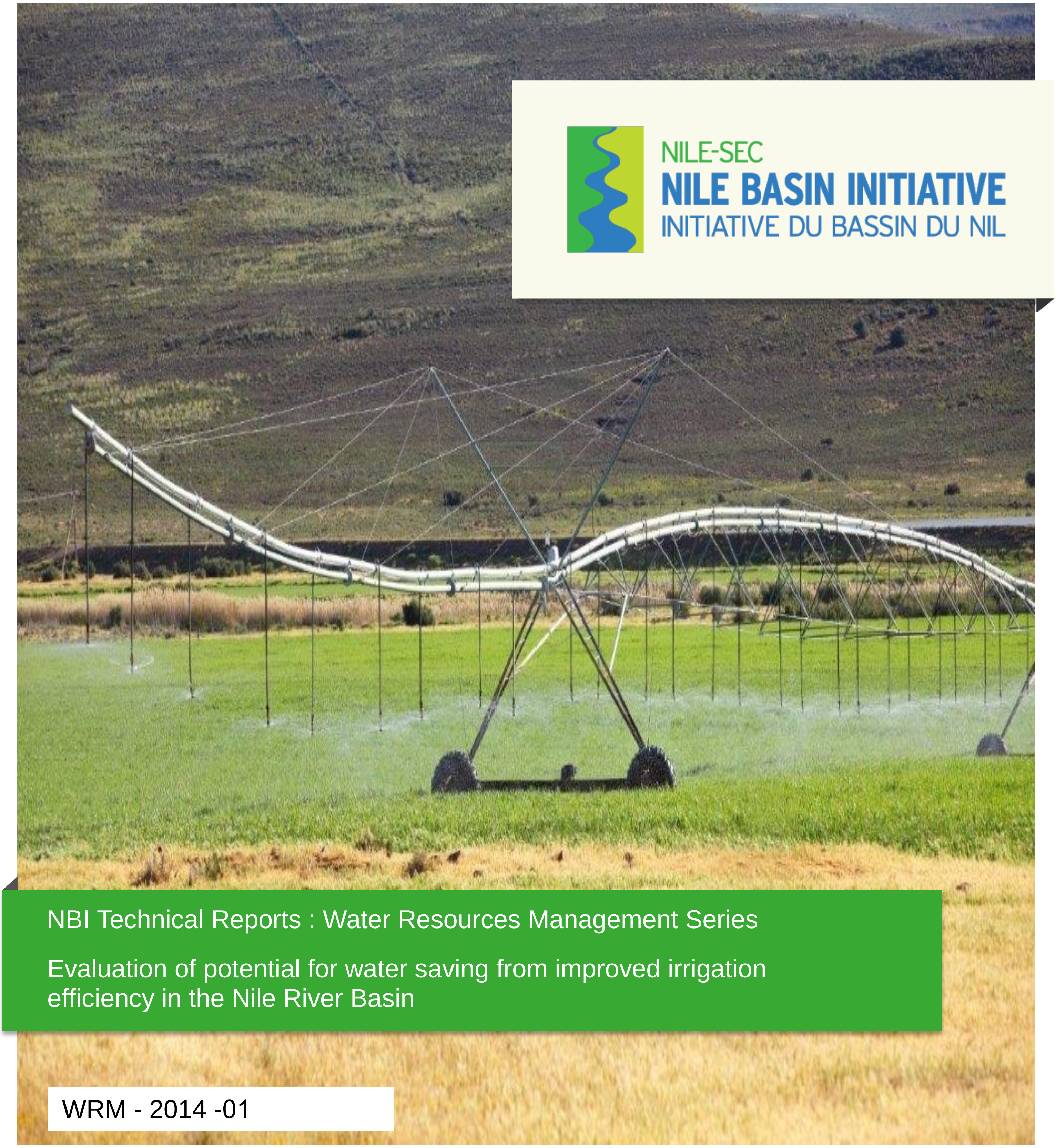


NILE-SEC
NILE BASIN INITIATIVE
INITIATIVE DU BASSIN DU NIL

NBI Technical Reports : Water Resources Management Series

Evaluation of potential for water saving from improved irrigation efficiency in the Nile River Basin

WRM - 2014 -01

german
cooperation
DEUTSCHE ZUSAMMENARBEIT

Implemented by: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Document Sheet

This Technical Report series publishes results of work that has been commissioned by the member states through the three NBI Centers (Secretariat based in Entebbe- Uganda, the Eastern Nile Technical Regional Office based in Addis Ababa - Ethiopia and the Nile Equatorial Lakes Subsidiary Action Program Coordination Unit based in Kigali - Rwanda. The content there-in has been reviewed and validated by the Member States through the Technical Advisory Committee and/or regional expert working groups appointed by the respective Technical Advisory Committees.

The purpose of the technical report series is to support informed stakeholder dialogue and decision making in order to achieve sustainable socio-economic development through equitable utilization of, and benefit from, the shared Nile Basin water resources.

Document	
Citation	NBI Technical Reports - WRM 2014-01, Evaluation of potential for water saving from improved irrigation efficiency in the Nile River Basin
Title	Evaluation of potential for water saving from improved irrigation efficiency in the Nile River Basin
Series Number	Water Resources Management 2014-01
Responsible and Review	
Responsible NBI Center	Nile-Secretariat
Responsible NBI	Dr. Abdulkarim Seid
Document Review Process	Strategic Water Resources Regional Expert Working Group
Final Version endorsed	
Author / Consultant	
Consultant Firm	Justus-Liebig-University Giessen
Authors	Prof. Hans-Georg Frede, Dr. Lutz Breuer, Prof. Dr. Sebastian Multsch, Dr. Abdulkarim H. Seid, Dr. Mohamed E. Elshamy,
Project	
Funding Source	German Cooperation BMZ, Implemented by GIZ
Project Name	Support to Transboundary Cooperation in the Nile Basin
Project Number	13.2249.4001.01

Disclaimer

The views expressed in this publication are not necessarily those of NBI’s Member States or its development partners. Trademark names and symbols are used in an editorial fashion and no intention of infringement on trade mark or copyright laws. While every care has been exercised in compiling and publishing the information and data contained in this document, the NBI regrets any errors or omissions that may have been unwittingly made in this publication.
The NBI is not an authority on International Administrative Boundaries. All country boundaries used in this publication are based on FAO Global Administrative Unit Layers (GAUL).

Contents

Terminology

For the purpose of this study, the terminologies given in Table 1 have been adopted to describe the various aspects of irrigation water requirements and demands.

Table 1: Terminology

Term	Definition (as used in this document)
Crop water requirement	Is the volume of water needed to meet the water loss through evapotranspiration (ETcrop) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment; this is a slightly modified definition to the one given by FAO (Doorenbos and Pruitt, 1977)
Leaching Requirement	Is the minimum amount of irrigation water supplied that must be drained through the root zone to control soil salinity at the given specific level (FAO, 1977).
Effective rainfall	Volume of rainfall that will be available for plant water uptake
Net irrigation requirement	Is the amount of water that must be made available to the crop to meet its water requirement that is not met by effective rainfall and any other source, such as groundwater
Field level irrigation demand	The amount of water that must be applied to the irrigation field. It is calculated as the net irrigation requirement increased to account for leaching and losses in field water application system.
Withdrawal requirement	The total amount of water that must be withdrawn from a water source (river, dam, groundwater) to meet field level irrigation demand. It is computed as the field level irrigation demand divided by the canal and distribution efficiency
On-farm irrigation efficiency	Is defined as the ratio of volume of water made available to plants on a block of irrigation fields to the total volume of water supplied at the inlet to the block of fields. It takes into account losses in field water distribution and application system.
Off-farm irrigation efficiency	This is defined in this study as the ratio between the volume of water at inlet to a block of fields to that withdrawn from a source, often a river. It takes into account all losses in the canal system.

Executive summary

The potential for water saving from improved irrigation efficiency in the Nile Basin is presented in this document. This is a result of analytic work carried out by NBI Secretariat (Nile-SEC) and the Justus Liebig University (Germany) under contract with the GIZ. The study is intended to provide indicative orders of magnitude of water saving that can be achieved by improving irrigation practices (focus on improving efficiencies).

2011 has been taken as baseline year and 2050 as the future date at which all national plans on expanding irrigated agriculture in the Nile Basin would have been implemented. While the expansion in irrigated agriculture is assumed to take place as per national plans and, hence, no scenarios of such expansions constructed, scenarios of plausible irrigation efficiency improvements have been used to estimate impacts of irrigation efficiency improvements on water saving. The study relied on NBI's own database, global datasets and data from published material and modeling tools at the NBI secretariat and the Justus Liebig University.

The Nile is the longest river in the world with a total length of nearly 6700 km. Its basin covers an area of approximately 3.1 million square kilometers. Compared to many large rivers of comparative size world-wide, the Nile has relatively small annual runoff with an average annual discharge between 40 and 150 $km^3\ yr^{-1}$ at the Aswan Dam (Johnston, 2012).

Currently some 5.3 M hectares of land are equipped for irrigation in the Nile Basin countries out of which 5.1 M hectares (97 %) are in Egypt (3.45 M hectares) and Sudan (1.71 M hectares). While the actual harvest area is about 68 per cent in Sudan (largely due to shortage of water), the harvest area in Egypt is 5 M hectares (cropping intensity of 146 per cent). The Nile Basin has quite substantial irrigable land yet to be tapped. According to consulted national documents from Nile Basin countries, there is a potential to expand the total irrigated area by additional 3.4 M hectares. Most of this expansion is expected in Ethiopia (1.4 M hectare), Sudan (about 1 M hectares) and Egypt (0.5 M hectares). The cropping intensity in Sudan can increase from current 68 per cent to 90 percent leveraging more regulated flow of water from the additional storage dams to be built in Ethiopia.

If all national plans for irrigation expansion are implemented, by about 2050, the aggregate irrigated area can increase to about 8.7 M hectares. This is an increase of about 65 per cent over the current irrigated area. These expansions are planned under purely national development agenda where the basin-wide water resource use is not adequately factored. In this regard, the study attempted to address the following questions:

- How much additional water is needed for planned irrigation expansions?
- Can the Nile support these expansions?
- How much water can be saved by improving irrigation efficiency (on-farm and off-farm)?

Currently nearly all withdrawal of water from the Nile for irrigated agriculture is used by Egypt (about 67 km^3 yr^{-1}net abstraction) and Sudan (about 19 km^3 yr^{-1}). In addition, Egypt uses some percent of the water drained from agriculture fields for irrigation after mixing with river water. The study estimated that, with the implementation of national plans for expansion of irrigated agriculture, the additional (field level) water requirement for the planned new irrigation schemes will be about 39 km^3 yr^{-1} and the total (field level) water requirements for all irrigation areas in the Nile Basin by 2050 would be around 120 km^3 yr^{-1} assuming poor irrigation infrastructure. When one takes into account losses in canal systems that transport water from source (river, dams) to the irrigation fields the total water abstractions needed to meet this field-level demand would be even higher. Hence, the planned expansions dramatically increase the water demand in the Nile river basin and the total future demand will be 1.5 times larger than today. This large amount of water cannot be supplied by the Nile as shown in this study. By estimating the river water flows it could be shown that the total deficit in meeting these total water abstraction requirements for all irrigated areas by 2050 can reach up to 44 km^3 yr^{-1} if current levels of (poor) irrigation efficiencies don't improve. Under a (purely) theoretical scenario of maximum possible irrigation efficiency improvement, the total deficit would be around 8 km^3 yr^{-1}. For plausible improvement scenarios (Scenario 1 and 2), the deficit ranges between 21 to 30 km^3 yr^{-1}.

The study shows that improving irrigation efficiencies can result in substantial water saving. However, the water saving through improved technologies cannot compensate the additional water requirement of the planned irrigation areas. Therefore, further solutions for balancing the water demand with the available supply need to be explored. These solutions need to be based on:

- Enhanced trade-off analysis between potentially competing water uses (e.g. environmental flow requirements, electricity production and irrigation for food security) – the NEXUS between Water, Food and Energy Security in the Basin using the NBI WEAP/DSS Model.
- A (macro-) economic study analysing economically optimal agricultural water use across the basin based on hydro-economic optimization models of the basin and macro-economic (Trade, CGE models) models of the countries' economies and their trade inter-linkages.
- An enhanced database on irrigation schemes in the Nile Basin integrating site-specific data collection.
-

1 Introduction

This is study on the ‘Evaluation of potential for water saving from improved irrigation efficiency in the Nile Basin’ was carried out by NBI Secretariat (Nile-SEC) and the Justus Liebig University Germany (JLU) under contract with the Gesellschaft für Internationale Zusammenarbeit’, GIZ.

GIZ is supporting the NBI on behalf of the German Government since 2002. The German Government however has a very substantial portfolio of engagement in Nile riparian states in the water, energy and agricultural sectors on a bilateral basis both through GIZ and KfW. In 2014, the German Government, through the Foreign Office, has commissioned GIZ to undertake a review of some elements of German support to Nile Basin cooperation. This is to provide input to the further strategic development of support at the bilateral and regional level.

One of the tasks under this assignment is to assess whether increased investments in water use efficiency in the irrigated agricultural sector in the riparian countries can make a substantial contribution towards addressing the key challenges of cooperative water resources management in the basin, for example by increasing the availability of water resources in the basin through water savings.

This assignment is deliberately designed to serve two purposes: (a) to inform the strategy development of the German government and (b) to make a contribution to further NBI’s agenda on agricultural water use in the basin and NBI’s capacities to provide policy inputs in this dimension.

The study was conducted during the period February– May 2015 based on published information on existing and planned future irrigation systems in the Nile Basin and modeling tools available at the two institutions, which carried out the study.

1.1 The Nile basin

The Nile is the longest river in the world with a total length of nearly 6700 km. Its basin covers an area of approximately 3.1 million square kilometers (10 percent of African landmass) spread over 11 Africa countries. The total population that lives within the basin boundary is estimated at about 240 million (NBI, 2012) whereas the total population of the riparian countries is over 400 million inhabitants. The Nile Basin region is characterized by rapid population growth (NBI, 2012). Estimations based on the World Bank World Development Indicators (World Bank, 2014) databank show that between 1960 and 2010 the population of the riparian countries grew four fold, from a mere 100 million to 416 million.

Compared to many large rivers of comparative size world-wide, the Nile has relatively small annual runoff with an average discharge between 40 and 150 km^3 yr^{-1} at the Aswan Dam (Johnston, 2012); a long-term average of 85 km^3 per year is frequently used in analyses. This is due to the fact that river flow in the Nile Basin is generated only from an area that is less than a third of its total basin area. Approximately 86 per cent of the river flow received at the High Aswan Dam (HAD) in Egypt is contributed from Ethiopian highlands whereas the remaining comes from the Equatorial Lakes region and South Sudan.

The downstream parts of the Nile Basin in Egypt and Sudan area characterized by relatively high level of water resources development for agriculture and power generation while the upstream parts largely depend on traditional subsistence level rain-fed agriculture and, as a result, very low level of water abstraction from the river. In line with this, the current level of dependence on Nile waters for energy and food production is also highly skewed with Egypt being the most Nile dependent country. Currently approximately 5.3 million hectares of land are under irrigation in all NBI countries with 97 per cent of this total area being in Egypt and Sudan.

However, this is going to change. National plans show considerable increase in water resources development over the coming decades (BCEOM (1999), Nedeco (1998), WREM (2006)). Plans are in place to expand hydraulic infrastructure for providing reliable water consumption, for energy and food production, which can be translated into increased water demand to meet the needs of growing population and economies. Based on national plans available to this study, the total increase in irrigation areas by 2050 is estimated at 3.2 million hectares. More than half of this increase, about 1.8 million hectares, is expected to be in upstream countries.

Given that the Nile is shared by 11 countries and that agriculture consumes most of the Nile waters, the question of how the Nile Basin water resources will evolve under the anticipated water abstractions to meet the growing demands for food production becomes one of the most critical questions to be addressed.

This study attempts to estimate the likely future water demand for irrigated agriculture in the entire Nile Basin given the planned expansions in irrigation in the Nile Basin countries. It is conducted as first-cut desk level analytic work designed to provide indicative range of future water needs for irrigated agriculture under scenarios of irrigation efficiency improvements and thereby highlight potential issues of water resources management in the Nile Basin.

1.2 Irrigation efficiency

Water consumption is globally driven by the agriculture demand to grow food and feed for people and animals, respectively, as shown in many studies (Aquastat, 2009; Rost et al., 2008; Siebert and Döll, 2010). As a consequence, surface and groundwater resources are under pressure worldwide (Gleeson et al., 2012; Hoekstra et al., 2012). River flows are reduced by human impacts through irrigation (Döll et al., 2009)and groundwater is often depleted (Wada et al., 2012) as a consequence of unsustainable irrigation. Nevertheless, irrigation is indispensable for feeding people; crop yield under irrigation is generally higher than those under rain-fed systems (Siebert and Döll, 2010).

In order to assess likely impacts of improved irrigation efficiency the actual volume of water withdrawn from surface and groundwater sources and water consumption by crops must be known. The former is often denoted as water withdrawal. Water consumption is the fraction which is actually evaporated by the soil on agriculture fields and transpired by plants. The residual (non-consumed fraction) may be recovered and used elsewhere, or be lost to inaccessible groundwater or be contaminated so that no further use is possible. For example, salinization makes further use of the water often impossible in irrigated agriculture.

Agriculture water consumption is often further divided into green (rainfall, soil moisture) and blue (surface and groundwater consumed by irrigation) water (Falkenmark and Rockström, 2006; Hoekstra et al., 2011).Both have been calculated for riparian countries of the Nile river with 227 $km^3 yr^{-1}$ green and 44 $km^3 yr^{-1}$ blue water (Mekonnen and Hoekstra, 2011). A third water component has been added from Hoekstra et al. (2011) who defined the water needed to dilute pollutants (e.g. fertilizer, pesticides) as grey water. Others have related the grey water to the amount of water needed to wash out salts from the soil in order to maintain a crop tolerable salinity level in the rooting zone (Multsch et al., 2013) which will be particularly addressed in this study.

Concepts to decrease water resource depletion include a better management of rainfall (Rockström et al., 2009) and irrigation water (Pereira et al., 2002) whereby the latter one is addressed in this study. An improvement of irrigation efficiency, i.e. the ratio between the water made available for plant water uptake and the water taken from the source (surface and groundwater), is a major goal to save freshwater resources. Irrigation efficiency has been recently discussed in a high detail (Howell, 2003; Jensen, 2007; Lankford, 2012) and general instructions are provided by FAO Irrigation and Drainage guidelines (Brouwer et al., 1989). Generally, two types of irrigation efficiencies are distinguished which are related to (i) the water losses during delivering water to the farms (e.g. through leakage from canals, evaporation from canals, through cracks in canal bunds) and (ii) during the application to the fields (evaporation, deep percolation). The scheme efficiency (e), which includes both terms, can then be calculated from the so called conveyance e_c (off-farm) and application e_a (on-farm) efficiency:

$$e = \frac{e_c * e_a}{100} \tag{1}$$

with e, e_c and e_a given in [%].

1.3 Irrigation in Nile Basin

Irrigation has a history of nearly 7,000 years in Egypt and one can say that the state has always been managing the Nile waters and irrigation in a highly centralized manner since the pharaohs' era to date. Since the mid-18th century, new practices and technologies have gradually been implemented on a wider scale. The last major attempt to harness the Nile flows for productive use was the construction of the Aswan High Dam completed in 1970. In Sudan, large scale irrigation development started in the 1920's with the construction of Sennar dam (completed in 1925) and the Gezira irrigation scheme for cotton "export" to Britain the then colonial ruler. The completion of the Jebel Awlia dam (1937) on the White Nile, some 20 km upstream of Khartoum, led to the rapid development of pumping schemes. The total irrigated area is estimated to be 3.4Mha in Egypt and 1.8 Mha in Sudan (ENTRO-IDS, 2009). However, the total harvest areas in Egypt is around 5 Mha (about 150% cropping intensity on average) while the total harvest area in Sudan is only 1.17 Mha (about 68% cropping intensity on average) (Bart et al, 2011).

In other parts of the basin, agriculture is mainly rain-fed or recession with several small holder scattered schemes that are irrigated in a, predominantly, supplementary way. For example, Ethiopian rural communities living nearby water sources have been developing small-scale irrigation for decades and sometimes centuries with minimal or no support from external bodies like the government or NGOs. Most of these so called "traditional irrigation schemes" are river diversions. Spring development and hand dug wells are also other sources of water for traditional irrigation. Irrigation management is usually organized by community-based irrigation committees run by elected leaders called the "Water Fathers". There is no systematic record of the traditional schemes in Ethiopia. However the estimated total development of traditional irrigation is assumed to be about 200,000 ha and it represents almost 60% of the total irrigated area of about 340,000 ha in the country. In the Nile basin total area of traditional irrigation is estimated at about 60,000 ha (ENTRO- IDS, 2009).

Irrigation in other countries (around the Equatorial Lakes as well as South Sudan) is similar to that of Ethiopia with estimated irrigated area of about 50,000 ha scattered mainly around Lake Victoria and on its feeding tributaries (NBI-NELSAP , 2012). The area equipped for irrigation may be higher but data collection is not systematic in the region.

In terms of irrigation efficiency, most farming systems within the basin use simple flood or furrow irrigation systems with few exceptions in Sudan and Egypt where some sprinkler or drip schemes can be found. Therefore, the efficiency of irrigation systems is generally low – in the order of 50% overall (Aquastat, 2009; Elamin,2011). Water lost from the system percolates to deep groundwater or evaporates from water courses (e.g. irrigation canals). There are no drainage systems except in Egypt. The irrigation system in Egypt is particularly unique. Despite the low efficiency at the field level, the overall efficiency is high due to reuse of drainage water.

Drains in upper and middle Egypt return to the Nile while drainage water in the Delta is officially pumped to canals and unofficially to fields by farmers at the tail ends of irrigation canals.

Another form of water recycling is done through pumping of shallow groundwater from the Nile aquifer whose main source is seepage from the distribution system, irrigated fields, and the Nile itself. Egypt had a policy of increasing drainage reuse since the completion of HAD and the officially reused drainage water increased from 2.8 km^3 yr^{-1} to 3.8 km^3 yr^{-1}over the period 1984-1995 (Abdel-Azim and Allam, 2005). The actual figure on volume of re-use water varies in the literature (e.g.Barnes (2014) and Ashraf El-Sayed (2011)). There is also another policy to improve the farming systems through the irrigation improvement program (IIP) which started as a pilot in the mid-1980s and with a first phase in the 1990s. The IIP aims at improving the on-farm efficiency through the introduction of raised and sometimes lined field canals (mesqas) or pipelines, involving farmers' participation in cash and labour, continuous flow in mesqas, and single pump lifting from branch canals (marwas) managed by Water Users Associations. These measures will of course reduce drainage water quantity and increase its salinity.

1.4 Objective, Scope and Approach of the Study

Objective: the objective of the study is to assess in the extent of potential water savings from improved irrigation efficiencies in the Nile Basin countries. The study has been designed to provide indicative values on quantities of water saved for a range of scenarios in plausible irrigation efficiency improvements.

Scope of study: the study has a geographic scope of the entire Nile Basin. Its thematic scope is the estimation of water demand and use for irrigated agriculture for current and planned future irrigation schemes in the Nile Basin countries. It relies on existing (published) data largely from NBI's own databases (such as the Nile Basin Decision Support System, Multi-Sector Investment Studies for the Eastern Nile and the Nile Equatorial Lakes region) and also from global data sources, such as the FAO database (Aquastat; 2009). Primary data collection has not been foreseen as part of this study.

The study approach: the study combines current level of knowledge in the Nile Basin regarding irrigated agriculture (current and anticipated future) with scenario based modeling of future water demands for irrigated agriculture. Key aspects of the approach are:

- **Combined modeling of the demand and supply side**: the study employed a set of two modeling frameworks with which the field level demands (irrigation requirements) and the water availability and allocation (from the river system) are modeled. While the field-level (demand side) models provide estimates of irrigation water demand, the actual water allocation, hence use, depend on water availability in the system. This, in turn, depends on the system of storage infrastructure (dams) and their operation to supply the needed water to meet the irrigation and other demands (such as municipal, industrial, energy production). The modeling framework used for this study, thus, models the process on irrigation field level as well as in the entire Nile Basin.

- **Calibration of the models** for current situation: the water availability and allocation model has been calibrated for current situation by comparing simulations with observations to fine-tune the parameters used in the model before they are further used to estimate future water demands. The field level demand model has been setup with site-specific crop parameters on a country scale which have been collected from various literature resources.

- **Scenario generation on irrigation efficiencies**: water saving potential has been estimated for a range of scenarios of plausible improvements in irrigation efficiencies. Expansion in irrigated agriculture is taken as given in national plans and, therefore, no scenarios of irrigation area expansion have been generated. The scenarios all concern about improvements in irrigation efficiencies. Detailed descriptions of the scenarios are given in section 2.3.

2 Methods

2.1 Modeling framework

The approach of the assignment is to develop a technical analysis of the potential water savings from increased irrigation efficiency based on the current knowledge available at the basin level and using a model based assessment approach. This assessment combines an agricultural water consumption modeling approach (SPARE:WATER, Multsch et al. (2013)) with a river basin water resources modeling approach (WEAP, Johnson et al. (1995)).

Field level irrigation water requirements were computed using Spare:Water and the irrigation water requirement module of WEAP while the basin-wide water allocation and water balance were estimated using WEAP.WEAP doesn’t provide modules for estimating leaching requirements and, hence, the estimates made by SPARE:WATER have been added to the crop water requirements estimated by WEAP. Moreover, WEAP used time series of climatic variables published by University of Princeton (Sheffield et al, 2006) whereas SPARE:WATER used average values of climatic variables from the FAO CLIMWAT 2 (described in section 3.2.1). This way, the crop water requirements have been computed using two approaches and two global datasets and this enabled comparison of the values from these two approaches.

2.2 Site-sPecificAgricultural water Requirement and footprint Estimator (SPARE:WATER)

The Site-sPecificAgricultural water Requirement and footprint Estimator (SPARE:WATER)(Multsch et al., 2013) is a spatial decision support system for estimating the fate of water consumption in agricultural production systems. SPARE:WATER enables the spatial explicit calculation (Figure 1) of the crop specific water requirements considering all water resources required, including green (precipitation), blue (irrigation) and grey (salt leaching) water (Figure 1).

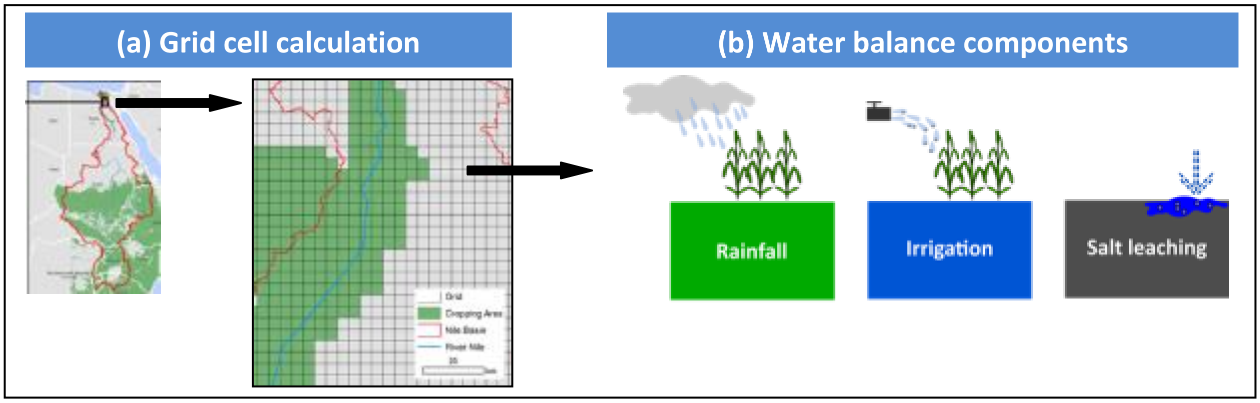


Figure 1. Water balance calculation in SPARE:WATER.

Equipped with a graphical user interface SPARE:WATER calculates the crop water requirement according to the Food and Agricultural Organization FAO56 crop water guidelines(Allen et al., 1998). The term water requirement is defined as the sum of irrigation and leaching per crop in $m^3\ ha^{-1}$. By multiplying the water requirement with the harvest area per region the total amount of water in $m^3\ yr^{-1}$ can be calculated (in case of large catchments m^3 are commonly converted to $km^3\ yr^{-1}$; 1,000,000,000 = 1 km^3). The irrigation requirement is calculated from the difference between the effective rainfall and the potential crop water requirement. The latter one refers to the amount of crop specific evapotranspiration, i.e. the amount of water which is transpired and evaporated without any water shortage. User defined parameters allow to set irrigation efficiencies, salinity of irrigation water or depression of yields due to salinization which enables the calculation of scenarios.

2.3 Water Evaluation and Planning (WEAP) tool

The Water Evaluation And Planning (WEAP) tool is an integrated water resources planning tool that is used to represent current water conditions in a given area and to explore a wide range of demand and supply options for balancing environment and development objectives. WEAP is widely used to support collaborative water resources planning by providing a common analytical and data management framework to engage stakeholders and decision-makers in an open planning process. WEAP combines a link-node water allocation model for river systems with a lumped rainfall-runoff model for catchments and irrigated areas if necessary.

At each time step, WEAP first computes the hydrologic flux, which it passes to each river. The water allocation is then made for the given time step, where constraints related to the characteristics of reservoirs and the distribution network, environmental regulations, and the priorities and preferences assigned to points of demands are used to condition a linear programming optimization routine that maximizes the demand “satisfaction” to the greatest extent possible (Yates et al. 2005). All flows are assumed to occur instantaneously; thus a demand site can withdraw water from the river, consume some, and optionally return the remainder to a receiving water body in the same time step. As constrained by the network topology, the model can also allocate water to meet any specific demand in the system, without regard to travel time. Thus, the model time step should be at least as long as the residence time of the study area. For this reason, a monthly time step was adopted for this study.

In the present study, the WEAP model developed earlier has been further enhanced with the inclusion of planned irrigation schemes and all results from Spare:Water integrated. The schematic of the model for the Nile Basin as part of this assignment is shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**.The Nile model comprises 177 flow generating catchments connected to about 86 rivers. Irrigation schemes are represented as catchments so that crop water requirements (based on evapotranspiration) are responsive to climatic conditions varying over time. The system includes all existing and planned schemes but some grouping is necessary for the small schemes in the Equatorial Lakes basins and the Blue Nile. Grouping is done by sub-basin. Each Irrigation node is supplied by a river or a dam through a transmission link where some conveyance losses are assumed. In Egypt, a percentage of those losses are routed back to the river and another portion is collected into a groundwater node that represents the Nile aquifer. A certain percentage of irrigation excess flow at the irrigation nodes is assumed to run-off naturally back to rivers. This percentage is assumed about 20% in Equatorial Areas and Ethiopia while it is set at 10% for Sudan and South Sudan as they have drier climates. In Egypt, drainage systems covering all old land areas collect drainage from fields and excess water at tail ends of canals. In Upper Egypt, drains flow back to the Nile while in Delta drainage eventually reaches the Mediterranean Sea but after being reused.

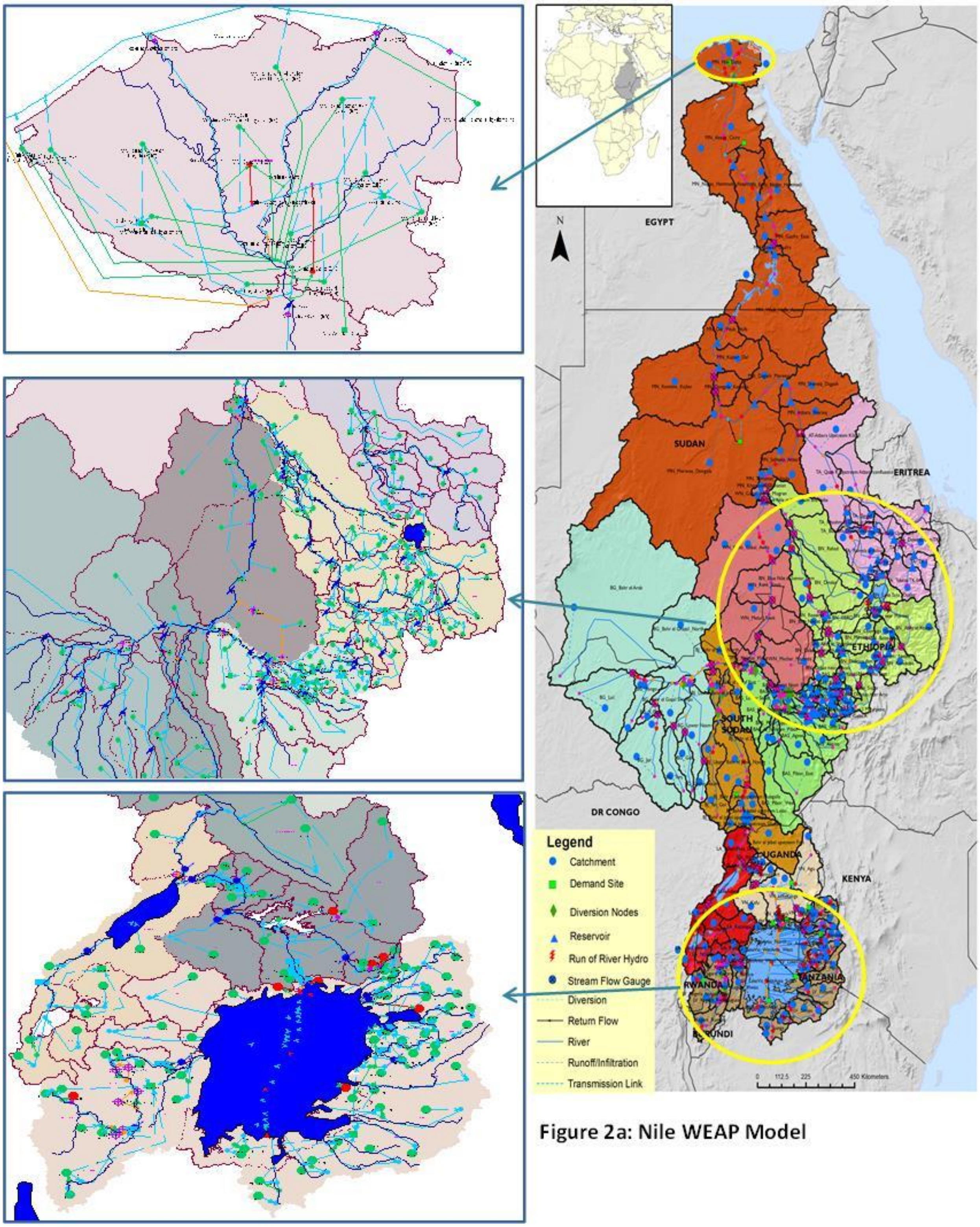


Figure 2a: Nile WEAP Model

Therefore, a main drain is schematized to collect all drainage from the Delta and groundwater and puts back to the river after transferring a fraction to the sea. This fraction decreases with time as drainage reuse increased and irrigation expanded (horizontally and vertically) after the High Aswan Dam (1970).

The system includes all existing dams (11) and major planned dams (28) and run-of-river hydropower plants (22). Major Lakes (Victoria, Albert, and Tana) and wetlands are also modeled as reservoirs. Lakes have defined level-outflow relationships while such relationships have been improvised as well as other reservoir parameters (capacity, level-volume relationship) to generate reasonably matching outflows. These relationships were calibrated if a downstream gauge record is available.

The model have been calibrated using about 50 gauging stations having records of varying lengths and sometimes only a long-term monthly hydrograph. In Egypt, the system is more complicated in addition to calibration using gauges along the Nile, water levels of the HAD have been matched as well as the overall pattern of drainage to Sea, in most cases. Selected calibration plots are shown in Figure 2b to 2e.

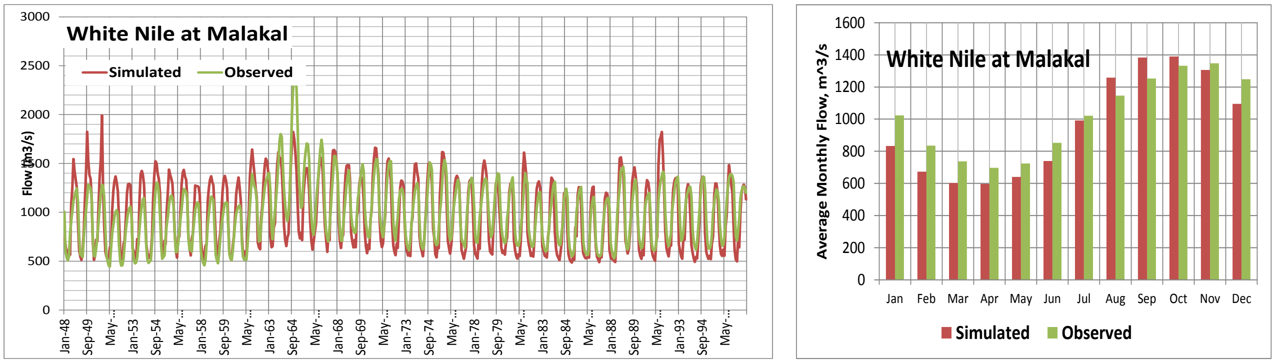


Figure 2b: Observed and (WEAP) simulated monthly flows for White Nile at Malakal

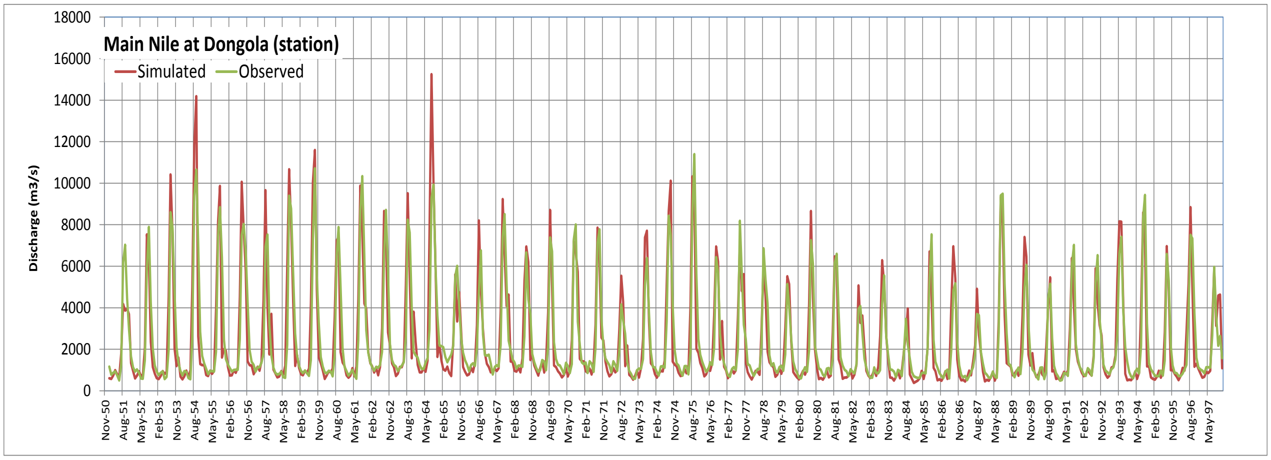


Figure 2c: Observed and (WEAP) simulated monthly flows for Main Nile at Dongola

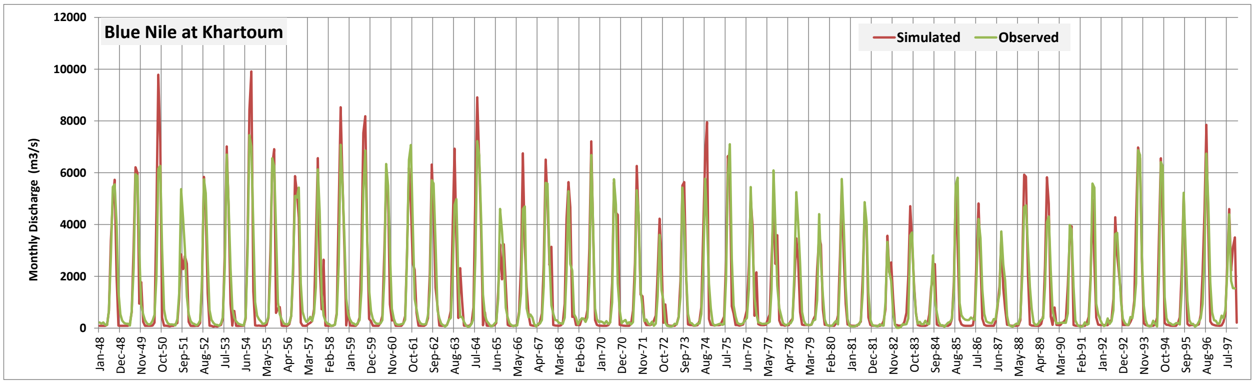


Figure 2d: Observed and (WEAP) simulated monthly flows for Blue Nile at Khartoum

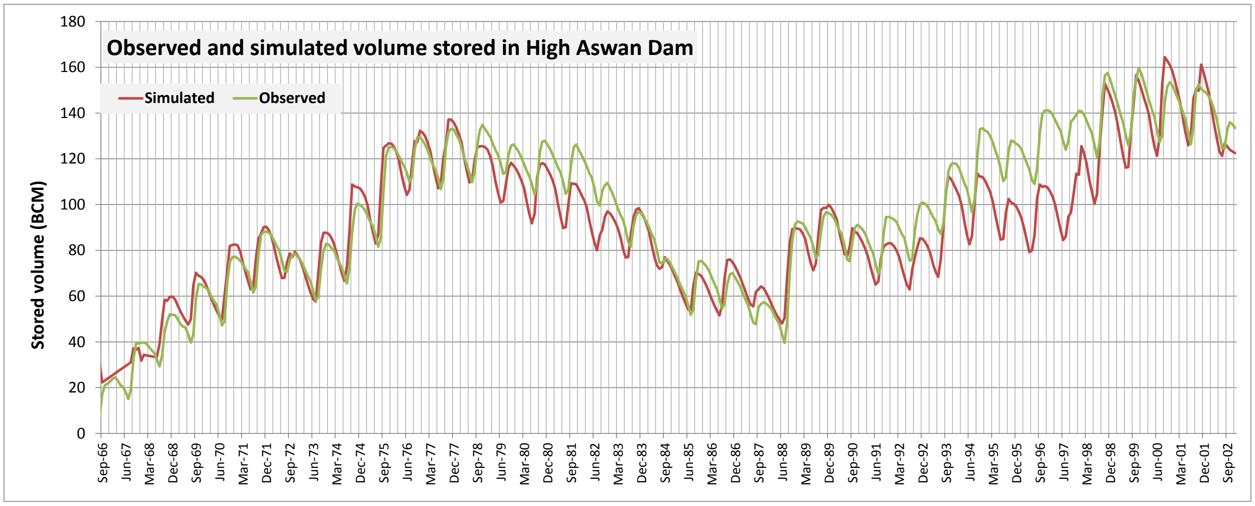


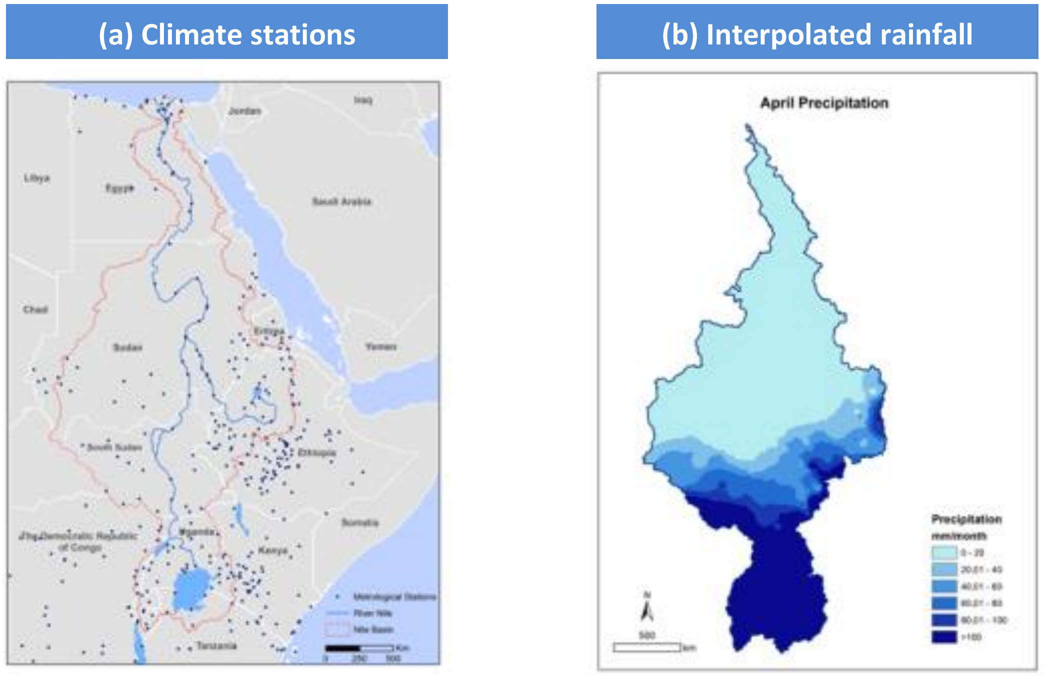
Figure 2d: Observed and (WEAP) simulated stored volume of water in High Aswan Dam

3 Data and scenarios

3.1 Hydro-meteorological data

3.1.1 Climatic data

Two sets of climatic data have been used for Spare:Water and the WEAP model, respectively. Spare: Water used the FAO Climwat 2.0 for this analysis(FAO, 2010). These dataset holds over 5000 climate stations worldwide from which 425 have been considered for this analysis (**Fehler! Verweisquelle konnte nicht gefunden werden.**). The climate time series provide long-term averages (1971-2000) of various variables (minimum and maximum temperature, relative humidity, wind speed, sunshine hours, rainfall) as monthly averages. Grid maps have been interpolated by using Inverse Distance Weighted method(Philip and Watson, 1982; Watson and Philip, 1985) to derive maps for the Nile river basin in a spatial resolution of 0.041° (~5 x 5 km at equator) by using ArcGIS^{TM} Spatial Analyst (**Fehler! Verweisquelle konnte nicht gefunden werden.**b).


(a) Climate stations

(b) Interpolated rainfall

Figure 2: (a) Climate station from Climwat 2.0 database in North-East Africa and (b) interpolated rainfall in April.

The climatic dataset published by the University of Princeton (Sheffield et al, 2006) has been used for the WEAP model together with river flow data taken from NBI database (largely from Nile Basin DSS database).

3.1.2 River flow data

River flow data is needed for building the Nile Basin model developed in WEAP. The current study has been carried out using the WEAP model developed by NBI under previous assignments. All river flow data used in the current model are from existing Nile Basin model developed by NBI. The model has been refined based on irrigation related data collected as part of this assignment. Some of the key stations used for developing the WEAP model are given in Table A2.

3.2 Irrigation and crop areas – current and future

3.2.1 Current and planned future irrigation areas

The study relied on data that has been collected from NBI's previous work, national plans and other published material. Data on irrigated areas in the Nile basin were collected from various reports and studies conducted by the Nile Basin Initiative (NBI-NELSAP, 2012;NBI-ENTRO, 2014; Bart et al, 2011). Table 1a provides a summary of existing and potential irrigation areas while Table 1b provides a summary of total irrigation and harvest areas by 2050. The estimates of future irrigation areas are taken from national plans and Nile Basin investment planning documents. Annex 1 provides details of the schemes by country. Most of the existing irrigated area falls within Egypt and Sudan as many of the Nile countries depend on rain-fed agriculture and recession agriculture with little irrigation. However, this is expected to change as other countries also implement their ambitious plans to develop irrigation schemes such as in Ethiopia, Kenya, and Tanzania. Areas that are currently equipped but not in production were assumed to be planned.

Table 1a: Existing (2011) irrigated areas within the Nile Basin

Country	Equipped area ('000 ha)	Harvest area ('000)	Cropping intensity
EG	3447.27	5021.01	146%
ET	90.32	130.80	145%
KN	20.05	20.05	100%
RW	7.05	7.05	100%
SS	0.50	0.50	100%
SU	1710.51	1170.45	68%
TN	10.48	10.48	100%
UG	9.72	9.72	100%
Total	5295.90	6370.05	

Table 1b: Areas under irrigation by 2050 as per national plans

	Total estimated irrigation areas (2050)			Increase over 2011 baseline		
Country	**Equipped area ('000 ha)**	**Harvest area ('000)**	**Cropping intensity**	**Increase in equipped area**	**% increase in equipped area**	**% increase in harvest area**
Egypt	3949.47	5708.50	145%	502	15%	14%
Ethiopia	1510.38	1973.34	131%	1420	1572%	1409%
Kenya	88.85	88.83	100%	69	343%	343%
Rwanda	11.50	11.50	100%	4	63%	63%

South Sudan	227.43	273.13	120%	227	45386%	54526%
Sudan	2829.02	2548.51	90%	1119	65%	118%
Tanzania	66.95	66.35	99%	56	539%	533%
Uganda	12.02	12.02	100%	2	24%	24%
Total	8695.61	10682.18		3399.71		

As can be seen from Tables 1a and 1b, huge increase in irrigated agriculture is expected if all country plans are implemented as planned. Overall, nearly 90 percent (89.4) of the planned expansion in irrigated areas is expected to be in the Eastern Nile countries of Egypt, Ethiopia and Sudan (Figure 4). There is also a potential increase in harvest area in Sudan from current 68 per cent to 90 percent, which translates in increased food production with increased water demand.

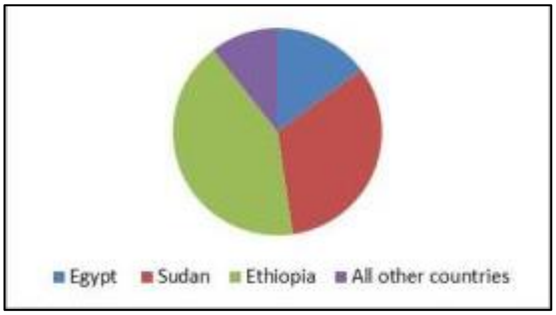


Figure 3: Increase in irrigated areas ('000 ha).

3.2.2 Cropping patterns

Cropping Patterns and crop coefficient (Kc) values for Egypt are taken from the FAO F4T (Bart et al, 2011) for the different districts (governorates). Cropping patterns for Sudan (and corresponding crop coefficients) are taken from the EN MSIOA (NBI-ENTRO, 2014) database. Cropping patterns for Ethiopia are taken from the ENIDS CRA2 documents (2009) supplemented by data from BaroAkoboSobat and Tekeze master plans. Data for Equatorial countries are taken from NEL MSIOA documents and GIS database (NBI-NELSAP, 2012).

Major crops in Egypt are Clover, Cotton, Rice and Wheat. In Sudan, Sugar Cane is a major crop as well as sorghum, wheat and cotton. In Equatorial Lakes, vegetables, Rice, and Maize are the major crops. In Ethiopia, Cotton, Maize and Sorghum are the main crops.

3.3 Irrigation efficiency

A comprehensive list with irrigation efficiencies according to the irrigation method has been published by FAO (Brouwer et al., 1989) and by Howell (2003) (see Annex3, Table A3.1 to A3.3). For this study, the ranges given in Table 2a have been analyzed.

Table 2a. Assumed irrigation efficiencies

Irrigation Method	Application efficiency (%)	Conveyance efficiency (%)
Surface	50–70%	40-70%

Sprinkler	55-75%	60-90%
Drip	70-95%,	70-95%

Conveyance efficiency, which to an appreciable extent depends on amount of leakage from canals, also depends on the dominant soil types in which the canals are dug. FAO (Brouwer, Prins and Heilbloem; 1989) provides indicative values of conveyance efficiencies of well-maintained canals in dug in different soils, which are given in Table 2b.

Table 2b: Indicative conveyance efficiencies

	Earthen Canals			Lined Canals
Canal length\Soil type	**Sand**	**Loam**	**Clay**	
Long (> 2000m)	60%	70%	80%	95%
Medium (200-2000m)	70%	75%	85%	95%
Short (< 200m)	80%	85%	90%	95%

The information about the irrigation methods in the Nile Basin countries have been taken from Aquastat (2009) and is listed inTable 3. The dominating method is surface irrigation in the Nile river basin. Sprinkler irrigation is used only in Egypt (5%), Ethiopia (2%), Uganda (25%) and Kenya (60%). An even lower percentage of areas are irrigated by drip irrigation, e.g. Egypt (6%), Uganda (3%) and Kenya (2%).

Table 3. Irrigation methods of Nile river basin countries [source: Aquastat (2009)]

	Egypt	Sudan	Ethiopia	Uganda	Tanzania	Rwanda	Kenya	Eritrea	DRC	Burundi
Surface (%)	88	100	98	73	100	100	38	100	100	100
Sprinkler (%)	5	0	2	25	0	0	60	0	0	0
Drip (%)	6	0	0	3	0	0	2	0	0	0

3.4 Water quality

The water quality is related to the salinity concentration in the irrigation water in this study. The salinity is commonly measured in terms of total dissolved solids (TDS in mg L^{-1} or ppm) or electric conductivity (EC, dS m^{-1}) whereby EC of 1 dS m^{-1} equals a TDS of approximately 640 ppm. Since a complete dataset on the salinity concentration in the Nile River is not available the data has been collected from literature and other sources as shown in Figure 5. The salt concentration at the Aswan dam is 250 ppm equal to 0.4 dS m^{-1} (personal communication with NBI). The salinity of the upstream areas (souther from Aswan dam) is constant (250 ppm) and a linerarly decreasing trend from Aswan dam to the Nile Delta

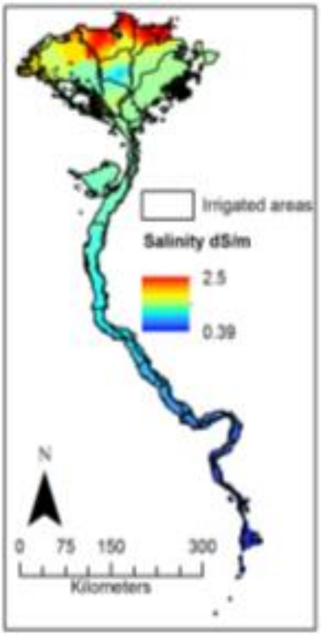


Figure 4: Salinity along irrigated areas in Egypt.

has been assumed.A detailed map is available for parts of the Nile Delta in Egypt (Murakami, 1995) which shows a strong downsteam increase of the Nile river salinity with values up to 13 dS m^{-1}in the coast area. Such high saline water is caused by mixing river water with brackish water from the Mediterranean Sea and unsuitable for irrigation. Hence, the total salinity level is limited to 2.5 dS m^{-1} in the Nile delta.

3.5 Scenarios

The primary objective of generating the scenarios is to provide a range of estimated irrigation water demands providing sufficient spectrum of values to assess likely impacts of irrigation efficiency improvements on water saving.

As stated above, four scenarios of irrigation efficiency improvements have been considered and potential water saving estimated for each one of them. Irrigation efficiency as defined earlier in this report, in a way, measures how much of the water withdrawn from the source (surface or groundwater) is finally made available for the crops. Higher efficiency indicates greater percentage of the water withdrawn from the source is made available for the crops. Thus, the higher the loss in transporting the water from the source to the plants, the lower becomes irrigation efficiency. This depends on the type of irrigation technology used, which can be surface-gravity systems or any variant of pressurized systems.

In surface (gravity flow) systems, water is often transported from the source by a system, of (open) canals and ditches, which can be lined (hence minimize leakage to the soil formation) or unlined. In such systems, there are a few different ways for applying the water to the irrigation field, such as basin inundation systems or furrows (small ditches between rows of plants). The efficiencies of such systems depend on many factors, such as:

- Whether the canals are lined or not
- The degree of maintenance of the canals. Well maintained canals provide little hydraulic resistance to the flow and hence reduce the resident time of the water in the canal system, which in turn contributes to reduced evaporation losses. Also, in well maintained canals and ditches, breaching of side walls of the canals (in elevated canals and ditches) can be minimized there by reducing loss of water
- Climate: those irrigation schemes in hot areas have higher evaporation losses from the system of open canals and ditches.

In pressurized systems (sprinkler or drip irrigation systems), water is conveyed in closed pipes under pressure and is either ‘spayed’ on the crops or provided through a system of flexible pipes with small nozzles, hence, ‘drip’s directly supplying water to the plants. Such systems have the highest irrigation efficiencies (often reaching 95 %, source) but have higher implementation costs.

For the present study: improvements in irrigation efficiencies are expected to be due to one of the following:

- Changes in water application techniques: for example, an irrigation area currently under surface-gravity system can evolve into one of the pressurized systems thereby increasing the overall efficiency
- Changes in water conveyance, distribution and field application for same water application technique, for instance, through lining canals, better land leveling, etc.

Theoretically, all irrigation schemes can be assumed to be equipped with most efficient water conveyance, distribution and field application technology and thereby achieve highest possible efficiency. However, this is not found to be plausible under prevailing and anticipated socio-economic conditions in the Nile Basin in the coming 30 – 35 years, which is taken as the planning horizon. Therefore, attempt has been made to estimate plausible irrigation efficiency improvements taking into account pertinent factors that influence performance of irrigated agriculture in the Nile Basin. The extent to which such improvements can be effected for a given irrigation area depends on many factors. The following are key factors considered in estimating plausible improvements in efficiencies

- **Size and ownership types of schemes**: for small scale, household owned irrigation systems, often financial capacities of the owners are low and efficiencies tend to be low and with no major improvements expected. In cases where individual schemes are part of the a bigger large scale irrigation schemes (e.g. Gezira in Sudan, most of the irrigation areas in Egypt, Koga scheme in Ethiopia), the conveyance and distribution system is maintained by the state or the WUA and tends to be in good condition while the farm level water application remains less efficient. Such distinctions need to be made in assigning improvements
- **Capacity** (technical, financial, institutional) in managing irrigated agriculture: more experienced regions/countries, such as Egypt and Sudan, tend to be aware of needs for irrigation efficiency improvements and hence can effect bigger improvements than those regions with little experience
- **Main purpose of irrigation:** irrigation for high value crop tend to be better management and have higher efficiencies and higher likelihood for improvements; often purpose could be defined as commercial or for own-consumption with some surplus being marketed.
- **Type of irrigation technology in use (for existing schemes)**
- **Degree of drainage collection:** irrigation systems whereby excess water is collected through a drainage system and diverted back to the river system, the loss of water will be reduced albeit with some loss in water quality duet to salt ‘washed’ with the drainage water.

Systems with no drainage system, most of the excess water is assumed lost thought some part of this water can be recovered from the groundwater aquifers.

Taking the above into account, three scenarios of irrigation efficiency improvements have been developed. The scenarios are described mainly as percentage increase to current (baseline) values of irrigation efficiencies; given in Table 4. The scenarios of irrigation efficiency improvements are given in Table 5.

Table 4: Current (baseline) values of irrigation efficiencies

Country	**On farm Efficiency**	**Off Farm Efficiency**	**Return Flow Collected**
Burundi	60%-70%	60%	20%
DRC	60%-70%	60%	20%
Egypt	70 – 80%	70%	56 – 100%
Ethiopia	60%-70%	60%	20%
Kenya	60%-70%	60%	20%
Rwanda	60%-70%	60%	20%
South Sudan	60%-70%	60%	10%
Sudan	65%-70%	70%	10%
Tanzania	60%-70%	60%	20%
Uganda	60%-70%	60%	20%

Table 5: Irrigation efficiency improvement scenarios

Scenario	Field Level (On farm) Efficiency		Conveyance (Off Farm) Efficiency	Share of drainage water collected (Except Egypt)	Share of pressurized (Except Egypt)
	Surface	Pressurized			
Baseline	Efficiencies and shares (of pressurized system, drainage water collection) as per current status				
Sc1	+5%	+5%	+5%	30%	Sprinkler: 25% 50% Kenya
Sc2a	+10%	+10%	+10%	40% 50% Sudan	Sprinkler: 25% 50% Kenya
Sc2b	+10%	+10%	+10%	40% 50% Sudan	Drip: 25% 50% Kenya
Sc3	+10%	to reach 95%	+15% +20% (Egypt, Sudan)	40% 50% Sudan	Drip: 100%

Note:*+x means Baseline + x; Figures for Drainage collected and Pressurized systems for Egypt vary by district – new lands are pressurized and old lands are surface and remain like that in the future*

4 Results and discussion

4.1 Irrigation water requirements for current (2011) level of irrigation

4.1.1 Water demand estimates with SPARE:WATER

As stated earlier, SPARE:WATER estimates crop water requirements and leaching requirements for given cropping patterns, climate and irrigation water quality (salt concentration). The sum of the crop water and leaching requirements gives the total amount of water that should be made available to the plants and the amount needed to wash-out salt to maintain tolerable growing conditions for the plants.

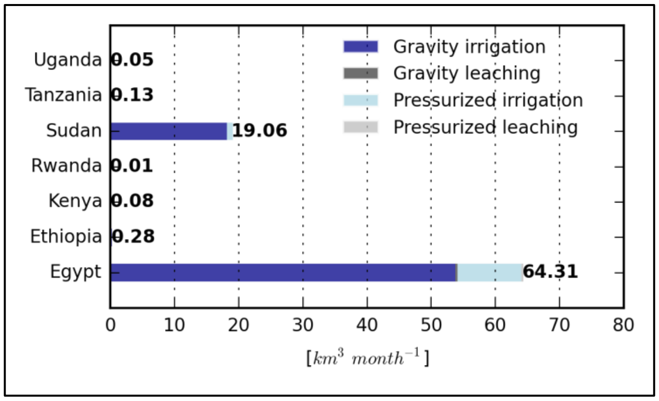


Figure 5: Water requirement of existing areas in the Nile basin (determined with SPARE:WATER).

The water requirement to grow crops in the Nile river basin has been calculated for existing (Figure 6) irrigation areas under the assumption of the baseline scenario with respect to field level irrigation efficiencies (low to medium efficiency, mostly gravity systems). The field level water requirement of existing areas is 84.12 km^3 yr^{-1} and dominated by the two countries Sudan (19 km^3 yr^{-1}) and Egypt (64 km^3 yr^{-1}).This sum is the volume of water that must be made available at irrigation field level (water for plants and leaching) and takes into account losses on field water application, i.e. it doesn't take into account losses in the conveyance systems (system of canals and ditches).The leaching requirement estimated as 0.58 km^3 yr^{-1}is a very small fraction of the total water demand. Potential reduction in water demand as a result of improvements in irrigation efficiencies is estimated and the results are shown in Figure 7.

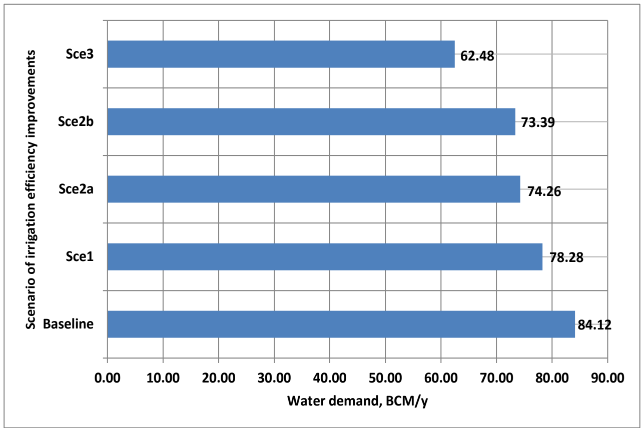


Figure 7: Potential reduction in (field-level) water requirement of existing areas in the Nile basin.

A closer look at the water requirement of the two countries Sudan and Egypt gives further insights into cropping pattern (Figure 8a). In Egypt, the four crops wheat, clover, rice and maize are covering a high percentage of 62% of the irrigated lands and consume 56% of water resources. These crops are characterized by a medium water requirement per vegetation period compared to others. A different situation can be found in Sudan (Figure 8b). The largest water requirement is related to the cultivation of cotton, wheat and sorghum with totally 55% whereby these crops cover 66% of the total irrigated area.

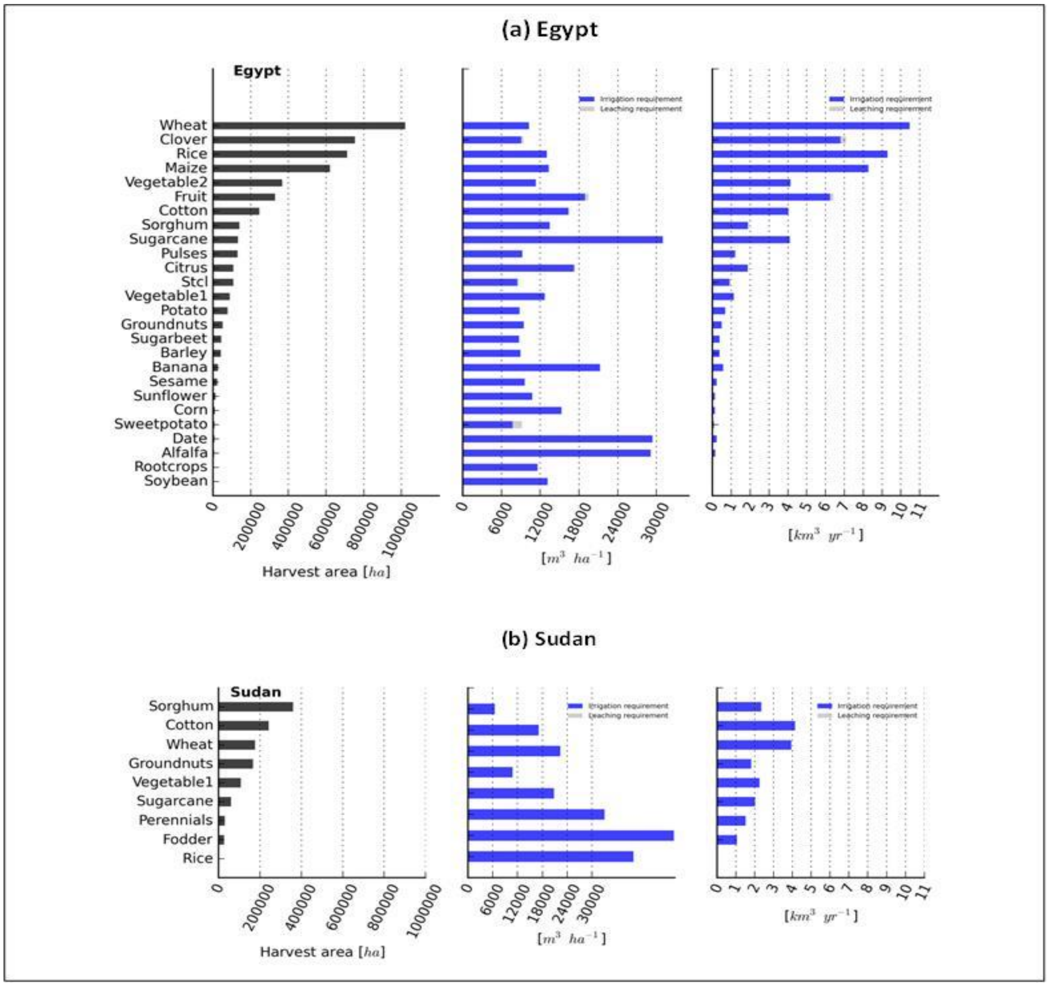


Figure 6: Annual harvest area, water requirement during vegetation period and total water requirement per year of crops grown in Egypt (a) and Sudan (b).

The monthly water requirement over time shows that the highest water requirements occur in the summer period and are related to the peak consumption of grains (Figure 7) such as maize and rice. During the time period between January and May clover and wheat are dominating the water requirement of crops in the Nile basin. Cotton is grown in different growing periods across Nile riparian countries and requires a constant amount of water throughout the year in total. The perennial crop sugarcane consumes also a constant amount of water in each month. All in all, the existing irrigated areas consume almost the total available flows of the Nile River which vary between 40 and 150 km³ yr^{-1} with an average of 85 km³ yr^{-1} at the Aswan Dam (Johnston, 2012).

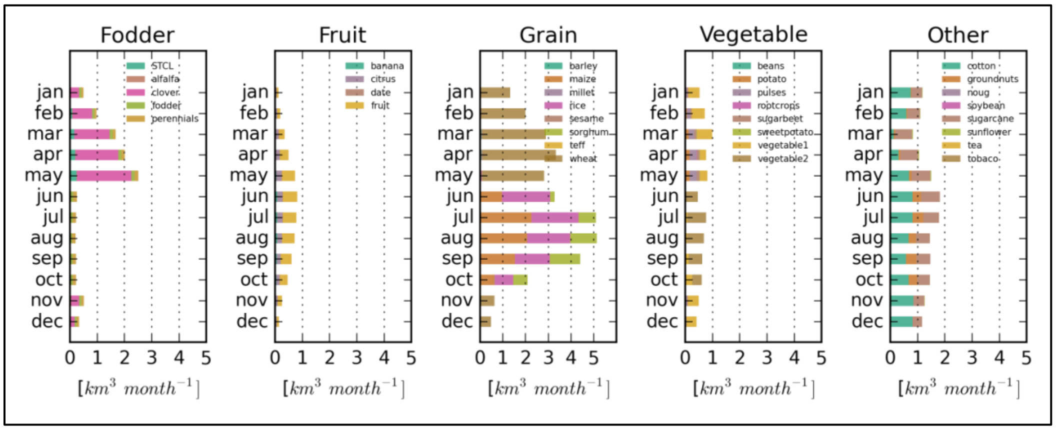


Figure 7: Monthly water requirement of crops grown the Nile river basin.

4.1.2 Water demand estimates with WEAP

In the study, irrigation water requirements have also been estimated using WEAP. A dataset of climatic variables (as time series) from Princeton University (Sheffield et al, 2006) was used in addition to the cropping patterns, and assumptions regarding efficiencies, which are kept the same as for the Spare:Water estimation.

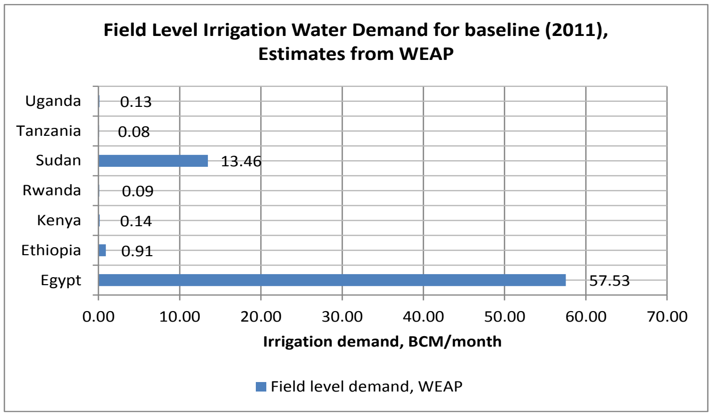


Figure 8: Field level irrigation water demand for baseline (estimates from WEAP).

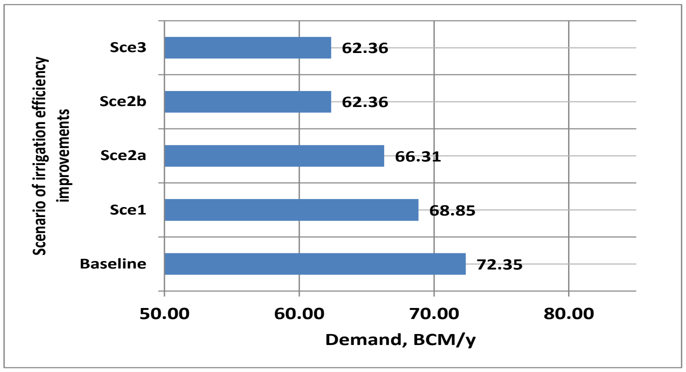


Figure 9: Field level irrigation water demand for baseline (estimates from WEAP).

Estimated water demands for under current levels of field water application efficiencies are given in Figure 10while those under scenarios of irrigation efficiencies given in Figure 11. The estimates made by WEAP hasn't taken into account leaching requirement, which is very small as shown by the estimate from Spare:Water. The total volume of field level irrigation water demand under current (2011) irrigation levels is 72.35 km³ yr^{-1}. The demand is dominated by Egypt and Sudan, whose demands collectively make 98 percent of the total demand.

4.2 Irrigation water requirement under future (2050) expansion of irrigation areas

Nile riparian countries are planning an expansion of irrigated areas in total of 3.4 million hectare in the time period to 2050 mainly in Ethiopia (~1,410,0000 hectare) and Sudan (~967,000 hectare) and Egypt (500,000 hectares).The expected increase in irrigation areas as per national plans is shown in Table 1b and Figure 1b.

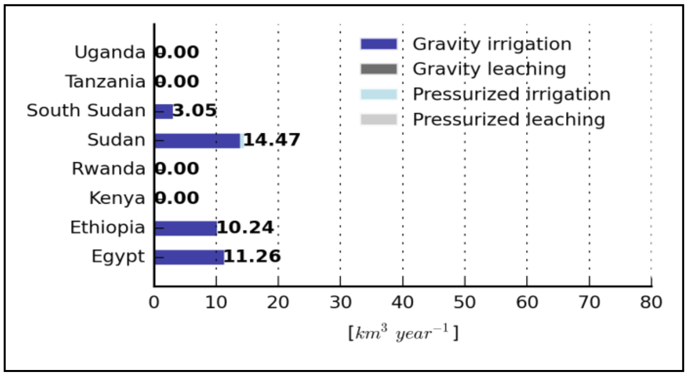


Figure 10a. Water requirement of all additional (planned) irrigation schemes by 2050 (baseline scenario, Spare:Water).

In this section, estimation of irrigation water demand to meet requirements of future (2050) irrigation areas shall be presented for current (baseline) efficiencies and scenarios of irrigation efficiency improvements.

The planned areas will require an additional water of 39 km³ yr^{-1} in total in future (Figure 12a). The evaluation of the scenarios of irrigation efficiency improvements is shown in Figure 12b.

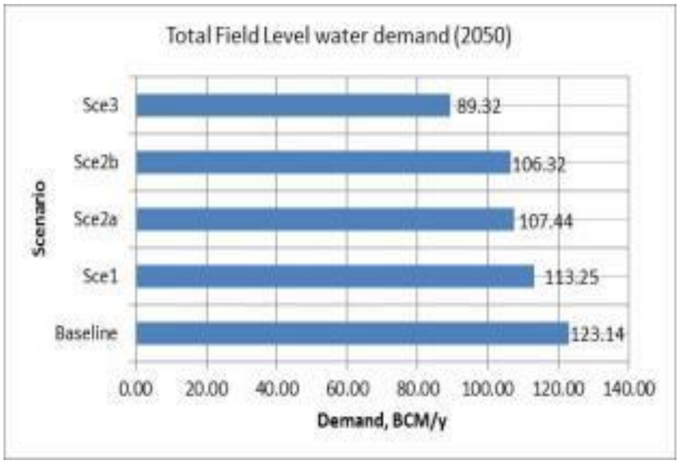
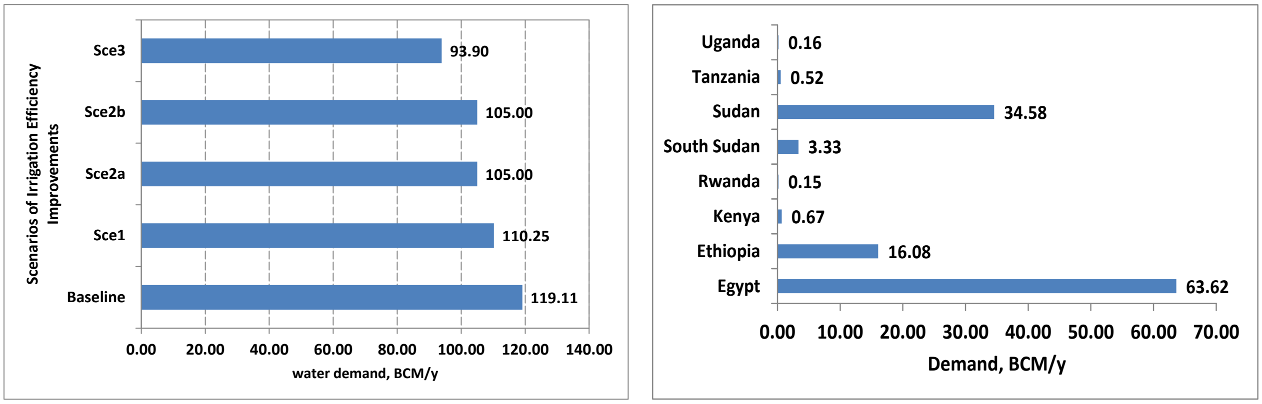


Figure 11: Water requirement of total areas of irrigation schemes by 2050 under different scenarios (estimate by Spare:Water).

Scenario 3, which corresponds to a (theoretical) maximum improvement in irrigation efficiency leads to a reduction in total demand of about 34 BCM. The values given in Figures9a and 9b are irrigation demands at field level. However, when one considers effect of losses in the conveyance and distribution system, the actual water demand is much higher and the Nile system cannot sustain this increased water demand.

The estimated field level irrigation water demands for forecasted irrigation areas by 2050 for current and a set of scenarios of irrigation efficiency improvements made using WEAP are given in Figures 13a and 13b.



(a) (b)

Figure 13: Estimates field level water requirement for all irrigation areas by 2050

A key finding of the study is that, with the implementation of national plans for expansion of irrigated agriculture, the total (field level) water requirements for all irrigation areas in the Nile Basin by 2050 would be around 120 km^3 yr^{-1}assuming irrigation infrastructure with current efficiencies. When one takes into account losses in canal systems that transport water from source (river, dams) to the irrigation fields the total water abstractions needed to meet this field-level demand would be even higher. Hence, the planned expansions dramatically increase the water demand in the Nile river basin and the total future demand will be 1.5 times larger than today demand.

4.3 Discussion of water demand estimates

The irrigation water demand estimates by Spare:Water are consistently higher than those by WEAP (Figure 14b). One main source of the difference between these estimates is believed to be the fact that WEAP used time series of climatic variables for computing the crop water requirements while Spare:Water used average values of climatic variables for the same calculation. Also, the two climatic datasets are not identical and this could also be a source of variation between the two estimates. Nevertheless, the results by the different models and datasets are quite close which underlines the reliability of the calculations presented in this study.

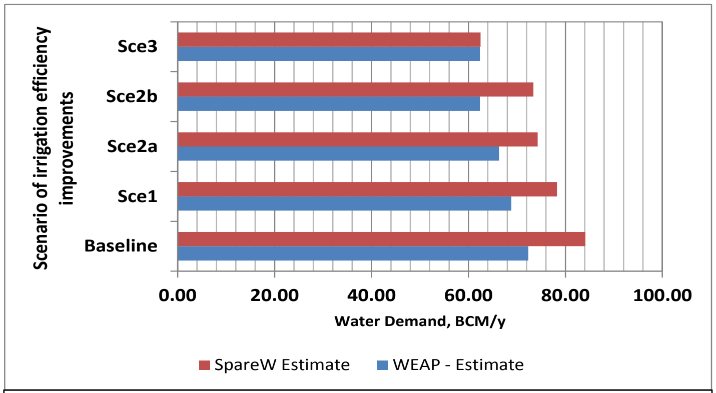


Figure 14a: Estimates of water requirements made by Spare:Water and WEAP for current irrigation areas

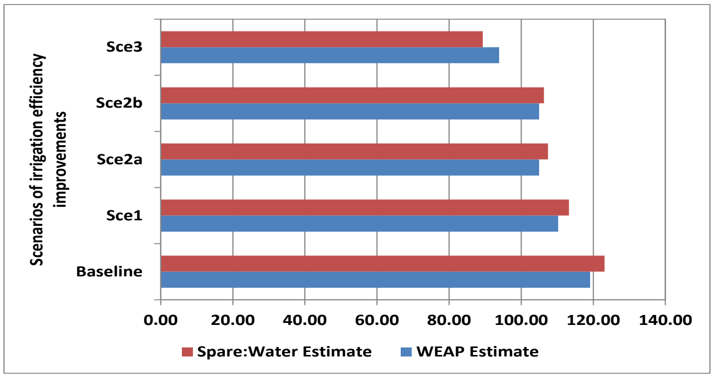


Figure 12: Comparison of field level water demand estimates for future (2050) irrigation area by Spare:Water and WEAP

The estimates given by the two models show a substantial increase in field level irrigation water demand. While the total planned expansion in irrigation (taking harvest area as basis) show an increase of 68 per cent over those of the 2011 baseline, the increase in water demand is under current levels of efficiencies is about 65 percent as per WEAP estimate and 46 per cent as estimate of Spare: Water.

It must be noted that the estimates given above are all field-level irrigation water demands. The actual water withdrawal requirements (from a river, reservoir, groundwater or other source) can be estimated by taking into account losses in transmission of water from the source to the field. That means, the actual water withdrawal requirement will be much higher. Given that the field level water demands under all scenarios are much bigger than the current total yield from the Nile Basin, the situation in terms of water demand deficit would be much more aggravated if irrigation expansion continues without commensurate improvements in efficiencies.

The estimation of water balance and the extent to which the Nile system will meet the water requirements for current and planned future irrigation areas can be estimated by taking into account the supply side of the picture, that is by modeling river flow in the basin with all water infrastructure included. This has been done using the WEAP model. The results of the basin modeling exercise are given in section 4.4.

4.4 Basin water balance and unmet irrigation water demand

The performance of the basin in meeting the increased water demands have been estimated using WEAP. An overview of the WEAP model is given in section 2.1.2. The following metrics have been used to assess the performance of the basin in meeting the demands.

a) Volume of unmet demand for specific locations in the basin: the unmet demand is defined as the deficit in water withdrawal requirement needed to meet the specific requirement for irrigation.
b) Water balance of the basin at selected flow gauging points
c) Changes in monthly water levels in the High Aswan Dam

The above metrics have been estimated for future irrigation levels and the four scenarios of irrigation improvements described earlier.

a) Unmet irrigation water demand

The total unmet irrigation water demand increases dramatically from a current value of about 0.5 km^3/y to about 44 km^3/y by 2050 if current irrigation efficiencies don't improve. The estimated unmet water demands for the four scenarios and basin countries are shown Figures15a and 14b.

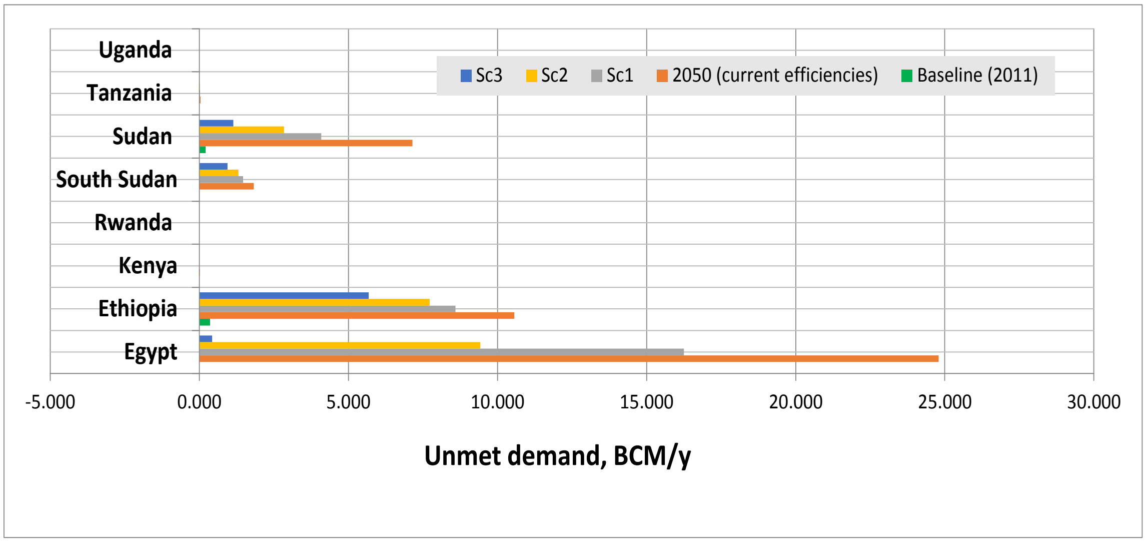


Figure 15a: Unmet irrigation water demand for current and future (2050) irrigation areas

The biggest unmet demand, as can be expected, is in Egypt, which is the most downstream country. It is interesting to note that the unmet demand for Ethiopia is higher than that for Egypt. This is because most irrigation planned schemes in Ethiopia are quite upstream above major storages (in the Blue Nile) and due to lack of data those small dams upstream of the planned irrigation schemes have not been implemented in the model. This will be further refined in future model development and the unmet demand for Ethiopia is expected to reduce significantly.

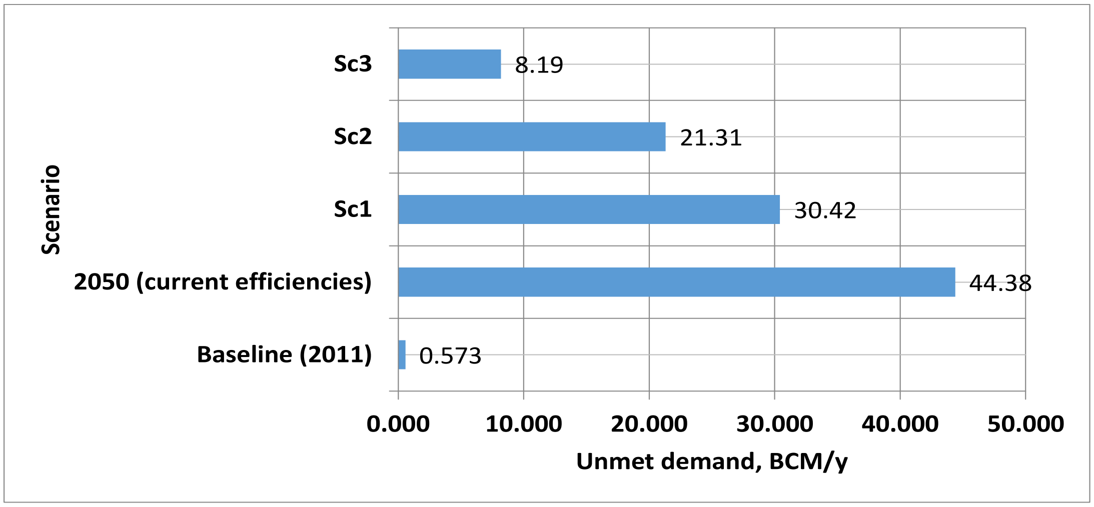
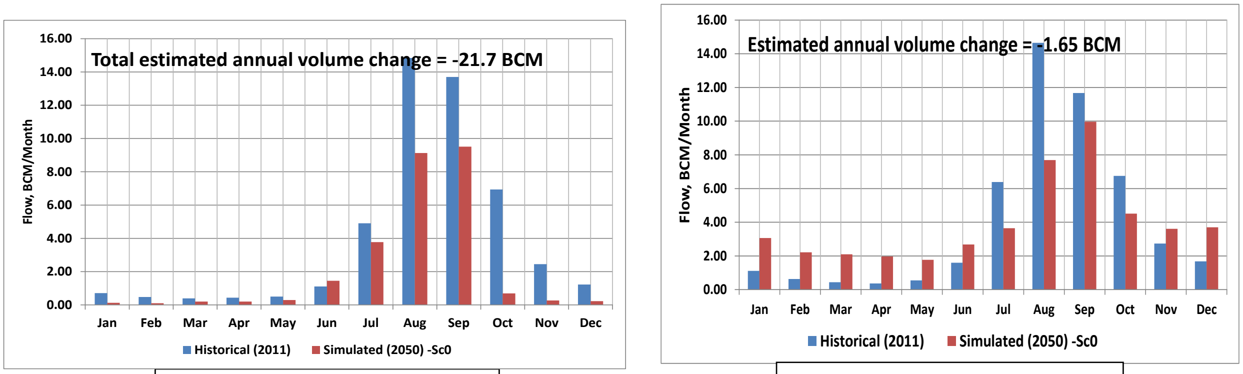


Figure 15b: Aggregate (total) unmet irrigation water demand for irrigation areas in 2050

The aggregate (total) unmet demand remains high except for scenario 3, which is assumes that all irrigation schemes adopt most efficient water application technology. Therefore, even with plausible improvement in irrigation efficiencies, the basin will be more and more stressed to meet all the demands of the ever expanding irrigated agriculture.

b) Water balance at selected points

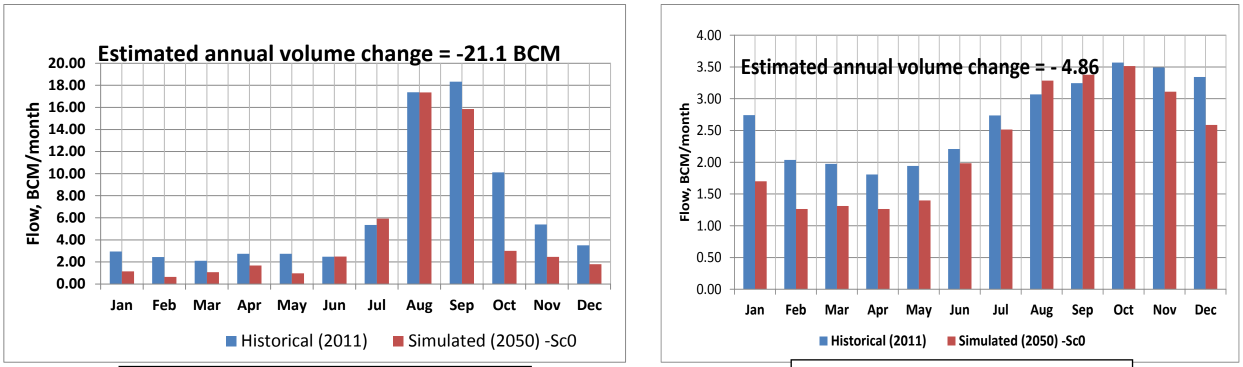
The changes in monthly flow patterns and in total annual volume of river flow have been estimated as proxy to changes in water balance. Figures 16a to 16d present the observed (2011 baseline) and estimated monthly flow hydrographs at selected points in the basin.



(a) Blue Nile at Khartoum

(b) Blue Nile at Roseries

Figure 16 (a and b): estimated changes to monthly flows: Blue Nile (Khartoum and Roseries)



(c) Main Nile at Dongola

(d) White Nile at Malakal

Figure 16 (c and d): estimated changes to monthly flows: Main Nile (Dongola) and White Nile (Malakal)

c) Storage levels for High Aswan Dam

The High Aswan Dam has been selected to review impacts of increased water use for irrigation for the downstream riparian, because it lies at the downstream end of the basin and, hence, will be impacted by effects of the aggregate water abstractions upstream. Figure 16 presents estimated reservoir levels for the four scenarios of irrigation improvements considered with total irrigation areas by 2050. In addition, monthly averages of historical water levels have been included in the plot. The estimates by the study show that the maximum drawdown of reservoir level can range from 8 m (for most efficient irrigation systems) to about 17 m if irrigation areas expand to 2050 levels without improvements in irrigation efficiencies).

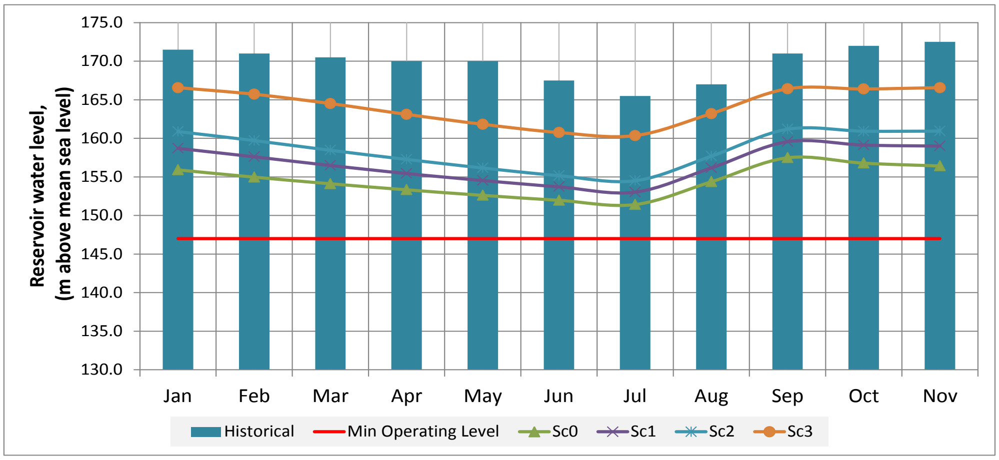


Figure 17: Reservoir levels for High Aswan Dam

It must be noted that the actual water levels would vary depending how upstream dams are operated, for example the Grand Ethiopian Renaissance Dam (GERD). The study hasn't explored different operation rules for upstream dams and, therefore, the results on HAD water level should be taken as indicative only.

5 Conclusions and recommendations

In this study the agriculture water requirement of Nile riparian countries was calculated for the irrigated areas which are fed by Nile River for existing as well as planned irrigation schemes. The water requirement was calculated with the model SPARE:WATER which calculates the water requirements of field crops on the basis of the potential evapotranspiration according to the FAO Crop water irrigation guidelines considering the existing irrigation technology.On the basis of this study the following conclusions can be drawn:

1. The total water withdrawal for irrigation of existing irrigation areas from the NILE River is dominated by the two countries Egypt and Sudan.
2. The annual water requirements are driven by wheat, clover, rice and maize in Egypt as well as cotton, wheat and sorghum in Sudan.

3. Water reuse increases the salinity level of irrigation water in a great extent and leads to a leaching requirement of ~8 km³ yr^{-1} on existing areas and of ~1.9 km³ yr^{-1} for planned areas, in particular in the Nile delta.
4. Monthly water requirements are highest in the summer period and are related to the peak consumption of rice and maize. In the period from January to June Wheat and clover are dominating water requirements.
5. Nile riparian countries are planning an expansion of irrigated areas of 3.3 million hectare in total mainly in Ethiopia (~1,410,0000 hectare) and Sudan (~967,000 hectare).
6. The additional water requirement for planned areas is 39.02km³ yr^{-1}.
7. Based on the existing water requirements scenarios are calculated for improved irrigation efficiency and technology. Depending on the technology the reduction of water requirements ranges from 10 to 21.6 km³ yr^{-1} for existing areas and between 25 and 33km³ yr^{-1} for planned ones.
8. The total unmet demand increases dramatically from a current value of about 0.5 km^3/y to about 44 km^3/y by 2050 if current irrigation efficiencies don't improve.
9. The water saving through improved technologies cannot compensate the additional water requirement of the planned irrigation areas.

The competing demand for water in the Nile river basin is high, in particular in the agriculture sector. Generally, modern irrigation technologies are helpful to reduce water resources. But the calculations of the water requirements with different irrigation technologies show that these saving potentials are not sufficient to meet the water requirement of planned irrigated areas.

Beyond increasing the efficiency of irrigation water management, other opportunities of improved water use efficiency should be taken into account. The large yield gap between the upstream and downstream countries reveals a great potential for optimisation of water use through improved crop yields. Such a potential could be greater than the impact of improved irrigation technology. This hypothesis has to be validated in future.

In general, the knowledge base about agricultural water use in the Nile from a basin perspective needs to be refined, which could be realized by the following tasks:

- Synthesize information about current practice and the potential for improved crop management (yield levels, input levels (fertilization, pesticides), management, crop varieties, crop rotations);
- Enhance the NBI database on irrigation systems to a fully-fledged irrigation information system to improve understanding (and monitor) of one of the key water users in the Nile system (information on equipped irrigation areas, cropped area, cropping pattern and yield levels, water quality (salinity));

Such knowledge would allow further studies to investigate water resource supply and demand in the Nile river basin:

- An enhanced scenario study building on the work of this study developing further the scenarios of agricultural water demand based on “water footprint analysis” and technology/cropping pattern trajectories that take technological change and economic aspects into account.
- A study on the salinization risks in the basin, especially Egypt and Sudan, in relation to basin water management
- Enhanced trade-off analysis between potentially competing water uses (between environmental flow requirements, electricity production and irrigation for food security – the NEXUS between Water, Food and Energy Security) in the Basin using the NBI WEAP/DSS Model. This would include improved economic indicators for valuing the key trade-offs
- A (macro-) economic study analysing economically optimal agricultural water use across the basin based on hydro-economic optimization models of the basin and macro-economic (Trade, CGE models) models of the country’s economies and their trade inter-linkages. This study would explore potential of agricultural trade and cross border investments to optimize use of the basins water resources for agricultural production.

The revitalization of the NBI agriculture water use agenda, which has not received much funding and attention in the last five years after the end of the Regional Agricultural Trade and Productivity Project, could help to realize the recommendations from this study.

6 References

Allan, J. A.: Virtual water: A strategic resource global solutions to regional deficits, Ground water, 36(4), 545–546, 1998.

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M.: Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56, FAO, Rome, 300, 6541, 1998.

Ashraf El-Sayed (2011): Egyptian Drainage water Re-use: Practice and Measures to Alleviate Risk of Failure, a presentation (http://www.arabwatercouncil.org/AWF/Downloads/Sessions/Topic2/P2-3-Ashraf_Egyptian-Drainage-Water.PDF)

Aquastat, F. A. O.: FAO's information system on water and agriculture, Food and Agriculture Organization (FAO) of the United Nation. Retrieved from http://www. fao. org/nr/water/aquastat/countries_regions/egypt/index. stm., 2009.

Barnes J (2014): Mixing waters: The reuse of agricultural drainage water in Egypt, Geoforum 57 (2014), 181 - 191.

Bart H., W. O. Balikuddembe, S. Thuo and P.Schuette (2011): Food for Thought: Demand for agricultural produce in the Nile Basin for 2030: four scenarios; FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, Rome 2011

BCEOM, 1999, Abbay River Basin Master Plan - Ethiopia, Phase 3, Main Report and Sectoral Reports

Brouwer, C., Prins, K. and Heibloem, M.: Irrigation water management: irrigation scheduling, Training manual, 4, 1989.

Döll, P., Fiedler, K. and Zhang, J.: Global-scale analysis of river flow alterations due to water withdrawals and reservoirs, Hydrology and Earth System Sciences, 13(12), 2413–2432, 2009.

Elamin A.W. M, A. B. Saeed, A. Boush (2011): Water Use Efficiencies of Gezira, Rahad and New Halfa Irrigated Schemes under Sudan Dry Land Condition; Sudan J. Des. Res. 3(1): 62-72, 2011.

ENTRO-IDS (2009): Eastern Nile Irrigation and Drainage Studies - Cooperative Regional Assessment, Analyses Report; ENTRO, Addis Ababa

Falkenmark, M. and Rockström, J.: The new blue and green water paradigm: Breaking new ground for water resources planning and management, Journal of water resources planning and management, 132(3), 129–132, 2006.

FAO (2010): CLIMWAT2.0 - Water Development and Management Unit | © FAO Division 2010, n.d.

Doorenbos J., and W. O Pruitt (1977): Guidelines for predicting Crop Water Requirements; FAO Irrigation and Drainage Paper 24, Rome

Gleeson, T., Wada, Y., Bierkens, M. F. and van Beek, L. P.: Water balance of global aquifers revealed by groundwater footprint, Nature, 488(7410), 197–200, 2012.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. and Mekonnen, M. M.: The Water Footprint Assessment Manual: Setting the Global Standard, Earthscan, London, 224, 2011.

Hoekstra, A. Y., Mekonnen, M. M., Chapagain, A. K., Mathews, R. E. and Richter, B. D.: Global monthly water scarcity: blue water footprints versus blue water availability, Plos One, 7(2), e32688, 2012.

Howell, T. A.: Irrigation efficiency, Encyclopedia of water science. Marcel Dekker, New York, 467–472, 2003.

Jensen, M. E.: Beyond irrigation efficiency, Irrigation Science, 25(3), 233–245, 2007.

Johnson, W., Williams, Q. and Kirshen, P.: Weap: A comprehensive and integrated model of supply and demand, 1995.

Johnston, R. (2012): Availability of water for agriculture in teh Nile Basin, in The Nile River Basin: water, agriculture, governance and livelihoods, Routledge., 2012.

Lankford, B.: Fictions, fractions, factorials and fractures; on the framing of irrigation efficiency, Agricultural Water Management, 108, 27–38, 2012.

Mekonnen, M. M. and Hoekstra, A. Y.: National water footprint accounts: the green, blue and grey water footprint of production and consumption, 2011.

Multsch, S., Al-Rumaikhani, Y. A., Frede, H.-G. and Breuer, L.: A Site-sPecific Agricultural water Requirement and footprint Estimator (SPARE: WATER 1.0), Geosci. Model Dev., 6(4), 1043–1059, 2013.

Murakami, M.: Managing water for peace in the middle east; alternative strategies, United Nations University Press., 1995.

NBI-StoBR (2012): State of the Nile River Basin Report, Chapter 4; Nile Basin Initiative, Entebbe.

NBI-ENTRO (2014): Eastern Nile Multi-Sector Investment Opportunity Analyses; Situation Analysis Report and Database; 2014.

NBI-NELSAP (2012): NILE EQUATORIAL LAKES MULTI SECTOR INVESTMENT

OPPORTUNITY ANALYSIS Situational Analysis Report Final main report; 2012.

Nedeco 1998.Tekeze River Basin Integrated Development Master Plan Project. Executive Summary. Prepared for the Federal Democratic Republic of Ethiopia Ministry of Water Resources by Nedeco Netherlands Engineering Consultants and DHV Consultants.

Pereira, L. S., Oweis, T. and Zairi, A.: Irrigation management under water scarcity, Agricultural water management, 57(3), 175–206, 2002.

Philip, G. M. and Watson, D. F.: A precise method for determining contoured surfaces, Australian Petroleum Exploration Association Journal, 22(1), 205–212, 1982.

Rockström, J., Falkenmark, M., Karlberg, L., Hoff, H., Rost, S. and Gerten, D.: Future water availability for global food production: the potential of green water for increasing resilience to global change, Water Resources Research, 45(7), 2009.

Rost, S., Gerten, D., Bondeau, A., Lucht, W., Rohwer, J. and Schaphoff, S.: Agricultural green and blue water consumption and its influence on the global water system, Water Resources Research, 44(9), 2008.

Sheffield J, Goteti G, Wood EF (2006): Development of a 50-Year High-Resolution Global Dataset of Meteorological Forcings for Land Surface Modeling. Journal of Climate 19:3088–3111

Siebert, S. and Döll, P.: Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation, Journal of Hydrology, 384(3), 198–217, 2010.

Wada, Y., van Beek, L. P. H. and Bierkens, M. F. P.: Nonsustainable groundwater sustaining irrigation: A global assessment, Water Resources Research, 48, W00L06, 2012.

Watson, D. F. and Philip, G. M.: A refinement of inverse distance weighted interpolation, Geo-processing, 2(4), 315–327, 1985.

World Bank (2014). World Development Indicators, the World Bank

WREM (2006), Study on Water Management of Lake Victoria, Technical Report 11; Power System Planning and Economic Assessment prepared for Uganda Ministry of Energy and Mineral Development

Yates D., J. Sieber, D. Purkey, Huber-Lee, A (2005): WEAP21 – A Demand-, Priority-, and Preference-Driven Water Planning ModelPart 1: Model Characteristics; International Water Resources Association, Water International, Volume 30, Number 4, 487 - 500, December 2005

Annexes

Annex 1: Existing (2011) and estimated future (2050) areas under irrigation

Table A1.1: Existing (2011 estimate) irrigation areas in the Nile Basin

Scheme	Country	Equipped Area (000 ha)	Harvest area (000 ha)	Cropping Intensity
MN_Assuit_Cairo Irrigation	Egypt	337.22	463.40	137%
MN_Aswan_Esna Irrigation	Egypt	225.61	249.80	111%
MN_DeltaMinufiyahGharbiyah Irrigation	Egypt	335.70	559.49	167%
MN_DeltaQahirah Irrigation	Egypt	6.89	8.11	118%
MN_Delta_Buhayrah Irrigation	Egypt	560.68	1173.86	209%
MN_Delta_Daqahliyah Irrigation	Egypt	306.13	416.71	136%
MN_Delta_Imailiyah Irrigation	Egypt	74.35	109.93	148%
MN_Delta_Iskandariyah Irrigation	Egypt	65.94	88.77	135%
MN_Delta_Kafr El Sheikh Dumyat Irrigation	Egypt	298.96	477.11	160%
MN_Delta_Matruh Irrigation	Egypt	135.30	84.82	63%
MN_Delta_Qalyubiyah Irrigation	Egypt	79.97	117.25	147%
MN_Delta_Sharqiyah Irrigation	Egypt	364.38	468.77	129%
MN_ElSalam Canal Irrigation	Egypt	64.80	52.11	80%
MN_Esna_NagaaHammadi Irrigation	Egypt	145.92	191.87	131%
MN_Fayyum Irrigation	Egypt	161.03	241.26	150%
MN_Jizah Irrigation	Egypt	139.78	82.05	59%
MN_NagaaHammadi_Assuit Irrigation	Egypt	144.61	235.70	163%
BAS_Alwero RB Abobo Irrigation	Ethiopia	10.52	10.52	100%
BN_Abbay@Kessie Irrigation	Ethiopia	21.50	34.40	160%
BN_Amerti_Neshe Irrigation	Ethiopia	7.20	7.92	110%
BN_Fincha Irrigation	Ethiopia	7.60	8.36	110%
BN_Koga Irrigation	Ethiopia	7.00	11.20	160%
BN_Tana Irrigation	Ethiopia	15.00	24.00	160%
BN_TisAbbay Irrigation	Ethiopia	21.50	34.40	160%
LV_Awach_Kibuon Irrigation	Kenya	0.54	0.54	100%
LV_Itare Irrigation	Kenya	2.66	2.66	100%
LV_LakeVicWetAreaEast KN Irrigation	Kenya	2.51	2.51	100%
LV_Migori Irrigation	Kenya	0.12	0.12	100%
LV_Nyando Irrigation	Kenya	1.31	1.31	100%
LV_Nzoia_DS Irrigation	Kenya	3.46	3.46	100%
LV_Nzoia_US Irrigation	Kenya	1.02	1.02	100%
LV_Nzoia_US1 Irrigation	Kenya	2.14	2.14	100%
LV_Sare Irrigation	Kenya	5.21	5.20	100%
LV_Sio Irrigation	Kenya	0.89	0.89	100%
LV_Yala Irrigation	Kenya	0.20	0.20	100%
LV_Kagera Irrigation	Rwanda	0.16	0.16	100%

LV_Nyabarongo Irrigation	Rwanda	6.42	6.42	100%
LV_Rwagitugusa Irrigation	Rwanda	0.48	0.48	100%
BG Aweil Irrigation	South Sudan	0.50	0.50	100%
BN_Gezira_Managil Irrigation	Sudan	924.00	660.80	72%
BN_Guneid Irrigation	Sudan	15.54	5.93	38%
BN_Hurga_Nourdin Irrigation	Sudan	9.35	5.58	60%
BN_NW_Sennar Irrigation	Sudan	22.46	14.50	65%
BN_Pumps_US_Sennar Irrigation	Sudan	105.00	52.50	50%
BN_Rahad I_II Irrigation	Sudan	94.50	80.50	85%
BN_Suki_Irrigation	Sudan	36.51	31.50	86%
MN_Hasanab_Merwoe Irrigation	Sudan	28.56	18.50	65%
MN_Khartoum_Tamaniat_Hasanab Irrigation	Sudan	23.10	15.00	65%
MN_Merowe_Dongola Irrigation	Sudan	89.88	73.00	81%
TA_NewHalfa Irrigation	Sudan	155.40	115.40	74%
WN_Assayla Sugar	Sudan	18.48	14.78	80%
WN_Kenana Sugar 3	Sudan	36.54	22.00	60%
WN_Pump Schemes	Sudan	151.20	60.45	40%
LV_Isanga Irrigation	Tanzania	0.32	0.32	100%
LV_LakeVicWetAreaEast TN Irrigation	Tanzania	1.33	1.33	100%
LV_LakeVicWetAreaSouth Irrigation	Tanzania	5.13	5.13	100%
LV_Mamwe Irrigation	Tanzania	2.19	2.19	100%
LV_Mara Irrigation	Tanzania	0.33	0.33	100%
LV_Rubana Irrigation	Tanzania	0.03	0.03	100%
LV_Rubare Irrigation	Tanzania	0.46	0.45	100%
LV_Ruvubu Irrigation	Tanzania	0.08	0.08	100%
LV_Simiyu Irrigation	Tanzania	0.61	0.61	100%
BJ_Agoro Irrigation	Uganda	0.13	0.13	100%
LA_Lake Edward Irrigation	Uganda	0.01	0.01	100%
LA_LakeGeorge_Mubuku Irrigation	Uganda	0.52	0.52	100%
VN_Lake Kyoga Irrigation	Uganda	7.96	7.96	100%
VN_Malaba UG Irrigation	Uganda	0.60	0.60	100%
VN_Olweny Irrigation	Uganda	0.50	0.50	100%
Sum		5295.90	6370.05	

Table A1.2: Total projected area under irrigation by 2050

Scheme	Country	Equipped Area ('000 ha)	Harvest Area ('000)	Cropping Intensity (Est)
MN_Assuit_Cairo Irrigation	Egypt	337.22	463.40	137%
MN_Aswan_Esna Irrigation	Egypt	225.61	249.80	111%
MN_DeltaMinufiyahGharbiyah Irrigation	Egypt	335.70	559.49	167%
MN_DeltaQahirah Irrigation	Egypt	6.89	8.11	118%
MN_Delta_Buhayrah Irrigation	Egypt	560.68	1173.86	209%
MN_Delta_Daqahliyah Irrigation	Egypt	306.13	416.71	136%
MN_Delta_Imailiyah Irrigation	Egypt	74.35	109.93	148%
MN_Delta_Iskandariyah Irrigation	Egypt	65.94	88.77	135%
MN_Delta_Kafr El Sheikh Dumyat Irrigation	Egypt	298.96	477.11	160%
MN_Delta_Matruh Irrigation	Egypt	135.30	84.82	63%
MN_Delta_Qalyubiyah Irrigation	Egypt	79.97	117.25	147%
MN_Delta_Sharqiyah Irrigation	Egypt	364.38	468.77	129%
MN_ElSalam Canal Irrigation	Egypt	260.40	260.59	100%
MN_Esna_NagaaHammadi Irrigation	Egypt	145.92	191.87	131%
MN_Fayyum Irrigation	Egypt	161.03	241.26	150%
MN_Jizah Irrigation	Egypt	139.78	82.05	59%
MN_NagaaHammadi_Assuit Irrigation	Egypt	144.61	235.70	163%
MN_Toshka Irrigation	Egypt	226.80	403.20	178%
MN_West Delta Irrigation	Egypt	79.80	75.81	95%
BAS_Alwero RB Abobo Irrigation	Ethiopia	10.52	10.52	100%
BAS_Alwero US Dumbong Irrigation	Ethiopia	15.00	17.00	113%
BAS_Baro LB Itang Irrigation	Ethiopia	245.74	287.74	117%
BAS_Baro RB Itang Irrigation	Ethiopia	128.54	146.27	114%
BAS_Gambella LB Irrigation	Ethiopia	57.03	65.04	114%
BAS_Gambella RB Irrigation	Ethiopia	67.75	77.19	114%
BAS_Gilo 1 LB Irrigation	Ethiopia	34.46	39.46	115%
BAS_Gilo 1 RB Irrigation	Ethiopia	46.90	53.38	114%
BAS_Gilo 2 LB Irrigation	Ethiopia	33.86	38.86	115%
BAS_Gilo 2 RB Irrigation	Ethiopia	61.33	68.33	111%
BN_Abbay@Kessie Irrigation	Ethiopia	58.14	93.03	160%
BN_Amerti_Neshe Irrigation	Ethiopia	11.87	13.06	110%
BN_Anger Irrigation	Ethiopia	35.11	47.39	135%
BN_Beko Abo Irrigation	Ethiopia	14.55	22.55	155%
BN_Fincha Irrigation	Ethiopia	7.60	8.36	110%
BN_GilgelAbbay Irrigation	Ethiopia	17.24	27.59	160%
BN_Karadobe Irrigation	Ethiopia	6.12	9.49	155%
BN_Koga Irrigation	Ethiopia	14.50	23.20	160%
BN_LowerBeles Irrigation	Ethiopia	85.00	140.25	165%
BN_LowerDabus Irrigation	Ethiopia	15.40	20.79	135%

Scheme	Country	Equipped Area ('000 ha)	Harvest Area ('000)	Cropping Intensity (Est)
BN_LowerDidessa Irrigation	Ethiopia	31.67	42.76	135%
BN_LowerDinder Irrigation	Ethiopia	50.00	82.50	165%
BN_LowerGuder Irrigation	Ethiopia	21.02	28.37	135%
BN_Mendaya Irrigation	Ethiopia	13.68	21.21	155%
BN_Middle_Birr Irrigation	Ethiopia	4.67	7.47	160%
BN_Muger Irrigation	Ethiopia	7.44	10.42	140%
BN_Rahad Irrigation	Ethiopia	55.00	90.75	165%
BN_Shegolie Irrigation	Ethiopia	10.60	14.32	135%
BN_Tana Irrigation	Ethiopia	104.55	156.88	150%
BN_TisAbbay Irrigation	Ethiopia	44.66	71.46	160%
BN_UpperBeles Irrigation	Ethiopia	53.72	59.09	110%
BN_UpperDabus Irrigation	Ethiopia	4.08	5.51	135%
BN_UpperDidessa Irrigation	Ethiopia	45.14	60.94	135%
BN_UpperDinder Irrigation	Ethiopia	16.60	27.39	165%
BN_UpperGuder Irrigation	Ethiopia	9.82	13.75	140%
TA_Angereb Irrigation	Ethiopia	16.54	16.54	100%
TA_Humera Irrigation	Ethiopia	42.97	42.97	100%
TA_Metema Irrigation	Ethiopia	11.56	11.56	100%
LV_Awach_Kibuon Irrigation	Kenya	0.93	0.93	100%
LV_Itare Irrigation	Kenya	4.37	4.37	100%
LV_LakeVicWetAreaEast KN Irrigation	Kenya	18.81	18.81	100%
LV_Migori Irrigation	Kenya	0.79	0.79	100%
LV_Nyando Irrigation	Kenya	3.93	3.93	100%
LV_Nzoia_DS Irrigation	Kenya	20.64	20.63	100%
LV_Nzoia_US Irrigation	Kenya	4.39	4.39	100%
LV_Nzoia_US1 Irrigation	Kenya	9.13	9.13	100%
LV_Sare Irrigation	Kenya	12.83	12.82	100%
LV_Sio Irrigation	Kenya	11.46	11.46	100%
LV_Yala Irrigation	Kenya	0.22	0.22	100%
VN_Malaba KN Irrigation	Kenya	1.35	1.35	100%
LV_Kagera Irrigation	Rwanda	0.28	0.28	100%
LV_Nyabarongo Irrigation	Rwanda	10.55	10.55	100%
LV_Rwagitugusa Irrigation	Rwanda	0.67	0.67	100%
BAS_Pibor Irrigation	South Sudan	126.00	177.00	140%
BAS_Sobat Irrigation	South Sudan	84.00	85.00	101%
BG Aweil Irrigation	South Sudan	4.62	4.62	100%
BG Wau Irrigation	South Sudan	0.02	0.02	100%
BJ Bor Irrigation	South Sudan	0.02	0.02	100%
BJ Jebel Lado Irrigation	South Sudan	0.08	0.08	100%
BJ Pagaru Irrigation	South Sudan	0.08	0.08	100%

Scheme	Country	Equipped Area ('000 ha)	Harvest Area ('000)	Cropping Intensity (Est)
WN_Melut Sugar	South Sudan	12.60	6.30	50%
BN_AbuNaama Irrigation	Sudan	12.60	10.20	81%
BN_Gezira_Managil Irrigation	Sudan	924.00	868.96	94%
BN_Guneid Irrigation	Sudan	29.40	23.58	80%
BN_Hurga_Nourdin Irrigation	Sudan	12.60	10.08	80%
BN_Kenana 2_3_4 Irrigation	Sudan	252.00	220.00	87%
BN_NW_Sennar Irrigation	Sudan	22.46	18.14	81%
BN_Pumps_US_Sennar Irrigation	Sudan	105.00	105.00	100%
BN_Rahad I_II Irrigation	Sudan	451.50	367.88	81%
BN_Roseries_Dinder Irrigation	Sudan	310.80	268.31	86%
BN_Suki_Irrigation	Sudan	36.51	30.00	82%
MN_Hasanab_Merwoe Irrigation	Sudan	28.56	23.00	81%
MN_Khartoum_Tamaniat_Hasanab Irrigation	Sudan	23.10	18.50	80%
MN_Merowe_Dongola Irrigation	Sudan	89.88	78.00	87%
TA_NewHalfa Irrigation	Sudan	155.40	186.00	120%
TA_Upper Atbara Irrigation	Sudan	168.00	157.00	93%
WN_Assayla Sugar	Sudan	19.48	14.78	76%
WN_Kenana Sugar 3	Sudan	36.54	22.00	60%
WN_Pump Schemes	Sudan	151.20	127.08	84%
LV_Isanga Irrigation	Tanzania	10.36	10.36	100%
LV_LakeVicWetAreaEast TN Irrigation	Tanzania	1.55	1.55	100%
LV_LakeVicWetAreaSouth Irrigation	Tanzania	14.42	14.42	100%
LV_Mamwe Irrigation	Tanzania	20.78	20.77	100%
LV_Mara Irrigation	Tanzania	4.46	4.46	100%
LV_Rubana Irrigation	Tanzania	0.41	0.41	100%
LV_Rubare Irrigation	Tanzania	10.03	10.03	100%
LV_Ruvubu Irrigation	Tanzania	0.35	0.35	100%
LV_Simiyu Irrigation	Tanzania	4.60	4.00	87%
BJ_Agoro Irrigation	Uganda	0.13	0.13	100%
LA_Lake Edward Irrigation	Uganda	0.36	0.36	100%
LA_LakeGeorge_Mubuku Irrigation	Uganda	0.52	0.52	100%
VN_Lake Kyoga Irrigation	Uganda	9.91	9.91	100%
VN_Malaba UG Irrigation	Uganda	0.60	0.60	100%
VN_Olweny Irrigation	Uganda	0.50	0.50	100%
Sum		8695.61	10682.18	

Annex 2: Locations in the Nile Basin with river flow data used for building the WEAP model

Table A2.1: Stations whose flow records were used in the WEAP model

Station Name	Lat	Long
Abay at Bahir Dar	37.41	11.61
Abay at Kessie	38.19	10.08
Abay at Shegolie	35.16	10.66
Agwei at its mouth into Pibor	33.02	7.64
Akobo at its mouth into Pibor	33.05	7.79
Atbara at Kilo 3	34.00	17.68
Atbara downstream of Khashm el Gibra Dam	35.91	14.93
Bahr el Ghazal downstream of KhorDoleib mouth	30.26	9.42
Bahr el Jebel at Buffalo Cape	30.39	9.21
Bahr el Jebel at Mongalla	31.77	5.20
Bahr el Zeraf near its mouth into White Nile	31.12	9.41
Baro at Gambella	34.59	8.25
Baro at its mouth into Sobat	33.22	8.43
Blue Nile at Deim	34.92	11.24
Blue Nile at Khartoum and Soba	32.53	15.61
Blue Nile at Roseires	34.39	11.80
Blue Nile at Sennar Dam	33.64	13.55
Dabus at its mouth into Abay	35.15	10.61
Dabus near Assosa	34.90	9.87
Didessa at its mouth into Abay	35.68	9.94
Didessa near Arjo	36.42	8.69
Dinder near its mouth into Blue Nile	33.67	14.08
Finchaa near Shambu	37.37	9.56
Geba at Suppi	27.77	6.39
Gel at new road bridge	29.13	7.04
Geti upstream of its mouth into River Jur at road Bridge	28.00	8.02
GilgelAbay near Merawi	37.04	11.37
Jinja Owen Falls	33.19	0.44
Jur at Wau	28.01	7.70
Kafu	32.05	1.55
Kagera at Kyaka ferry	31.42	-1.25
Kagera at Rusumo Falls	30.78	-2.78
Kamdini	32.27	2.27
Khor Gila at its mouth into pibor	33.20	8.14
Koga at Merawi	37.05	11.37
Lake Albert at its exit	31.42	2.32
Lol at Nyamlel	26.98	9.14
Masindi	32.10	1.70
Naam at Mvolo	29.95	6.05

Nile at Dongola	30.49	19.10
Nile at Dongola	30.49	19.10
Nile at Esna Barrage	32.56	25.32
Nile at Gaafra	32.91	24.33
Nile at Hawatka (downstream of Assiut)	31.02	27.29
Nile at Mogren	32.49	15.61
Nile at Tamaniat and Shambat	32.53	15.71
Nile at WadiHalfa and Kajnarty	31.16	21.66
Nile downstream of Nag Hammadi Barrage	32.25	26.05
NZOIA AT RUAMBWA FERRY 1EF01	34.09	0.12
Pibor at Pibor post	33.13	6.80
Pibor ds Gilo	33.03	7.80
Pibor upstream of Akobo mouth	33.03	7.80
Pibor upstream of KhorMakwai mouth	33.21	8.34
Pibor us Akobo	33.03	7.80
Q_Orig_83209_KyogaNileParaa	31.58	2.28
Rahad near its mouth into Blue Nile (at Abu Haraz)	33.52	14.47
Semliki	30.18	0.95
Sobat at 2 kms downstream of Nyandig mouth	32.69	8.68
Sobat at its mouth into White Nile (at HilletDoleib)	31.60	9.36
Sor at metu	35.60	8.31
Tekeze at Ambamadre	38.20	13.74
Tonj at Tonj Road Bridge	28.69	7.27
White Nile at Kosti	32.77	13.11
White Nile at Malakal	31.64	9.55
White Nile at Melut	32.19	10.43
White Nile at Mogren (Khartoum)	32.49	15.61
White Nile downstream of Jebel Aulia Dam	32.49	15.25
Yala	34.27	0.04

Annex 3

Table A3.1. Conveyance irrigation efficiency [source: (Brouwer et al., 1989)].

	Earthen canals			**Lined canals**
Soil type	**Sand**	**Loam**	**Clay**	
Canal length				
Long (> 2000m)	60%	70%	80%	95%
Medium (200-2000m)	70%	75%	85%	95%
Short (< 200m)	80%	85%	90%	95%

Table A3.2. Application irrigation efficiency [source: (Brouwer et al., 1989)]

Irrigation method	**Field application efficiency**
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

Table A3.3. Application and conveyance efficiencies (red: systems and efficiencies which have been considered in this study) [source: Howell (2003)].

	Application efficiency			**Conveyance efficiency**		
Irrigation method	**Attainable**	**Range**	**Average**	**Attainable**	**Range**	**Average**
Surface						
Graded furrow	75	**50-80**	65	70	**40-70**	65
Level furrow	85	65-95	80	85		
Graded border	80	50-80	65	75		
Level basins	90	80-95	85	80		
Sprinkler						
Periodic move	80	**60-85**	75	80	**60-90**	80
Side roll	80	60-85	75	80	60-85	80

Moving big gun	75	55-75	65	85	60-80	70
Center pivot (impact heads)	85	75-90	80	85	75-90	80
Center pivot (spray heads)	95	75-95	90	85	75-95	90
Drip						
Trickle	95	**70-95**	85	95	**75-95**	85
Subsurface	95	70-95	90	95	75-95	90
Microspray	95	70-95	85	95	75-95	85

ONE RIVER

ONE PEOPLE

ONE VISION

Nile Basin Initiative Secretariat
P.O. Box 192
Entebbe – Uganda
Tel: +256 414 321 424
+256 414 321 329
+256 417 705 000
Fax: +256 414 320 971
Email: nbisec@nilebasin.org
Website: http://www.nilebasin.org

Eastern Nile Technical Regional Office
Dessie Road
P.O. Box 27173-1000
Addis Ababa – Ethiopia
Tel: +251 116 461 130/32
Fax: +251 116 459 407
Email: entro@nilebasin.org
Website: http://ensap.nilebasin.org

Nile Equatorial Lakes Subsidiary Action Program Coordination Unit
Kigali City Tower
KCT, KN 2 St, Kigali
P.O. Box 6759, Kigali Rwanda
Tel: +250 788 307 334
Fax: +250 252 580 100
Email: nelsapcu@nilebasin.org
Website: http://nelsap.nilebasin.org

/Nile Basin Initiative

@nbiweb

ENTRO

NELSAP-CU