48	3.57	5.34	-5.50	26.49
Blue Nile	308 198	1 042	321.27	248.28	5 902.11	3.00	4.88	9.87	266.03	24.80	39.76	55.24	55.24
Atbara	237 044	433	102.55	91.59	2 978.20	1.67	0.85	0.00	94.11	4.21	6.57	8.44	8.44
Main Nile d/s Khartoum	34 523	114	3.92	3.57	421.58	0.28	0.00	3.42	7.27	0.00	0.11	-3.35	78.37
Main Nile d/s Atbara confluence	877 866	45	39.10	36.76	32 641.94	41.97	13.17	16.93	108.83	0.04	1.09	-69.73	14.96
Egypt outside Nile) ****	0	--	18.32	17.80	2 238.77	2.64	0.00	0.00	20.44	0.00	0.51	-2.13	-2.13
Total	**3 170 419**	**--**	**2 026**	**1 613**	**53 665**	**55**	**139**	**203**	**2011**	**83**	**106**	**15**	**--**

(Continued)

** CRU data sets 1960-1990*
*** IRWR = Internal Renewable Water Resources*
**** TRWR = Total Renewable Water Resources*
***** not included in basin totals*
I = upstream inflow

Table 22: *(Continued)*

Actual water balance	Area (km^2)	Mean Annual Preciptiation (mm)*	Precipitation (km^3)	ET over land (km^3)	Area irrigated (km^2)	Incremental ET over irrigated areas (km^3)	ET over open water (km^3)	ET over wetlands (km^3)	Total ET (km^3)	Ground water drainage (km^3)	Direct Runoff (km^3)	IRWR ** (km^3) P-Total ET	TRWR *** (km^3) I+P-Total ET
Country													
Burundi	13 250	1 190	15.76	12.00	32.12	0.01	0.11	0.21	12.33	2.13	1.28	3.43	--
Dem. Rep. of the Congo	20 191	1 165	23.52	16.99	0.00	0.00	5.88	0.00	22.86	1.37	0.87	0.66	--
Egypt	303 084	80	24.10	22.46	34 017.17	43.93	9.98	4.95	81.33	0.00	0.63	-57.23	--
Eritrea	24 578	439	10.78	9.96	58.65	0.02	0.00	0.00	9.98	0.16	0.66	0.80	--
Ethiopia	3 64 925	1 186	432.73	337.60	880.24	0.12	4.73	0.00	342.45	35.88	55.21	90.29	--
Kenya	70 248	1 159	81.41	65.65	145.01	0.04	7.10	1.88	74.67	5.39	3.92	6.74	--
Rwanda	20 823	1 163	24.22	19.03	78.85	0.01	0.43	1.23	20.69	2.25	1.61	3.53	--
Sudan	1 993 082	491	978.46	852.56	18 309.08	10.98	4.30	169.63	1 037.46	24.41	30.32	-59.01	--
United Rep. Tanzania	120 768	1 147	138.58	73.87	9.34	0.00	52.18	6.26	132.31	3.51	3.79	6.27	--
Uganda	239 468	1 237	296.19	202.90	90.63	0.01	54.70	19.08	276.69	7.65	7.36	19.50	--
Total	**3 170 418**		**2 026**	**1613**	**53 621**	**55**	**139**	**203**	**2 011**	**83**	**106**	**15**	**--**

** CRU data sets 1960-1990*
*** IRWR = Internal Renewable Water Resources*
**** TRWR = Total Renewable Water Resources*
I = upstream inflow

calibration, open water evapotranspiration is assumed to be 1.3 times reference evapotranspiration, while evapotranspiration over swamps and wetlands is at least 60 percent of reference evapotranspiration.

Basin balance results

The runoff and groundwater discharge results of the water balance were summarized for sub-basins of the Nile, to compare outflows with measured discharges under assumed natural conditions (with no agricultural development) and actual (developed). These model results are presented in Table 20.

The detailed results for the natural balance are set out in Table 21, and the results for the actual balance after irrigation in Table 22. This confirms that the incremental ET over irrigated areas in the Nile Basin amounts to 52.51 km^3. Taking into account irrigated areas sourced from the Nile but lying outside the basin, the total incremental ET is 55.15 km^3.

Agricultural water use

A baseline for 2005

Baseline data for 2005 were compiled under the project's agricultural water use (AWUS) component. To do this, a set of national studies were carried out in each country and a set of agricultural water use reports were compiled. For the purpose of this study, the NBI groupings were used to allow broad comparison between the Equatorial lakes countries (Uganda, Kenya, the United Republic of Tanzania, Rwanda and Burundi – excluding the Democratic Republic of the Congo, for which data were not available) and the Eastern Nile sub-basin (Egypt, the Sudan, Eritrea and Ethiopia).

The detailed methodology and results of the basin compilation are explained in detail in the projections report. For the baseline, a suite of rainfed and irrigated, district-level cropping calendars was compiled for the reported cropping systems and reconciled with FAOSTAT data to establish a Nile Basin data set for rainfed and irrigated crops. This set has been compiled in spreadsheets (Annex 1 of the projections report) that detail irrigated and rainfed crop production at the district level across the whole basin. Data were compiled for 216 districts. Cropping calendars for rainfed crops were compiled from project data collected at the district level for each country. For irrigated crops, cropping calendars were derived from FAO's AQUASTAT database and related country reports. The baseline data compiled for the AWUS work are summarized in Table 23 and compared with the GMIA and prior estimates derived from basin profiles in FAO (1997).

The comparison of rainfed and irrigated areas compiled by the project reflects the most recent attempts to consolidate cultivated area statistics. However, the discrepancies with the data compiled for a 2000 baseline for the Africa AQUASTAT update of 2005 need explanation as reflected in the GMIA published in 2007. These areas have been derived from simple GIS 'clipping' of the raster data falling inside the national boundaries of the Nile Basin, and this represents a first-order approximation. However, the increase in the project data could reflect statistical growth, methodological differences, or real growth (or contraction) since 1989. Kenya and Ethiopia record the most notable discrepancies, which probably relate to systematic over- and underreporting.

Water withdrawals for irrigation for the basin in 2005 have been estimated using the cropping calendar data compiled at the district level throughout the basin and consolidated for each country (excluding the Democratic Republic of the Congo) and into the two major NBI groupings. The results are presented for the country level in Table 24 and for the district level in Annex B of the projections report. It is important to stress that these quantify annual demand for evapotranspiration for rainfed production and water withdrawals for irrigated production for a 2005 baseline.

The difference between the two sub-basins is clear. Agricultural water use in the Eastern Nile is dominated by irrigation, whereas the opposite is the case in the Equatorial lakes. This will be shown to have significant implications on the agricultural water productivity projections analysed in the following section. Of interest are the high irrigation abstractions in Egypt and the Sudan, both being greater than their

Table 23: Harvested rainfed and irrigated areas and areas equipped for irrigation in the Nile Basin 2005 baseline and FAO comparisons (hectares)

Country	Harvested areas (ha)		Areas equipped for irrigation (ha)		
	Harvested areas rainfed	Harvested areas irrigated	FAO 1989	Global map of irrigation areas (FAO GMIA 2007)	Potential (FAO 1997)
Egypt	-	3 927 039	3 078 000	3 401 717	4 420 000
Sudan	14 044 805	1 156 747	1 935 200	1 830 908	2 750 000
Eritrea	58 715	4 143	15 124	5 865	150 000
Ethiopia	2 978 340	14 171	23 160	88 024	2 220 000
Eastern Nile total	**17 081 860**	**5 102 100**	**5 051 484**	**5 326 514**	**5 540 000**
Uganda	8 188 584	33,203	9 120	9 063	202 000
Kenya	2 204 922	41 693	6 000	14 501	180 000
United Rep. Tanzania	1 971 035	130	10 000	935	30 000
Rwanda	1 159 197	15 637	2 000	7 885	150 000
Burundi	562 104	3 158	0	3 212	80 000
Dem. Rep. of the Congo	0	0	0	0	0
Equatorial Lakes total	**14 085 842**	**93 821**	**27 120**	**35 596**	**642 000**
Basin total	**31 167 702**	**5 195 921**	**5 078 604**	**5 362 109**	**10 192 000 < 8 000 000***

** Constrained by water availability at basin level*

Table 24: Irrigation water requirements in the Nile Basin 2005 (project baseline)

Country	Irrigated crop water requirements and withdrawals (km^3)		
	Crop water requirements	Water use requirement ratio	Irrigation withdrawal (km^3)
Egypt	36.461	53%	68.795
Sudan	11.004	40%	27.511
Eritrea	0.041	32%	0.127
Ethiopia	0.106	22%	0.483
Eastern Nile total	**47.612**		**96.916**
Uganda	0.249	30%	0.829
Kenya	0.323	30%	1.076
United Rep. Tanzania	0.001	30%	0.003
Rwanda	0.095	30%	0.317
Burundi	0.014	30%	0.048
Equatorial Lakes total	**0.682**		**2.274**
Nile Basin total	**48.294**		**99.190**

allocations under the 1959 Nile Waters Agreement, which allows 55.5 km^3 to Egypt and 18.5 km^3 to the Sudan. This was calculated in proportion to population at the time and based on a mean annual flow of 84 km^3 at Dongola/Aswan inflow, less 10 km^3 of reservoir. Egypt's abstractions are more or less equal to the long-term flow into Egypt (Abu Zeid *et al.*, 2007). However, this can probably be explained by the high rates of reuse known to characterize Egypt's highly productive irrigation sector. If correct, the Sudan's abstractions are more difficult to explain, as downstream reuse is generally not factored in.

A similar exercise undertaken in 1997 (FAO, 1997) estimates the total equipped area in the basin at 5 079 000 ha and the irrigation withdrawal at 67.7 km^3. This 2005 maximum estimate of 99.2 km^3, based on district-level data and cropping patterns, would indicate a 30 percent increase in irrigation withdrawals. While there would have been some growth in withdrawals since the early 1990s, much of this apparent increase could be explained by "statistical" growth as surveys have become more detailed over the basin, and the use of reference evapotranspiration to obtain crop water requirements. As overall agricultural production from the Nile Basin countries has remained low or constant over the past two decades, it can reasonably be concluded that agricultural withdrawals have increased only marginally.

Projections in cultivated areas in the Nile Basin

The projections of harvested rainfed and irrigated areas within the Nile Basin can be estimated, but only by assuming that the baseline areas distributed across the basin grow in line with the AT2030/50 national projections. Table 25 summarizes these national projections and includes the Democratic Republic of the Congo. These projections simply give national growth rates, which for most Nile Basin countries are

Table 25: Nile Basin country AT2030/50 projections

Country	2005 baseline harvested areas (ha)		2030 harvested areas (ha)						2050 harvested areas (ha)					
	Harvested areas rainfed	Harvested areas irrigated	Harvested areas rainfed	% increase 2005-2030	Annual growth rate	Harvested areas irrigated	% increase 2005-2030	Annual growth rate	Harvested rainfed	% increase 2030-2030	Annual growth rate	Harvested areas irrigated	% increase 2030-2030	Annual growth rate
Egypt	-	6 042 000	-			7 182 000	19	0.69	-			7 699 000	7	0.35
Sudan	11 818 000	1 096 000	13 916 000	18	0.66	1 198 000	9	0.36	15 203 000	9	0.44	1 356 000	13	0.62
Eritrea	617 000	13 000	735 000	19	0.70	25 000	92	2.65	777 000	6	0.28	30 000	20	0.92
Ethiopia	12 826 000	285 000	16 110 000	26	0.92	367 000	29	1.02	20 307 000	26	1.16	441 000	20	0.92
Eastern Nile total	**25 261 000**	**7 436 000**	**30 761 000**	**22**	**0.79**	**8 772 000**	**18**	**0.66**	**36 287 000**	**18**	**0.83**	**9 526 000**	**9**	**0.41**
Uganda	6 924 000	11 000	9 675 000	40	1.35	14 000	27	0.97	11 932 000	23	1.05	17 000	21	0.98
Kenya	4 702 000	100 000	5 057 000	8	0.29	158 000	58	1.85	5 330 000	5	0.26	197 000	25	1.11
United Rep. Tanzania	8 768 000	165 000	10 240 000	17	0.62	243 000	47	1.56	11 137 000	9	0.42	324 000	33	1.45
Rwanda	1 647 000	10 000	1 898 000	15	0.57	16 000	60	1.90	2 048 000	8	0.38	22 000	38	1.61
Burundi	1 120 000	49 000	1 602 000	43	1.44	79 000	61	1.93	1 890 000	18	0.83	112 000	42	1.76
Dem. Rep. of the Congo	5 795 000	8 000	11 656 000	101	2.83	12 000	50	1.64	14 770 000	27	1.19	14 000	17	0.77
Equatorial Lakes total	**28 956 000**	**343 000**	**40 128 000**	**39**	**1.31**	**522 000**	**52**	**1.69**	**47 107 000**	**17**	**0.80**	**686 000**	**31**	**1.38**
Basin total	**54 217 000**	**7 779 000**	**70 889 000**	**31**	**1.08**	**9 294 000**	**19**	**0.71**	**83 394 000**	**18**	**0.82**	**10 212 000**	**10**	**0.47**

Table 26: Nile Basin rainfed and irrigated harvested area projections

Country	2005 baseline harvested areas (ha)		2030 harvested areas (ha)						2050 harvested areas (ha)					
	Harvested areas rainfed	Harvested areas irrigated	Harvested areas rainfed	% increase 2005-2030	Annual growth rate	Harvested areas irrigated	% increase 2005-2030	Annual growth rate	Harvested rainfed	% increase 2030-2050	Annual growth rate	Harvested areas irrigated	% increase 2030-2050	Annual growth rate
Egypt	-	3 927 039	-			4 667 990	19	0.69	-			5 004 017	07	0.35
Sudan	14 044 805	1 156 747	16 538 120	18	0.66	1 264 400	09	0.36	18 067 623	9	0.44	1 431 158	13	0.62
Eritrea	58 715	4 143	69 944	19	0.70	7 967	92	2.65	73 941	6	0.28	9 561	20	0.92
Ethiopia	2 978 340	14 171	3 740 921	26	0.92	18 248	29	1.02	4 715 511	26	1.16	21 928	20	0.92
Eastern Nile total	**17 081 860**	**5 102 100**	**20 348 986**	**19**	**0.70**	**5 958 606**	**17**	**0.62**	**22 857 076**	**12**	**0.58**	**6 466 664**	**09**	**0.41**
Uganda	8 188 584	33 203	11 442 021	40	1.35	42 258	27	0.97	14 111 234	23	1.05	51 314	21	0.98
Kenya	2 204 922	41 693	2 371 393	8	0.29	65 875	58	1.85	2 499 412	5	0.26	82 135	25	1.11
United Rep. Tanzania	1 971 035	130	2 301 939	17	0.62	191	47	1.56	2 503 583	9	0.42	255	33	1.45
Rwanda	1 159 197	15 637	1 335 857	15	0.57	25 019	60	1.90	1 441 430	8	0.38	34 401	38	1.61
Burundi	562 104	3 158	804 009	43	1.44	5 091	61	1.93	948 551	18	0.83	7 218	42	1.76
Dem. Rep. of the Congo														
Equatorial Lakes total	14 085 842	93 821	18 255 218	30	1.04	138 435	48	1.57	21 504 210	18	0.82	175 324	27	1.19
Basin total	**31 167 702**	**5 195 921**	**38 604 204**	**24**	**0.86**	**6 097 041**	**17**	**0.64**	**44 361 285**	**15**	**0.70**	**6 641 988**	**9**	**0.43**

in the order of 1 percent per annum up to 2030, with thereafter an overall reduction to approximately 0.5 percent up to 2050. There are wide variations, but generally the drivers of population and income are expected to see a general tailing off to 2050.

These growth rates are applied to the 2005 baseline areas to project harvested rainfed and irrigated areas (Table 26). The 19 percent increase in harvested irrigated areas to 2030 and thereafter the slower rate to 2050 – averaging 10 percent – are in line with projections for the rest of sub-Saharan Africa. But applying the national growth rates to the national areas of the Nile Basin remains an assumption that does not reflect regional differences.

Projections in agricultural water use

To obtain an estimate of the most probable outcome given current macroeconomic trends in each of the Nile countries, the water withdrawals for 2030 and 2050 are set out in Table 27.

Table 27 applies weighted mean unit water use values to each country's resulting irrigated areas for 2030 and 2050 (the 2005 values being those developed in Table 23). Water use requirement ratios for 2030 and 2050 are calculated on the basis of FAO AT2030/50 projection assumptions and are assumed to change from the 2005 baseline presented in Table 24. The 2005 ratios are established on the basis of calculated crop water requirements over the known cropped areas as part of reported withdrawals. However, for the 2030 and 2050 projections, the ratios are modelled on the basis of projected responses to water scarcity and the capacity to adopt more progressive irrigation technology and management. The rate of increase from 2005 to 2030 is 8 percent, slowing to 7 percent between 2030 and 2050, below the rate of growth of irrigated harvested areas. Clearly some increases in water productivity are expected to occur as farming practices become more sophisticated. But the more sobering

Table 27: AT2030/50 projections of irrigation water use requirementsin the Nile Basin (km^3)

Country	Weighted mean unit water requirements (m^3/ha)	2005		2030		2050	
	Irrigated	Water use requirement ratio	Irrigation water withdrawals (km^3)	Water use requirement ratio	Irrigation withdrawals (km^3)	Water use requirement ratio	Irrigation withdrawals (km^3)
Egypt	9 285	53%	68.795	61%	71.740	64%	73.636
Sudan	9 513	40%	27.511	43%	30.182	50%	34.635
Eritrea	9 847	32%	0.127	33%	0.216	33%	0.247
Ethiopia	7 498	22%	0.483	22%	0.663	22%	1.083
Eastern Nile total	**-**	**-**	**96.916**		**102.802**		**109.600**
Uganda	7 493	30%	0.829	30%	2.263	31%	2.693
Kenya	7 746	30%	1.076	31%	1.484	31%	1.892
United Rep. Tanzania	8 071	30%	0.003	31%	0.005	30%	0.007
Rwanda	6 076	30%	0.317	30%	0.381	31%	0.447
Burundi	4 557	30%	0.048	31%	0.085	30%	0.131
Equatorial Lakes total	-	-	2.274	-	4.218	-	5.170
Nile Basin total	**-** **-**		**99.190**		**107.020**		**114.770**

conclusion to draw from this projection of agricultural trends in the Nile Basin is that water requirement ratios for irrigated agriculture will have to improve significantly to stay within overall limits of water resource availability in the Eastern Nile basins.

Farming systems and agricultural water productivity

In a related but separate exercise, a set of national farming systems reports were commissioned for the project, to examine the state of agricultural water productivity within specific farming systems across the basin. This was an attempt to superimpose a socio-economic layer on the rather more mechanical cropping pattern analysis carried out for the agricultural water use study – an effort to appraise the human face of agricultural production in the Nile Basin, based on FAO/World Bank (2001).

Farming systems

"A farming system ..... is defined as a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate. Depending on the scale of the analysis, a farming system can encompass a few dozen or many millions of households." (FAO/World Bank, 2001).

The following criteria are used as the basis for any classification of farming systems:

- available natural resource base, including water, land, grazing areas and forest;
- climate, of which altitude is an important determinant;
- landscape, including slope;
- farm size, tenure and organization;
- dominant pattern of farm activities and household livelihoods, including field crops, livestock, trees, aquaculture, hunting and gathering, processing and off-farm activities, taking into account the main technologies used, which determine the intensity of production and integration of crops, livestock and other activities.

Based on these criteria, the following main categories of farming systems have been distinguished in the Nile Basin:

- irrigated – large-scale, traditional;
- irrigated – small-scale, traditional;
- irrigated – commercial;
- pastoral;
- agropastoral – dry and hot (millet);
- dryland farming;
- highland – tropical;
- highland – temperate (wheat);
- highland – cold (barley, sheep);
- lowlands – tropical;
- forest-based;
- woodland.

These 12 systems are mapped in Figure 9. In addition, two additional farming systems whose spatial occurrence cannot be mapped at this general scale are included in the analysis. These are:

- market-oriented agriculture: urban, peri-urban and commercial;
- riverside.

The farming system is considered an appropriate criterion for zonation of the basin for this synthesis as:

- it is the result of the interactions among cultural, agrobiological and socio-economic factors and the farmers' own priorities and resource capabilities; it reflects, better than any other single criterion, the balance of factors that are important for identifying homogeneous zones;
- farmers operating a similar system generally have the same priorities and resource endowments, and thus face similar

Figure 9: Farming systems in the Nile Basin

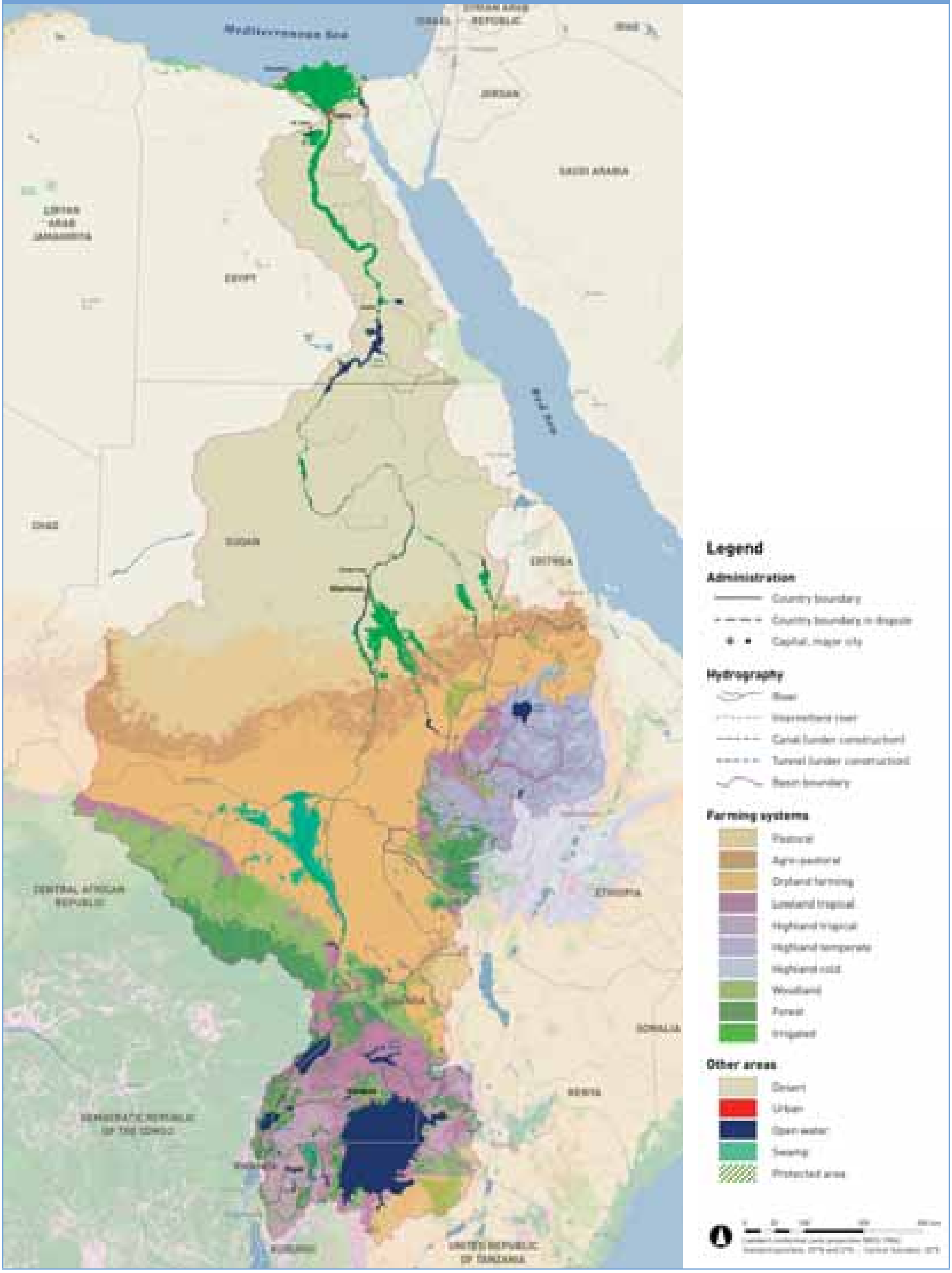


Table 28: Area of farming systems in the Nile Basin countries

Farming system	Area (ha) in Nile Basin	Egypt	Sudan	Eritrea	Ethiopia	Kenya	Uganda	Dem. Rep. of the Congo	United Republic of Tanzania	Rwanda	Burundi
Irrigated (3 typologies)	7 312 675	3 884 949	2 774 226	21 404	438 976	107 865	15 895	0	2 125	50 660	16 575
Pastoral	29 673 966	237 043	25 459 986	676 745	229 907	1 875 865	63 070	11 815	1 085 535	34 000	0
Agropastoral	18 400 051	0	15 885 661	1 470 526	718 144	322 830	2 890	0	0	0	0
Dryland farming	64 745 370	0	52 868 341	153 859	8 669 630	66 555	1 627 580	765	1 358 640	0	0
Highland tropical	8 169 690	0	0	0	0	1 734 425	2 496 195	136 765	1 225 105	1 572 330	1 004 870
Highland cold	3 650 464	0	0	0	3 489 899	101 150	40 290	6 715	0	12 325	85
Highland temperate	13 224 484	0	2 614	0	13 221 870	0	0	0	0	0	0
Lowland tropical	17 986 563	0	2 915 301	0	3 763 967	1 189 490	8 467 190	294 440	1 355 750	0	425
Forest-based	13 393 767	0	5 693 060	0	2 892 682	529 125	2 939 130	539 155	762 875	32 045	5 695
Woodland	18 429 032	64 268	12 360 950	0	1 749 479	400 945	2 592 670	36 890	854 165	154 360	21 5305
Subtotal	**194 986 062**										
Market-oriented agriculture	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
River-or lakeside	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Other land-use categories											
Protected areas	7 773 025	162 622	2 480 903	84 904	739 176	199 325	1 735 700	573 835	1 592 390	150 025	54 145
Swamps	3 787 863	0	3 568 818	0	0	14 110	60 775	0	125 545	17 595	1 020
Water	9 362 152	586 517	309 118	0	315 357	437 920	3 662 140	402 050	3 597 455	32 385	19 210
Cities	196 790	107 312	67 973	0	0	3 400	18 105	0	0	0	0
Desert	98 240 828	2 4817 829	73 354 310	48 134	18 260	0	0	0	340	1 955	0
Total	**314 346 720**	**29 860 540**	**197 741 261**	**2 455 572**	**36 247 347**	**6 983 005**	**23 721 630**	**2 002 430**	**11 959 925**	**2 057 680**	**1 317 330**

Table 29: General statistics, by farming system, within the Nile Basin

Farming system	Area (ha)	Area (% of total)	Population (thousand)	Population density (per km^2)	Population (% of total)	Cropland (ha)	Cropland (% of total)	Cropland (% of area)	Cropland per inhabitant (ha/pers.)
Irrigated (subdivided into 3 levels)	7 312 675	2	56 315	770	34	4 274 212	12	58	0.08
Pastoral	29 673 966	9	7 189	24	4	1 415 280	4	5	0.20
Agropastoral	18 400 051	6	3 119	17	2	6 613 428	18	36	2.12
Dryland farming	64 745 370	21	9 169	14	6	7 971 337	22	12	0.87
Highland tropical	8 169 690	3	18 289	224	11	3 085 776	9	38	0.17
Highland temperate	13 224 484	4	12 473	94	8	3 588 573	10	27	0.29
Highland cold	3 650 464	1	4 489	123	3	1 254 426	3	34	0.28
Forest	13 393 767	4	6 283	47	4	900 507	3	7	0.14
Woodland	18 429 032	6	5 323	29	3	769 724	2	4	0.14
Lowland tropical	17 986 563	6	18 019	100	11	4 264 893	12	24	0.24
Market-oriented agriculture	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
River- or lakeside	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Protected areas	7 773 025	2	2 026	26	1	1 060 061	3	14	0.52
Swamps	3 787 863	1	672	18	0	37 986	0	1	0.06
Water	9 362 152	3	1 506	16	1	144 141	0	2	0.10
Cities	196 790	0	11 222	5703	7	35 753	0	18	0.00
Desert	98 240 828	31	7 860	8	5	554 713	2	1	0.07
Total	**314 346 720**	**100**	**163 954**	**52**	**100**	**35 970 810**	**100**	**11**	**0.22**

Note: Land-use highlighted in pink are not included in this review; farming systems in turquoise are too small and dispersed to appear on the map.

Table 30: Basin-wide distribution of farming system areas

Farming system	Area (ha) in Nile Basin
Agropastoral	18 400 051
Dryland farming	64 745 370
Forest-based	13 393 767
Highland cold	3 650 464
Highland temperate	13 224 484
Highland tropical	8 169 690
Irrigated	7 312 675
Lowland tropical	17 986 563
Pastoral	29 673 966
Woodland/forest	18 429 032
Subtotal	**194 986 062**
Protected areas	7 773 025
Swamps	3 787 863
Water	9 362 152
Cities	196 790
Desert	98 240 828
Subtotal	**119 360 658**
Total	**314 346 720**

problems and development opportunities;

- it is the starting point for development and the foundation on which productivity improvements have to be constructed.

A map showing the spatial distribution of the farming systems is presented in Figure 9; the systems' occurrence in the basin countries is outlined in Table 28 and general statistics provided in Table 29. The total area of the Nile Basin under this calculation is slightly less (at 3.14 million km^2) than the 3.16 million km^2 calculated for the hydrological basin. This difference is attributed to the resolution of the raster count from the AFRICOVER data sets.

While the Nile Basin holds significant opportunities for cooperative management and development, some of its farming systems have evolved, while others have stagnated. Understanding the present performance of the farming systems in the basin, and their environmental and social constraints, can help to give a clearer indication of the opportunities for improved productivity. This report outlines the agricultural productivity and water management issues and opportunities in the main farming systems.

A basin-wide differentiation of farming systems in the Nile Basin is give in Table 30, derived from the farming systems analysis presented in Figure 9.

Within the Nile Basin, the full spectrum of systems of water management for agriculture are found, from purely rainfed (mainly in the south), through the continuum of practices including rainwater harvesting and other supplementary irrigation, to purely irrigated (from groundwater and/or surface water sources). In the past, attention has focused on agricultural water use for irrigation, with varying interest in rainfed systems. Overall, however, the sites at which available water can be applied to available land have already been taken or are planned to be taken. Hence, a large question mark faces the future of rainfed production in the basin.

Acute poverty is found particularly in communities of smallholders practising rainfed farming systems, where the unpredictability of rainfall hampers agricultural yields and constrains wider rural development. Smallholders have long been very vulnerable to the impacts of short-term dry periods, seasonal droughts and floods – all of which are expected to increase in frequency with climate change. Improved management of water in smallholder agriculture offers promising opportunities for increasing crop yields, reducing hunger and poverty and contributing to development goals. Improved water management, through soil water conservation (SWC) in combination with other sustainable land management (SLM) approaches, also offers low-cost opportunities for both adaptation to and mitigation of climate change.

A review and analysis of crop yield differences among the ten countries of the basin are given on the basis of available data, before presenting a synthesis of the reports prepared by national consultants

Table 31: National-level statistics of the Nile Basin countries

Country	Area in basin (km^2)	Percentage of total country area in Nile Basin	Percentage of the Nile Basin in each country	Human Development Index (2008) (ranking out of 179 countries)	Population (millions)	
					2005	2015 (medium-variant projections)
Burundi	13 000	46	0.4	172	7.9	11.2
Dem. Rep. of the Congo	22 300	1	0.7	177	58.7	80.6
Eritrea	25 700	21	0.8	164	4.5	6.2
Ethiopia	366 000	32	11.8	169	79.0	101.0
Egypt	307 900	33	9.9	116	72.8	86.2
Kenya	52 100	9	1.7	144	35.6	46.2
Rwanda	20 400	83	0.7	165	9.2	12.1
Sudan	1 943 100	78	62.5	146	36.9	45.6
United Rep. of Tanzania	118 400	13	3.8	152	38.5	49.0
Uganda	238 700	98	7.7	156	28.9	40.0
Total	**3 107 600**		**100**		**372.0**	**478.1**

Sources: FAO; *United Nations*, 2008.

Table 32: Yield gaps for major Nile Basin crops (a) (calculated using the average yield per ha for each country (1998–2007) from FAOSTAT, the figures are percentages achieved by each country of the basin country, compared with the highest yield, (highlighted))

Country	Grains					Roots and tubers			Others					
	Maize	Sorghum	Millet	Wheat	Barley	Potatoes	sweet Potatoes	Cassava	Bananas	Sunflower seed	Tea	Coffee	Sugar cane	Cotton
Burundi	14	22	70	13	n/a	11	24	68	13	n/a	38	87	59	
Dem. Rep. of the Congo	10	12	42	20	23	19	18	63	9	n/a	24	46	35	
Egypt	100	100	n/a	100	86	100	100	n/a	100	100	n/a	n/a	100	
Eritrea	5	9	20	6	17	28	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
Ethiopia	24	23	65	22	40	35	33	n/a	18	n/a	42	100	81	
Kenya	21	14	37	35	100	33	35	67	36	39	100	41	71	
Rwanda	10	17	51	12	0	34	21	45	n/a	n/a	56	84	23	
Sudan	11	11	17	38	0	70	49	14	82	37	n/a	n/a	78	
United Republic of Tanzania	22	15	51	22	78	26	8	60	13	14	63	48	88	
Uganda	21	25	100	27	n/a	29	16	100	12	41	78	84	74	

for each Nile Basin country. These reports analyse agricultural production by farming system, contrasting productivity in the different systems among countries and the implications for water resources management. Agricultural productivity is commonly quantified as crop yield per unit area (tonnes/ha), but water already limits crop production in many parts of the basin, where possible water productivity is also considered. In particular, productivity gaps (in both yield/ha and yield/m^3 of water) in rainfed and irrigated systems are highlighted, the main causes of these gaps are identified, and options for addressing them are offered.

National-level analysis of agricultural yields

Although the prime focus of this analysis is on agricultural production in the different farming systems of the Nile Basin, it is essential to commence with a review of agricultural production at the national level for the ten basin countries, as this is the lowest level of disaggregation for which comprehensive recent data on agricultural crop yields and harvested areas are available. Use of national-level data is necessary but not ideal, as they do not necessarily reflect conditions in the basin. National data are most useful in countries that have a high proportion of their areas within the basin (notably Uganda, Rwanda and the Sudan, with 98, 83 and 78 percent respectively, see Table 2), but less useful in those with very small proportions of the basin in their areas (notably the Democratic Republic of the Congo). An additional problem arises in drawing conclusions; for example, both the Democratic Republic of the Congo and Rwanda have 0.7 percent of the basin in their areas, but this represents 83 percent of Rwanda's total area and only 1 percent of the Democratic Republic of the Congo's. Accordingly, the following information must be used judiciously.

For each of the ten basin countries, Table 31 indicates the area that lies within the Nile Basin, in km^2, the percentage of each country that lies within the basin, the percentage of the basin that lies within the country, the UNDP Human Development Index (2007), the most recent population data, and the projected population figures for 2015.

Yield gaps

Table 32 demonstrates the huge differences in crop yields achieved among the countries of the Nile Basin, measured as the average yield of each country as a percentage of the yield of the highest-yielding country (per ha, averaged for 1998 to 2007), rather than as absolute yield. Full details of the statistics used in these analyses, from FAOSTAT, are presented in Annex 1, including annual yield and harvested area figures for each crop in each country and a figure that represents the global average yield (Bruinsma, 2009).

Table 32 clearly demonstrates that Egypt achieves the highest yields in eight of the 13 crops analysed. This was predictable, as these crops are grown under irrigated conditions in Egypt, where there is also high use of other inputs (agrochemicals, including fertilizers and pesticides). Table 32 also shows that Uganda has the highest yields of both millet and cassava, with Kenya achieving the highest yields of tea, and Ethiopia the highest coffee yields. None of these crops are recorded as growing in Egypt, and all are grown under rainfed conditions.

Considering major grain crops, Table 32 shows that Ethiopia's maize yield is closest to Egypt's (but only 24 percent), while Eritrea's maize yield is the lowest in the basin, at only 5 percent of that achieved in Egypt (maize is harvested from only a very small area in Eritrea, averaging about 18 300 ha). In the case of sorghum, Uganda, Ethiopia and Burundi achieve yields that are 22 to 25 percent that of Egypt, while Eritrea, the Sudan and the Democratic Republic of the Congo have much lower yields. There are no data for millet in Egypt, but for this notably drought-tolerant crop, Uganda achieves the highest yields and is thus the base for calculations, followed by Burundi (70 percent) and Ethiopia (65 percent). Rwanda and the United Republic of Tanzania, which are geographically close to Uganda, achieve only 51 percent of Uganda's yield, and again the lowest yield is achieved in Eritrea (20 percent). In the case of wheat, Kenya and the Sudan achieve 35 and 38 percent respectively, with the Democratic Republic of the Congo, Ethiopia, the United Republic of Tanzania and Uganda in the range of 20 to 30 percent. The three lowest-yielding countries (Burundi with only 13 percent, Rwanda 12 percent and Eritrea 6 percent) all have only small areas of wheat harvested (as does Uganda). Barley growing is predominantly concentrated in Ethiopia (with an average of more than 1 million ha harvested per year) – contrasting with the Democratic Republic of the Congo, which has an average of only 759 ha across its enormous land area. Kenya achieves the highest yields in barley, followed closely by Egypt (86 percent of Kenya's yield) and the United Republic of Tanzania (78 percent).

Evaluating the results for roots and tubers is important for this study as they form a major part of diets in Nile Basin countries. There is a wide range of potato yields across the basin, with the Sudan achieving 70 percent of Egypt's yield (probably under irrigation), most countries achieve only 25 to 40 percent, and Burundi achieves only 11 percent. Again, Egypt achieves the highest results for sweet potatoes, with the Sudan achieving the second highest at 49 percent of Egypt's (possibly under irrigation). Yields are moderate for Kenya (35 percent) and Ethiopia (33 percent), but low for the remaining countries – notably the United Republic of Tanzania (8 percent). Uganda achieves the highest yield for cassava – for which there are no data (possibly because it is not grown) for Egypt, Eritrea and Ethiopia. Most other basin countries achieve 60 to 70 percent of Uganda's yield, with the notable exception of Rwanda (45 percent) and the Sudan (14 percent). It should be noted that very little cassava is harvested in the Sudan (less than 6 000 ha).

As well as roots and tubers, bananas also form a vital component of diets in many southern countries of the Nile Basin, although again the highest yield is obtained (under irrigation) in Egypt. The Sudan achieves a banana yield of 82 percent that of Egypt (probably under irrigation or in oases, and only from a very small area of 2 250 ha). There is then a huge gap in yields, to Kenya (36 percent), followed by the other countries, which all achieve only within the range of 9 to 18 percent of Egypt's yield. Sunflower seeds are an important crop (and possibly increasingly valuable, as potential feedstock for biodiesel), grown in five basin countries. Again, the highest yield is obtained in Egypt, with Uganda, Kenya and the Sudan obtaining yields of about 40 percent that of Egypt. The

Table 33: Yield gaps for major Nile Basin crops (b) (calculated using the average yield per ha for each country (1998–2007) from FAOSTAT, the figures are percentages achieved by each country of the basin country, compared with the highest yield excluding Egypt, (highlighted))

Country	Grains				Roots and tubers			Others					
	Maize	Sorghum	Millet	Wheat	Barley	Potatoes	Sweet potatoes	Cassava	Bananas	Sunflower seed	Tea	Coffee	Sugar cane	Cotton
Burundi	59	87		34		16	49		16	n/a				
Dem. Rep. of the Congo	43	45		53		27	37		11	n/a				
Eritrea	21	36		17		40	n/a		n/a	n/a				
Ethiopia	100	91		59		49	67		22	n/a				
Kenya	90	57		93		47	71		44	95				
Rwanda	43	68		32		49	43		n/a	n/a				
Sudan	45	43		100		100	100		100	91				
United Republic of Tanzania	93	60		58		37	16		15	33				
Uganda	89	100		72		41	33		14	100				

(Millet and cassava excluded from this table as data n/a for Egypt; barley yields are not highest in Egypt; tea and coffee not grown in Egypt and sugar cane, presumed irrigated, in all countries.)

United Republic of Tanzania has a notably lower sunflower seed yield (14 percent). Tea is grown in seven of the ten basin countries, with the highest yield obtained in Kenya, followed by Uganda (78 percent), the United Republic of Tanzania (63 percent, but not in the Nile Basin area). Rwanda achieves 56 percent of the yield attained by Kenya, followed by Ethiopia (42 percent), Burundi (38 percent) and the Democratic Republic of the Congo (24 percent). The same seven countries also grow coffee – with Ethiopia achieving the highest yield, closely followed by Burundi (87 percent), Rwanda and Uganda (both 84 percent) – the remaining three all achieve considerably lower yields (the United Republic of Tanzania 48 percent, the Democratic Republic of the Congo 46 percent, and Kenya 41 percent).

Reviewing yields of sugar cane at the national level is problematic. The large range of values support the notion that data encompass both irrigated and rainfed cane, including statistics from estates with high usage of agrochemicals and smallholder farms with limited availability of inputs. Variations among countries may therefore reflect differing proportions of cane grown under the differing conditions. Egypt again achieves the highest yield – attributable to the fact that all cane in that country must be grown under irrigated conditions. Five countries achieve average yields of between 70 and 90 percent of Egypt's (the United Republic of Tanzania 88 percent, Ethiopia 81 percent, the Sudan 78 percent, Uganda 74 percent, and Kenya 71 percent), while the Democratic Republic of the Congo and Rwanda have much lower average yields (35 and 23 percent respectively).

Table 33 is derived from the same statistics as used in Table 32, but in calculating the yield gaps Egypt has been excluded from the calculations, on the basis that all agriculture in Egypt is irrigated, whereas the majority of production in other countries is rainfed. In the context of this study, the differences in yields shown in Table 33 are of greater significance than those shown in Table 32, as they more closely reflect the yields gaps that could feasibly be reduced, for example by rainwater harvesting.

Ethiopia had the highest average maize yield of the basin countries, with the United Republic of Tanzania, Kenya and Uganda all achieving yields of about 90 percent of that achieved by Ethiopia. The other basin countries achieve notably lower yields of this staple food crop: Burundi (59 percent), the Sudan (45 percent), Rwanda and the Democratic Republic of the Congo (both 43 percent), and Eritrea (only 21 percent). Uganda achieves the highest sorghum yield, followed by Ethiopia (91 percent), Burundi (87 percent) and Rwanda (68 percent). The United Republic of Tanzania (60 percent), Kenya (57 percent) and the Democratic Republic of the Congo (45 percent) are modest, with the Sudan (43 percent) and Eritrea once more lowest at 36 percent. Wheat yields vary more widely across the basin, with the Sudan achieving the highest and Eritrea only 17 percent that of its geographical neighbour. Of the other countries, Kenya achieves 93 percent, Uganda 58 percent, Ethiopia, the United Republic of Tanzania and the Democratic Republic of the Congo each 50 to 60 percent, Burundi 34 percent and neighbouring Rwanda 32 percent.

The Sudan achieves the highest yields of the three other crops in Table 33 (potatoes, sweet potatoes and bananas) – possibly all also under irrigated agriculture and all on very small areas of harvested land. No other country manages to achieve 50 percent of the Sudan's average potato yield, with Ethiopia and Rwanda achieving 49 percent, Kenya 47 percent, Uganda 41 percent, Eritrea 40 percent and the United Republic of Tanzania 37 percent, followed by the Democratic Republic of the Congo and Burundi with much lower yields (27 and 16 percent respectively). Kenya achieves 71 percent and Ethiopia 67 percent of the Sudan's average sweet potato yield, followed by Burundi (49 percent), neighbouring Rwanda (43 percent), nearby Democratic Republic of the Congo 37 percent, Uganda only 33 percent, and the United Republic of Tanzania only 16 percent. Banana yields across the basin are all much lower than in the Sudan – with Kenya achieving only 44 percent and all other countries in the range of 22 to 11 percent (note that there are no data for Eritrea – probably because this crop is not grown there).

Conclusions

This section has attempted to account for the agricultural use of the Nile waters using field-derived district-level data to refine former estimates based on aggregated data. In the absence of a comprehensive set of hydro-meteorological data and land-use and production statistics of matching periods of record, its value is indicative.

The consistent view is that the upper limit for crop water requirements for harvested irrigated areas in the basin is in the order of 45 km^3. On the basis of the AT2030/50 projections, this crop water requirement is expected to grow at an annual rate of 0.64 percent and then slow to an annual rate of 0.43 percent from 2030 to 2050. Annual growth rates for rainfed harvested areas are expected to be higher – averaging 0.86 percent and then 0.70 percent per annum for the same periods. These averages mask national and subregional variability set out in Table 26, but the overall trend is consistent with the saturation of demand for agriculture as populations and their calorie requirements peak.

The harmonization of agricultural data across the basin remains a persistent challenge, not least in distinguishing consistently between land cover and land use and between rainfed and irrigated areas. The inherent accumulation of errors in compiling such data manually is not trivial. While advances in medium–and high–resolution radiometric data and their associated monthly time series (notably MODIS and NOAA-AVHHR models) help bound manual estimates derived from reference evapotranspiration, in practice the actual evapotranspiration attributable to cropped areas will always be estimates that require calibration with field data. Direct measurement of energy balances at the boundary layer remains an expensive and laborious process, and the network of high-quality meteorological stations across the Nile Basin is limited or absent in the main water bodies and wetlands that determine much of the basin's hydrological response. Pioneering attempts have been made to use other water balance proxies, notably satellite (GRACE) gravity anomalies (Bonsor *et al.*, 2009) and no doubt these will become refined over time, but will still be limited by the lack of contemporary control data to calibrate the derived soil moisture and groundwater storage changes. This is why the maintenance of hydrometric networks and the technical capacity to keep them functioning will remain essential.

Nevertheless, the figures obtained from this project should be sufficiently representative, particularly for policy-making at the regional level.

Several key observations stand out:

- The hydrological regime of the Nile main watercourse is characterized by downstream loss. Beyond the confluence with the Blue Nile, there is little or no gain from lateral inflow or groundwater.
- The broad NBI classification into the Equatorial lakes and Eastern Nile countries distinguishes between the characteristic hydrological regimes. But within these groupings, significant variation in rainfall/runoff relationships and flow regimes stand out. The regulating function of Lake Victoria and the Sudd are prime examples, and other observations need to be made. For instance, runoff from Uganda is very low; only 2 percent of the average annual rain volume on the Ugandan land area appears in the transboundary flows into Lake Edward.
- The high runoff coefficients observed in Burundi, some parts of Ethiopia, Kenya and Rwanda, combined with the small gap between annual precipitation and potential evaporation values suggest that rainfall is not the main constraining factor for agricultural production here, and that rainfed production is generally stable in the Equatorial Lakes, making it suitable for low-value staple foods. However on steeper slopes, maintaining soil moisture levels through a combination of local storage and soil management will always be necessary, to maintain production levels. For instance, Rwanda uses 52 percent of its annual rain volume for cultivation practices; this figure stands at 44 percent for Kenya's Lake Victoria land area, but is lower for the other riparians.
- With the exception of parts of the southern Sudan, the progressive hydrological losses and rainfall decay away from the Equator will always give irrigated production an advantage in terms of reliability and economic productivity.
- Given the observed water balance for the Nile Basin, and the state of agricultural productivity across the farming systems of the basin, the projections for rainfed and irrigated areas made in Table 26 can be broadly validated. These projections have been used to provide benchmark data around which the quantified scenarios can be compared. Such comparison is elaborated in the following chapter. However, although these assumptions of applying the nationally estimated area and yield growth factors to the district level give one level of approximation, the growth estimates in the projections are still constrained by the existing harvested areas – growth has to occur from an existing baseline.

5. Prospects for the future

2030 nutrition requirements in the Nile Basin

Inherent uncertainties

Food for human consumption is the main element in the demand function for agricultural produce in the Nile Basin. With rural populations dominating in all Nile countries, most food is still produced in close vicinity to its final consumers.

Scenario thinkers divide the historic driving forces into "predetermined" and "uncertain" elements. The first exhibit significant inertia, while the latter can be much more random in nature. Some are forces with both predetermined and uncertain elements, such as demographic developments. Although in the short term these have sufficient momentum to be forecast, in the long term they become unpredictable. The effects of policy measures, changing cultural values, the economic environment, new diseases or medicine, etc., will have significant impacts on the two main demographic variables – birth rate and mortality – and can alter the long-term course of demographic development. International migration is another component that is hard to predict.

Figure 10 shows the typical balance of predictability and uncertainty when progressing into the future. Although predetermined elements dominate to begin with, the degree of predictability gradually decreases, and uncertainty goes up. For the immediate future, phenomena exhibit sufficient inertia to justify forecasting (F). For the medium term, scenario thinking (S) is more appropriate, while for the very long term (the H = hope zone) little can be predicted or even hoped for.

The horizon year of the F4T analysis is 2030. For this time frame, the two principal components of food requirement – population number and nutrition pattern – display a certain level of predictability but also considerable uncertainty. Here, the use of traditional forecasting methods that ignore uncertainty is no longer justified. For this reason, FAO Nile has adopted a scenario approach.

The scenario approach carries other advantages. Notably, explicitly assessing the uncertainties involved should lead to a better appreciation of the required level of detail in the analysis.

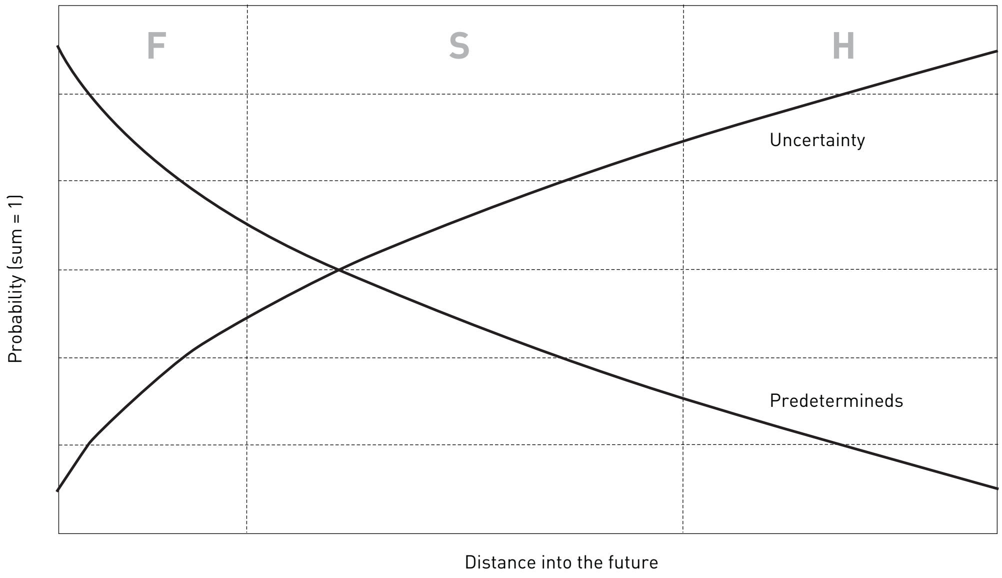
The calculations combine information from three main sources: 1) demographic prospects from UNDESA; 2) nutrition statistics and trends reported by FAO; and 3) the F4T scenario set prepared by the project.

The approach draws heavily on the work presented in the FAO interim report (FAO, 2003), but in contrast to this detailed study, it produces four plausible but alternative outcomes rather than making a single projection.

Demographic baseline

UNDESA provides the baseline data for the analysis. The base year 2005 is used. It should be noted that the 2005 values are not necessarily accurate, but estimates. National

Figure 10: The balance of uncertainty and predictability when moving into the future



Source: Van der Heijden, 1996.

population censuses are typically conducted every ten years – in some countries the interval is longer because of political circumstances – and projections are used between census years.

UNDESA projects the last available census year to 2005, using all available data on fertility, mortality, international migration and other parameters that affect population dynamics.

Table 34 presents the last census year as well as the 2005 estimates from UNDESA and the United States Bureau of Census.

Recent census data are not available for a number of countries. For instance, the last national censuses for the Democratic Republic of the Congo and Eritrea date back as far as 1984. The same applies to the southern Sudan. For comparison, both UNDESA and United States Bureau of Census estimates for 2005 are presented. The figures are quite similar but there are a number of discrepancies, notably for Egypt and Ethiopia. This provides an indication of the level of precision that should be attributed to the overall analysis of total nutrition requirements.

2030 population prospects

Population prospects are a function of assumptions about the future paths of fertility, mortality and international migration. This analysis uses *World population prospects: The 2006 Revision 2,* prepared by UNDESA.

Because future trends are uncertain, UNDESA has produced a number of projection variants. Low, medium and high variants are considered. The only assumption that differs

Table 34: 2005 Population estimates for the Nile riparians

Country	Census year	UNDESA 2005 (x 1 000)	US Census Bureau 2005 – mid-year (x 1 000)
Burundi	1990	7 859	7 795
Dem. Rep. of Congo	1984	58 741	60 474
Egypt	1996	72 850	77 562
Eritrea	1984	4 527	4 670
Ethiopia	1994	78 986	73 053
Kenya	1999	35 599	34 912
Rwanda	2002	9 234	9 378
Sudan	1983 1993 (excl South)	36 900	37 763
United Rep. Tanzania	2002	38 478	37 771
Uganda	2002	28 947	28 199

among the three projections concerns the future path of fertility. Issues such as new medicines (e.g., AIDS vaccine or malaria eradication) or new diseases are not taken into account. Hence, it should be noted that the actual 2030 population numbers could still be outside the range defined by the low-high variants.

Fertility decline is related to economic development. Under conditions of increasing prosperity and other policy measures, UNDESA projects fertility to fall to 0.5 children/woman fewer than the medium variant. By contrast, the high-growth variant assumes fertility of 0.5 children more than the medium variant.

The medium-growth variant is based on recent trends in each country. UNDESA assumes that fertility in high- and medium-fertility countries will follow a path derived from models based on past experience in countries with declining fertility during 1950 to 2000.

Mortality is projected on the basis of models of change of life expectancy produced by UNDESA.

Table 35 presents the three projections for the Nile countries.

The Nile Basin covers only part of the national territory of the Nile riparians. LandScan 2004 is used to calculate the number of people actually residing within the basin. LandScan is a worldwide population database compiled on a latitude/longitude grid of 30-inch x 30-inch (763 cm) cells. Census counts (at the sub-national level) were apportioned to each grid cell, based on likelihood coefficients, which are a function of proximity to roads, slope, land cover, nighttime lighting and other information. LandScan was developed by the Oak Ridge National Laboratory (ORNL). It is based on United States Bureau of Census data sets. Hence, an adjustment is required to bring the layer into line with United Nations population information.

The following assumptions were used to convert LandScan 2004 into a distributed population projection for 2030:

1. Country totals are derived from UNDESA 2005 data and the 2030 medium variant.
2. Relative population distribution is according to LandScan 2004.

3. Differences between United States Bureau of Census and UNDESA 2005 country totals are adjusted proportionally per grid cell
4. Urban growth is spread proportionally over urban areas.
5. Rural growth Is spread proportionally over rural areas.
6. Areas classified as urban in 2005 remain urban in 2030.
7. Areas classified as rural in 2005 remain rural in 2030, with the exception of those in close proximity to existing urban areas.

Table 35: UNDESA 2030 population prospects for the ten Nile countries

Year 2030	Total populationlow variant (x 1 000)	Total population medium variant (x 1 000)	Total population high variant (x 1 000)
Burundi	16 367	16 367	18 103
Dem. Rep. of the Congo	116 119	116 119	128 220
Egypt	96 189	96 189	112 045
Eritrea	7 895	7 895	8 975
Ethiopia	128 639	128 639	145 530
Kenya	58 563	58 563	67 015
Rwanda	15 683	15 683	17 614
Sudan	54 460	54 460	62 464
United Rep. Tanzania	61 096	61 096	69 991
Uganda	57 968	57 968	65 163
Total	612 979	612 979	695 120

Source: UNDESA: World Population Prospects: The 2006 Revision

Table 36: Nile Basin 2030 population estimates

Country	Total 2005 UNDESA (x 1 000)	Nile Basin 2005 (x 1 000)	Nile Basin medium variant 2030 (x 1 000)
Burundi	7 859	4 615	9 870
Dem. Rep. of the Congo	58 741	1 851	4 178
Egypt	72 850	72 617	101 542
Eritrea	4 527	1 721	3 489
Ethiopia	78 986	31 044	50 466
Kenya	35 599	13 359	25 441
Rwanda	9 234	7 685	14 021
Sudan	36 900	32 406	53 803
United Rep. Tanzania	38 478	7 933	15 189
Uganda	28 947	28 477	61 086
Total	372 121	201 708	339 086

Table 36 presents population numbers in the Nile catchment for 2005 and the projected values for 2030, based on the medium-growth variant.

It may seem strange that Eritrea's figure is high, relative to the small size of its Nile catchment area. This is because the current Nile Basin delineation includes the Gash Barka – sometimes considered an internally drained basin – on whose fringes Asmara, Eritrea's capital, is located.

2003 nutrition patterns

Table 37 presents calorie consumption per capita for the ten Nile countries for 2003. The data originate from FAOSTAT. Note that – apart from actual nutrition – the consumption figures also include: 1) household waste; 2) processing waste; and 3) transport losses.

Table 37: Daily calorie intake per capita for the ten Nile riparians, 2003 (kcal/day/capita)

2003	BUR	DRC	EGY	ERI	ETH	KEN	RWA	SUD	TAN	UGA
Cereals – excl. beer	294	312	2 135	1 009	1 270	1 060	281	1 145	998	533
Starchy roots	589	915	49	52	230	146	894	12	376	551
Plantain	0	20	0	0	0	56	350	0	29	419
Sugar crops	0	1	42	0	0	1	0	7	0	4
Sugar and sweeteners	32	29	287	54	45	196	22	208	73	86
Pulses	339	32	90	125	114	136	274	81	93	206
Tree nuts	0	0	4	0	7	5	0	0	2	0
Oil crops	6	61	57	19	8	15	31	50	27	171
Vegetable oils	17	131	143	158	37	175	31	204	131	52
Vegetables	20	17	107	4	10	21	15	28	18	14
Fruits – excl. wine	164	23	154	2	14	15	11	63	20	35
Stimulants	1	2	2	0	2	1	0	1	0	7
Spices	0	5	8	2	14	2	0	3	4	2
Alcoholic beverages	148	24	2	8	12	18	96	3	61	146
Meat	17	18	86	44	44	77	22	116	49	62
Offals, edible	1	1	5	5	4	6	2	10	4	4
Animal fats	4	2	53	9	13	10	9	21	12	7
Milk – excl. butter	8	2	93	24	33	172	31	294	43	45
Eggs	1	0	11	2	2	5	1	5	3	2
Fish, seafood	4	10	26	3	0	8	2	3	16	13
Miscellaneous	0	0	2	0	0	0	0	6	0	0
Total	1 647	1 606	3 356	1 519	1 858	2 155	2 071	2 260	1 959	2 360

Other losses, such as on-farm, harvest, post-harvest and farm storage losses, have been accounted for in the production data.

Observations:

1. Calorie intake is very low in Burundi, the Democratic Republic of the Congo and Eritrea. It is significantly less than 1 900 kcal/capita/day, the rule-of-thumb value for minimum nutrition requirement for an average population group (Box 6).
2. Egypt is at the same level as the developed world in terms of calories used per person. Hence, its scope for per capita increase should be limited.
3. Food consumption in Ethiopia, Kenya, Rwanda, the Sudan, the United Republic of Tanzania and Uganda is more or less at the same level, but substantially lower than the level that represents the absence of undernourishment in society (Box 6),
4. Plantain is a main staple in Rwanda and Uganda, but it is not of significance in the other riparians.
5. Cereals dominate the diet in Egypt, Eritrea, Ethiopia, Kenya and the Sudan.
6. Root crops (e.g., cassava and yam) are important in Burundi, the Democratic Republic of the Congo, Rwanda, the United Republic of Tanzania and Uganda.
7. Total consumption of livestock products is modest, with the Sudan having the highest share, at 18 percent of the diet.
8. In Egypt, livestock products make up only 8 percent of the diet, which is very low relative to the total calorie consumption of more than 3 300 kcal/capita/day.

Box 6: The absence of undernourishment

Absolute nutrition requirements depend on the population structure and vary by country. They are a function of age/sex structure, as well as of the main activities of the working population. A rule-of-thumb value is 1 900 kcal/person/day. If an average individual in a population group regularly has an intake below this level, the group is undernourished. In this case, calorie intake is not enough to maintain health and body weight, and to engage in light activity.

In theory, no undernourishment should exist in a country with average food availability equal to the threshold. However, an allowance is required for societal inequality. Some people consume more than the average, or more than they need. As in the developed world, obesity is rising in developing countries. Food produce is also lost in transport and processing and as household waste.

As a rule of thumb, daily calorie availability of 3 000 kcal/person is used as a threshold for adequate average food consumption that implies the absence of undernourishment in a nation.

While acknowledging that satisfying calorie intake requirements alone does not imply a healthy diet, these thresholds are used as a proxy for adequate nutrition.

Nutrition trends

There is a historic trend towards increased food consumption per capita with rising income. Typically, when starting from low calorie intake levels, food consumption tends to increase rapidly with economic growth. It subsequently slows down and levels off at a certain stage. Average per capita food consumption for industrial countries is now at some 3 450 kcal/day. However, for some countries, for instance the United States of America, it is higher.

Economic growth is normally accompanied by structural change in the diet. Although culture plays a role (e.g., India has a relatively large proportion of vegetarians), it is typical to see more use of livestock products (milk, meat, eggs), vegetable oils and, to a smaller extent, sugar as sources of food calories. Their share in industrial countries is about 48 percent and has been relatively stable for several decades. In richer countries, diets tend to shift away from roots and tubers.

Projections of existing agricultural trends and water use

Methodology

A detailed analysis of district-level data was made to project current water use patterns in line with the national rainfed and irrigated area projections used to compile the FAO report (FAO, 2006).

All the methodological details and results can be found in the accompanying projections report.

Table 38 shows the expansion of rainfed harvested areas by 50 percent and of irrigated land by 40 percent needed by 2050 to meet demand for production. Although the increase in harvested areas under rainfed conditions is not expected to have an impact on overall water balances in the basin, the 40 percent increase in irrigated harvested areas is expected to translate into a 14 percent increase in water withdrawals (Table 39). These rates of growth indicate what can be expected to happen if no major policy or other driver changes. Using an analytical framework or model (Figure 11), these overall water use assumptions were then converted into a suite of water productivity (in terms of calories) curves for the 2005 baseline and the 2030 projections across the basin (Figure 12) .

Results

The important point to note is that agricultural water productivity in the Equatorial Lakes is expected to see the most rapid boost in low-level water productivity (associated with rainfed production), while the Eastern Nile will see more districts increasing water productivity in the higher ranges.

There is a clear trend towards lower agricultural water productivity as cropping systems shift from subsistence towards cash crops, indicating that when water becomes scarce in comparison with demand, intersectoral demand is likely to intensify. For instance, energy demand will increase in line with both increasing industrialization and rising socio-economic conditions, while industry itself may become a larger user of water, and agricultural use will necessarily be cut back – even with higher-value cropping.

The second result concerns sugar, an important agro-industrial crop that is expected to expand considerably over the period studied, at least in some countries. It was shown that this is likely to reduce agricultural water productivity (AWP) because of low yield expectations for some new plantings, in spite of large productivity increases forecast for the Equatorial Lakes. If a significant amount of sugar expansion is predicated on bio-energy demand, the question then arises as to whether or not the losses in productivity would be less if the same water were stored primarily for power generation, with irrigation being merely the residual, second benefit.

The final result concerns the difference between AWP-rainfed and AWP-irrigated, not least with respect to their relative differences in the two sub-basins. This showed that water allocation and AWP are dominated by Egypt, particularly in the Eastern Nile and also in the basin as a whole. However, this does not mean that it is irrigation or nothing throughout the basin. In the Equatorial Lakes, the model revealed a greater degree of similarity between rainfed and irrigated AWP, although rainfed productivity remained greater than irrigated except at the lower and upper portions of the range.

These similarities apply to the AT2030 baseline and projections and to each of the scenarios – although the similarity is less pronounced under scenarios 3 and 4, for which rainfed trends towards greater productivity than irrigated (but this is most likely due to the influence of highly productive rainfed maize and millet in Uganda and barley in Kenya). Nonetheless, if as seems likely, the overall similarity is explained by better hydrological conditions in the sub-basin, the model points to the possibilities of a more heterogeneous approach to agricultural development and expansion than in the Eastern Nile.

Figure 11: The analytical framework

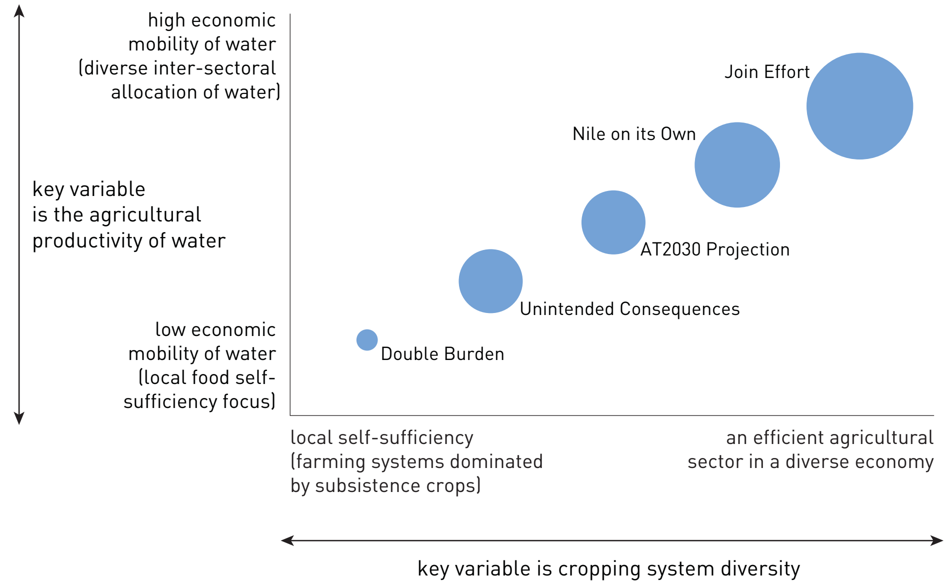


Table 38: AT2030/50 projections of harvested areas in the Nile Basin (ha)

Country	2005 baseline		2030		2050	
	Harvested areas rainfed	Harvested areas irrigated	Harvested areas rainfed	Harvested areas irrigated	Harvested areas rainfed	Harvested areas irrigated
Egypt	-	3 927 039	-	4 713 319	-	5 075 778
Sudan	14 044 805	1 156 747	17 174 350	1 364 266	19 205 528	1 820 407
Eritrea	58 715	4 143	57 387	7 238	51 131	8 270
Ethiopia	2 978 340	14 171	3 843 100	19 462	4 844 934	31 764
Eastern Nile total	**17 081 860**	**5 102 100**	**21 074 837**	**6 104 285**	**24 101 593**	**6 936 218**
Uganda	8 188 584	33 203	12 072 721	90 612	15 443 741	111 407
Kenya	2 204 922	41 693	2 309 804	59 377	2 483 212	75 701
United Rep.Tanzania	1 971 035	130	2 419 828	197	2 683 097	266
Rwanda	1 159 197	15 637	1 354 825	18 800	1 472 641	22 796
Burundi	562 104	3 158	749 155	5 813	949 287	8 654
Equatorial Lakes total	**14 085 842**	**93 821**	**18 906 334**	**174 799**	**23 031 978**	**218 825**
Nile Basin total	**31 167 702**	**5 195 921**	**39 981 171**	**6 279 083**	**47 133 571**	**7 155 043**

Figure 12: AT2030 AWP excess by district (percentages)

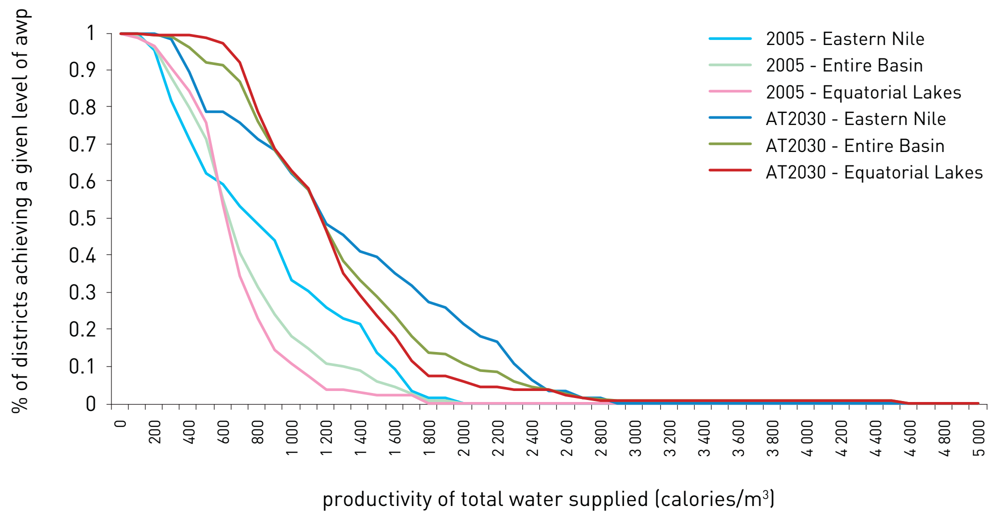


Table 39: AT2030/50 projections of irrigation water use requirements in the Nile Basin (km^3)

Country	Weighted mean unit water withdrawals (m^3/ha)	2005		2030		2050	
	Irrigated	Water use requirement ratio	Irrigation water withdrawals (km^3)	Water use requirement ratio	Irrigation withdrawals (km^3)	Water use requirement ratio	Irrigation withdrawals (km^3)
Egypt	9 285	53%	68.795	61%	71.740	64%	73.636
Sudan	9 513	40%	27.511	43%	30.182	50%	34.635
Eritrea	9 847	32%	0.127	33%	0.216	33%	0.247
Ethiopia	7 498	22%	0.483	22%	0.663	22%	1.083
Eastern Nile total	-	-	**96.916**		**102.802**		**109.600**
Uganda	7 493	30%	0.829	30%	2.263	31%	2.693
Kenya	7 746	30%	1.076	31%	1.484	31%	1.892
United Rep. Tanzania	8 071	30%	0.003	31%	0.005	30%	0.007
Rwanda	6 076	30%	0.317	30%	0.381	31%	0.447
Burundi	4 557	30%	0.048	31%	0.085	30%	0.131
Equatorial Lakes total	-	-	**2.274**	-	**4.218**	-	**5.170**
Nile Basin total	-		**99.190**		**107.020**		**114.770**

The use of scenarios to open up the policy space

Introduction

Through a highly participatory process, FAO Nile developed the F4T scenario set. More than 75 Nile stakeholders participated in its development. The original objective was to determine a plausible range of demand for agricultural produce in the Nile Basin for the horizon year 2030. This evolved into a systematic and participatory analysis of a broad set of development issues in the Nile Basin.

F4T demonstrated the potential of a multi-stakeholder scenario process to analyse a complex issue in a short period. It provided suggestions to decision-makers on how to address the various underlying drivers of resource conflict. It put rural areas back on the agenda, and examined the potential role of agricultural development and trade, both to ensure food security and to foster economic development. The exercise also confirmed the scope for regional cooperation.

By taking a wider view, F4T proved useful for expanding the Nile debate. A number of shared interests were identified and examined, particularly related to agricultural trade. Crucially, these are not directly related to river flow and therefore offer much better prospects for negotiated solutions. F4T demonstrated the effectiveness of scenarios in supporting a negotiation or reconciliation process.

What are scenarios?

The word scenario carries various meanings.

Scenarios are stories about the external environment, not about people, but about their strategies or (contingency) plans. These stories can help make sense of what might happen, structuring participants' views on a complex and uncertain future, and creating new perceptions, insights and shared options. Scenarios are tools for perception and preparation.

Scenarios are not predictions, but stories about what might be possible. Nobody can forecast the future. The longer-term future is full of uncertainties and unknowns; it is much wiser to take such uncertainties into account than to discard them or wrap them up in some kind of prediction.

Scenarios must be used as a set. All scenarios in the set are plausible, and should therefore be considered. No probabilities should (and could) be assigned to the various scenarios.

Supporting a negotiation process with scenario thinking

The Nile issue concerns complex and protracted negotiations on the use and joint development of shared water resources. The parties involved have divergent views on the historic context and on key concepts such as water security or the potential of rainfed agriculture. Positions have become stuck and polarized.

The principles of interest-based negotiation prescribe focusing on interests rather than positions, and creating options to satisfy mutual and separate interests. This sounds straightforward, but it is not. Perceptions – which serve as the starting points for identifying interests and options – can differ fundamentally among individuals as well as cultures. There are a number of reasons for this.

Terrence Hopmann (1996) regards the limits to rationality in individual behaviour as having three aspects: 1) cognitive psychology that looks at the dynamics of image formation and change; 2) group norms within a specific cultural context; and 3) individual personality attributes.

An individual's world view is the composite of experiences, values, knowledge and dispositions that formulate his or her mental model. It serves as the perception and conception structure that dictates how the individual interprets, reacts and acts in the world (Selin, 2007). Mental models rarely represent reality. Because mental models differ from one person to another, finding joint points of departure for identifying and analysing interests or win-win options is difficult.

Things get worse when dealing across cultures. In society, understanding of the issues at stake is often controlled by ideas, experience and psychological perspectives that establish a paradigm. This paradigm creates a lens through which the world should be seen. When a sufficient number of people within society converge on this paradigm, making it dominant, it becomes a "sanctioned discourse". This sets out the boundaries for accepting, modifying or rejecting further information and ideas from whatever source (Hilhorst, Schütte and Thuo, 2008).

The sanctioned discourse can become institutionalized and so powerful that policies and decisions are made within its parameters. The Nile discourse exhibits traits of the sanctioned discourse. Some riparians believe that rural development in upstream areas can only occur with access to Nile waters for irrigation, and that Egypt and the Sudan have unfairly appropriated a disproportionate share of the Nile waters. For their part, the Sudan and Egypt think that their national security is critically challenged by diminished Nile flows. These views are not always stated publicly, but are always present and should be accommodated as they represent powerful elements of public opinion.

So how are perceptions aligned and joint points of departure created? This is where scenario thinking comes in. Pierre Wack – who introduced this concept at Royal Dutch Shell in the 1970s – realized that existing mental models form a barrier to seeing the world in a broader perspective. He saw as his task the creation of scenarios that would "lead decision-makers to question their inner models of reality and change it as necessary ....".

He asserted: "... in times of rapid change and increased complexity... the decision-maker's mental model becomes a dangerous mixed bag: enormously rich detail and deep understanding that can coexist with dubious assumptions, selective inattention to alternative ways of interpreting evidence, and illusionary projections. In these times, the scenario approach has leverage to make a difference" (Wack, 1985).

Scenarios open the minds of decision-makers, enabling them to approach a problem or strategy from a fresh perspective. This was the aim of the F4T scenario process. By systematically probing the "what if" question – from the perspective of multiple stakeholders – in the context of four plausible but different futures, parties broaden their perspectives and capture a more comprehensive range of interests and options. This also leads to fresh insights regarding the dynamics and underlying structure of the issue at stake. An interactive scenario building exercise such as F4T is effective in an accelerated learning process.

When individual insight sets start to overlap, far broader shared insights are developed, and mental models begin to align. Joint points of departure emerge. This is what a negotiation or conflict management process aims to achieve.

The scenario method

Participants and set-up

FAO Nile initiated F4T to examine the uncertain future of demand for agricultural produce in the Nile Basin, with 2030 as the horizon year.

Active stakeholder participation was considered critical to ensure the relevance of the exercise. A scenario group was formed comprising members from all Nile countries, from inside and outside government, and mostly with a background in water resources and agriculture. The group changed during the course of the exercise, but key elements such as full Nile Basin representation and a multi-disciplinary perspective were carefully maintained.

F4T development comprised the following main activities:

- series of interviews to set the scenario agenda;
- first workshop to develop the scenario frame and first-generation scenario stories (Cairo, November 2006, two days);
- research phase, in which a number of key questions were examined in depth;
- second workshop examining critical assumptions and verifying and deepening the scenario logics and stories (Entebbe, February 2007, two days);
- third workshop in which the scenario set was presented to a new audience; F4T was used to analyse implications and identify signposts and trend-breaking events (Cairo, April 2007, one day);
- fourth workshop, which focused on analysing impacts, stakeholder reactions, areas of influence and options for influencing the course of events or adapting to new realities (Entebbe, May 2007, two days).

The process started with a round of more than 50 interviews with government officials, experts, academicians and business people in the countries involved. The aim was to collect perceptions, issues and concerns on the future of the countries. The focus of the interviews was clearly agriculture and agricultural demand in relation to water resources. The goal of this interview round was to provide an overview of views and issues that could serve to develop an initial strategic agenda for the workshops. The content of the interviews ranged well beyond narrow water-related issues into broader areas such as international trade, rural development, population growth, poverty, education and health, and (national) food security.

The interview feedback served as an input for the first workshop, where a group of 25 participants discussed issues and uncertainties for the basin’s future. During this meeting, the participants agreed on a so-called “first-generation” scenario framework that reflected those uncertain factors that were considered key for future developments in the region. Alignment among the participants on the factors that would “really make a difference” emerged very early during this workshop. Both of the key uncertainties that emerged from the group’s discussions were not directly related to water or agriculture, but to international trade opportunities for the countries involved and to the quality of governance in times to come. Notably, this latter factor, on which consensus was very high, had hardly been touched on during the initial interviews, but moved to the centre of the group's strategic conversations about the future.

In much the same composition, the group reconvened for three subsequent workshops, which were used to discuss and probe the initial framework, develop and test the four emerging scenario story-lines and so-called "story maps", and subsequently to ponder scenario implications and the question of "what if we do nothing?". During the final workshop the group addressed new insights and the question "what would/could we do if..?". A series of new insights was agreed on, and options were developed for each scenario and across all four scenarios. Over time, confidence grew that the group's scenarios – as a set – were both highly plausible and highly relevant. More important, alignment grew among the participants on ways forward (along with shared insights on risks and "dead-ends").

The scenarios

Four scenario story-lines were developed based on two principal uncertain elements: 1) effectiveness of governance; and 2) international agricultural trade regime. It is important to consider the scenarios as a set, with none being regarded as more likely than the others. The following are summaries of the scenarios.
The scenarios are summarized in Figure 13.

Unintended Consequences: Nile countries suffer high food prices when they fail to increase their agricultural output after Organisation for Economic Co-operation and Development (OECD) countries cut surplus production. Only large export-oriented farms benefit from improved market conditions. The majority of smallholders are unable to respond to price incentives because of lack of an enabling environment. Subsistence farming dominates. With persistent high population growth rates, livelihood conditions deteriorate and economic development stagnates.

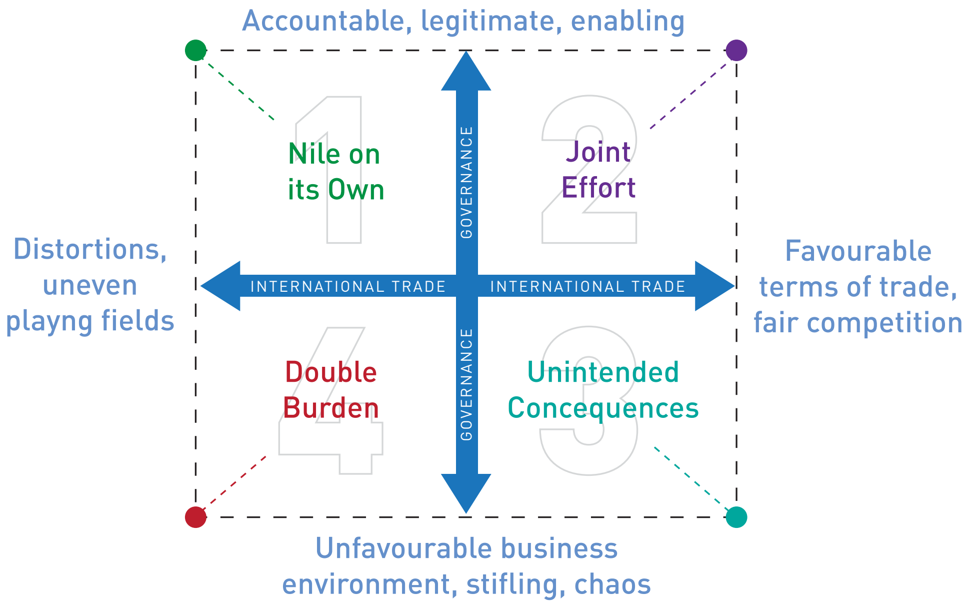
Joint Effort: Robust governance and improved agricultural market conditions propel Nile countries into the middle class. Governments stimulate rural development and, responding to higher commodity prices, agricultural productivity increases. Rural economies benefit and improve. Favourable economic conditions result in smaller families and reduced population growth.

Nile on its Own: Regional trade grows owing to improved Nile governance and limited international trade options. World commodity prices remain low but governments stabilize prices through regional tariffs. Policies promote local production and interregional trade. Gradually, Nile countries experience increases in wealth and food security and a decline in poverty.

Double Burden: Inefficient governance conspires with unfavourable international trade conditions to frustrate agricultural development and keep Nile countries in poverty. Rural areas stagnate. High poverty levels and insecurity lead to adoption of family-based survival strategies, resulting in accelerated population growth and a downward spiral of economic decline.

A scenario booklet presents the four comprehensive narratives, together with information on starting conditions, key uncertainties and predetermined factors. A DVD Flash presentation has been developed

Figure 13: The F4T Scenarios



and distributed, presenting the scenario frame, the annotated scenario logics and the four story-lines.

F4T: why is it relevant?

The Nile issue is characterized by high dynamic, generative and social complexity. A problem has high dynamic complexity when cause and effect are far apart in time and space, for instance, agricultural commodity prices. Profitable farm-gate prices are a key driving force for improving agricultural productivity in rural areas in the Nile countries. But factors far outside the region, such as the international trade regime or biofuel policies in the United States of America, effectively determine local prices and thus directly affect rural development.

Generative complexity occurs when familiar and tested solutions are no longer applicable. For instance, high population growth in the Nile region puts unprecedented pressure on natural resources, infrastructure and government capacity. Old solutions, for example increasing water supply or expanding irrigated areas, no longer work. New, unfamiliar and often untested solutions are required. Some governments no longer feel in control in this environment of unpredictability, which conflicts with long-established practices of solving problems from above.

Kahane (2004) proposes that highly complex problems require an approach that is systemic, emergent and participatory. F4T fulfils these requirements.

The scenario group confirmed this assessment: "we have strong mental barriers and we need tools that help us lower or eliminate them … we need new ways of thinking – this is where scenarios and scenario thinking plays a very important role" (Cairo workshop, July 2008).

At the start, F4T aimed to explore the uncertain future of the dominant water user in the Nile Basin: demand for agricultural produce. The anticipated outcome was a realistic range of future demand for agricultural commodities to 2030, quantified in terms of calorie requirements and export potential.

This seemed a rather technical subject. To capture it, F4T evolved into a much bigger exercise – a joint analysis of a broad set of development issues related to demography, rural-urban migration, and conditions in rural areas in the Nile countries.

By taking a wider focus, F4T proved instrumental for expanding the Nile debate. The discussions moved from water allocation and hydrologic regime – a near-zero-sum topic – to agricultural trade regime, rural development and effective management and governance. A number of new shared interests emerged. These are related particularly to agricultural trade and, crucially, not directly related to river flow. This opens opportunities for enlarging common ground.

F4T proved useful in stretching mental models and providing a fresh perspective on the Nile issue.

The key factor here is not the change of focus itself. The insights obtained are not new. The relevance of F4T lies in the joint discovery of these insights by a group of Nile experts and decision-makers, from all riparian countries. The strong communality of views that emerged in the scenario group is seen as an important outcome of the exercise.

Subsequent interviews with participants confirmed key observations about the F4T scenario process:

- Rapidly moving away from the problems and differences of today, to a conversation about the future enabled a quick process of "unfreezing" among participants.
- The scenario process has contributed to mutual understanding and trust among participants, to the reframing of mental models, and to seeing the world in a new way ("re-perceiving").
- Specifically, the process has made it possible to discuss the sensitive issue of the effectiveness of governance.
- Mutual understanding and alignment on issues and options have markedly grown among participants (a number of interviewees considered this to be the single most important outcome of the process).

Scenario interpretation

The four scenarios

The F4T scenario set consists of four stories. They were developed at the extreme corners of a two-dimensional scenario space with polar axes: 1) quality of governance; and 2) international trade regime.

It is important to note that the four scenarios should be used as a set. None of them should be considered more likely than the others. The probability that a particular scenario will unfold in all details is near to zero, but as a set they represent a good understanding of the range of future events that may unfold.

With economic growth and rapidly rising prosperity, Joint Effort (JE) follows the lowest

Table 40: 2030 assumptions of key state variables

Scenario	Demographic variant	Calorie consumption (kcal/capita/day)	Nutrition
Joint Efforts (JE)	Low	3 350	From root crops to cereals More livestock products
Unintended Consequences (UC)	High	2 250 or current (if higher)	As 2003
Double Burden (DB)	High	Current	As 2003
Nile on its Own (NO)	Medium	3 000	From root crops to cereals Rest as 2003

demographic growth path, while the newly found and well-distributed wealth lifts food consumption towards the upper boundary. This scenario sees a shift in diet towards more livestock products, and away from roots and tubers.

In Unintended Consequences (UC), population growth rates remain high. The dominance of subsistence farming ensures that food consumption in rural areas is similar to the 2005 situation. Only urbanites consume more food in 2030. With dominant rural populations, average calorie consumption for the nation as a whole increases only marginally.

In Double Burden (DB), the Nile countries follow the highest demographic growth path. Calorie intake is similar to the 2005 situation and remains grossly inadequate for many riparians.

The good policies in Nile on its Own (NO) reduce undernourishment as average food consumption reaches the 3 000 kcal/capita/day threshold. Gradual increase in wealth steers the Nile countries towards the medium demographic growth variant. With reduced poverty levels, a diet shift is witnessed from roots and tubers towards cereals.

Food supply requirements per scenario

The 2030 food supply requirements were calculated for each of the four scenarios using the assumptions in Table 40.

Detailed lists of food supply requirements by country and scenario are available at the project Web site:
http://www.fao.org/nr/water/faonile/index.htm

It should be noted that Table 41 presents food requirements for only human consumption in the Nile Basin. Export crops, biofuels and animal feed are not included. Table 41 does also not take into account: internal trade (with parts within the nation that are outside the basin), seed requirements, domestic processing for export, or unnecessary waste.

Relative to the 2005 baseline, food consumption in the Nile Basin effectively doubles by the horizon year 2030. JE and NO have almost identical 2030 food requirements. They are some 15 percent higher than DB's, which provides the lower boundary. However, as absolute population numbers in NO and JE are substantially lower than in DB and UC, they offer much better prospects after 2030. Demand for water and food is ultimately determined by human consumption.

Table 41: Annual calorie requirements in 2030, per scenario

Country	2005 baseline (tera-kcal)	JE (tera-kcal)	NO (tera-kcal)	DB (tera-kcal)	UC (tera-kcal)
Burundi	2.8	11.5	10.8	6.2	8.5
Dem. Rep. of the Congo	1.1	4.8	4.6	2.6	3.6
Egypt	89.0	115.0	124.4	133.9	133.9
Eritrea	1.0	4.0	3.8	2.1	3.0
Ethiopia	21.1	57.9	55.3	36.3	44.0
Kenya	10.5	29.0	27.9	21.4	22.3
Rwanda	5.8	16.2	15.4	11.2	12.2
Sudan	26.7	61.3	58.9	47.4	47.4
United Rep.Tanzania	5.7	17.3	16.6	11.6	13.3
Uganda	24.5	70.3	66.9	55.7	55.7
Total	188.1	387.3	384.5	328.5	344.0

The calculations are based on a number of assumptions. Some of these may turn out to be wrong or only partly valid. In addition, unknown and unpredictable events, such as discoveries of new medicines or devastating natural disasters, could alter the 2030 picture quite dramatically. The scenario approach – where multiple plausible futures are examined – explicitly considers the underlying causal structures and should thus accommodate, to a considerable extent, the dynamics created by these unknown events. Hence, the range calculated should have a reasonable probability of occurrence, strengthening the overall validity of the analysis.

Some observations on export and bioproducts

Although this chapter is about food requirements, there may be value in making a few observations on the prospects for two other key elements of the demand function – agricultural export and biofuels – within the context of the F4T scenario set.

Agricultural exports, notably biofuels and biomaterials, are subject to much higher uncertainties than human food consumption. It is therefore risky to attach figures to their future development. In particular, this study's thoughts on biofuels are, to a certain extent, speculations. The future of energy is now very dynamic and involves very significant uncertainties regarding, for instance, technological developments, oil price and measures against global warming.

This suggests that:

- export and biomaterials are insignificant in DB;
- they should not constitute a problem in JE, as food commodities could be procured from international markets and agriculture is optimized as a function of the specific comparative advantage of the various Nile subregions;
- export does not change the overall calculation in NO – biofuels/materials could; however, in NO, rising prosperity takes away the need for food self sufficiency;

Table 42: Observations on export and demand for feedstock for biomaterials

Joint Efforts (JE)	JE foresees a significant increase in export of agricultural produce, and could experience a dramatic rise of demand for feedstock for biomaterials. However, this scenario also implies increased prosperity to the level that food produce could be procured from international markets. With rapidly decreasing rural populations and rural poverty, the need for food self-sufficiency has disappeared.
Unintended Consequences (UC)	With a favorable international trade environment, export can increase significantly in UC. Export produce will originate mostly from large commercial farms. Demand for feedstock for biofuels/materials could experience a dramatic rise. However, given the state of the railroad network in the southern Nile region, biofuels produced here cannot compete on international markets and are for national import substitution only. With large rural populations still depending on subsistence agriculture, UC will witness severe internal competition over land and water. It will pit exporters and biofuels/materials farmers against food producers for the domestic market.
Double Burden (DB)	Export and biomaterials/fuels production in DB will be marginal as the socio-political environment is simply not enabling.
Nile on its Own (NO)	NO implies sustained barriers to international trade in agricultural produce. Most trade in this scenario, therefore, is within the Nile region, and export to international markets will remain limited. It therefore does not affect the overall calculation. We could, however, see a dramatic increase in demand for feedstock for biofuels and biomaterials production, in particular for regional consumption.

- only in UC would export and biofuels/materials lead to an increase in absolute demand for agricultural produce that, if not met, could result in food insecurity.

2030 demand for agricultural produce: summary

With high demographic growth rates and large and growing rural populations in the upstream riparians – who are mostly poor and dependent on rainfed subsistence agriculture for their livelihood – food security is a concern for policy-makers in the Nile Basin. It is predetermined that demand for food commodities – either locally produced or imported – is set to rise. Policy-makers need a realistic assessment of future food requirements in the Nile Basin to be able to design and implement policies to meet this demand. This study calculated upper and lower limits by combining population prospects, nutrition trends and the F4T scenario set.

By using a scenario approach, important information has been added to the calculations. First, by providing a plausible range for the 2030 nutrition requirement – instead of a single projection – the uncertainties involved with demand forecasting have been kept explicitly on the agenda. For many decision-makers, no doubt, a single projection would be more comfortable, but it would also provide a false sense of confidence.

The second advantage of the approach is that it adds qualitative insights to the figures obtained, making it possible to judge their relevance more accurately.

Take, for instance, the 2030 upper boundary for food requirements. Without additional information, this would be the worst-case scenario. It occurs if the JE and NO story-lines materialize, but these two scenarios anticipate rising prosperity for large segments of the population in the Nile Basin in 2030. These people can now afford to procure food from international markets, making food security much less dependent on local production. From a problem defined by available land and water resources, it has now become an issue determined more by trade variables, economic policy and global agricultural output.

The UC scenario arguably represents the most challenging environment in 2030. It serves as a reference point for the food calorie requirement that – for a large part – has to be produced within the basin. UC sees an increase of food demand of some 83 percent in the horizon year.

With a difference of about 15 percent between the upper and lower boundaries of the 2030 nutrition requirements, it can be concluded that the quantitative assumptions made – in nutrition trends and the distribution of urban and rural population – are acceptable and do not lead to a notable distortion of the assessment.

Insights and key observations from F4T

This section presents a number of key observations and insights from the F4T process:

1. The natural resource base was not considered among the main constraints for economic development in the Nile countries; instead, under current conditions, institutional issues such as international agricultural trade regime and governance, political accountability, the quality of bureaucracy and the rule of law, were regarded as more critical.
2. With dominant rural populations, the state of rural areas is a critical determinant of demographic developments in the upstream riparians. This underscores the importance of rural development with regard to the future shape of the water demand function.
3. Water scarcity in the Nile Basin is essentially a development issue. Water is not scarce in absolute terms, but because too many people have no alternative to subsistence agriculture for their livelihood and food security.
4. With agriculture being the dominant water consumer, trade in agricultural commodities has potential as an effective, practical and non-controversial means of alleviating water scarcity and providing water security. This is the concept of "virtual water" – creating the conditions that allow for, or stimulate trade in agricultural commodities could serve as a unifying factor in the basin.
5. Rural development is of crucial importance when discussing the Nile issue. Improving agricultural productivity is at the basis of rural development. The benefits of industrialization, growth in the service sector, and exploitation of natural resources or tourism typically by-pass rural areas. A tentative discussion in the scenario group linked rural development to the following issues, presented in order of importance: peace and security, stable and profitable farm-gate prices, secure land tenure, well-functioning extension services, followed by issues

such as rural infrastructure, easy market access, availability of credit, water control, improved seeds and varieties, and so on.

6. Improving terms of agricultural trade is instrumental for providing effective economic incentives for agricultural development. Profitable farm-gate prices are key starting conditions for all agricultural activities. Hence, a coordinated agricultural trade policy, regarding both the Nile and the international markets, could have significant benefits for the riparian community. Stabilizing prices and creating an internal market could stimulate badly needed rural development in the upstream Nile countries.
7. Without effective governance, prospects for rural development are limited. Rural smallholders are mostly restricted to subsistence farming if the right conditions – price stability, stable land tenure, extension services, infrastructure, etc. – are not in place.
8. Improved terms of agricultural trade are not always a blessing. The outcome is only positive when prevailing conditions can stimulate local production. Ending OECD surplus production at a time when local farmers are unable to respond to price incentives would create higher food prices across the board without promoting rural development. This is the situation described in UC. This scenario underscores the importance of proper sequencing and timing of changes in the agricultural trade regime.
9. Positive developments in the Nile region are not conditional on a supportive international environment or trade regime. Regional cooperation and effective governance have the potential of bringing the region to a significantly higher level of prosperity. This is described in the NO scenario.
10. Reducing escalating tariffs holds the promise of a low-cost and practical measure to create employment and promote development, particularly in urban areas in the Nile countries. Benefits are significant and could materialize quickly. Potential spin-offs are equally important and related to: 1) building trade infrastructure, networks and expertise; 2) increasing demand for high-value agricultural produce; and 3) industrial development in general. Agroprocessing is also effective in attenuating seasonal production fluctuations.

These represent only some of the insights gained in the F4T process. The reader is referred to the F4T booklet for a full overview.

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Annex 1: Districts covered in the agriculture water use analysis

Country	Province or region	Districts		
Egypt	Frontier Governorates	Al Wadi/Al Jadid Ganub Sina	Matruh Shamal Sina	
	Lower Egypt	Al Bahayrah Al Daqahliyah Al Gharbiyah	Al Minufiyah Al Qalyubiyah As Ismailiyah	Ash Sharqiyah Dumyat Kafr-El-Sheikh
	Upper Egypt	Al Fayyum Al Jizah Al Minya	Aswan Asyiut Beni Suwayf	Luxor Qina Suhaj
	Urban Governorates	Al Iskandariyah Al Qahirah	As Suways Bur Said	
Sudan	Bahr Al Ghazal	North Bahr Al Ghazal		
	Central	Al Jazeera Blue Nile	Sennar	White Nile
	Darfur	North Darfur	South Darfur	West Darfur
	Eastern	Gadaref	Kassala	
	Equatoria	East Equatoria		
	Khartoum	Khartoum		
	Kordofan	North Kordofan	South Kordofan	West Kordofan
	Northern	Northern	River Nile	
	Upper Nile	Jonglei	Unity	Upper Nile
Eritrea	Not applicable	Gash-Barka		
Ethiopia	Amhara	Agew Awi E.Gojam N.Gonder	N.Shewa N.Wello S.Gonder	S.Wello Western W.Hamra
	Gambella	Gambella		
	Oromiya	E.Wellega Illubabor	Jimma S.W. Shewa	W.Shewa W.Wellega
	SNNPR	Bench Maji	Keffa	Sheka
	Tigray	Central Eastern	Southern	Western

(Continued)

Annex 1: Districts covered in the agriculture water use analysis

Country	Province or region	Districts		
Uganda	Central Uganda	Kalangala Kampala Kayunga Kiboga Luwero	Masaka Mpigi Mubende Mukono Nakasongola	Rakai Ssembabule Wakiso
	Eastern Uganda	Bugiri Busia Iganga Jinja Kaberamaido Kamuli	Kapchorwa Katakwi Kumi Mayuge Mbale Namutumba	Pallisa Sironko Soroti Tororo
	Northern Uganda	Adjumani Apac Arua Gulu	Kitgum Kotido Lira Moroto	Moyo Nakapiripirit Nebbi Pader
	Western Uganda	Buliisa Bundibugyo Bushenyi Hoima Ibanda Isingiro Kabale	Kabarole Kamwenge Kanungu Kasese Kibaale Kiruhura Kisoro	Kyenjojo Masindi Mbarara Ntungamo Rukungiri
Kenya	Nyanza	Bondo Gucha Homa Bay Kisii	Kisumu Kuria Migori Nyamira	Nyando Rachuonyo Siaya Suba
	Rift Valley	Bomet Buret Keiyo Kericho	Marakwet Nakuru Nandi Narok	Transmara Transzoia Uasin Gishu
	Western	Bungoma Busia Butere Mumias	Kakamega Lugari Mt. Elgon	Teso Vihiga

(Continued)

Country	Province or region	Districts		
United Rpublic of Tanzania	Kagera	Biharamulo Bukoba Rural Bukoba Urban	Karagwe Muleba Ngara	
	Kigoma	Kigoma		
	Mara	Bunda Musoma	Musoma Urban Serengeti	Tarime
	Mwanza	Geita Ilemela Kwimba	Magu Missungwi Mwanza	Sengerema Ukerewe
	Shinyanga	Bariadi Bukombe Kahama	Kishapu Maswa Meatu	Shinyanga Rural Shinyanga Urban
	Tabora	Nzenga		
Rwanda	Not applicable	Butare Byumba Cyangugu Gikongoro	Gisenyi Gitarama Kibungo Kibuye	Kigali Ruhengeri Umutara
Burundi	Not applicable	Bubanza Bujumbura Rural Bururi Cankuzo Gitega Karuzi	Kayanza Kirundo Makamba Muramvya Muyinga Mwaro	Ngozi Rutana Ruyigi

Annex 2: Estimated agricultural water use in the Nile Basin

The following table sets out the estimated district level crop water requirements for rainfed and irrigated areas.

Country	Province or region	District	Water used km^3		
			Rainfed	Irrigated	Total
Egypt	Frontier Governates	Al Wadi/Al Jadid		1.202	1.202
Egypt	Frontier Governates	Ganub Sina		0.005	0.005
Egypt	Frontier Governates	Matruh		1.472	1.472
Egypt	Frontier Governates	Shamal Sina		0.888	0.888
Egypt	Lower Egypt	Al Bahayrah		17.145	17.145
Egypt	Lower Egypt	Al Daqahliyah		6.275	6.275
Egypt	Lower Egypt	Al Gharbiyah		3.675	3.675
Egypt	Lower Egypt	Al Minufiyah		3.918	3.918
Egypt	Lower Egypt	Al Qalyubiyah		2.152	2.152
Egypt	Lower Egypt	As Ismailiyah		1.967	1.967
Egypt	Lower Egypt	Ash Sharqiyah		7.152	7.152
Egypt	Lower Egypt	Dumyat		1.011	1.011
Egypt	Lower Egypt	Kafr-El-Sheikh		5.694	5.694
Egypt	Upper Egypt	Al Fayyum		4.212	4.212
Egypt	Upper Egypt	Al Jizah		2.158	2.158
Egypt	Upper Egypt	Al Minya		5.377	5.377
Egypt	Upper Egypt	Aswan		2.221	2.221
Egypt	Upper Egypt	Asyiut		4.363	4.363
Egypt	Upper Egypt	Beni Suwayf		3.041	3.041
Egypt	Upper Egypt	Luxor		0.464	0.464
Egypt	Upper Egypt	Qina		4.750	4.750
Egypt	Upper Egypt	Suhaj		3.556	3.556
Egypt	Urban Governates	Al Iskandariyah		1.207	1.207
Egypt	Urban Governates	Al Qahirah		0.207	0.207

(Continued)

Country	Province or region	District	Water used km^3		
			Rainfed	Irrigated	Total
Egypt	Urban Governates	As Suways		0.151	0.151
Egypt	Urban Governates	Bur Said		0.151	0.151
Sudan	Bahr Al Ghazal	North Bahr Al Gh	0.155	0.013	0.168
Sudan	Central	Al Jazeera	0.365	10.897	11.263
Sudan	Central	Blue Nile	.891	0.687	4.579
Sudan	Central	Sennar	4.472	5.689	10.160
Sudan	Central	White Nile	2.447	2.869	5.316
Sudan	Darfur	North Darfur	0.950	0.163	1.113
Sudan	Darfur	South Darfur	3.946	0.000	3.946
Sudan	Darfur	West Darfur	.823		0.823
Sudan	Eastern	Gadaref	.626	1.263	10.889
Sudan	Eastern	Kassala	.068	2.273	3.341
Sudan	Equatoria	East Equatoria	.036		2.036
Sudan	Khartoum	Khartoum	.033	0.629	0.663
Sudan	Kordofan	North Kordofan	.409	0.196	3.605
Sudan	Kordofan	South Kordofan	.663		4.663
Sudan	Kordofan	West Kordofan	.638		6.638
Sudan	Northern	Northern	.017	2.283	2.299
Sudan	Northern	River Nile	.037	1.258	1.294
Sudan	not known	Southern States	.920		6.920
Sudan	Upper Nile	Unity	.226		0.226
Sudan	Upper Nile	Upper Nile	.054	0.044	1.098
Eritrea	Gash-Barka	Gash-Barka	.227	0.100	0.327
Ethiopia	Amhara	Agew Awi	.460		0.460
Ethiopia	Amhara	E.Gojam	.583	0.041	1.624
Ethiopia	Amhara	N.Gonder	.651	0.004	2.654
Ethiopia	Amhara	N.Shewa	.240	0.016	0.256
Ethiopia	Amhara	N.Wello	.766		0.766
Ethiopia	Amhara	S.Gonder	.715		1.715
Ethiopia	Amhara	S.Wello	.777		1.777
Ethiopia	Amhara	W.Hamra	.322	0.004	0.326
Ethiopia	Amhara	Western		0.002	0.002
Ethiopia	Benishangul Gumuz	Benishangul	.606		0.606

(Continued)

Country	Province or region	District	Water used km^3		
			Rainfed	Irrigated	Total
Ethiopia	Gambella	Gambella	.059	0.309	0.368
Ethiopia	Oromiya	E.Wellega	0.797	0.011	0.808
Ethiopia	Oromiya	Illubabor	0.844	0.009	0.853
Ethiopia	Oromiya	Jimma	0.726		0.726
Ethiopia	Oromiya	S.W. Shewa	0.046	0.012	0.058
Ethiopia	Oromiya	W.Shewa	1.755	0.019	1.773
Ethiopia	Oromiya	W.Wellega		0.026	0.026
Ethiopia	SNNPR	Bench Maji	0.762		0.762
Ethiopia	Tigray	Central (Tigray)		0.006	0.006
Ethiopia	Tigray	Eastern (Tigray)		0.016	0.016
Ethiopia	Tigray	Southern (Tigray)		0.030	0.030
Ethiopia	Tigray	Tigray	1.485		1.485
Ethiopia	Tigray	Western (Tigray)		0.001	0.001
Uganda	Central Uganda	Kalangala	0.141		0.141
Uganda	Central Uganda	Kampala	0.176		0.176
Uganda	Central Uganda	Kayunga	0.837		0.837
Uganda	Central Uganda	Kiboga	1.057		1.057
Uganda	Central Uganda	Luwero (inc Nakaseke)	1.760	0.001	1.761
Uganda	Central Uganda	Masaka	2.845	0.000	2.846
Uganda	Central Uganda	Mpigi	1.484	0.013	1.498
Uganda	Central Uganda	Mubende (inc Mityana)	1.637		1.637
Uganda	Central Uganda	Mukono	2.422	0.017	2.439
Uganda	Central Uganda	Nakasongola	0.800		0.800
Uganda	Central Uganda	Rakai (inc Lyatonde)	1.218		1.218
Uganda	Central Uganda	Ssembabule	0.660		0.660
Uganda	Central Uganda	Wakiso	1.564	0.005	1.569
Uganda	Eastern Uganda	Bugiri	0.970	0.104	1.074
Uganda	Eastern Uganda	Busia	1.235	0.016	1.251
Uganda	Eastern Uganda	Iganga	2.848	0.064	2.911
Uganda	Eastern Uganda	Jinja	0.776	0.107	0.883
Uganda	Eastern Uganda	Kaberamaido	0.335	0.000	0.335
Uganda	Eastern Uganda	Kamuli (inc Kaliro)	2.857	0.546	3.403
Uganda	Eastern Uganda	Kapchorwa	0.454	0.003	0.457

(Continued)

Country	Province or region	District	Water used km^3		
			Rainfed	Irrigated	Total
Uganda	Eastern Uganda	Katakwi (inc Amuria)	1.054		1.054
Uganda	Eastern Uganda	Kumi	1.174	0.001	1.176
Uganda	Eastern Uganda	Mayuge	0.718	0.002	0.721
Uganda	Eastern Uganda	Mbale	1.894	0.001	1.895
Uganda	Eastern Uganda	Pallisa	0.006		0.006
Uganda	Eastern Uganda	Pallisa (inc Budaka)	1.433	0.084	1.517
Uganda	Eastern Uganda	Sironko	1.062	0.002	1.064
Uganda	Eastern Uganda	Soroti	1.085	0.006	1.091
Uganda	Eastern Uganda	Tororo (inc Butaleja)	2.369	0.060	2.428
Uganda	Northern Uganda	Adjumani	0.465	0.000	0.465
Uganda	Northern Uganda	Apac (inc Oyam)	1.215		1.215
Uganda	Northern Uganda	Arua (inc Koboko, Maracha, Terego, Yumbe)	1.921		1.921
Uganda	Northern Uganda	Gulu (inc Amuru)	0.719		0.719
Uganda	Northern Uganda	Kitgum	0.331		0.331
Uganda	Northern Uganda	Kotido (inc Abim)	0.405		0.405
Uganda	Northern Uganda	Lira (inc Amolatai, Dokolo)	1.208	0.029	1.236
Uganda	Northern Uganda	Moroto	0.214		0.214
Uganda	Northern Uganda	Moyo	0.535		0.535
Uganda	Northern Uganda	Nakapiripirit	0.127		0.127
Uganda	Northern Uganda	Nebbi	0.999		0.999
Uganda	Northern Uganda	Pader	0.633		0.633
Uganda	Western Uganda	Bundibugyo	0.239		0.239
Uganda	Western Uganda	Bushenyi	2.311		2.311
Uganda	Western Uganda	Hoima	0.773		0.773
Uganda	Western Uganda	Kabale	2.288		2.288
Uganda	Western Uganda	Kabarole	1.073		1.073
Uganda	Western Uganda	Kamwenge	0.902		0.902
Uganda	Western Uganda	Kanungu	0.845		0.845
Uganda	Western Uganda	Kasese	1.092	0.045	1.137
Uganda	Western Uganda	Kibaale	1.551		1.551
Uganda	Western Uganda	Kisoro	0.980		0.980
Uganda	Western Uganda	Kyenjojo	1.101		1.101

(Continued)

Country	Province or region	District	Water used km^3		
			Rainfed	Irrigated	Total
Uganda	Western Uganda	Masindi, Buliisa	1.068		1.068
Uganda	Western Uganda	Mbarara	3.047		3.047
Uganda	Western Uganda	Ntungamo	1.319		1.319
Uganda	Western Uganda	Rukungiri	1.470		1.470
Kenya	Nyanza	Bondo	0.248	0.005	0.254
Kenya	Nyanza	Gucha	0.816	0.027	0.844
Kenya	Nyanza	Homa Bay	0.756	0.023	0.779
Kenya	Nyanza	Kisii	0.538	0.071	0.609
Kenya	Nyanza	Kisumu	0.224	0.105	0.329
Kenya	Nyanza	Kuria	0.474	0.006	0.480
Kenya	Nyanza	Migori	1.195	0.224	1.418
Kenya	Nyanza	Nyamira	0.945	0.132	1.077
Kenya	Nyanza	Nyando	0.749	0.062	0.811
Kenya	Nyanza	Rachuonyo	0.776	0.033	0.809
Kenya	Nyanza	Siaya	0.644	0.088	0.732
Kenya	Nyanza	Suba	0.144	0.007	0.151
Kenya	Rift Valley	Bomet	0.383	0.003	0.387
Kenya	Rift Valley	Buret	0.711	0.006	0.717
Kenya	Rift Valley	Kericho	0.647	0.008	0.655
Kenya	Rift Valley	Nandi	0.811	0.011	0.822
Kenya	Rift Valley	Narok	1.295	0.026	1.321
Kenya	Rift Valley	Transmara	0.420		0.420
Kenya	Rift Valley	Transzoia	0.749	0.094	0.843
Kenya	Rift valley	Uasin Gishu	0.396	-	0.396
Kenya	Western	Bungoma	1.038	0.049	1.087
Kenya	Western	Busia	1.235	0.016	1.251
Kenya	Western	Butere Mumias	0.689	0.058	0.747
Kenya	Western	Kakamega	0.739	0.014	0.753
Kenya	Western	Lugari	0.301	0.004	0.306
Kenya	Western	Mt. Elgon	0.202	0.003	0.204
Kenya	Western	Teso	0.107	0.008	0.116
Kenya	Western	Vihiga	0.355	0.003	0.358
United Rep.Tanzania	Kagera	Biharamulo	0.623		0.623

(Continued)

Country	Province or region	District	Water used km^3		
			Rainfed	Irrigated	Total
United Rep.Tanzania	Kagera	Bukoba		0.000	0.000
United Rep.Tanzania	Kagera	Bukoba Rural	0.813		0.813
United Rep.Tanzania	Kagera	Bukoba Urban	0.065		0.065
United Rep.Tanzania	Kagera	Karagwe	0.710		0.710
United Rep.Tanzania	Kagera	Muleba	0.672		0.672
United Rep.Tanzania	Kagera	Ngara	0.440		0.440
United Rep.Tanzania	Kigoma	Kigoma		0.000	0.000
United Rep.Tanzania	Mara	Bunda	0.298	0.002	0.299
United Rep.Tanzania	Mara	Musoma	0.929	0.001	0.930
United Rep.Tanzania	Mara	Musoma Urban	0.007		0.007
United Rep.Tanzania	Mara	Serengeti	0.471	-	0.471
United Rep.Tanzania	Mara	Tarime	1.033	0.001	1.034
United Rep.Tanzania	Mwanza	Geita	1.217		1.217
United Rep.Tanzania	Mwanza	Ilemela	0.119		0.119
United Rep.Tanzania	Mwanza	Kwimba	0.836		0.836
United Rep.Tanzania	Mwanza	Magu	0.663		0.663
United Rep.Tanzania	Mwanza	Missungwi	0.520		0.520
United Rep.Tanzania	Mwanza	Mwanza	0.072		0.072
United Rep.Tanzania	Mwanza	Sengerema	1.567		1.567
United Rep.Tanzania	Mwanza	Ukerewe	0.326		0.326
United Rep.Tanzania	Shinyanga	Bariadi	1.530		1.530
United Rep.Tanzania	Shinyanga	Bukombe	0.858		0.858
United Rep.Tanzania	Shinyanga	Kahama	1.373		1.373
United Rep.Tanzania	Shinyanga	Kishapu	0.719		0.719
United Rep.Tanzania	Shinyanga	Maswa	0.696		0.696
United Rep.Tanzania	Shinyanga	Meatu	0.602		0.602
United Rep.Tanzania	Shinyanga	Shinyanga Rural	0.557		0.557
United Rep.Tanzania	Shinyanga	Shinyanga Urban	0.094		0.094
Rwanda	Butare	Butare	0.965	0.178	1.143
Rwanda	Byumba	Byumba	0.985		0.985
Rwanda	Cyangugu	Cyangugu	0.626	0.165	0.791
Rwanda	Gikongoro	Gikongoro	0.627		0.627
Rwanda	Gisenyi	Gisenyi	1.025		1.025

(Continued)

Country	Province or region	District	Water used km^3		
			Rainfed	Irrigated	Total
Rwanda	Gitarama	Gitarama	1.412	0.068	1.480
Rwanda	Kibungo	Kibungo	1.207	0.104	1.311
Rwanda	Kibuye	Kibuye	0.744		0.744
Rwanda	Kigali	Kigali	1.197	0.161	1.358
Rwanda	Ruhengeri	Ruhengeri	1.135		1.135
Rwanda	Umutara	Umutara	0.529	0.078	0.606
Burundi	Bubanza	Bubanza			0.000
Burundi	Bujumbura Rural	Bujumbura Rural	0.293		0.293
Burundi	Bururi	Bururi	0.440		0.440
Burundi	Cankuzo	Cankuzo	0.154		0.154
Burundi	Cibitoke	Cibitoke	0.371		0.371
Burundi	Gitega	Gitega	0.644		0.644
Burundi	Karuzi	Karuzi	0.273		0.273
Burundi	Kayanza	Kayanza	0.701		0.701
Burundi	Kirundo	Kirundo	0.480		0.480
Burundi	Makamba	Makamba	0.237		0.237
Burundi	Muramvya	Muramvya	0.229		0.229
Burundi	Muyinga	Muyinga	0.559		0.559
Burundi	Mwaro	Mwaro	0.168		0.168
Burundi	Ngozi	Ngozi	0.891		0.891
Burundi	Rutana	Rutana	0.109		0.109
Burundi	Ruyigi	Ruyigi	0.194		0.194

Information Products for Nile Basin Water Resources Management

Reports:

- Food For Thought
- Synthesis Report
- Projections Report
- Farming Systems Report

Manuals:

- ADCP Measurement of the Blue Nile under High Sediment Condition
- ArcView Watershed Delineator
- Blue Water Poster for the Nile Sub Basin
- Map Projections
- Retrieval, Processing and Final Storage in the LVBD of Hydrometeorological Data from the Lake Victoria Monitoring Network
- Data Retrieval, Processing and Final Storage into the Nile Basin Database
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The project “Information Products for Nile Basin Water Resources Management” is intended to strengthen the ability of the governments of the eleven Nile countries to take informed decisions with regard to water resources policy and management in the Nile basin. A thorough understanding of the state of the Nile resource, and the current use and productivity of its waters, will enable decision makers to better assess trade-offs and implications of shared-vision development scenarios.

The project was supported by the Government of Italy and carried out between 2004 and 2009 under the umbrella of the Nile Basin Initiative, of which Italy is a full partner. It is implemented by the eleven Nile riparians with technical and operational assistance of the Food and Agriculture Organization of the United Nations (FAO).