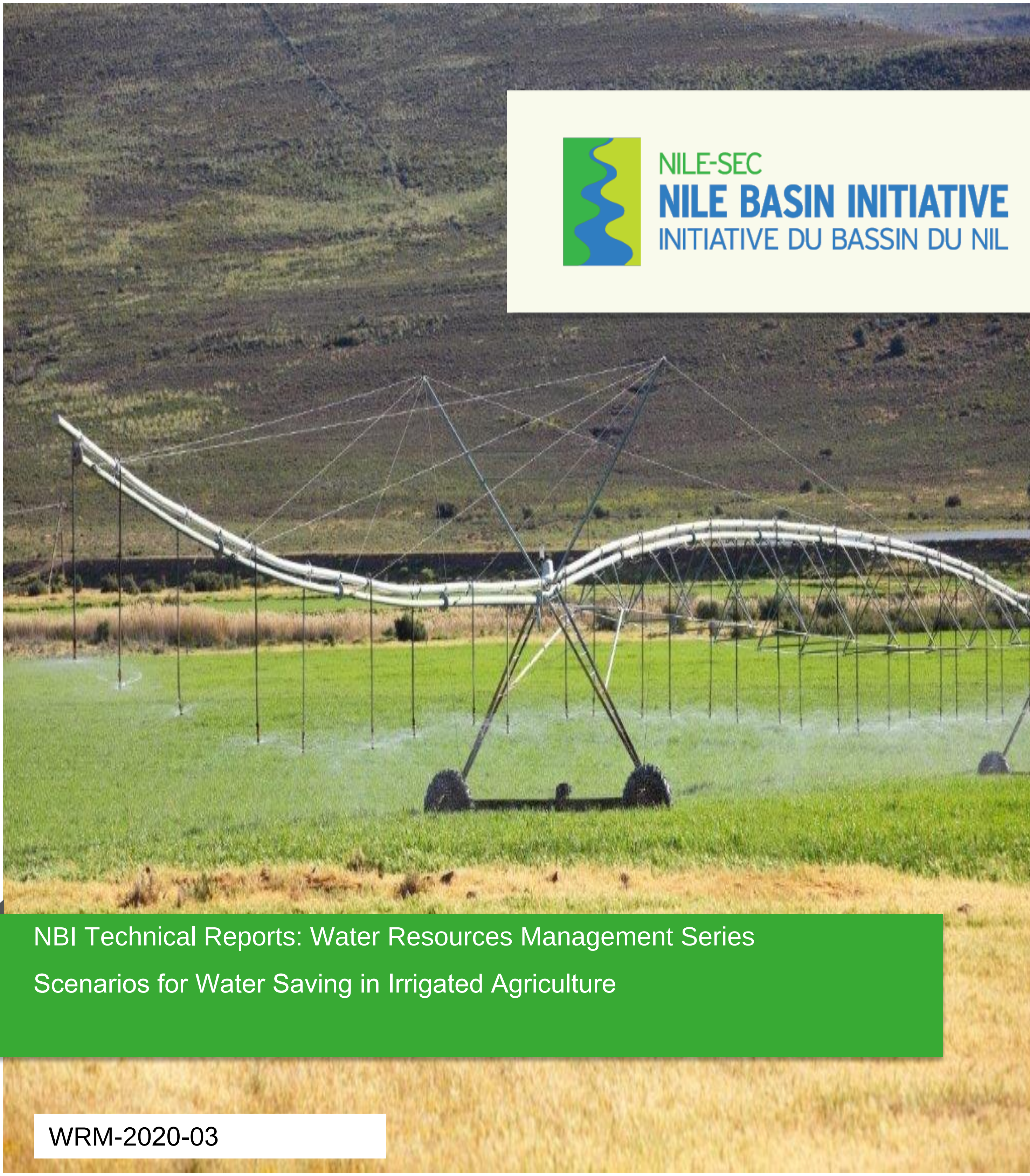

NILE-SEC
NILE BASIN INITIATIVE
INITIATIVE DU BASSIN DU NIL

NBI Technical Reports: Water Resources Management Series

Scenarios for Water Saving in Irrigated Agriculture

WRM-2020-03

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.

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ACRONYMS AND ABBREVIATIONS

BaUScen	Business as Usual Scenario
BCM	Billion Cubic Meters
DRC	Democratic Republic of the Congo
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
GERD	Grand Ethiopian Renaissance Dam
IWMI	International Water Management Institute
JJAS	June-July-August-September
MCM	Million Cubic Meters
mm	Millimeter
NB	Nile Basin
NBI	Nile Basin Initiative
PLANScen	Planned Scenario
PPP	Public-private Partnership
SDG	Sustainable Development Goal
SWRA	Strategic Water Resources Analysis
SWCWU	Seasonally Weighted Conjunctive Water Uses
WC	Water consumption
WDI	Water Deficit Irrigation
WUE	Water-use Efficiency

SUMMARY

In 2015, the Nile Basin Initiative (NBI) Secretariat (Nile-Sec) conducted a Strategic Water Resources Analysis (SWRA) with the aim of developing sustainable options for satisfying the growing water needs of the Nile riparian countries and mitigating the current and future water stress. However, Nile-Sec felt that the study had gaps in data sets; in particular, it lacked an integration of economic modeling of water use in terms of assessing the value of irrigation water. Another limitation was that the impact of increased water productivity on food security and water utilization was not analyzed across the basin. The SWRA assessment did not also analyze the impact of optimal planning of cropping patterns on specific climate and soil conditions. Therefore, this second-phase study was mandated to refine the current estimates of agricultural water demand/use and projections. The findings of the study are meant to contribute to sustainable and efficient investment planning to meet the growing water demand envisaged in the Nile-Sec plan. This study aims at aiding the development of options for water savings through measures such as adoption of improved irrigation technologies, optimization of cropping patterns across the basin and other measures that can result in substantial water savings across the Nile Basin (NB). The NB countries will likely face physical and economic water scarcity unless water development gives due consideration to water savings.

As far as the existing situation is concerned, it is generally recognized that improving rainfed agriculture can have a great impact on the economic and food security of the upper riparian countries by enhancing the reliability of rainfed agriculture. Further, incorporating effective water-saving methods and technologies into large irrigation schemes in the lower riparian countries can enhance water availability and thus help those countries in meeting their future water demands. Therefore, plans for future irrigation schemes in the basin might consider the water saving options discussed in this report.

The water-saving scenarios presented here are organized as per two time horizons, 2018-2030 and 2030-2050, and two distinct agricultural typologies, rainfed and irrigated. Five categories of water-saving scenarios are suggested: (i) intensification of rainfed agriculture in the upper riparian countries; (ii) improving overall water-use efficiencies, mainly of large-scale irrigation schemes; (iii) improving the cropping patterns; (iv) application of water deficit irrigation (WDI); and (v) improving water management and basin water supply.

The following water-savings recommendations can be made:

1. **Enhancing rainfall productivity**. Given the current production gap in rainfed agriculture in the upper riparian countries of the Nile Basin, doubling of productivity is possible by improving inputs and agronomic management. This highlights the need for financial and human resources investments. Effective investment in and visible benefits from rainfed agriculture will undoubtedly shift financial and human resources investments away from irrigation to rainfed activity: (i) Improving rainfed agriculture would cost USD 250-500/ha while irrigation investment not including water storage infrastructure would require an expenditure ranging from USD 4,500/ha (small scale) to USD 12,000/ha (large scale); and (ii) Improving rainfed agriculture has a distributive nature in that more smallholder farmers can benefit from the investment. This is anticipated to lower the rate of irrigation expansion by 25% and 50% in the 2030 and 2050 time horizons, respectively, as other regional studies have also indicated. Note that rainfed productivity enhancement in the upper riparian countries is likely to have a larger societal impact than irrigation as it is more distributed and large scale.

2. **Enhancing irrigation efficiency.** Our literature review showed that there is enough room to enhance irrigation efficiency in the Nile Basin, especially in the large-scale irrigation schemes of Egypt and Sudan. Up to 20–30% improvement in overall irrigation efficiency is possible, most importantly in traditional irrigation systems. Efficiency improvements of 5–15% and 15–30% are suggested for implementation by 2030 and 2050, respectively, in tandem with other water-saving measures.

3. **Improving local and regional cropping patterns.** In Egypt, an estimated 109,000 ha of land is given over to sugarcane cultivation and 760,000 ha to rice. In Sudan, sugarcane occupies over 74,600 ha of land. Cropping pattern changes are recommended for implementation in the existing large-scale irrigation schemes that serve such crops that have high water consumption.

• Locally, it may be imperative to convert at least 50% of the sugarcane land in Egypt and Sudan to sugar beet. One hectare of sugarcane production on average requires 3.44 times more water than one hectare of sugar beet. It is estimated that if 50% of the sugarcane land is converted to sugar beet by 2050, it would save about 1.9 billion cubic meters (BCM) of water in the existing irrigation schemes in Sudan and Egypt.

• With regional cooperation taking hold in the Nile Basin, some of the rice and sugarcane production can be shifted to humid tropical climate regimes as part of cooperation and virtual water trade. Highland countries with a lesser evaporative demand (e.g., Ethiopia) and equatorial countries with a longer rainfall season (e.g., Uganda) may be persuaded to shoulder the regional responsibility of rice and sugarcane production.

• Plans for expansion of irrigation area in all the Nile Basin countries must consider introducing optimal cropping patterns at the local and regional scales through cooperative engagement and discussion. For this to be implemented, detailed scheme-level data are required from the basin countries.

4. **Water deficit irrigation (WDI).** For selected crops, there is potential for implementation of up to 20% deficit irrigation in the basin without noticeable yield reduction. Careful selection of crops is important for this because some crops are sensitive to WDI. A list of crops locally researched and suggested for WDI by the Food and Agriculture Organization of the United Nations (FAO) has been considered and included in this report. It is projected that by the 2030s, some 15% of the total irrigation area of Egypt and 7.5% of Sudan will be under a deficit irrigation regime. By 2050, some 15% and 30% of the irrigated area of Egypt and Sudan, respectively, would be under deficit irrigation. While application of deficit irrigation is currently negligible in the existing irrigation schemes of the upper riparian countries, these countries would need to incorporate it into their planned irrigation schemes by 2030 and 2050. Especially, commercial farm developments would need to adapt to a deficit irrigation system. Envisaging a full cooperation scenario beyond 2030, policy initiatives encouraging agronomic management and pricing mechanisms have to be implemented basin-wide.

5. **Basin water supply management.** The study considered optimal basin-wide operation of reservoirs and conjunctive uses of surface water and groundwater for saving water.

• Seasonally weighted conjunctive use of surface water and groundwater provides significant water-saving opportunities in the Nile Basin. In the lower riparian countries of Egypt and Sudan, maximum use of groundwater during the hot season of June to September and surface water in winter while saving more water in the cooler upland reservoirs renders additional water-saving opportunities. It is suggested that 5-10 BCM of groundwater in Sudan and 10-20 BCM in Egypt could be available for conjunctive use by 2050. Groundwater resources need to be studied and incorporated in the water-saving plans of upper riparian countries.

• Large-scale joint development of water resources in the highland and cool areas of the Nile Basin can be potential water-saving options in the basin. Water savings from optimal joint operation of reservoirs need to be estimated using model-based analysis by incorporating existing and planned future storage dams in the basin.

It is important to understand that implementation of water-saving options in the basin requires a full cooperation agreement that evolves into regional institutional and legal mechanisms. Such a mechanism must provide for basin-wide tools for measurement, monitoring and evaluation; implementation of virtual water trade and additional economic mechanisms; and enforcement of the environmental and ecological integrity of the basin. This cooperation agreement needs to have the following elements:

• A highly functional permanent basin organization leading to regional hydro-solidarity and sustainable development of the basin water and natural resources.

• A standard water and irrigation data measurement, monitoring and evaluation system for accurate water prediction, water saving and accounting of the regional resources; establishment of a strong Nile Basin economic bloc with robust trade relationships that facilitate virtual water trade of regional crops and economic diversification.

1. INTRODUCTION

Future water scarcity in the Nile Basin is a well-explored topic (e.g., Awulachew et al. 2012; Gebrehiwot et al. 2019; Swain 2011). Increasing population, economic growth and anticipated climate change are likely to be the major causes of future physical and economic water scarcity in the basin (Karimi et al. 2012). Growing food demand and consequently demand for irrigation are likely to put pressure on water resources in all the riparian countries. Sustainable development and shared benefits, therefore, require cooperative management of the basin's water resources.

Past studies have recommended efficiency improvement as a means of improving water availability in the Nile Basin (e.g., Awulachew et al. 2012; FAO 2000). However, the success of such approaches is often limited. A recent study has indicated that irrigation water-use efficiency improvement may not be sufficient to improve future water availability in the basin (Multsch et al. 2017). A 5–20% increased efficiency in both gravity and pressurized irrigation systems was found to be insufficient to meet future water demand. Similarly, expansion of the irrigation area alone would likely not be sufficient to fulfill the future food demand in the basin due to the limit in the surface water stock. Therefore, multiple water-saving options as well as enhancement of water supply stocks need to be explored. For instance, many of the upper riparian countries have extensive areas under rainfed agriculture, and improvement of productivity of rainfed agriculture would enhance food security. Provided there is regional cooperation, hydro-solidarity (Gerlak et al. 2009) and a higher common purpose of humanity, there are numerous regional and local mechanisms to conserve water and pursue societal goals in the basin.

This study (Component III) is intended to explore and provide potential water-saving and supply-enhancement scenarios for evaluation of future water management pathways in the Nile Basin. In the context of this study, water-saving options in the Nile Basin include comprehensive, practically feasible soft (management) or hard (infrastructure) means of water conservation for shared and sustainable use of the Nile water. The study looks into different existing management-based water-saving approaches such as efficiency improvements, change in cropping pattern, water deficit irrigation, and conjunctive management of available water. In addition, water supply enhancement based on improving rainfed agriculture, basin-wide water augmentation and joint operation of storage reservoirs is also explored. The study also suggests inclusion of infrastructure-based water saving as part of a comprehensive water-saving mechanism in the basin. First, a list of potential water-saving methods in the basin is generated. Second, potentially feasible combinations of variants of each scenario are selected to be manageably used as input to the Nile Basin water resources model during the course of evaluation of the likely impacts of water savings under future scenarios of irrigation expansion, intensification and cooperation.

2. Review of Potential Water-Saving Methods in the Nile Basin

There have been several studies on the water management aspects of the Nile Basin. For this study, we selected and reviewed only those that were the most relevant to our objectives. Several of the studies we reviewed described the regional and local water-saving and efficiency-improvement measures that can be taken up in the Nile Basin. While the regional or basin-wide studies provide qualitative suggestions and recommendations (FAO 2000; Awulachew et al. 2012), many local scientific studies provide targeted quantitative suggestions (Abou-Hadid 2006; Omar and Moussa 2016; Mohamed et al. 2011). A sample of the basin- and local-level water-saving studies we reviewed are discussed below to provide a framework for this study.

2.1 Regional Studies

The FAO (2000) study was an early regional investigation that attempted to provide water-saving suggestions for different reaches of the Nile Basin. As a long-term engagement, the study recommends two areas of improvement: enhanced end-user efficiency (producing more with less water); and improved water-allocative efficiency (producing higher economic value for available water). It also suggests location-dependent measures for water savings in some agricultural sub-basins:

i) Lower Nile (Egypt): Pollution and salinization control; reduce irrigation canal losses; reduce inefficient agricultural production; alleviate land congestion; and promote change in meat consumption patterns.

ii) Main Nile (Sudan): Cropping intensification; improve irrigation use efficiency; enhance agricultural development; and expand inland fisheries.

iii) Upper Eastern Nile (Ethiopia): Improve management for water conservation and flow regulation; relocate crop and livestock husbandry to humid areas; diversification and structural change away from subsistence agriculture; environmentally sound control of local flooding; and adapt land use to land capability.

iv) White Nile (South Sudan and Sudan): Local flood protection and control; infrastructure development for flow control and flood relief; and reduce current high reservoir and irrigation canal losses.

v) Lake Victoria (Equatorial Lake Nile countries): Water pollution control; coastal and terrestrial catchment land-use management and control; lake level and flow regulation; water weed control; and biodiversity preservation.

A study by the International Water Management Institute (IWMI) discussed in Awulachew et al. (2012) reviews the status of water management in the Nile Basin and provides a spectrum of prospective basin-wide management approaches:

- Integrated management of the basin reservoirs as one unit and locating new storage schemes in the highland areas where higher storage per surface area and less evaporation are attained.
- Improving the efficiency of irrigation systems. According to Awulachew et al. (2012), irrigation efficiency was then assumed to be about 50%.
- Water productivity should be improved by shifting water from an economic sector that uses more water per unit of production to one that uses less water, thereby giving more value per unit of water.
- Reduce non-beneficial water losses through efficient reservoir operation and irrigation water management. This could also improve water availability in the basin.
- Manage occurrences of high system losses due to evaporation and seepage, and implement water storage in less evaporative areas.
- Explore alternative sources of water such as groundwater, which may be lost in the system, without contributing to river flows and/or irrigation demands.
- Manage the flooding regime in the wetlands, thereby reducing water spreading and evapotranspiration (ET).

The regional scale recommendations may be technically possible to implement but require full-scale regional cooperation and agreement. However, many technical and engineering-based water-saving studies do not indicate how regional water-saving recommendations can be implemented. As a result, many such scientific studies remain shelved. If there is no cooperation, there is limited scope to fully implement regional recommendations. Assuming that future Nile cooperation is a possibility, our study too incorporated some regional water-saving recommendations, as given in Section 4.

2.2 Local Studies

The technical report of this study presents a review of different studies of water-saving options pertaining to Egypt and Sudan.

i) Egypt

Abou-Hadid (2006) provides the following insights and recommendations for water saving in Egypt. This study focused on water productivity and improved cropping patterns.

a) Improving water-use efficiency (WUE) or water productivity

- The study refers to WUE as the obtained yield per unit of consumed water during the growing season (water productivity). Improving water productivity helps water saving.
- The average irrigation application efficiency (Ea) at the national level in Egypt stood at 62.5% in 2006 (Abou-Hadid 2006). There is evidence that WUE has significantly improved in Egypt.

b) Improving cropping patterns to save water

- Rice and sugarcane are the most water-consuming crops. Therefore, switching some sugarcane area to sugar beet, which requires less water, can be a water-saving option. Reducing the rice area to 294,000 ha, which is the minimum limit required for protecting the Nile Delta from seawater intrusion (Abou-Hadid 2006), is another such option.
- Decreasing the gap between the net return from winter and summer cultivation.
- Mandating a cropping pattern for each region that is suitable to the local climatic conditions, soil type and water quantities, and sensitizing violators of the mandated cropping pattern.

These methods provide a framework that can inform decisions on sustainable use of land and water for improved rural livelihoods in the developing world's irrigated areas.

Evidence of water-saving technologies in Egypt as reviewed in the Technical Report I (Baseline Report)

- Land leveling. In Egypt, land leveling is practiced on a large scale by the government and the public and private sectors. The government subsidizes laser leveling in sugarcane fields by about 50% of the cost. Land leveling through animal traction has also been implemented in paddy fields to minimize deep percolation losses.
- Tertiary canal improvement project (New Mesqa). Replacement of old tertiary canals was a major initiative taken up to reduce loss due to water seepage, thereby improving irrigation performance. The old canal system (old Mesqa) used to have unlined channels where water was abstracted at multiple points in an unregulated manner. In their place, the newly introduced conveyance systems are: (i) lined canals with the normal water level 15 cm above the field; and (ii) low-pressure pipes buried 1 m below the surface and provided with risers at a spacing of 100 m. Flow from each riser is controlled by an alfalfa valve.
- Gated and perforated pipe system for sugarcane fields. The Egyptian government initiated a program for improvement of on-farm water management in sugarcane fields. It included a package of practices: land leveling, use of gated pipes, increased furrow spacing and soil fertility management. As a result, irrigation application losses dropped to almost nil and crop yield increased by 25% in the pilot areas. According to the source document, there was a plan for scaling up this bundle of technologies/practices.
- Sprinkler/drip irrigation. Sprinkler and drip irrigation methods were introduced in the fringe areas of the Nile Delta and Valley, particularly in areas having soils characterized by relatively higher permeability. The source document stated that in 2005, the area under modern irrigation systems was about 202,937 ha (483,185 feddans), accounting for about 6% of the total irrigated area.
- Raised-bed technology. Research on irrigation water management has identified raised-bed systems as an important component for improved wheat production. The advantages of raised-bed planting (based on the average of data for 2011, 2012, 2013 and 2014 in Egypt) were:

  - 30% increase in grain yield;
  - 25% saving in irrigation water; and
  - 74% increase in water-use efficiency.

Omar and Moussa (2016) reported that the agriculture sector of Egypt consumed 38.5 BCM, or

67%, from the total withdrawal of 57.5 BCM in 1997. By 2017, estimated consumption was reduced to 60%, indicating that about 40% of the agricultural withdrawal was being lost due to evaporation from canals and fallow lands, seepage from the Nile and 31,000 km of irrigation canals, infiltration from land or consumption by aquatic weeds in streams (Omar and Moussa 2016). Similarly, about 15% of deep groundwater withdrawal is being lost either due to increased pumping rate, unofficial withdrawal, damaged drip systems, or application of sprinkler systems in zones where drip systems are more suitable.

The baseline report of this study (Technical Report I) (NBI 2020a) summarizes the average estimated water-use efficiencies for traditional earthen, lined and buried-pipe conveyance systems in Egypt as 82.4%, 92.7% and 98.38%, respectively, while the reported average application efficiency is 81.5% under improved on-farm surface irrigation (i.e., with precision laser land leveling) compared to 59% under traditional surface irrigation (i.e., with no land leveling).

Overall, despite inconsistencies in the reporting of efficiency values, there is room for further improvement, especially in traditional irrigation systems.

ii) Sudan

The baseline report (Technical report I) of this study (NBI 2020a) reported that the overall efficiency of gravity-based irrigation in Sudan was 68% (conveyance and application efficiencies of 85% and 80%, respectively). An overall irrigation efficiency of 78% (conveyance and application efficiencies of 93% and 84%, respectively) was reported for the 34,020 ha Kenana Sugar Estate, a private irrigation scheme where water is delivered through a closed-gate pipe system.

In contrast, Mohamed et al. (2011) studied large-scale performance indicators in the Gezira irrigation scheme in Sudan. The results indicated that section-level irrigation efficiency varies between 19% and 36%, while it stands at 22% for the whole Gezira scheme. In terms of productivity, while the average land productivity (crop yield divided by area) over the whole Gezira is 1.3 tons/ha for cotton, 1.1 tons/ha for wheat, 0.9 tons/ha for groundnut and 0.85 tons/ha for sorghum, the average water productivity (crop yield divided by actual ET) is 0.28 kg/m^3 for cotton, 0.47 kg/m3 for wheat, 0.22 kg/m3 for groundnut and 0.23 kg/m^3 for sorghum. The study noted that the overall productivity in Gezira was lower than that obtained at the Gezira Agricultural Research Station, indicating room for improvement. Current studies (NBI 2020a; and the NBI technical note [NBI 2015]) indicate overall water-use efficiency in Sudan of the order of 68% for gravity and 75% and above for pump and mixed systems (pump and gravity). This indicates that more work is required to be done to collect additional specific data to develop justified efficiency values across the country. This holds true for all countries in the Nile Basin.

iii) Upper riparian countries

Irrigation in the upper riparian countries amounts to only about 2% of the total irrigated area in the Nile Basin as indicated in the Technical Report I (NBI 2020a). There are few studies on irrigation efficiencies in this part of the basin from which to draw lessons as far as water saving is concerned. Generally, overall surface irrigation efficiencies are low, as reported the baseline report (Technical Report I) of this study (NBI 2020a). There is significant room for water saving as far as future irrigation expansion is considered.

3. Review of Phase I Irrigation Technologies and Application Efficiency Scenarios (Technical Note IV)

3.1 Review

As part of the Phase I study, the Nile Basin Initiative (NBI) explored three irrigation technologies and irrigation efficiency improvement scenarios (NBI 2015).

i) Current level efficiency continues: Using the same technology for both the application of water and conveyance;

ii) Current level for existing schemes + 50% for new system: Existing schemes continue to use the same technology but future developments have 50% reduction in losses both in application as well as conveyance of water; and

iii) Increased efficiency for all: In this case, irrigation technology enhancement in which 50% loss reduction is applied in existing as well as future schemes in both application and conveyance.

The irrigation efficiency values generated on the basis of the above scenarios and used for each country are given in Table 1. According to the Technical Note (NBI 2015), information on the current efficiency values of existing schemes was obtained for schemes in Sudan and Ethiopia. Where sufficient information was not available for other countries, surface irrigation was assumed to have 70% conveyance efficiency. In the case of Egypt, general efficiency values were assumed on the basis of suggested values from literature and publications, and they were applied to all irrigation schemes. Overall, the efficiencies reported in the NBI Technical Note IV (NBI 2015) and other reviewed literature bear a discrepancy with local studies, which set irrigation efficiencies in Egypt and Sudan on the lower side (e.g., Abou-Hadid 2006; Omar and Moussa 2016; Mohamed et al. 2011). The use of higher efficiencies as the current baseline might have contributed to the recent seemingly conclusive research study by Multsch et al. (2017) which indicated that future improvements in irrigation water-use efficiency would be insufficient to improve water availability in the basin.

Table 1. Irrigation efficiency scenarios in the Nile Basin countries.

Nile Basin Countries	Methods	Existing			50% enhancement		
		Application	Conveyance	Overall	Application	Conveyance	Overall
Sudan	Gravity & Pumping	80%	94%	75%	90%	97%	87%
	Flood & Pumping	80%	95%	76%	90%	58%	88%
	Pumping	90%	95%	86%	55%	58%	53%
	Gravity	80%	85%	68%	90%	93%	83%
Ethiopia	Surface	70%	70%	49%	85%	85%	72%
	Sprinkler	70%	93%	65%	97%	85%	72%
Egypt	General	85%	85%	72%	56%	53%	89%
Kenya	Surface	70%	70%	49%	35%	35%	72%
Tanzania	Surface	70%	70%	49%	85%	85%	72%
Rwanda	Surface	70%	70%	49%	85%	85%	72%
Uganda	Surface	70%	70%	49%	85%	85%	72%
South Sudan	Surface	70%	70%	49%	85%	85%	72%
Burundi	Surface	70%	70%	49%	85%	85%	72%
DRC	Surface	70%	70%	49%	85%	85%	72%

Source: NBI Technical Note IV (NBI 2015).

3.2 Limitations of Phase I Study

The efficiency values indicated in Table 1 appear slightly higher than the research values reported in Section 2.2. The reported values for traditional furrow irrigation systems in Egypt and Sudan, where efficiency improvement matters, are higher than the values reported in Table 1. In both countries the coverage of traditional irrigation is large. Lands under old irrigation systems in Egypt cover over 2.25 million hectares (Mha) (5.36 million feddans) and are irrigated by traditional surface irrigation systems. These lands, compared to modern and improved irrigation systems, have a very low field water-application efficiency of around 50% (ICARDA 2011). Saad Eddin et al. (2016) put the efficiencies of these systems higher at 59%.

Similarly, efficiency values for Sudan appear to significantly differ from the values reported in field studies cited in literature. Mohamed et al. (2011) put the efficiency of the large-scale Gezira scheme at 22%. Assuming this value is an isolated case, overall efficiency in Sudan appears to be on the higher side. In future, NBI needs to undertake a broader field campaign to establish reasonable efficiency values in each country. In the long run, institutionalized cooperative management of the Nile Basin water will undoubtedly improve consistency in data collection across the basin. Therefore, analysis of water demand for the current scenario needs to consider the traditional irrigation system separately.

4. Proposed Water-Saving Scenarios for NBI

Water-saving analysis in the Nile Basin has to take into account existing and future conditions. As far as the current water-saving scenario is concerned, it is generally recognized that improving rainfed agriculture will enhance its reliability and thereby have a great impact on improving the economic and food security of the upper riparian countries. Currently, water saving from irrigation in the upper riparian countries, which amounts to only about 2% of the total irrigated area in the Nile Basin, is negligible. On the other hand, implementing effective water-saving methods and technologies in the large irrigation schemes of the lower riparian countries of Egypt and Sudan would have a greater impact in enhancing water availability and meeting future water demands. These two contrasting aspects of agriculture in the Nile Basin should primarily drive national and basin-wide policy and investment as we head toward 2030 and aim at achieving the United Nations Sustainable Development Goals (SDGs) related to food, energy and water supply.

As far as future water saving is considered, all countries with significant existing and planned irrigation development need to revert to pressurized irrigation from the outset of development. Further, significant water saving can be achieved when basin countries have established a full cooperation agreement that is institutionalized and managed with a legal framework. National and regional policies need to encourage and support investment in pressurized irrigation systems.

Taking into account irrigation expansion projections across the Nile Basin, Technical Report 2 of this project (NBI 2020b), we visualized water-saving scenarios for two time horizons: 2018-2030 and 2030-2050. Five categories of water-saving scenarios are suggested (Figure 1):

I. Intensification of rainfed agriculture in the upper riparian countries
II. Improving water-use efficiency
III. Improving cropping pattern
IV. Implementation of water deficit irrigation
V. Improving basin water supply management

I. Intensification of Rainfed Agriculture	• Improving rainfed agriculture through policy-supported intensification. Allocating more financial and technical resources (fertilizer, seed varities,market access, capacity building, clustering approach, etc.). This can bridge the food deficit and hence offset the need for irrigation expansion.
II. Improving Water-use Efficiency	• Improving overall efficiency (conveyance and application) alone is not sufficient to offset future water demand in the basin. But it contributes as part of the solution.
III. Improving Cropping Pattern	• Improving the cropping pattern based on irrigation water consumption (lower riparian countries) • Changing irrigation technology from gravity to pressurized
IV. Implementation of Water Deficit Irrigation	• Implementation of WDI for water-intensive crops at the regional scale or country level significantl e hances water saving. Crops grown basin-wide and crops specific to countries with significant water-saving benefits are considered.
V. Basin Water Supply Management	• Upstream=downstream joint operation of reservoirs • Seasonally weighted conjunctive use of surface water and groundwater saves water (lower riparian countries)

Figure 1. Suggested water-saving scenarios and variants.

4.1 Intensification of Rainfed Agriculture

We cannot ignore the fact that rainfed agriculture produces much of the food consumed globally and by poor communities in developing countries. It accounts for more than 95% of farmed land in sub-Saharan Africa; 90% in Latin America; 75% in the Near East and North Africa; 65% in East Asia; and 60% in South Asia[1]. One of the findings from global studies is that there is generally enough rainfall to double and often even quadruple yields in rainfed farming systems, even in water-constrained regions, through improved risk management techniques[2].

Rainfall improvement is a very relevant issue in the upper riparian countries of the Nile Basin. Several of them have enough rainfall to efficiently tap it. The highly rainfed regimes are in the highlands of upper riparian countries Burundi, Democratic Republic of the Congo (DRC), Ethiopia, Kenya, Rwanda, South Sudan, Tanzania and Uganda. Rainfall in many of these upstream countries exceeds 1,000 mm per annum. In terms of volume, FAO-NBI (2011) estimated total rainfall in the basin at 2,000 BCM, of which undivided Sudan (51%), Ethiopia (23%) and Uganda (13%) accounted for 87% of the total volume. However, rainfall here is highly variable: it can occur at the wrong time; its onset and cessation can vary; high-intensity, short-duration rainfall events and dry spells are common; and the frequency is unpredictable. All these variables complicate rainfed agriculture. Past studies show that productivity of rainfed agriculture across the Nile Basin is one of the lowest in the world, which tends to fuel food insecurity (FAO-NBI 2011). Recent studies (Siderius et al. 2016) have reported that it continues to remain relatively low (Table 2). This, however, also means that there is room to enhance productivity in several of these countries. Siderius et al. (2016), using a simplified average estimate of five crops in each country, highlighted the opportunity of doubling rainfed agriculture productivity in the basin. A compilation of World Bank data for cereal crops shows low productivity of a similar order except for

[1] http://www.iwmi.cgiar.org/issues/rainfed-agriculture/summary/
[2] http://www.iwmi.cgiar.org/issues/rainfed-agriculture/summary/

Table 2. Current and future rainfed crop productivity of dominant crops in the Nile Basin countries.

Country	Siderius et al. (2016) Current yield (t/ha)	Siderius et al. (2016) Potential yield (t/ha)	World Bank* Current cereal yield (t/ha)
Current			
Burundi	3.6	4	1.41
Egypt (irrigated)	19.5	19.5	
Ethiopia	1.5	4	2.54
Kenya	2.4	4	1.47
Rwanda	3.9	4	1.28
South Sudan			1.42
Sudan	0.6	4	0.67
Sudan (irrigated)	9.7	9.7	
Tanzania	1.7	4	1.54
Uganda	2.9	4	2.05
Future			
Future intensive	4		
Ethiopia (newly irrigated)	19.5		
Sudan (newly irrigated)	19.5		

* ***Source:*** https://data.worldbank.org/indicator/ag.yld.crel.kg

Burundi and Rwanda[3]. Overall, it is clear that there is potential for doubling of rainfed crop productivity in the Nile upper riparian countries.

As described above, on the one hand, there is enough rainfall to double—or in some cases even quadruple—yields in the rainfed farming systems; on the other hand, current crop yields for most countries in the basin are less than half the yield capacity of the major crops (Table 2). In addition, it is indicated in the suitability mapping report of this study (NBI 2020b) that there is ample land to expand rainfed agriculture development. Given these facts, it is reasonable to assume that yields from rainfed agriculture can potentially be improved by more than 100% in several upper riparian countries and in Sudan. Given the resources and skills this would need, however, revamping to reach full potential productivity is not practically possible, especially in the initial stages. It requires improved agronomic inputs (such as fertilizer, seed varieties, water management under conditions of extreme variability), market access, capacity building, technology and innovation and clustering of smallholder rainfed fields for efficient input management. So, we assume that by 2030, average rainfed agriculture productivity can increase by approximately 50% and reach 3.0 tons/ha; and by 2050 it can reach 100% of the potential level of 4.0 tons/ha (Table 3). Note that the potential given in Siderius et al. (2016) is the average of major crops in each country; it does not mean that productivity of any of the crops cannot be above or below the indicated level of 4.0 tons/ha. The bottom line is that countries in the Nile Basin need to strive, by improving rainfed agriculture productivity, to attain an average productivity level of 3.0 tons/ha by 2030 and 4.0 tons/ha by 2050 in order to achieve food security and economic growth. Rainfed agriculture is vulnerable to climate shocks, and supplementary irrigation needs to be considered as part of a whole rainfed agriculture improvement package.

The question remains whether expansion of and investment in rainfed agriculture would impact irrigation water saving. There is no definite mathematical relationship between increase in rainfed agriculture productivity and decrease in irrigation water use. What is certain, however, is that if productivity enhancement bears results, countries would likely be encouraged to invest more in it than in irrigation. Enhancing rainfed agriculture productivity is cheaper than expanding irrigation. Abrams (2018) provides us a comparative cost-per-hectare study of improved smallholder rainfed agriculture (water

[3] The high rainfed crop productivity reported for Burundi and Rwanda, almost close to potential yield, presented in the Siderius et al. (2016) study may be due to a data error. Rainfed cereal crop yield figures for Burundi (1.41 tons/ha) and Rwanda (1.28 tons/ha) accessed from the World Bank data portal are significantly less than those presented by Siderius et al. (2016) (Table 2) and appear relatively reasonable. This inconsistency may have resulted from a misreporting of the rice yield values as rainfed yield values. According to Bastiaanssen and Perry (2009), the rice yields of Burundi and Rwanda are 3.62 tons/ha and 3.25 tons/ha, respectively. This is at par with the global average rice production.

Table 3. Future rainfed crop productivity and its impact on irrigation development

Nile Basin countries	Potential yield (t/ha)	Future projection			
		2030		2050	
		Yield (t/ha)	Reduction in irrigation area (%)*	Yield (t/ha)	Reduction in irrigation area (%)*
Burundi	4.0	3.0	25	4.0	50%
Egypt (irrigated)	19.5		-	-	
Ethiopia	4.0	3.0	25	4.0	50%
Kenya	4.0	3.0	25	4.0	50%
Rwanda	4.0	3.0	25	4.0	50%
South Sudan	4.0	3.0	25	4.0	50%
Sudan	4.0	3.0	25	4.0	50%
Tanzania	4.0	3.0	25	4.0	50%
Uganda	4.0	3.0	25	4.0	50%

Note:
[a] No rainfed agriculture productivity data are available for South Sudan.
*Reduction in irrigation area (%) refers to the land that is planned for irrigation expansion but not developed as planned due to encouraged productivity enhancement through intensification of rainfed agriculture. So the indicated percentages are land rescued from planned irrigation.

harvesting included), small-scale community irrigation and large-scale irrigation in sub-Saharan Africa. The study indicates that yield per USD 1,000 investment is 4 tons for improved rainfed farming, 0.44 tons for small-scale irrigation and 0.67 tons for large-scale irrigation. Furthermore, the yield per dollar of in-field expenditure is six times larger for improved rainfed agriculture compared to commercial irrigation. This means that an investment of USD 1 in improved smallholder rainfed agriculture provides nine times more food than investment in small-scale irrigation and six times more food than investment in large-scale irrigation. Furthermore, rainfed agriculture productivity enhancement benefits a larger number of farmers. Despite the attractive benefits of investment in rainfed agriculture, the total investment cost due to the scale of rainfed agriculture and its vulnerability to climate change shocks may discourage countries from making a total shift from irrigation to enhanced rainfed agriculture. An attractive rainfed agriculture policy and attractive investment packages can sway countries into shifting their investment priorities away from irrigation. We, however, cannot develop a functional relationship to estimate the reduction in irrigated agriculture as a function of increased rainfed productivity improvement because there is no evidence from the past. So, we reverted to using a different kind of evidence to estimate irrigation decline in relation to rainfed agriculture productivity.

As discussed in Technical Report II (NBI 2020b), it is predicted that the irrigation development trend is likely to be halved by 2030 and beyond in sub-Saharan Africa. However, it is not possible to curtail irrigation development expansion by 50% at the end of 2030, given that no significant investment is taking place in rainfed agriculture productivity in the basin. Once tangible investment in rainfed productivity starts taking root, it is assumed that public investment in irrigation development would shift to enhancing rainfed productivity. Based on the above considerations, it is assumed that rainfed productivity enhancement would lead to reduction of the rate of irrigation expansion by at least 25% (in relation to planned irrigation) at the end of 2030 and by 50% by 2050 in the upper riparian countries. Of the lower riparian countries, no rainfed agriculture intensification is anticipated in Egypt. Sudan, however, has less developed rainfed agriculture, and needs to revamp it at least in consonance with the upper riparian countries. Note that Sudan once had sizable traditional and semi-mechanized rainfed agriculture, but that is currently declining[4]. So there is potential to revamp rainfed agriculture,

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Rainfed agriculture in Sudan has performed poorly in the past decade. The traditional rainfed farming sub-sector declined from a share of 24.6% of the total agriculture in the 1990s to 2.4% during 2000-2008. Drought and declining average yields are mentioned as causes of the decline. Semi-mechanized farming has also shrunk from 6.3% in the 1990s to 3.1% in the 2000s, and has ceased to be the dominant source of food (sorghum) for Sudan. Generally, low yields are the main reason driving the decline in sorghum production in the semi-mechanized farming systems. Yields in Sudan are well below their research potential and below those in other countries with broadly similar production conditions (e.g., Argentina, China and Nigeria) (IMF 2013).

at least to recover the 1990s level. However, rainfed productivity cannot be realized without proper knowledge, skill and access to financial resources. International and basin-wide efforts are required to bring about visible changes in rainfed agriculture. Without it, rapid irrigation growth will undoubtedly continue to prevail in the basin.

4.2 Improved Water-use Efficiency

Irrigation efficiency is an important aspect of improving water use. In the large-scale irrigation schemes of the Nile Basin, improved water-use efficiency needs to be taken up seriously as one of a series of water-saving measures. As shown in the baseline report (Technical Report I) (NBI 2020a, Table 2), almost 98% of the existing irrigation systems are in Egypt (58%) and Sudan (30%); hence a sensible water-saving strategy would focus on improving the overall irrigation efficiency in these two countries. According to ICARDA (2011), over 2.25 Mha (5.36 million feddans) in Egypt are irrigated by traditional surface irrigation systems. Compared to modern and improved irrigation systems, these systems have a very low field water- application efficiency of around 50% (ICARDA 2011). Recent research results from Saad Eddin et al. (2016) indicate that average conveyance efficiencies were 82.4%, 92.7% and 98.38% for traditional earthen, lining and buried-pipe ***mesqas***[5], respectively, whereas the average application efficiency under improved on-farm surface irrigation (precision laser land leveling) was 81.5% compared with 59% under traditional surface irrigation. Therefore, there is room for improving irrigation efficiencies in Egypt, especially in areas under traditional surface irrigation. Tables 4 and 5 provide the conveyance, application and overall efficiencies for major irrigation schemes in Egypt.

With respect to Sudan, data on irrigation efficiencies vary, as indicated by the review presented in Technical Report I (Baseline Assessment). It has been estimated that the overall efficiency of long-furrow irrigation of sugarcane schemes varies between 68% and 78%. However, another study by Mohamed et al. (2011) on the large-scale Gezira irrigation scheme indicates significantly lower irrigation efficiency. While a section-by-section study indicated irrigation efficiency varying between 19% and 36%, for the Gezira scheme as a whole it stood at 22% (Mohamed et al. 2011). Indeed, efficiency values obtained from research and the NBI office significantly varied for

Table 4. Application and conveyance efficiencies (%) for major irrigation schemes in Egypt.

	Irrigation structure	Efficiency (%)
Conveyance efficiency (%)	Traditional	82.4
	Lined canal	92.7
	Buried canal	98.4
Application efficiency		
	Improved surface	81.5
	Traditional surface	59
	Sprinkler	
	Day-time irrigation	60
	Morning/night	85

Source: NBI-validated Excel sheet databases.

Table 5. Overall efficiency (%) of major irrigation schemes in Egypt.

Overall efficiency (%)	Irrigation application		
Conveyance (morning/night)	Improved surface	Traditional surface	Sprinkler
Traditional	67.2	48.6	70.0
Lined canal	75.6	54.7	78.8
Buried canal	80.2	58.2	83.6

Overall efficiency (%) = Conveyance x Application efficiency

[5] In the traditional irrigation system, water is supplied by publicly-owned branch canals to privately-owned mesqas from which farmers take their water. Operation of the branch canals is based on a rotation system.

the Gezira scheme. Despite these inconsistencies, there is significant room for improving irrigation efficiency in Sudan.

Irrigation efficiency improvement in the basin needs to be viewed not separately but in tandem with the other water-saving measures explored in this study. The potential efficiency improvement for existing and new development systems is separately discussed. As far as future irrigation is concerned, improved irrigation efficiency measures need to be applied throughout the basin countries (both upstream and downstream).

4.2.1 Existing Irrigation Schemes

As discussed in Section 4.2, the total irrigation area of the upper riparian countries constitutes only 2% of the irrigation in the Nile Basin; so investing in efficiency improvement renders negligible water saving for the basin as a whole. Basin-wide strategies and investment to improve irrigation efficiency therefore need to be focused on the large-scale irrigation schemes of Egypt and Sudan. For both Egypt and Sudan, modernizing surface irrigation systems is an important objective. Egypt, for instance, has a long tradition of implementing technologies such as precision laser-guided land leveling. Replacement of old unlined tertiary canals with lined canals, pressurized irrigation systems (sprinklers/drip) and introduction of raised-bed irrigation (Swelam 2016) are some of the innovations that need to be up-scaled and implemented in both Sudan and Egypt. Given the hot summer and the future warming tendency, converting significant areas that are presently under gravity-based irrigation technologies to buried conveyance systems and pressurized application systems can render better water-saving outcomes. Implementation of pressurized irrigation application systems can be considered for high water-consuming crops such as sugarcane, cotton and tomato. Even some of the other countries such as Ethiopia[6] and Kenya that are less experienced with large-scale irrigation systems have adopted pressurized irrigation systems.

Regardless of the reported inconsistencies in irrigation efficiency, there is room for up to 30% efficiency improvement in Egypt and Sudan, especially in the traditional gravity-based irrigation schemes. On the basis of this study and past studies, Egypt and Sudan's overall irrigation efficiency can be improved 15-30% by 2050 with intermediate improvement of 5-15% by 2030. In both countries, the maximum improvement can be achieved in traditional gravity irrigation schemes. Table 5 provides a guide as to the improvement for each irrigation type in Egypt.

In the upper riparian countries, as we have noted above, extracting higher efficiency from the current irrigation system only yields negligible water savings for the region as a whole. It does, however, benefit local water availability.

Similar values of overall efficiency improvement in the range of 5-15% by 2030 and 15-30% by 2050 are achievable in the upper riparian countries. We assumed the lower limit of efficiency improvement to reflect the experience of the upper riparian countries.

The exercise helps in local water-saving capacity development and garnering water management experience for future planned irrigation systems. The improvement values are given in Table 4. Higher values of efficiency improvements are anticipated from traditional gravity-based irrigation and less from modern irrigation systems. The overall assumption is that countries engage in diverse efficiency improvement activities such as transforming part of the gravity irrigation to pressurized, canal lining/buried, precision land leveling, changing water application time, etc.

4.2.2 New Planned Irrigation Schemes

For new planned irrigation systems, all basin countries need to seriously consider implementing high-end water-saving technologies. Closed conveyance systems, pressurized distribution systems and improved water application technologies may have to be considered right from the inception stage of future projects. This should be possible if there is a regime of full or partial regional cooperation among Nile Basin countries. In a future scenario of warmer climate and surface irrigation impacting the water table and salinity, high-end irrigation technologies are useful for both water saving and environmental protection. Informed by past experience and a hot climate, Egypt and Sudan are anticipated to include modern pressurized systems in all their future

[6] The Finchaa sugarcane project is 100% pressurized.

irrigation plans. Similarly, many upper riparian countries also are anticipated to gradually develop modern pressurized irrigation systems. In the future, surface irrigation systems are not going to be tenable in the Nile Basin due to high irrigation demand, climate warming and environmental concerns. The NB countries need to start developing a mixed surface/pressurized system and gradually move to a full pressurized system by 2050. From past experience and due to practical considerations related to resources and skills, it is projected that the overall irrigation efficiency of upper riparian countries will improve to about 65% by 2030 and 75% by 2050. The 2050 projection is based on the Phase I study by the Nile Basin Initiative (Technical Note IV [NBI 2015]); it assumes greater adoption of sprinkler irrigation, with which there already is a good deal of experience in the basin. In Egypt and Sudan, new planned schemes need to include pressurized systems and aim for efficiency levels nearly as high as those suggested in Technical Note IV (NBI 2015). It is assumed that the overall efficiency of the new schemes will improve to 80% and 85% for Sudan and Egypt, respectively, by 2030, and to 85% and 90% by 2050.

Table 6 shows the relative increase in overall efficiencies for existing schemes and planned schemes at the country level. Due to inconsistencies in the irrigation efficiencies reported in literature and NBI-supplied data and the lack of information on scheme-level efficiencies, the study suggested relative increases to be included as such information is available.

In addition to conventional efficiency improvement, implementation of smart irrigation[7] and greenhouse irrigation systems is likely in the basin. Under current circumstances, Egypt appears to have better capacity to initiate and manage high-end water-saving possibilities. Other countries in the basin too can implement high-end smart agriculture technologies in their future planned schemes in order to reap far-reaching benefits in terms of water savings and sustainable water use.

4.3 Improving Cropping Patterns

In water-stressed regions like the Nile Basin, current cropping patterns are important points of concern in respect of water saving. They need to be modified for long-term sustainable use and better irrigation management within a voluntary or legal cooperative framework.

At this stage it might be technically and politically daunting to develop and agree on a regionally optimized cropping pattern for the entire Nile Basin given the lack of a legal and institutional cooperative framework and weak agricultural trade relations. A legally binding cooperative framework would be the first step toward such regional activities. In fact, the

Table 6. Improvement in overall irrigation water-use efficiency

Nile Basin country	Efficiency improvement (%)					
	Existing schemes*				New development**	
	2030		2050		2030	2050
	Range	Adapted	Range	Adapted		
Burundi	5-15	5	15-30	10	15	20
Egypt	5-15	10	15-30	20	15	25
Ethiopia	5-15	5	15-30	10	15	20
Kenya	5-15	5	15-30	10	15	20
Rwanda	5-15	5	15-30	10	15	20
South Sudan+	5-15	5	15-30	10	15	20
Sudan	5-15	10	15-30	20	15	25
Tanzania	5-15	5	15-30	10	15	20
Uganda	5-15	5	15-30	10	15	20

* Indicates relative efficiency improvements over the current level. These values are added to the current efficiencies of country-specific topologies in the case of Egypt and Sudan and to country-level efficiencies in the rest of the riparian countries.
**Indicates the relative efficiency increase in the planned irrigation schemes in each country relative to the current efficiency. It is expected that a significant portion of the planned schemes would be of high efficiency.
+ No rainfed agriculture productivity data are available for South Sudan.

[7] Smart irrigation can be defined as a system operated by an automatic control system using a series of sensors buried in the soil to measure optimal moisture availability.

movement could start with improving in-country cropping patterns, at least partially, by replacing some of the more water-intensive crops with some less water-consuming ones. The next step would be to develop a regionally optimized cropping pattern for the basin under an agreement of cooperation. Improving the cropping pattern for sugarcane and rice has indeed been considered in the existing irrigation schemes. For instance, no sugarcane or rice production is likely to be considered in the future development plans made by Egypt and Sudan.

4.3.1 Improving In-Country Cropping Patterns

Sugarcane to sugar beet. Countries with large-scale irrigation systems need to introduce optimal cropping patterns with the objective of saving water. This involves moving away from high water-consuming crops in the current cropping patterns. Sugarcane is one such crop that is extensively grown in the lower parts of the Nile. Studies show that countries like Egypt have started to improve cropping patterns through research-based comparison studies. A comparative study of sugarcane and sugar beet in Egypt (Farag et al. 2017) shows that the average amount of water used (water applied) to grow sugarcane is 11,000 m^3/*feddan*[8] (26,190 m^3/ha) compared to 3,200 m^3/*feddan* (7,620 m^3/ha) for sugar beet (Table 7). A *feddan* of sugarcane requires 3.44 times more water than a *feddan* of sugar beet. As this study focuses on water-saving analysis, it is clear that sugar beet has a clear advantage over sugarcane. Given the possibility of future water scarcity and the critical need for basin-wide water-use sustainability, priority should be given to promoting sugar beet. If the average sugar production capacity of sugar beet is improved, its water-saving potential would be attractive. Therefore, replacing sugarcane with sugar beet in existing sugar production will gradually phase out sugarcane cultivation and may be beneficial in terms of water saving. However, as the existing infrastructure of the sugar industry is built around sugarcane, it may be difficult to completely avoid sugarcane in both Sudan and Egypt within the foreseeable future. Both countries could convert at least a part of their sugarcane production to sugar beet by 2050. This analysis assumes that 50% (20% by 2030 and 30% by 2050) of sugarcane production in Egypt and Sudan can be converted to sugar beet. Based on atypical study on sugarcane and sugar beet production (Table 5), converting 50% of the sugarcane area to sugar beet would save about 1,275 million cubic meters (MCM) of water. However, converting 50% of sugarcane fields into sugar beet would reduce the total yield by about 55%. This can create regional virtual trade opportunities by growing the deficit sugar in the upper riparian countries (see Section 4.2.3).

Table 7. Comparison of sugarcane and sugar beet crop production in Egypt

Parameter	Unit	Sugarcane	Sugar beet
Crop duration	Months	12	7
Area under cultivation	*Feddan* (fed)	326,900	480,113
	Hectare (ha)	137,298	201,647
Water applied	m^3/fed	11,000	3,200
	m^3/ha	26,190	7,619
Water consumption	m^3/fed	8,218	2,100
	m^3/ha	19,566	5,000
Field water-use efficiency	Kg/m^3	4.41	6.79
Crop water-use efficiency	Kg/m^3	5.9	10.3
Average yield	Tons/fed	48.48	21.73
	Tons/ha	115.4	51.7
50% of sugarcane area converted to sugar beet	Fed	-163,450	163,450
	Ha	-68,649	68,649
Water saving from converting 50% sugarcane to sugar beet	MCM		1,275
Total sugar yield from 50% of crop area	Tons	3,328,104	1,492,429
Yield reduction due to conversion from sugarcane to sugar beet	%	55	-

Source: Farag et al. 2017.

[8] 1 feddan = 0.42 ha. Note that crop water requirement varies with location within the country. The values may vary in literature.

Assuming institutional cooperation, the upper riparian countries would need to produce over 2 million tons of sugar to trade with Egypt.

Rice. The second crop selected for in-country cropping pattern change is rice. As indicated in earlier studies by Abou-Hadid (2006), production of rice in Egypt can be limited to the minimum required for protecting the delta from seawater intrusion, which is estimated at about 294,000 ha. This figure may need to be updated based on current data. Studies on modifying in-country cropping patterns for optimal water saving are a continuous process and need regular revision by the countries concerned. For this study, Egypt may curtail rice production from the current 760,000 ha to 294,000 ha. Sudan has negligible rice production, but other crops may be considered in future studies.

4.3.2 Improving Regional Cropping Patterns

Sugarcane and rice are the two most water-intensive crops grown on a large scale in Egypt (Section 2.2). Sugarcane is grown extensively also in Sudan. Both crops are grown using gravity irrigation. Under these circumstances, and given also that they are grown extensively in a warm and high water-consuming part of the basin, these two crops can be considered for regional crop trade by growing them in less water-consuming countries in the basin. Such a strategy would, apart from saving water, facilitate regional cooperation, enhance regional economy, virtual water trade and build trust and hydro-solidarity between upstream and downstream countries. As such institutional cooperation grows, other crops can be produced in less water-consuming areas and traded with other basin countries.

Sugarcane. The area sown to sugarcane varies from year to year. According to USDA (2019), sugarcane irrigated area in Egypt was about 130,000 ha in 2019/20. Similarly, FAOSTAT[9] estimates that about 74,672 ha was covered by sugarcane in Sudan in 2017. The average water requirement for sugarcane is around 2,000 mm/season[10] in Egypt (see Technical Report I: Baseline Report) and 1,600 mm/season in Ethiopia (Finchaa sugarcane plantation). However, the net irrigation requirement has fallen to almost 900 mm/season due to rainfall availability in the Blue Nile part of the Nile (Geleta 2019). Irrigation requirement for sugarcane in warm humid regions fell significantly due to the high seasonal rainfall that supplemented irrigation.

Rainfed sugarcane production (with supplemental irrigation) is prevalent in long-duration rainfall regions of the Nile Basin, such as in Uganda. Expanding such practices in areas of the upper riparian countries (mostly high-rainfall regions of equatorial countries) should be possible. There is a misconception that expanding rainfed agriculture may significantly alter the water balance of the basin. In fact, rainfed agriculture consumes less than the atmospheric evaporation demand of the location. Shifting sugarcane production to countries with low evaporative demand, as explained by the Finchaa case study in Ethiopia, and to equatorial countries with long rainfall seasons (such as Uganda) can lead to significant water savings. Assuming that 25% of the total sugar production is shifted to upper riparian countries with relatively low ET and long rainfall seasons under a supplementary irrigation system, it can offset sugarcane cultivation in Egypt and Sudan by 25% of current levels, as 50% of the land would be converted to sugar beet cultivation as per the in-country cropping pattern change. Such regional arrangements require major commitments and institutional cooperation in the basin.

Rice and other crops. The Nile Basin countries can consider rice as a regional crop and cooperate to produce it in the humid parts of the basin. Since rice does not require complicated infrastructure as sugarcane does, it is possible to treat it as a regional crop as long as the countries concerned formally cooperate and commit to do so.

Currently, much of the basin's irrigated rice is produced in Egypt. It should be possible to reduce production area from the current 760,000 ha (USDA 2019) to a minimum of 294,000 ha, as recommended by a local study (Abou-Hadid 2006)[11], with the rest of the production produced in the upper riparian countries. This is equivalent to shifting 61% of rice production to upper riparian countries. Such a move will bring advantages of water saving, regional cooperation and flow of goods and services,

[9] Sudan sugarcane production fact sheet: FAOSTAT – http://www.factfish.com/statistic-country/sudan/sugar%20cane%2C%20area%20harvested

[10] Water requirement and irrigation water requirement are assumed to be equal in Egypt due to little or no additional rainfall contributing to the irrigation system.

[11] Abou-Hadid (2006) suggested reduction in rice area to a minimum of 294,000 ha, which is the minimum limit for protecting the Nile delta from seawater intrusion. This is explained in Section 2.2.

enhanced regional economy, virtual water trade and trust and hydro-solidarity between upstream and downstream basin countries.

Assuming that 30% of the rice production in Egypt is converted to other cereal crops (such as barley or wheat) by 2030, and another 30% by 2050, in return, the upper riparian countries can produce about 60% of the rice for export to Egypt by 2050.

Since Sudan has negligible rice production, this study did not factor other crops for regional trade.

4.4 Implementation of Water Deficit Irrigation (WDI)

Deficit irrigation involves reducing the amount of water provided to the crop during the growing season by way of soil moisture, rainfall and irrigation to a level below that needed for maximum plant growth (Galindo et al. 2018). When practiced scientifically, this can produce near-maximum crop yields with less water than would otherwise be used. Many countries in the Mediterranean are gradually shifting from conventional full irrigation to deficit irrigation to cope with water scarcity (Galindo et al. 2018). In its early experimental study in various agroecological geographies, FAO (2002) published evidence that proper application of deficit irrigation practices can generate significant savings in irrigation. The report demonstrates that substantial savings of water can be achieved with little impact on the quality and quantity of the harvested yield, provided it is backed by sound knowledge of crop behavior as crop response to water stress varies considerably. Galindo et al. (2018) underlined the importance of reliable or guaranteed water supply for implementing deficit irrigation, which induces a gradual water deficit due to depletion of soil water reserves. When crops are faced with water scarcity beyond the amount required under deficit irrigation due to uncontrollable factors, it may result in reduced harvestable yields than anticipated. Hence, reliable or guaranteed water supply can compensate for low water storage in the soil.

In the context of the Nile Basin, limited field-scale research on deficit irrigation in Egypt, Ethiopia and Sudan have given mixed results. In the case of clover, which is grown widely in many parts of Egypt, application of deficit irrigation (Ouda et al. 2010) using freshwater and drainage water at 95%, 90%, 85% and 80% of full irrigation showed acceptable yield reduction of 3.2%, 5.4%, 7.1% and 8.8% for freshwater and 1.9%, 4.4%, 7.8% and 12% for drainage water. This study concluded that 10% water-deficit irrigation (90% of full irrigation) can be practiced safely in Egypt. It also indicated that up to 20% water reduction (80% of the full application) can be applied with an acceptable level of yield reduction.

In contrast, experimental studies on sunflower under five irrigation treatments in the Gezira scheme in Sudan showed less encouraging results in terms of water saving (Farah 2018; Elsheikh et al. 2015). Farah (2018) skipped one irrigation cycle at the heading stage. Deficit irrigation at the heading stage gave results comparable to full irrigation. Sunflower was found highly sensitive to deficit irrigation at the flowering stage. Though the study recommended application of deficit irrigation at the heading stage, overall water saving amounted to only about 3%, which doesn't justify its application on a large scale given the high level of management and costs it involves. Elsheikh et al. (2015) showed low water productivity under deficit irrigation for the same crop due to inefficiency in water use, weak performance of the irrigation system and mismanagement. However, a study by Al-Solaimani et al. (2017) showed that interactive application of 10% deficit irrigation and a higher rate of nitrogen (200 kg/ha) improved Sudan's grass growth, biomass and water-use efficiency, indicating the potential of a combination of deficit irrigation and enhanced agronomic innovation.

The Nile Basin is one of the water-scarce basins in the world where proper application of deficit irrigation can be initiated in the short and long terms. The application can begin in the existing large-scale irrigation schemes in Egypt and Sudan, and gradually expand basin-wide. In a scenario of cooperative collaboration, the experience thus gained can be transferred to small-scale irrigation schemes and large-scale schemes planned in the upper riparian countries. The process should begin with extensive experimental application on candidate crops in different agroecological zones and under different water depletion rates (from full irrigation) and agronomic management regimes. Where found successful, the countries concerned can immediately convert a portion of their irrigation area to deficit irrigation. It is projected that by 2030, some 15% of Egypt's and 7.5% of Sudan's total irrigation will be under deficit irrigation. By 2050, Egypt is projected to have 30% and Sudan 15% of their irrigated area under deficit irrigation. While there is negligible application of deficit irrigation in the existing irrigation schemes of upper riparian countries, these countries too would need to incorporate it in their planned irrigation schemes by 2030 and 2050. Commercial farms too may need to adopt deficit irrigation. In a scenario of full regional cooperation beyond 2030, policy initiatives encouraging agronomic management and pricing mechanisms need to be implemented basin-wide.

Following an examination of deficit irrigation studies on various crops under different ecological conditions, FAO (2002) published a list of crops appropriate for water-deficit irrigation (Table 8). Crops such as groundnut, soybean, common bean and sugarcane showed less yield reduction than other crops. Cotton, maize, wheat, sunflower, sugar beet and potato are all well suited for deficit irrigation applied either throughout the growing season or at pre-determined growth stages. Table 8 shows the expected relative yield of different crops with a 25% deficit in evapotranspiration. This information could serve as a general guideline for countries that have no specific studies.

4.5 Quantitative Demonstration of Deficit Irrigation in the Nile Basin

We discuss two crops here, one country-specific and one for basin-wide application, for demonstration purposes. Clover is a dominant crop in Egypt, and recent data from NBI show that it is grown over 1.7 Mha (see Technical Report I: Baseline Assessment). Clover has been used to demonstrate deficit irrigation in Egypt by Ouda et al. (2010). The average water consumption rate of clover for the five agroecological zones in Egypt is about 592 mm (see Technical Report I: Baseline Assessment). Total water consumption in the irrigated area in Egypt is about 10,032 MCM. Let us assume that Egypt initiates and gradually implements deficit irrigation in 15% and 30% of the total clover area by 2030 and 2050, respectively. Given the country's experience, we assume water-deficit application of 10% in 2030 and 20% in 2050. In this scenario, a total of 150.5 MCM (from 15% of the clover area) and 602 MCM (from 30% of the clover area) of water can be saved by 2030 and 2050, respectively. Table 9 provides a range of deficit application scenarios. This amount of saved water can irrigate about 36,900 ha by 2030 and 147,599 ha by 2050. If, for instance, 50% of the land is under deficit irrigation by 2050, an equivalent of 246,000 ha land can be available for wheat in Egypt. If country-specific water saving is possible in the basin countries, more wheat or other less water-consuming crops can be produced. Water resources decision-support models may reveal a more elaborate and optimal water allocation analysis by incorporating deficit irrigation in the basin.

For policy-driven basin-wide application of deficit irrigation (assuming full cooperation), commonly grown crops such sugarcane and cotton were considered for demonstration purposes. Almost all countries in the Nile Basin grow both crops. The net water saving in each basin country is approximately equivalent regardless of significant

Table 8. Expected relative yield from different crops following a 5% deficit in evapotranspiration (ET)

Crop	Stage when ET deficit occurred	Irrigation method	Expected relative yield (t/ha)
Common bean	Vegetative	Furrow	0.86
	Yield formation		0.78
	Whole season	Drip	0.79
Cotton	Boll formation and flowering	Furrow	0.88
Groundnut	Flowering	Furrow	0.82
Maize	Whole season	Sprinkler	0.82
Potato	Whole season	Drip	0.79
	Vegetative	Furrow	0.9
Soybean	Vegetative	Furrow	0.86
Sugar beet	Whole season	Furrow	0.79
	Mid-season		0.84
Sugarcane	Tillering	Furrow	0.9
Sunflower	Whole season	Furrow	0.77
	Vegetative yielding		0.79
Wheat	Whole season	Sprinkler	0.81
	Flowering and grain filling	Basin	0.9

variations in ET. This study demonstrates the potential for water saving in deficit irrigation based on area coverage in Egypt and Sudan. Sugarcane irrigation covers about 325,912 ha as given in the baseline report (Technical Report I) (NBI 2020a). The average water consumption rate of sugarcane is about 2,000 mm, which is equivalent to 6,518 MCM. For practical purposes, considering the high management required in deficit irrigation, similar to the clover case mentioned earlier, Egypt applies deficit irrigation on 15% and 30% of the total sugarcane area by 2030 and 2050, respectively. Based on a 10% and 20% water deficit (in relation to full irrigation) by 2030 and 2050, respectively, the total water saving would amount to 97.8 MCM by 2030 and 391 MCM by 2050. This saved water is equivalent to full irrigation of 23,976 ha and 9,504 ha of sugar beet by 2030 and 2050, respectively (Table 9). If, for instance, 50% of the sugarcane area is covered by deficit irrigation by the end of 2050, about 652 MCM of water can be saved, equivalent to irrigating almost 160,000 ha of additional sugar beet. This would be almost half of the area currently covered under sugarcane. An additional analysis is provided for wheat in Table 9. Combined with other water-saving measures described in this report, there is great potential to apply WDI basin-wide in the Nile Basin provided it is done properly.

The seasonal configuration of the upper and lower riparian countries of the Nile are such that during the June-July-August-September (JJAS) summer, the evaporative demand from Ethiopia and the equatorial Nile countries is relatively less than in the rest of the months. The highest evaporation occurs in the lower riparian countries of Sudan and Egypt. This unique configuration allows for the conjunctive use of surface water and groundwater in a weighted proportion. While a significant amount of water can be stored during JJAS in the cool highlands of Ethiopia in a series of reservoirs, a significant share of irrigation in Sudan and Egypt can be facilitated using groundwater. Thus, part of the water lost through evaporation in the reservoirs and canals during the hot months of June, July and August can be put to beneficial use. Furthermore, groundwater needs to be seen as an important component of water supply to reduce future demand.

Many studies indicate that Egypt and Sudan share the largest non-renewable groundwater aquifer in the world with Libya and Chad. It is estimated that of the more than 500,000 km3 of water stored in the aquifers, about 14,818 km3 is recoverable (AbuZeid 2003); about 5,525 km3 in Egypt and 4,787 km3 in Sudan (AbuZeid and Elrawady 2011). Studies indicate that this recoverable groundwater can be tapped for 120 years (AbuZeid and Elrawady 2011), and even longer with innovations and technology. In this study, it was projected that Egypt would increase its estimated groundwater utilization from the current 5 BCM/year to 10 BCM/year by 2030 and to 20 BCM/year by 2050. Similarly, it is assumed that Sudan would improve its groundwater utilization to 2.5 BCM/year by 2030 and 5 BCM/year by 2050. Utilization of groundwater directly contributes to

Table 9. Estimated evidence of significant water savings from WDI in sugarcane in Egypt.

Crop		Water deficit (over full irrigation) (%)	Water consumption (MCM) for % area under deficit irrigation					
Type	**Sugarcane**		**10.0**	**15.0**	**20.0**	**30.0**	**50.0**	**100.0**
Area	325,912	Full irrigation	651.8	977.7	1,303.6	1955.5	3259.1	6,518.2
WC (mm)	2,000	10	586.6	880.0	1,173.3	1,759.9	2,933.2	5,866.4
WC (MCM)	6,518.24	20	521.5	782.2	1,042.9	1,564.4	2,607.3	5,214.6
			Water saved (MCM) (%)					
Area	325,912	Full irrigation						
WC (mm)	2,000	10	65.2	97.8	130.4	195.5	325.9	651.8
WC (MCM)	651.82	20	130.4	195.5	260.7	391.1	651.8	1,303.6
			Equivalent area irrigated by the saved water - sugar beet (ha)					
Crop	**Sugar beet**	10	10,792	16,188	21,584	32,375	53,959	107,918
WC (mm)	604	20	21,584	32,375	43,167	64,751	107,918	215,836
			Equivalent area irrigated by the saved water - wheat (ha)					
Crop	**Wheat**	10	15,984	23,976	31,968	47,952	79,920	159,839
WC (mm)	407.8	20	31,968	47,952	63,936	95,904	159,839	319,678

Note: WC – Water consumption.

reducing the future unmet demand. Integrated water resources modeling needs to consider seasonally weighted conjunctive use of surface water and groundwater to save on water being lost due to weather conditions.

However, exploiting deep aquifers may have undesirable environmental consequences unless it is carefully studied and a sustainable yield is determined. Moreover, water withdrawal from deep aquifers is expensive, and so affordability and accessibility would have to be considered.

In the upper riparian countries, the groundwater base is not as well explored. As indicated in NBI (2012), groundwater resources across the upper riparian countries are limited to domestic water supply and not agriculture. Agriculture is dependent on rainfed systems and limited surface flow irrigation systems. As more data becomes available, a detailed study is suggested on groundwater in the Nile Basin for planned irrigated agriculture.

4.5.1 Large-Scale Joint Development for Water Saving

Building large-scale storage dams on the Blue Nile has long been touted as an opportunity for cooperation in the basin. For instance, Goor et al. (2010) provided scientific evidence that if the operation of the four cascaded reservoirs to be constructed in the Blue Nile gorge (Karadobi, Beko-Abo, Mandaya and Border dams) were to be coordinated with the existing ones, it would enable an average annual saving of at least 2.5 BCM through reduced evaporation losses from Lake Nasser.

Independent studies commissioned by World Bank (Blackmore and Wittington 2008) indicate that the construction of more cascaded large storage dams on the Upper Blue Nile (Abbay) would provide more economic benefit and enhance water availability in the system. Building cascaded reservoirs on the Upper Blue Nile reduced system-wide evaporation losses from 16.6 BCM to 15.5 BCM. However, unless large-scale development projects are viewed as regional common pool resources and developed and operated jointly, the desired outcomes of water saving may not come about. Gains in water saving from joint reservoir operations can only be estimated by tuning the regional water resources model for optimal operation. Two sets of models can be configured. The first model can represent the time horizon up to 2030, where the modeling scenario represents all dams, including those under construction (Grand Ethiopian Renaissance Dam (GERD) and others) in the basin. The second modeling configuration needs to include all planned dams in the eastern and equatorial Nile..

5. Building an Environment Conducive to Saving Water

Not only are physical or economic water scarcities a challenge to the future of the Nile Basin, so is institutional support. Implementing the water-saving mechanisms presented in this study would require regional and national policy support. Primarily, the basin countries have to enter into a collaborative agreement, establish permanent regional institutional and legal mechanisms to monitor water-saving resolutions, explore regional financing mechanisms and facilitate economic cooperation and virtual water trading. These initiatives will lay the foundation for future sustainable management of both blue and green water (rainfall-based productivity enhancement) in the basin. The following four areas are where public policy support is recommended:

Improve rainfed agriculture. The main drawback of rainfed agriculture is its highly variable availability in time and space. Abrams (2018) reports that farmers who contend with variable annual rainfall and erratic rainy seasons cannot risk expenses such as fertilizer or high-yielding seed varieties. Under such circumstances, improving rainfed agriculture productivity, apart from agronomic inputs and management, requires a policy that enables (i) building of safeguard mechanisms for extreme drought conditions, such as farmers' rainfed agriculture insurance; and (ii) incorporates a storage continuum approach (McCartney et al. 2013) throughout the community to temporarily arrest rainwater, conserve it and then release it as supplementary irrigation. Suggestions to improve rainfed agriculture productivity in the Nile Basin would entail the following regional policy support:

- Sustained and widespread investment in rainfed productivity innovations and technology, and sharing of responsibility between basin countries and other countries who wish to participate as a regional group in seeking funds and building capacity.
- Sustained capacity building of professionals, development agents and farmers through research and piloting of inputs and technologies requires cross fertilization of ideas and skills globally.
- Countries need to adopt an open door policy for joint investment, knowledge transfer and establishing trade relationships within the Nile Basin bloc and outside.
- Harmonized basin-wide policies, strategies and enforcement mechanisms, and commitment from decision-makers and stakeholders are key instruments that can rapidly expedite regional-scale rainfed agriculture productivity enhancement in the basin.

Enhance the performance of large-scale irrigation. The study indicated that there are inconsistencies and gaps in scheme-level irrigation data on variables such as efficiency, productivity, timing (day or night) and frequency of irrigation application and other related data required for planning irrigation improvements in the basin. This would call for:

- Detailed surveys and benchmarking of irrigation performance in the basin, especially in large-scale irrigation schemes such as those of Sudan and Egypt. Without detailed irrigation data, steps to improve efficiency, modify cropping patterns and applying water deficit irrigation would be futile.
- Regional support in exploring international funds to implement water-saving activities and monitoring efforts in the basin.
- Introducing incentive mechanisms for farmers adopting smart irrigation activities such as automated greenhouse irrigation systems.

Build an uncontested and improved common water resources database. Scientific analysis of water and irrigation systems under transboundary conditions requires us to build uncontested and consistent hydrological and water resources datasets.

- The basin countries need to agree to either set up or update existing highly accurate hydrological and irrigation measurement stations. This is fundamental to obtaining highly reliable data, accurate interpretation of water management decisions and consensus building.
- Adopt regional hydro-meteorological and flow forecasting systems to guide regional water management decisions and reduce uncertainties.

Promote an inclusive public-private partnership (PPP) scheme. Public-private partnerships need to be promoted to inject the required investment, knowledge and diversification of incomes into the community. For instance, while entrepreneurs with the needed capital can be supported by providing inputs and farm implements, agriculture/water scientists with critical agronomic and farm management knowledge can be supported to join a consortium of farmers (cluster of smallholder farmers). Government policies to support such ventures and arrangements are desirable. Abrams (2018) underlines the critical role of the private sector and social enterprise (through the use of instruments such as community saving clubs, cooperative local banks and bulk-buying clubs) in rejuvenating rural economies and building wealth, as this cannot be done by the public sector alone. Abrams (2018) believes that successful smallholder farmer support programs are bound by common characteristics such as a wide range of players and stakeholders, including traditional leadership structures, local government, community structures such as water committees, faith-based communities and organizations, civil society, farmers' organizations, the private sector, financiers and nongovernmental organizations. This diverse spectrum provides a support base for smallholder farmers, especially the most vulnerable in terms of poverty, through which messages of enhanced rainfed agriculture can be conveyed.

Concluding Remarks

Water scarcity is a daunting challenge in the Nile Basin due to an imminent increase in population, economic growth and climate change. Countries in the basin are likely to face physical and economic water scarcity unless water-saving measures are implemented swiftly.

Improving rainfed agriculture is one policy option that can improve the economy and food security of the upper riparian countries of the Nile, thereby enhancing the reliability of rainfed agriculture. This will, in the long run, help these basin countries realize the potential of rainfed agriculture and slow down the rate of irrigation expansion. In the lower riparian countries on the other hand, implementing effective water-saving methods and technologies in the large irrigation schemes is the way to go to enhance water availability to meet future demand. If national and regional policies and investments are focused on these two aspects of agriculture in the Nile Basin, achieving the SDGs related to food, energy and water is possible as we head toward 2030. Better irrigation is possible in the Nile Basin if future planned irrigation schemes consider the following five water-saving options:

1. Intensification of rainfed agriculture;
2. Improving water-use efficiency;
3. Improving cropping patterns;
4. Implementation of water deficit irrigation (WDI); and
5. Improving basin water supply management.

Implementation of these measures will hinge on cooperation and agreement between and among the basin countries, evolving into regional institutional and legal mechanisms, basin-wide tools of measurement, monitoring and evaluation mechanisms, implementation of virtual water trade and additional economic mechanisms, and enforcing the environmental and ecological integrity of the basin. These synergies will culminate in a highly functional basin organization, leading to regional hydro-solidarity and sustainable development of basin water and natural resources. Table 10 provides a summary of one ensemble of potential future water saving scenarios for different projected irrigation development scenarios. The table is intended to provide initial input to an integrated river basin modeling that explored future sustainable development of the Nile Basin.

Table 10. Summary of water-saving scenarios and irrigation projections for projected areas in Component II.

Country	Scenarios for existing and planned development			Area (ha) expansion (from Component II) aquifers	Decline in planned irrigation due to rainfall (%)	Overall efficiency improvement (gravity %)	Irrigation technology (gravity to pressurized irrigation) (%)	Shift in in-country croppin pattern from sugarcane to sugar beet (%)*	Shift in regional cropping pattern of sugarcane/rice gproduction from lowland area to humid regions**		Water Deficit Irrigation (%)	Additional Supply from groundwater aquifers (BCM)
									Rice %	Sugar cane %		
BURUNDI	BaUScen+											
	(variant I)	Existing	2030	8,802	0	0	0	0	0	0	0	0
		Planned	2030	19,013	0	0	0	0	0	0	0	0
		Existing	2050	8,802	0	0	0	0	0	0	0	0
		Planned	2050	34,857	0	0	0	0	0	0	0	0
	BaUScen											
	(variant II)	Existing	2030	8,802	0	0	0	0	0	0	0	0
		Planned	2030	2,039	0	0	0	0	0	0	0	0
		Existing	2050	8,802	0	0	0	0	0	0	0	0
		Planned	2050	5,855	0	0	0	0	0	0	0	0
	PLANScen++											
	(variant I)	Existing	2030	8,802	0	5	0	0	0	0	0	0
		Planned	2030	1,569	25	10	0	0	0	0	10	0
		Existing	2050	8,802	0	15	0	0	0	0	0	0
		Planned	2050	4,707	50	20	0	0	0	0	20	0
	PLANScen											
	(variant II)	Existing	2030	8,802	25	5	0	0	0	0	0	0
		Planned	2030	3,138		10	0	0	0	0	10	0
		Existing	2050	8,802	50	15	0	0	0	0	0	0
		Planned	2050	6,276		20	0	0	0	0	20	0

*In-country cropping pattern shift of 50% of sugarcane to sugar beet in Egypt and Sudan by 2050.

**Regional cropping pattern shift of 25% sugarcane from Egypt and Sudan to upland countries, keeping rice to literature-recommended minimum of 294,000 ha.

+ BaUScen means Business as Usual Scenario.

++ PLANScen means Planned Scenario.

Table 10. (continued)

Country	Scenarios for existing and planned development			Area (ha) expansion (from Component II)	Decline in planned irrigation due to rainfall (%)	Overall efficiency improvement (gravity %)	Irrigation technology (gravity to pressurized irrigation) (%)	Shift in in-country croppin pattern from sugarcane to sugar beet (%)*	Shift in regional cropping pattern of sugarcane/rice gproduction from lowland area to humid regions**		Water Deficit Irrigation (%)	Additional Supply from groundwater aquifers (BCM)
									Rice %	Sugar cane %		
EGYPT	BaUScen (variant I)	Existing	2030	3,823,736	0	0	0	0	0	0	0	0
		Planned	2030	367,079	0	0	0	0	0	0	0	0
		Existing	2050	3,823,736	0	0	0	0	0	0	0	0
		Planned	2050	672,978	0	0	0	0	0	0	0	0
	BaUScen (variant II)	Existing	2030	3,823,736	0	0	0	0	0	0	0	0
		Planned	2030	316,606	0	0	0	0	0	0	0	0
		Existing	2050	3,823,736	0	0	0	0	0	0	0	0
		Planned	2050	606,430	0	0	0	0	0	0	0	0
	PLANScen (variant I)	Existing	2030	3,823,736	0	10		20	30	10	10	5
		Planned	2030	132,350	0	15		0	0	0	20	5
		Existing	2050	3,823,736	0	20		30	30	15	10	5
		Planned	2050	397,050	0	20		0	0	0	20	5
	PLANScen (variant II)	Existing	2030	3,823,736	0	10		20	30	10	10	5
		Planned	2030	264,700	0	15		0	0	0	20	5
		Existing	2050	3,823,736	0	20		30	30	15	10	5
		Planned	2050	529,400	0	20		0	0	0	20	5

Table 10. (continued)

Country	Scenarios for existing and planned development			Area (ha) expansion (from Component II)	Decline in planned irrigation due to rainfall (%)	Overall efficiency improvement (gravity %)	Irrigation technology (gravity to pressurized irrigation) (%)	Shift in in-country croppin pattern from sugarcane to sugar beet (%)*	Shift in regional cropping pattern of sugarcane/rice gproduction from lowland area to humid regions**		Water Deficit Irrigation (%)	Additional Supply from groundwater aquifers (BCM)
									Rice %	Sugar cane %		
ETHIOPIA	BaUScen (variant I)	Existing	2030	547,387	0	0	0	0	0	0	0	0
		Planned	2030	1,182,357	0	0	0	0	0	0	0	0
		Existing	2050	547,387	0	0	0	0	0	0	0	0
		Planned	2050	2,167,654	0	0	0	0	0	0	0	0
	BaUScen (variant II)	Existing	2030	547,387	0	0	0	0	0	0	0	0
		Planned	2030	67,001	0	0	0	0	0	0	0	0
		Existing	2050	547,387	0	0	0	0	0	0	0	0
		Planned	2050	180,048	0	0	0	0	0	0	0	0
	PLANScen (variant I)	Existing	2030	547,387	0	5	0	0	0	0	0	0
		Planned	2030	355,016	25	10	0	0	0	0	10	0
		Existing	2050	547,387	0	15	0	0	0	0	0	0
		Planned	2050	1,065,046	50	20	0	0	0	0	20	0
	PLANScen (variant II)	Existing	2030	547,387	0	5	0	0	0	0	0	0
		Planned	2030	710,031	25	10	0	0	0	0	10	0
		Existing	2050	547,387	0	15	0	0	0	0	0	0
		Planned	2050	1,420,061	50	20	0	0	0	0	20	0

Table 10. (continued)

Country	Scenarios for existing and planned development			Area (ha) expansion (from Component II)	Decline in planned irrigation due to rainfall (%)	Overall efficiency improvement (gravity %)	Irrigation technology (gravity to pressurized irrigation) (%)	Shift in in-country croppin pattern from sugarcane to sugar beet (%)*	Shift in regional cropping pattern of sugarcane/rice gproduction from lowland area to humid regions**		Water Deficit Irrigation (%)	Additional Supply from groundwater aquifers (BCM)
									Rice %	Sugar cane %		
KENYA	BaUScen (variant I)	Existing	2030	61,257	0	0	0	0	0	0	0	0
		Planned	2030	132,315	0	0	0	0	0	0	0	0
		Existing	2050	61,257	0	0	0	0	0	0	0	0
		Planned	2050	242,578	0	0	0	0	0	0	0	0
	BaUScen (variant II)	Existing	2030	61,257	0	0	0	0	0	0	0	0
		Planned	2030	13,599	0	0	0	0	0	0	0	0
		Existing	2050	61,257	0	0	0	0	0	0	0	0
		Planned	2050	30,217	0	0	0	0	0	0	0	0
	PLANScen (variant I)	Existing	2030	61,257	0	5	0	0	0	0	0	0
		Planned	2030	16,671	25	10	0	0	0	0	10	0
		Existing	2050	61,257	0	15	0	0	0	0	0	0
		Planned	2050	50,012	50	20	0	0	0	0	20	0
	PLANScen (variant II)	Existing	2030	61,257	0	5	0	0	0	0	0	0
		Planned	2030	33,341	25	10	0	0	0	0	10	0
		Existing	2050	61,257	0	15	0	0	0	0	0	0
		Planned	2050	66,682	50	20	0	0	0	0	20	0

Table 10. (continued)

Country	Scenarios for existing and planned development			Area (ha) expansion (from Component II) aquifers	Decline in planned irrigation due to rainfall (%)	Overall efficiency improvement (gravity %)	Irrigation technology (gravity to pressurized irrigation) (%)	Shift in in-country croppin pattern from sugarcane to sugar beet (%)*	Shift in regional cropping pattern of sugarcane/rice gproduction from lowland area to humid regions**		Water Deficit Irrigation (%)	Additional Supply from groundwater aquifers (BCM)
									Rice %	Sugar cane %		
RWANDA	BaUScen (variant I)	Existing	2030	8,868	0	0	0	0	0	0	0	0
		Planned	2030	19,155	0	0	0	0	0	0	0	0
		Existing	2050	8,868	0	0	0	0	0	0	0	0
		Planned	2050	35,114	0	0	0	0	0	0	0	0
	BaUScen (variant II)	Existing	2030	8,868	0	0	0	0	0	0	0	0
		Planned	2030	2,022	0	0	0	0	0	0	0	0
		Existing	2050	8,868	0	0	0	0	0	0	0	0
		Planned	2050	5,528	0	0	0	0	0	0	0	0
	PLANScen (variant I)	Existing	2030	8,868	0	5	0	0	0	0	0	0
		Planned	2030	1,112	25	10	0	0	0	0	10	0
		Existing	2050	8,868	0	15	0	0	0	0	0	0
		Planned	2050	3,335	50	20	0	0	0	0	20	0
	PLANScen (variant II)	Existing	2030	8,868	0	5	0	0	0	0	0	0
		Planned	2030	2,224	25	10	0	0	0	0	10	0
		Existing	2050	8,868	0	15	0	0	0	0	0	0
		planned	2050	4,447	50	20	0	0	0	0	20	0

Table 10. (continued)

Country	Scenarios for existing and planned development			Area (ha) expansion (from Component II)	Decline in planned irrigation due to rainfall (%)	Overall efficiency improvement (gravity %)	Irrigation technology (gravity to pressurized irrigation) (%)	Shift in in-country croppin pattern from sugarcane to sugar beet (%)*	Shift in regional cropping pattern of sugarcane/rice gproduction from lowland area to humid regions**		Water Deficit Irrigation (%)	Additional Supply from groundwater aquifers (BCM)
									Rice %	Sugar cane %		
SOUTH SUDAN	BaUScen (variant I)	Existing	2030	111,355	0	0	0	0	0	0	0	0
		Planned	2030	240,526	0	0	0	0	0	0	0	0
		Existing	2050	111,355	0	0	0	0	0	0	0	0
		Planned	2050	440,965	0	0	0	0	0	0	0	0
	BaUScen (variant II)	Existing	2030	111,355	0	0	0	0	0	0	0	0
		Planned	2030	4,810	0	0	0	0	0	0	0	0
		Existing	2050	111,355	0	0	0	0	0	0	0	0
		Planned	2050	19,215	0	0	0	0	0	0	0	0
	PLANScen (variant I)	Existing	2030	111,355	0	5	0	0	0	0	0	0
		Planned	2030	53,582	25	10	0	0	0	0	10	0
		Existing	2050	111,355	0	15	0	0	0	0	0	0
		Planned	2050	160,747	50	20	0	0	0	0	20	0
	PLANScen (variant II)	Existing	2030	111,355	0	5	0	0	0	0	0	0
		Planned	2030	107,165	25	10	0	0	0	0	10	0
		Existing	2050	111,355	0	15	0	0	0	0	0	0
		Planned	2050	214,330	50	20	0	0	0	0	20	0

Table 10. (continued)

Country	Scenarios for existing and planned development			Area (ha) expansion (from Component II) aquifers	Decline in planned irrigation due to rainfall (%)	Overall efficiency improvement (gravity %)	Irrigation technology (gravity to pressurized irrigation) (%)	Shift in in-country croppin pattern from sugarcane to sugar beet (%)*	Shift in regional cropping pattern of sugarcane/rice gproduction from lowland area to humid regions**		Water Deficit Irrigation (%)	Additional Supply from groundwater aquifers (BCM)
									Rice %	Sugar cane %		
SUDAN	BaUScen (variant I)	Existing	2030	2,023,837	0	0	0	0	0	0	0	0
		Planned	2030	194,289	0	0	0	0	0	0	0	0
		Existing	2050	2,023,837	0	0	0	0	0	0	0	0
		Planned	2050	356,196	0	0	0	0	0	0	0	0
	BaUScen (variant II)	Existing	2030	2,023,837	0	0	0	0	0	0	0	0
		Planned	2030	378,863	0	0	0	0	0	0	0	0
		Existing	2050	2,023,837	0	0	0	0	0	0	0	0
		Planned	2050	1,075,646	0	0	0	0	0	0	0	0
	PLANScen (variant I)	Existing	2030	2,023,837	0	10	0	20	0	10	10	1
		Planned	2030	279,450	25	15	0	0	0	0	10	1.5
		Existing	2050	2,023,837	0	20	0	30	0	15	20	1.5
		Planned	2050	838,350	50	20	0	0	0	0	20	6
	PLANScen (variant II)	Existing	2030	2,023,837	0	10	0	20	0	10	10	1
		Planned	2030	558,900	25	15	0	0	0	0	10	1.5
		Existing	2050	2,023,837	0	20	0	30	0	15	20	1.5
		Planned	2050	1,117,800	50	20	0	0	0	0	20	6

* In-country cropping pattern shift of 50% of sugarcane to sugar beet in Egypt and Sudan by 2050.
** Regional cropping pattern shift of 25% sugarcane from Egypt and Sudan to upland countries, keeping rice to literature-recommended minimum of 294,000 ha.
+ BaUScen means Business as Usual Scenario.
++PLANScen means Planned Scenario.

Table 10. (continued)

Country	Scenarios for existing and planned development			Area (ha) expansion (from Component II)	Decline in planned irrigation due to rainfall (%)	Overall efficiency improvement (gravity %)	Irrigation technology (gravity to pressurized irrigation) (%)	Shift in in-country croppin pattern from sugarcane to sugar beet (%)*	Shift in regional cropping pattern of sugarcane/rice gproduction from lowland area to humid regions**		Water Deficit Irrigation (%)	Additional Supply from groundwater aquifers (BCM)
									Rice %	Sugar cane %		
TANZANIA	BaUScen (variant I)	Existing	2030	33,407	0	0	0	0	0	0	0	0
		Planned	2030	72,159	0	0	0	0	0	0	0	0
		Existing	2050	33,407	0	0	0	0	0	0	0	0
		Planned	2050	132,292	0	0	0	0	0	0	0	0
	BaUScen (variant II)	Existing	2030	33,407	0	0	0	0	0	0	0	0
		Planned	2030	3,889	0	0	0	0	0	0	0	0
		Existing	2050	33,407	0	0	0	0	0	0	0	0
		Planned	2050	11,199	0	0	0	0	0	0	0	0
	PLANScen (Variant I)	Existing	2030	33,407	0	5	0	0	0	0	0	
		Planned	2030	12,669	25	10	0	0	0	0	10	
		Existing	2050	33,407	0	15	0	0	0	0	0	
		Planned	2050	38,008	50	20	0	0	0	0	20	
	PLANScen (variant II)	Existing	2030	33,407	0	5	0	0	0	0	0	
		Planned	2030	25,339	25	10	0	0	0	0	10	
		Existing	2050	33,407	0	15	0	0	0	0	0	
		Planned	2050	50,677	50	20	0	0	0	0	20	

Table 10. (continued)

Country	Scenarios for existing and planned development	Area (ha) expansion (from Component II)	Decline in planned irrigation due to rainfall (%)	Overall efficiency improvement (gravity %)	Irrigation technology (gravity to pressurized irrigation) (%)	Shift in in-country croppin pattern from sugarcane to sugar beet (%)*	Shift in regional cropping pattern of sugarcane/rice gproduction from lowland area to humid regions** Rice %	Sugar cane %	Water Deficit Irrigation (%)	Additional Supply from groundwater aquifers (BCM)
UGANDA	BaUScen									
	(variant I) Existing 2030	21,190	0	0	0	0	0	0	0	0
	Planned 2030	45,770	0	0	0	0	0	0	0	0
	Existing 2050	21,190	0	0	0	0	0	0	0	0
	Planned 2050	83,912	0	0	0	0	0	0	0	0
	BaUScen									
	(variant II) Existing 2030	21,190	0	0	0	0	0	0	0	0
	Planned 2030	1,627	0	0	0	0	0	0	0	0
	Existing 2050	21,190	0	0	0	0	0	0	0	0
	Planned 2050	3,590	0	0	0	0	0	0	0	0
	PLANScen									
	(Variant I) Existing 2030	21,190	0	5	0	0	0	0	0	
	Planned 2030	1,012	25	10	0	0	0	0	10	
	Existing 2050	21,190	0	15	0	0	0	0	0	
	Planned 2050	3,036	50	20	0	0	0	0	20	
	PLANScen									
	(variant II) Existing 2030	21,190	0	5	0	0	0	0	0	
	Planned 2030	14,342	25	10	0	0	0	0	10	
	Existing 2050	21,190	0	15	0	0	0	0	0	
	Planned 2050	4,048	50	20	0	0	0	0	20	

*= In-country cropping pattern shift of 50% of sugarcane to sugar beet in Egypt and Sudan by 2050.
** = Regional cropping pattern shift of 25% sugarcane from Egypt and Sudan to upland countries, keeping rice to the literature-recommended minimum of 294,000 ha.
+ BaUScen means Business as usual scenario,
++ = PLANScen means Planned Scenario

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