15

Water management intervention analysis in the Nile Basin

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Key messages

- Agricultural water management (AWM) interventions in the Nile Basin are a key to improve agricultural production and productivity. AWM interventions can be categorized based on spatial scales, sources of water and type of technologies for water management in control, lifting, conveyance and application. Various combinations of these interventions are available in the Nile Basin. Successful application of AWM interventions should consider the full continuum of technologies in water control, conveyance and field applications.
- AWM technology intervention combined with soil fertility and seed improvement may increase productivity up to threefold. Similarly, data sets used from a representative sample of 1517 households in Ethiopia shows that the average treatment effect of using AWM technologies is significant and has led to an income increase of US$82 per household per year, on average. The findings indicated that there are significantly low poverty levels among users compared to non-users of AWM technologies, with about 22 per cent less poverty incidence among users compared to non-users of *ex situ* AWM technologies.
- The Nile basin has 10 major man-made water control structures that are used for various purposes including irrigation, hydropower, flood and drought control, and navigation. The Water Evaluation And Planning (WEAP) model is applied to the Nile Basin, considering existing infrastructure, and scenarios of water use under current, medium term and long term. The major water use interventions that affect water availability in rivers are related to irrigation development. Accordingly, the irrigation areas of the current, medium-term and long-term scenarios in the Nile Basin are, respectively, about 5.5, 8 and 11 million ha, with water demands of 65,982 million m^3, 94,541 million m^3 and 127,661 million m^3, respectively. The total irrigation water demand for the current scenario is lower than the Nile mean annual flow. The total irrigation water demand for the medium-term scenario exceeds the Nile mean annual flow marginally. The irrigation demands for the long-term scenario are considerably greater than the mean annual flow of the Nile basin, assuming the existing management practice and irrigation water requirement estimation of the countries. The river water would therefore not satisfy irrigation water demands in the long term unless the irrigation efficiency is improved, water saving measures are implemented and other sources of water and economic options are explored.

Introduction

The major objective of AWM interventions is to enhance growth of agricultural productivity, poverty reduction and livelihood improvement. This can be achieved through increasing the positive role of water and reducing the negative impacts of water. The purpose of this chapter is to identify the major types of water management intervention that exist in the Nile Basin, analyse options that may be considered for further development and management, and evaluate their impacts, particularly focusing on interventions already implemented and planned for the future to improve access to water. If the interventions are carefully planned and implemented, they contribute to national and regional economic transformations and development. The methods used here include inventorying and characterization of existing interventions in various parts of the basin and production systems, review of performance of existing interventions, trade-off analysis, ranking, scenario analysis and modelling to select and evaluate the high-impact interventions and implementation strategy.

Interventions may be categorized as:

- interventions based on water availability, access and management;
- agricultural and non-agricultural water use interventions;
- water interventions based on the production system, livelihood and hydro-economic modelling; and
- small- and large-scale interventions.

In this chapter we will use the last type of categorization. The next section deals with detailed identification, listing and characterization of smallholder water interventions, shortlisting of interventions as they fit the various agro-ecologies, and associated impacts on productivity and poverty with considerations of typical case studies. Subsequent sections deal with the large-scale interventions, modelling, scenario analysis and implications on access to water and availability in the basin.

Small-scale water interventions in the Nile Basin

The water management interventions for agriculture

The small-scale interventions here are primarily those of AWM (Molden, 2007) that range from field conservation practices to irrigation and drainage associated with crop production. However, the broader definition of AWM may include water not only for crops but also for animals, agro-forestry and a combination with multiple uses such as drinking water, environment, and so on. Rain-fed agriculture, supported to some extent by small-scale irrigation (SSI) and water harvesting systems, is the dominant form of agriculture in the upstream countries of the Nile such as Ethiopia, Rwanda and Uganda, whereas the downstream countries – Egypt and Sudan – are dominated by irrigated agriculture in large-scale irrigation (LSI) schemes. In the transition, the system is dominated by pastoral and agro-pastoral systems. Rainfall management strategies through (i) on-farm water management, (ii) maximizing transpiration and reducing soil evaporation, (iii) collecting excess run-off from farm fields and using it during dry spells and as supplementary irrigation, (iv) draining of water-logged farm areas, and (v) enhancing livestock productivity are crucial for transformation of rain-fed agriculture to higher productivity. In addition, stream diversions and groundwater management with appropriate technology for control, conveyance and application in

supplementary and full irrigation are the interventions that may enhance smallholder agricultural productivity.

AWM interventions include water control, water lifting, conveyance, field application and drainage/reuse technologies. Figure 15.1 provides an illustration of the major categories of small-scale water management interventions, with emphasis on crop production (see also Molden *et al.*, 2010). Most of the categories related to water control and management are also applicable to the livestock sector and some for fishery and aquaculture, with certain modifications on the part of conveyance and application/use.

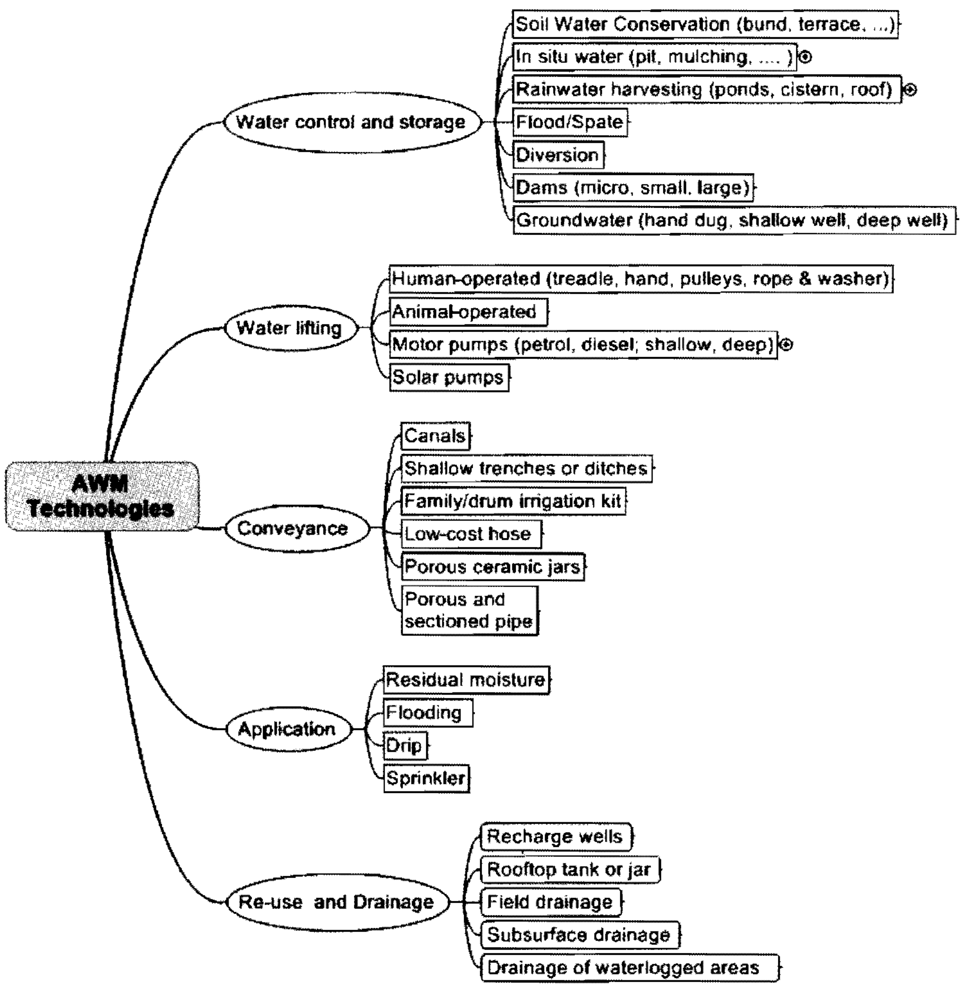

Figure 15.1 Agricultural water management continuum for control, lifting, conveyance and application

Furthermore, numerous combinations of this continuum are possible, creating what is termed here as 'AWM technology suites' that can be applicable at the household or farm level, community or small catchment/watershed level, sub-basin, basin or regional level. Table 15.1 lists these suites categorized by the scale of application and source of water. An inventory of SSI practised in the Nile Basin countries is given in Anderson and Burton, 2009.

Impacts of interventions on productivity

The impacts of AWM interventions on productivity and poverty alleviation may be evaluated using simple and complex techniques ranging from simple mean separation tests, estimation of average treatment effects using propensity score matching, poverty analysis and modelling. Here, impacts related to productivity and poverty reduction are evaluated by taking Ethiopian Highlands as an example.

The rampant rain-fed mixed crop-livestock farming system in the Ethiopian Highlands is characterized not only by growing one crop per year but also by poor land and water productivity, which perpetuates poverty and vulnerability to shocks caused by climate variability, among others. Low productivity is reinforced by continued decline in landholding per household due to rapid population growth and severe land degradation. In order to overcome these constraints, technological interventions are essential. The possibilities to (i) improve productivity of maize under the prevailing climatic conditions and a range of soil fertility management and (ii) enhance the productive use of water are examined here as an example. Maize is one of the dominant crops in crop livestock system of Ethiopian Highlands. It is typical for areas with high rainfall and relatively productive soils.

The Food and Agriculture Organization of the United Nations (FAO) AquaCrop model was used after validation with data from agricultural research stations in and around the basin in Ethiopian Highlands. The attempt was made to simulate the productivity of maize under varying soil fertility levels (poor, near-optimal and non-limiting) using hybrid seed under the prevailing climatic conditions, and to examine potential gains of productivity that can be achieved. Results suggest that improving soil fertility can tremendously enhance grain and biomass productivity (Anchala *et al.*, 2001; Erkossa *et al.*, 2009). Grain yield increased from 2.5 t ha^{-1} under poor to 6.4 and 9.2 t ha^{-1} with near-optimal and non-limiting soil fertility conditions, respectively. Correspondingly, soil evaporation decreased from 446 to 285 and 204 mm, while transpiration increased from 146 to 268 and 355 mm. Consequently, grain water productivity increased by 48 and 54 per cent, respectively, due to the near-optimal and non-limiting soil fertility conditions. The model predicts that about 593 mm of the seasonal rainfall are lost as run-off. If harvested, this can be used to grow a second crop on a fraction or the whole area depending on the type of crop, irrigation efficiency and availability of labour. Part of the excess water can also fulfil domestic needs or livestock consumption. Both productivity gain during the main season and the secondary production constitute evidence of significant untapped potential in the area and similar agro-ecosystems in sub-Saharan Africa. This result also clearly shows that the lack of integration of measures such as fertilizers, seeds and management of rainfall is limiting productivity potential.

Impacts of interventions on poverty and food security

In the past, a lack of clear understanding of the issues that link AWM to poverty reduction and agricultural productivity has been one of the reasons for underdevelopment of agriculture (Anderson and Burton, 2009). AWM technologies are expected to have significant impact on

Table 15.1 Agricultural water management technology suites and scale of application

Scale	*Water source*	*Water control*	*Water lifting*	*Conveyance*	*Application*	*Drainage and reuse*
Smallholder farmlevel	Rainwater	*In situ* water Farm ponds Cistern and underground ponds Harvesting roof water Recession agriculture	Treadle pumps Water cans	Drum Channels Pipes	Flooding Direct application Drip	Drainage of waterlogging Surface drainage channels Recharge wells
	Surface water	Spate and flooding Diversion Pumping	Micro pumps (petrol, diesel) Motorized pumps	Channels Canals Pipes (rigid, flexible)	Flood and furrow Drip Sprinkler	Surface drainage channels Drainage of waterlogging
	Groundwater	Spring protection Hand-dug wells Shallow wells	Gravity Treadle pumps Micro pumps (petrol, diesel) Hand pumps	Channels Canals Pipes (rigid, flexible)	Flood and furrow Drip Sprinkler	Surface drainage channels Drainage of waterlogging Recharge wells
Community or catchment	Rainwater	Soil Water Conservation Communal ponds Recession agriculture Sub-surface dams	Treadle pumps Water cans	Drum Channels Pipes	Flooding Direct application Drip	Drainage of waterlogging Surface drainage channels
	Surface water	Spate and flooding Wetland Diversion Pumping Micro dams	Micro pumps (petrol, diesel) Motorized pumps Gravity	Channels Canals Pipes (rigid, flexible)	Flood and furrow Drip Sprinkler	Surface drainage channels
	Groundwater	Spring protection Hand-dug wells Shallow wells Deep wells	Gravity Treadle pumps Micro pumps (petrol, diesel) Hand pumps Motorized pumps	Channels Canals Pipes (rigid, flexible)	Flood and furrow Drip Sprinkler	Surface drainage channels Recharge wells and galleries
Sub-basin, Basin	Surface water	Large dams	Gravity Large-scale motorized pumps	Channels Canals Pipes (rigid, flexible)	Flood and furrow Drip Sprinkler	Surface drainage channels Drainage reuse

household well-being through increasing food production and income (Namara *et al.*, 2007). The Comprehensive Assessment of Water Management in Agriculture (Molden, 2007) states that:

> Improving access to water and productivity in its use can contribute to greater food security, nutrition, health status, income and resilience in income and consumption patterns. In turn this can contribute to other improvements in financial, human, physical and social capital simultaneously alleviating multiple dimensions of poverty.

An attempt is made to explore whether adoption of AWM technologies has led to such improvements and, if so, to identify which technologies have a higher impact. The study quantified the average treatment effect of using AWM technologies. Analysis on the state of poverty among sample farm households with and without access to AWM technologies can reveal the impact of these technologies on poverty. In this study welfare indicators such as per capita income and expenditure per adult equivalent are used in matching econometrics and in poverty analysis, respectively. The inflation adjusted poverty lines equivalent to US$200 and US$120 were adopted to show overall poverty and food poverty/insecurity, respectively (MoFED, 2006). Data sets from a representative sample of 1517 households from 30 kebeles in four regions of Ethiopia have been used. The interventions include rainwater harvesting, groundwater, surface water using ponds, wells, diversions and small dams. The results indicate that the average effect of using AWM technologies is significant and has led to an income increase of, on average, US$82 per household. It also shows that there is about 22 per cent less poverty incidence among users compared to non-users of ex-situ AWM technologies. Furthermore, from the poverty analysis (severity indices), it is found that AWM technologies are not only effectively poverty-reducing but also equity-enhancing interventions.

The magnitude of poverty reduction is found to be technology-specific. Accordingly, deep wells, river diversions and micro dams are associated with reductions in poverty incidence of 50, 32 and 25 per cent, respectively, compared with the purely rain-fed systems. The use of modern water withdrawal technologies (treadle pumps and motorized pumps) was also found to be strongly related to lower poverty. The use of motorized pumps was associated with a reduction in poverty incidence of more than 50 per cent. Similarly, households using gravity irrigation had significantly lower poverty levels than those using manual (cans) applications because of scale benefits. While access to AWM technologies seems to unambiguously reduce poverty, the study also indicates that there is a plethora of factors that can enhance this impact. Figures 15.2 and 15.3 show sample results of poverty and food security status of reduction of users and non-users of technologies and the relative impacts of poverty reduction with respect to technology.

It was also found that the most important determinants of poverty include asset holdings, educational attainment, family labour and access to services and markets. To enhance the contribution of AWM technologies to poverty reduction, therefore, there is a need to (i) build assets, (ii) develop human resources and (iii) improve the functioning of labour markets and access to markets (input or output markets).

In summary:

- Various AWM technologies for water control, lifting, conveyance and field applications exist. It is essential to identify the best suites of AWM technologies.
- Based on the sample survey data, access to AWM in water control and management help farmers to decrease poverty incidence by about 22 per cent. Some technologies, such as deep wells, reduced poverty by 50 per cent.

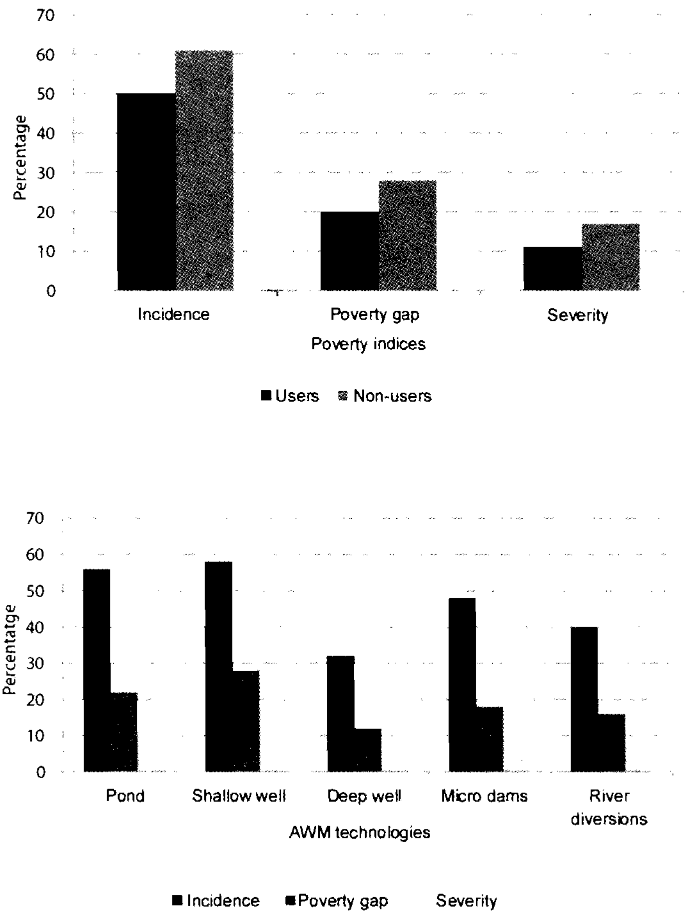

Figure 15.2 Poverty profiles and agricultural water management technologies

- Rainwater harvesting technologies are generally successful in areas with high variability and low rainfall to increase household agricultural production for food, cash crops and livestock production.
- The impact on productivity gain can be tripled if access to AWM technology can be increased and combined with access to improved soil fertility (fertilizer use) management and seeds.

There is therefore significant scope for managing rain-fed and small-scale irrigation systems in the Nile Basin to increase productivity, reduce poverty and enhance food availability. The combined interventions for more gains should be exploited.

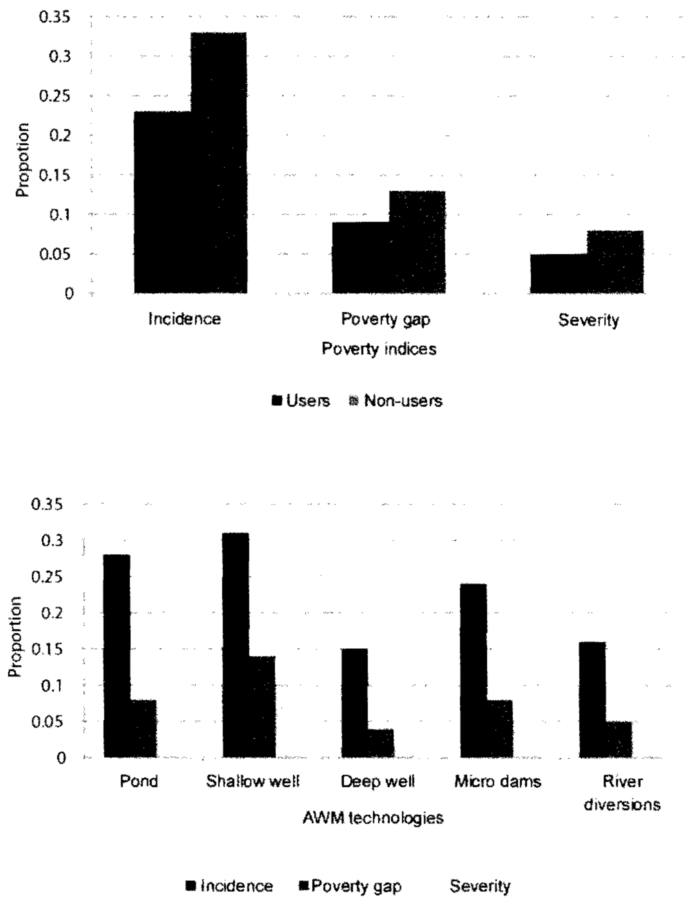

Figure 15.3 Food poverty profiles and agricultural water management technologies

Large-scale interventions in the Nile

The Nile River Basin is characterized by complex topography, high climate variability, low specific discharge and high system losses through conveyance and evaporation (see also previous chapters). Most of the Nile flow is generated from the Ethiopian Highlands plateau and the equatorial lakes regions that cover only 20 per cent of the basin, and only 25 per cent of the basin receives rainfall exceeding 1000 mm (see also Chapters 3–5). The remainder of the basin is in arid and semi-arid regions where the demand for water is comparatively large due to high evaporation and seepage losses. In order to provide a buffer for climatic and hydrological variability, large storage infrastructures were built along the Nile River in Egypt and Sudan. More large-scale infrastructures are planned for meeting the food and energy demands of the fast-growing population of the Nile Basin.

The large infrastructures considered in this study are those that mainly serve district (provincial), national and trans-national (regional) spatial domains, and rarely community or household levels directly. These large infrastructures can also be defined as those interventions undertaken at river basin or sub-basin scales leading to significant temporal and spatial modifications of the natural flow or implying substantial socio-economic impacts. We identify large-scale interventions relevant to water management, and analyse their impact on water availability and access in the Nile Basin, considering specifically:

- water control and storage infrastructures (single or multi-purpose);
- irrigation schemes;
- hydropower plants; and
- environment and wetlands.

The Nile water and its infrastructure

Operational systems

Water control infrastructures have been used for a long time in the Nile Basin to regulate and utilize the seasonally varying river flow for irrigation, hydropower and flood-control purposes. They are located either at the outlet of natural lakes, such as Owen Fall Dam at Lake Victoria and CharaChara weir at Lake Tana, or along the major river courses. The High Aswan Dam provides storage over the year. The storage dams in Sudan are losing significant amounts of storage volume through time due to sediment flow from the Ethiopian Highlands. For example, the capacity of the Roseires reservoir was reduced from about 3.4 billion m^3 in 1966 to 1.9 billion m^3 in 2007 (Bashar and Mustafa, 2009). The details of control and storage infrastructures listed in Table 15.2 were compiled from published literature (Yao and Georgakakos, 2003), national master plan documents (TAMS Consulting, 1997; BCEOM, 1998; NEDECO, 1998) and from personal communication with experts in the basin.

Table 15.2 Existing water control structures in the Nile Basin

Dam	*Country (million m^3)*	*Live storage*	*Year built*	*Purpose*
Abobo	Ethiopia	57	1992	Irrigation; not yet used
Finchaa	Ethiopia	1050	1971	Irrigation, hydropower
Aswan	Egypt	105,900	1970	Irrigation, hydropower
Jebel El Aulia	Sudan	3350	1937	Irrigation, hydropower
KhashmEl Gibra	Sudan	835	1964	Irrigation, hydropower
Koga	Ethiopia	80	2008	Irrigation
Chara Chara	Ethiopia	9126	2000	Hydropower
Owen Falls	Uganda	215,586	1954	Irrigation, hydropower
Roseires	Sudan	2322	1966	Irrigation, hydropower
Sennar	Sudan	753	1925	Irrigation, hydropower

Emerging developments

The Nile Basin countries are facing challenges of meeting food and energy demands for their rapidly growing populations. Therefore, a number of water resource developments have been planned by the riparian countries. Some of the planned projects are already being implemented. The Merowe Dam in Sudan and the Tekeze Dam in Ethiopia were recently constructed for hydropower generation, and these dams would have become fully operational in 2010. The construction of the Bujagali hydropower plant in Uganda is under progress. Sudan will raise the height of the Roseires Dam by 10 m to further increase its storage capacity. Ethiopia is currently undertaking the Tana-Beles hydropower project through intra-basin diversion of 77 $m^3 s^{-1}$ of water from Lake Tana to the Beles River (tributary of the Abbay River) and is planning to build other storage infrastructures mainly for hydropower.

Apart from these emerging water resources developments, the riparian countries are unilaterally planning to expand their irrigated agriculture and hydropower generation. Most countries have developed integrated master plans for parts of the Nile Basin within their territories. Under the subsidiary action programmes of the Nile Basin Initiative (NBI), the regional offices, Nile Equatorial Lakes Subsidiary Action Program (NELSAP) and Eastern Nile Technical Regional Organization (ENTRO), are also planning joint multi-purpose projects that benefit the riparian countries.

The Nile Basin modelling framework

The WEAP System model was applied to the entire Nile Basin for simulating the water supply and demands of the large-scale intervention scenarios. WEAP has the capability of integrating the demand and supply sides of water accounting with policy and management strategies (SEI, 2007). The model (Figure 15.4) was set up for the Nile Basin at monthly time intervals. For better illustration, the basin-wide topology (framework) of the WEAP model is independently displayed for the major regions of the basin in Figures 15.5–15.8.

The release rules from natural lakes are defined as flow requirements downstream of the lakes. The flow rate at these nodes of the release rules is defined in terms of the water level of the lakes. The ecological water needs of wetlands are represented as flow requirement nodes that take up the predefined percentage of the incoming flow into the wetland system. The contribution of wetlands to the dry season river flow is schematized in the WEAP model as streams, such as Ghazal Swamps and Machar Return (Figure 15.6).

The details of the WEAP schematization depend upon availability of climatic, hydrological and infrastructural information. The tributaries in the equatorial lakes region are aggregated into a number of streams since the datasets obtained for that region are very minimal. However, the WEAP modelling schematics is well detailed for the Ethiopian and, to some extent, for the Sudanese parts of the Nile Basin as the required datasets are obtained from master plans and project reports.

Wubet *et al.* (2009), Ibrahim *et al.* (2009) and McCartney *et al.* (2009) successfully applied Mike Basin, HEC-Res and WEAP models for Ethiopia, Sudan and Blue Nile, respectively, to evaluate the impacts of consumptive water use on water availability and implications on the water balance. The current WEAP schematization of the Nile Basin has attempted to incorporate their modelling features. However, the Nile Basin WEAP modelling was conducted using mean values of monthly flow and net evapotranspiration.

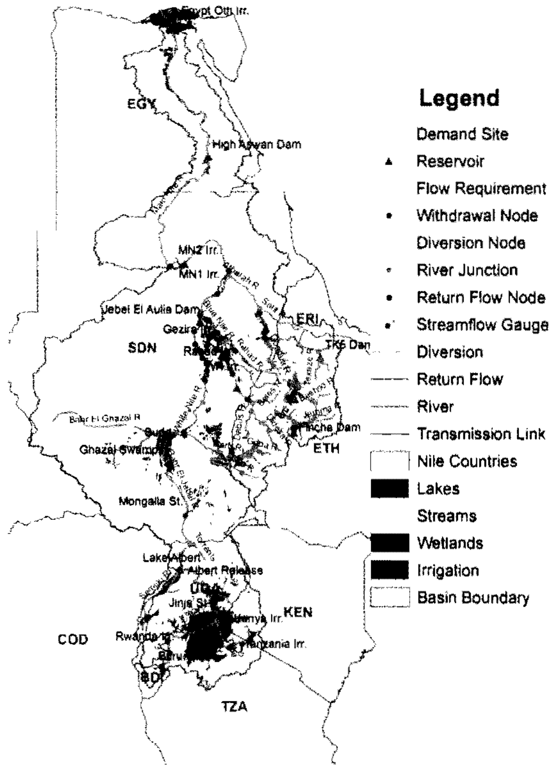

Figure 15.4 Water Evaluation And Planning model schematization of the Nile Basin for the current situation

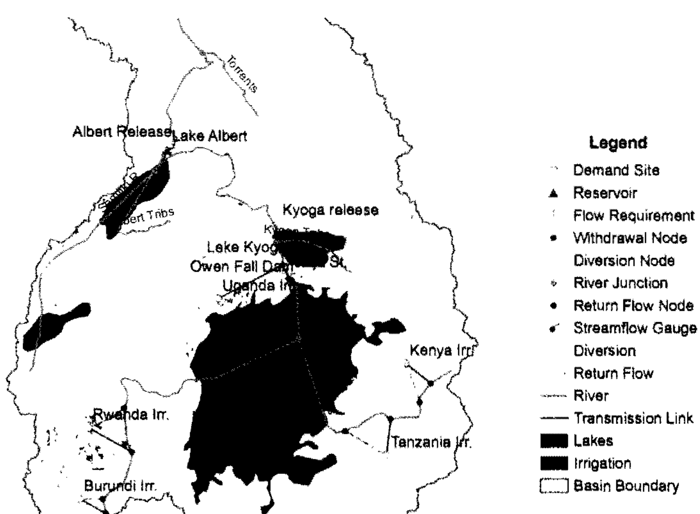

Figure 15.5 Water Evaluation And Planning model schematization of the equatorial lakes part of the Nile Basin

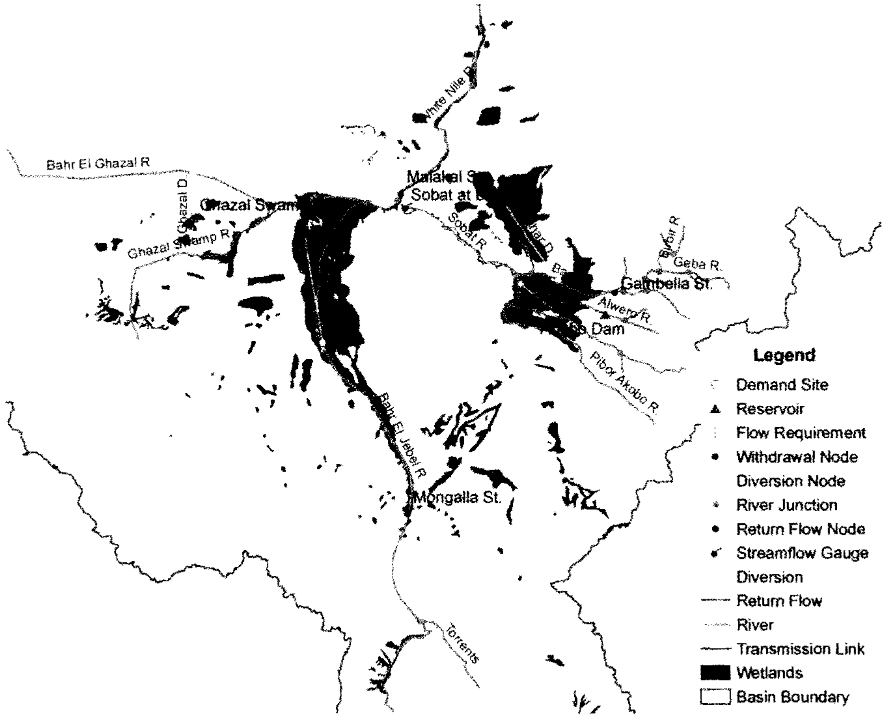

Figure 15.6 Water Evaluation And Planning model schematization of the wetlands and Sobat-Baro parts of the Nile Basin for the current situation

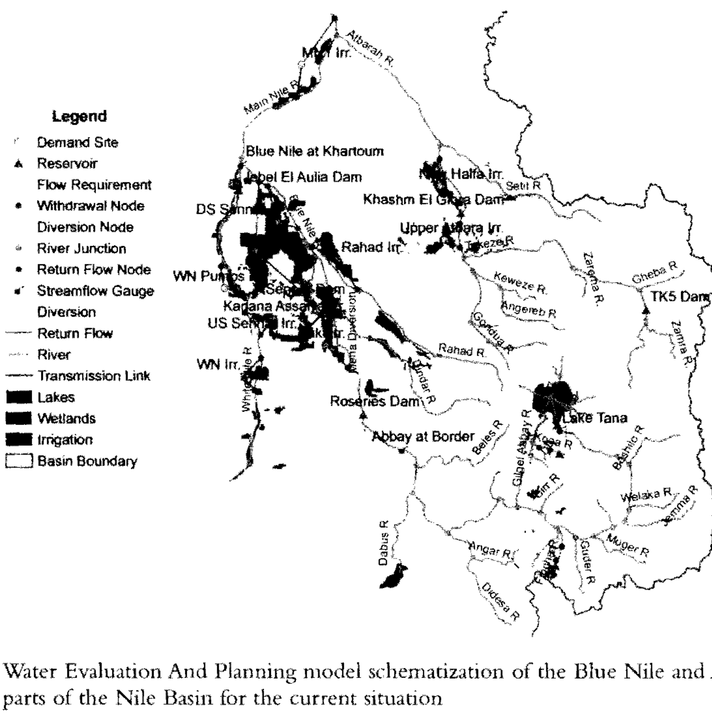

Figure 15.7 Water Evaluation And Planning model schematization of the Blue Nile and Atbara-Tekeze parts of the Nile Basin for the current situation

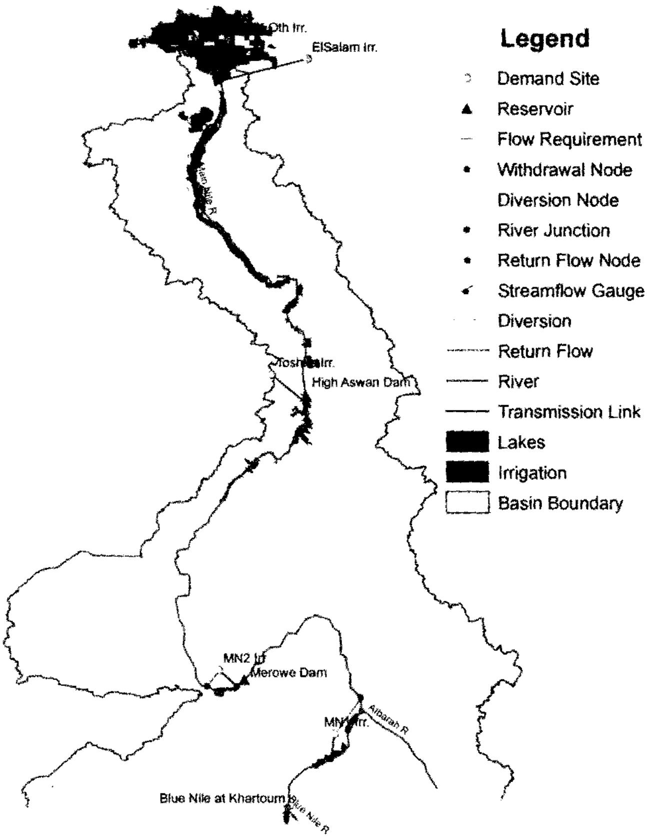

Figure 15.8 Water Evaluation And Planning model schematization of the main Nile part of the Nile Basin

The water resources development scenarios and implications

Scenarios

The large-scale water development and management interventions that are operational, emerging and planned in the entire Nile Basin are categorized into three different scenarios for the purpose of analysing their plausible impacts on the availability of, and access to, water. While the operational interventions form the *current (baseline) scenario*, the emerging and fast-track (planned) interventions are considered as the *medium-term scenario*. Other planned large-scale interventions that approach towards utilizing the potential land and water resources are categorized under *long-term scenarios*. It may not be possible to assign a strict timeline between these development scenarios since the riparian countries have different planning horizons. Some countries, for example Sudan, have clearly identified their development plans for the medium and long term. When such information is not available, about one-third of potential developments of countries is assumed to be implemented during the medium-term scenario period, and the remaining near-potential developments are also assumed to be realized during the long-term scenario period.

The existing and planned irrigation areas of the riparian countries and regions in the Nile Basin for the three development scenarios (Table 15.3) are determined from country-specific feasibility studies and master plans (TAMS Consulting, 1997; BCEOM, 1998; NEDECO, 1998), published literature (FAO, 2000) and project documents (ENTRO, 2007). Accordingly, the irrigation areas of the current, medium-term and long-term scenarios in the Nile Basin are about 5.5, 8 and 11 million ha, respectively.

The water requirements of the irrigation scenarios are (i) determined from literature on the annual rate of irrigation and (ii) compiled from project documents, feasibility studies and relevant master plans cited above. The monthly distributions of the irrigation water requirement are either compiled from the above sources whenever available or determined from rainfall and evapotranspiration data. The percentage of water returning from the irrigation system to the river network is assumed to be based on the topography of the irrigation field. In flat irrigation fields no return flow is considered. As shown in Table 15.4, the annual irrigation water requirement for the Blue Nile part of Sudan is less than that for the Ethiopian part. Even though this conflicts with prevailing climatic conditions, the figures are retained in this study in order to value both sources of data.

The environmental water requirements are expressed in terms of the percentage of incoming flow to the wetland in the previous month. The one month lag is adopted due to model restrictions in accessing the incoming flow of the current month. However, the lag helped to account for the routing effect of the wetlands.

Table 15.3 The irrigation areas (ha) for the current, medium- and long-term scenarios

Country/sub-basin	*Current*	*Medium term*	*Long term*
Burundi	0	18,160	80,000
Egypt	3,324,300	3,764,733	4,205,166
Nile valley	*3,324,300*	*3,521,133*	*3,717,966*
El-Salam	*0*	*130,200*	*260,400*
Toshka	*0*	*113,400*	*226,800*
Ethiopia	15,900	343,503	1,216,130
Blue Nile	*15,900*	*217,023*	*489,726*
Baro-Akobo-Sobat	*0*	*71,954*	*536,904*
Tekeze-Atbara	*0*	*54,526*	*189,500*
Kenya	5600	70,000	200,000
Rwanda	5000	50,000	155,000
Sudan	2,175,600	3,574,620	4,503,240
Tekeze-Atbara	*391,440*	*412,440*	*731,640*
Blue Nile	*1,304,940*	*2,125,620*	*2,194,080*
Main Nile	*130,620*	*449,820*	*781,200*
White Nile	*348,600*	*586,740*	*796,320*
Tanzania	475	10,000	30,000
Uganda	9120	80,000	247,000
Total	5,535,995	7,911,016	10,636,536

The total irrigation water demand for the current scenario is lower than the Nile mean annual flow. The total irrigation water demand for the medium-term scenario exceeds the Nile mean annual flow marginally. However, the irrigation demand for the long-term scenario is considerably greater than the mean annual flow of the Nile Basin. This shows that the river water would not suffice for future irrigation water demands unless irrigation efficiency is improved, measures of water saving and loss are implemented and other sources of water and economic options are explored.

Table 15.4 The annual irrigation requirement rate ($m^3.ha^{-1}$) and total irrigation water demands (million.m^3) for the current, medium- and long-term scenarios

Country/Sub-basin	*Rate*	*Current*	*Medium term*	*Long term*
Burundi	11,000	0	200	880
Egypt		43,216	48,942	54,668
Nile valley	*13,000*	*43,216*	*45,775*	*48,334*
El-Salam	*13,000*	*0*	*1693*	*3385*
Toshka	*13,000*	*0*	*1474*	*2948*
Ethiopia		152	4190	15,178
Blue Nile	*10,196*	*152*	*2497*	*5523*
Baro-Akobo-Sobat	*13,140*	*0*	*945*	*7055*
Tekeze-Atbara	*13,566*	*0*	*748*	*2600*
Kenya	8500	48	595	1700
Rwanda	12,500	63	625	1937
Sudan		22,425	39,239	50,992
Tekeze-Atbara	*13,776*	*5392*	*5682*	*10,079*
Blue Nile	*9861*	*11,565*	*21,266*	*21,949*
Main Nile	*13,250*	*1720*	*5879*	*10,203*
White Nile	*13,000*	*3749*	*6413*	*8761*
Tanzania	11,000	5	110	330
Uganda	8000	73	640	1976
Total		65,982	94,541	127,661

Implications

The water availability in the Nile River system was found to decrease for the medium-term and long-term scenarios than in the current scenario. The impact of the development interventions on water availability increases along the river course following the direction of flow (Table 15.5). For both medium- and long-term scenarios, the inflows to Lake Victoria and Lake Nasser are expected to decrease. During the future scenarios, the river flow from Lake Victoria to the Sudd wetland are not significantly affected since more water is released from the equatorial lakes to satisfy the downstream irrigation demands.

The spatial distribution of the mean annual river flow for the long-term scenario is portrayed in Figure 15.9. Other development scenarios have similar patterns of river flow volume.

Table 15.5 Mean annual flow (km^3) at major nodes in the Nile Basin for current, medium- and long-term scenarios

River junction	*Current*	*Medium term*	*Long term*
Main Nile after Egypt irrigation	28.56	11.83	2.42
Main Nile at Aswan outlet	69.61	53.95	51.70
Main Nile at Aswan inlet	80.62	64.93	54.04
Main Nile after Atbara	82.44	71.35	65.29
Main Nile after Blue Nile	74.46	63.22	58.37
Atbarah at Kilo3	8.57	8.94	8.22
Atbarah after Tekeze inflow	9.21	8.66	8.25
Tekeze at Sudan border	6.56	6.13	5.81
Blue Nile at Khartoum	40.49	31.54	30.82
Blue Nile at Sudan Border	48.20	46.11	46.27
White Nile at Khartoum	33.97	31.68	27.55
White Nile at Malakal	38.76	37.64	35.03
Sobat at outlet	13.66	13.36	11.14
Baro at outlet	9.42	8.98	7.49
Baro before Machar	12.73	12.00	9.61
Bahr El Ghazal at oulet	0.30	0.60	0.31
Bahr El Ghazal before swamp	11.33	11.33	11.33
Bahr El Jebel after Sudd	24.80	23.68	23.58
Bahr El Jebel before Sudd	47.61	44.33	46.95
Kyoga Nile at lake outlet	41.02	39.05	41.35
Victoria Nile at lake outlet	40.23	38.84	41.26
Inflow to Lake Victoria	22.87	21.97	19.89

All irrigation water demands are satisfied for the current (baseline) scenarios as expected. However, the irrigation demands for the medium-term and long-term scenarios are not fully met. Most of the unmet irrigation demands could be satisfied by improving irrigation efficiency, saving water through alternative storage strategies and implementing carryover storages on seasonal tributaries and sub-basins.

In summary, an integrated basin-wide simulation of the large-scale water development and management interventions in the Nile Basin revealed that the Nile flow would not meet the irrigation water demands for long-term development scenarios, and somewhat short for medium-term scenario, taking 84.5 billion m^3 as the benchmark for average water availability. The parts of the basin that have pronounced seasonal flows, the Blue Nile and the Tekeze-Atbara sub-basins, are the most affected regions in terms of meeting irrigation demands.

The water availability in the Nile River system was found to significantly decrease for the medium- and long-term development scenarios. The impact of large-scale interventions on the river flow increases along the river course in the direction of flow. This pattern of future water availability could be explained by higher water demands in the downstream part of the basin.

The impact of the large-scale water management interventions on the water availability and irrigation schemes could be mitigated by adopting interventions in water-saving and water-demand management. The current irrigation water requirement is very high. In order to meet future challenges, the following recommendations can be made:

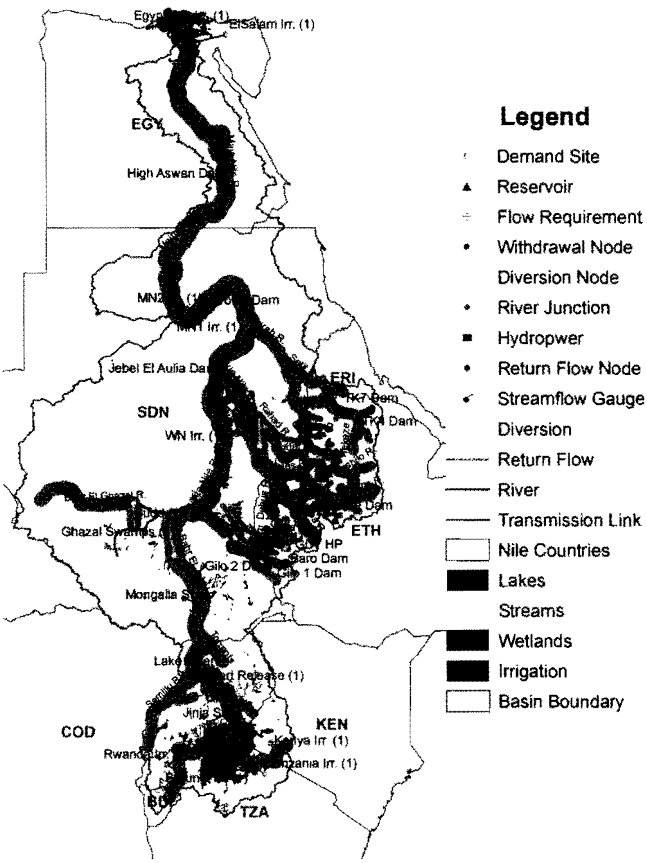

Figure 15.9 Simulated Nile River flow for the long-term development scenario

- Reservoirs developed for hydropower and irrigation with carryover storage capacity could provide more reliable water for the planned irrigation schemes. This demands integrated management of reservoirs as one unit and placing new storage schemes in the highland areas, where higher storage per surface area and less evaporation are attained.
- Irrigation demand could be substantially reduced by improving the efficiency of irrigation systems. Most of the current irrigation efficiency is assumed to be about 50 per cent, and if the efficiency could be increased to 80 per cent, over 40 billion m^3 of water can be saved in the long-term scenario, which can nearly offset the deficit even in the long-term scenario.
- Water productivity should be improved by shifting water from the economic sector that uses more water per unit production to that which uses less water (more value per unit of water). For example, the water used for cooling thermal energy plants could be used for other productive systems by importing hydropower energy from other riparian states, even at more competitive costs.
- Reduce non-consumptive 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 flooding regime in the wetlands.

The above are recommendations, which are amenable to further research on their implications and impact. On the other hand, it was shown in the previous section of this chapter that, upgrading rain-fed systems with the scope of enhancing beneficial use of rainfall can also contribute significantly to meet the food production and demand in the basin.

Conclusion

Water management interventions are complex in river system, and these range from what we undertake at household or micro watershed level to the national, regional and basin scales to improve water access for productive, consumptive and environmental purposes.

We have analysed options of small-scale agricultural interventions focusing on water control in rain-fed systems, small-scale irrigation technologies and suites, their productivity and poverty reduction impacts, and large-scale interventions with respect to meeting future water needs and water availability.

Other types of interventions such as those related to policy, institutions and benefit-sharing are discussed in other relevant chapters of this book. Future intervention analysis work can link hydronomic zones covered in Chapter 4 with interventions, so that proposed interventions take into consideration the various biophysical factors and resources availability. The hydronomic zoning combined with production system zoning provides numerous options that have potential within the Nile, but need to be tailored to site-specific needs in terms of technologies choices and scales.

The poverty analysis pointed to the widespread rural poverty. It also showed that access to water, productivity gains and actions to reduce vulnerability would help reduce poverty. This shows the clear role of water management interventions. The sections on water availability (related to Chapters 4 and 5) and the above WEAP modelling results demonstrate that there is a certain scope for large-scale irrigation development, but that there is ample water (as rainfall) in rain-fed systems that can be managed. Where poverty is high, water productivity is low. Basically, the main message in poverty reduction is clear and simple – there is ample work that needs to be done to improve water access and water productivity to reduce poverty. In a sense, nearly all rural water actions within the basin have poverty implications (except in Egypt where other actions outside agriculture probably have more impact on poverty reduction than in agriculture). The real work is identifying where and how to make these interventions.

Our key recommendation is to transform rain-fed systems by focusing on water access for agriculture, and good agricultural practices. In the small-scale and smallholder interventions, we have developed generic and comprehensive lists of AWM interventions that are most common in the basin, which can enhance agricultural water access in rain-fed, small-scale irrigated and livestock production systems. The generic tabular matrix of Table 15.1 can help with identification of AWM interventions for water control, lifting, conveyance and applications customized per sources of water as rainfall, surface water and groundwater (including reuse and drainage). In addition to AWM technologies, other factors related to economic, policy, institutions, social factor, environment and health factors as well as operation and maintenance influence the success of use of AWM technologies. Furthermore a combination of interventions beyond

AWM techniques creates the expected optimal impact on productivity. Supported by experimental evidence and modelling, it was shown that productivity can be gained up to threefold from a single harvest by integration of AWM, soil fertility and improved seed.

In relation to large-scale interventions, the whole Nile Basin was modelled as one integrated system, and current, medium- and long-term scenarios were analysed considering irrigation, hydropower, environment and wetlands. While the irrigation, environment and wetland requirements are sensitive, the hydropower demand, which is a non-consumptive use, was taken as unimportant in affecting the water availability in the basin. A thorough study of the plans of the countries reveals that planned irrigation in various countries is 10.6 million ha, compared with the current total of 5.5 million ha. With the current level of water application, absence of reservoir management and irrigation efficiency the total water withdrawal requirement in the long term would be 127 billion m^3, far beyond the 84.5 billion or 88.4 billion m^3 of available water (see Chapter 5). While there is scope for some irrigation expansion, in order to come close to future plans, mitigation measures are required that include improvements in water productivity, increase in the storage capacity upstream to reduce evaporation in the downstream storage, enhanced carryover storage and implementation of demand management and water saving practices. Countries should also consider which priority areas of investment should be taken on board and work together to achieve optimal benefits from the available common resource.

All the above are first-time baseline results that point to areas of further research and analysis. Research detailing specific interventions per hydronomic zone, further refinement of the small-scale interventions and analysis per agro-ecological and spatial area, more in-depth analysis of impacts of interventions on poverty alleviation, analysis of suggested options to balance future demand and water balance – all these deserve further investigation. While there is scope for such strategic research, there is an even more pressing need for immediate implementation of already identified efficient interventions.

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