NeWater

Adaptive Spatial Planning

Spatial adaptation in the Nile Basin

Report of the NeWater project -
New Approaches to Adaptive Water Management under Uncertainty

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Preface

This report has been written within the framework of the EU funded NeWater project (511179 IP priority 6.3: Global Change and Ecosystems) which focused on adaptive water management under uncertainty. 'Adaptive spatial Planning, spatial adaptation in the Nile Basin' (D 3.7.6) can be read in combination with the report 'Applications of Waterwise and leassons learnt in the NeWater case study areas of Rhine, Elbe and Nile' (D1.4.4). Co-financing for the research was provided by Rijkswaterstaat, of the Dutch Ministry of Transport, Public Works and Water management
The work has been supportive to Newater Work Packages assigned to RIZA. former part of Rijkswaterstaat. It concerns especially the support of new methods for linking adaptive water management and spatial planning (W1.4) and the assessment of climate change impact on water quality and ecosystems (WP2.3). It has been tested at various levels of implementation in Rhine, Elbe, and most notable effort in the Nile (WP3.7).
The work of both documents is based on NeWater activities on action research in participatory processes and the development of scenarios and models to support these processes in NeWater case studies. The activities took place from May 2005 till February 2009.
The study developed land use scenarios taking into account desired water allocation strategies, and waterquality and ecosystem requirements in the basin. In the Nile basin options for spatial adaptation were formulated integrating the impacts on agriculture and hydropower and especially taking into account the uncertainties connected to a changing climate, making use among others of National Adaptation Programmes of Action (NAPA). It includes an analysis of up-scaling sub-basin results for a balanced basin management with a focus on spatial planning.
The NeWater period was relatively short to test the complete participatory process. Follow-up activities are expected to be implemented in co-production with the Water Resources Planning and Management (WRPM) and the Confidence Building and Stakeholders Involvement (CBSI) both organisations of the Nile Basin Initiative, in the near future.

Wageningen, August 2009

Policy Summary

Spatial adaptation

Water and land use are inextricably linked. Part of the Newater project specifically focuses on the interaction between land use (spatial planning) and water management; the spatial adaptation. This spatial adaptation includes local, specific options, like finding space for flood mitigation. But in a broader sense it also relates to the way land is used, which crops are planted or where nature is preserved. This report addresses several aspects of spatial adaptation in the Nile Basin and shows the various interrelations using the WaterWise tool.

The link between water use and land use is of direct importance for many European policies like the Water Framework Directory, the EU Water Initiative or the United Nations Millennium Development Goals. These policies have far-reaching consequences and require drastic actions. It is envisaged that their goals cannot be met within the narrow decision space of traditional water management alone.

The Nile region forms an interesting case study to find out how spatial adaptation can be an option within the context of climate change adaptation and the reduction in poverty and famine, both being part of the Millennium Development Goals. Efforts to promote a water agreement between all Nile Basin countries have failed to materialize due to several factors. The historical mistrust between the riparians is an important element here. Another key factor is the lack of a clear basin-wide water resources development strategy. No reliable tool for accurately evaluating different Nile water allocation and land-use development options exists to date.

The WaterWise tool

In this study the WaterWise Tool is developed and tested on the Nile basin. WaterWise is a holistic biophysical-economical model and method to explore consequences of changes in land and water use in a spatially explicit way. By supporting an integrated discussion on land and water use WaterWise aims to strengthen the creation of sustainable water-space partnerships.

The integrative land-use and water use oriented approach of WaterWise broadens the discussion on transboundary cooperation versus individual country objectives into two new areas:

- Achieving food self-sufficiency, i.e. evaluate the agricultural production for the entire basin, both rainfed and irrigated;
- Adapting to climate change and climate variability in rainfed agriculture, irrigated agriculture and hydropower.

This creates the possibility to investigate whether individual countries will be able to maintain food self-sufficiency or be able to produce excess food to cover up shortages in other countries. WaterWise also provides the opportunity to quantify gains of mutual cooperation within the Nile basin through options addressing land reclamation at suitable locations including shifts in water allocations. The viability of all options is tested within the context of climate change and climate variability.

Conclusions

Different investment levels lead to different choices within the basin. Hydropower needs high investments but brings also swift revenues. The model shows that for certain countries there is still space for extension of agricultural lands. Watershed improvement is effective mainly in combination with an intensification of agriculture.

The climate change and food sufficiency tests show, at first sight, more trivial results. Differences between alternatives are smaller, choices logical. A controlling factor is the high agriculture productivity in (downstream) Egypt compared to the low productivity in upstream countries. Any agricultural development more upstream, at the expense of Egypts production, is under this situation not increasing the Nile Basin income. This dominance in profitability, however, could change in the future with upstream countries improving their agricultural management and associated physical, economical and educational infrastructure.

Giving upstream countries a higher priority for investments does not show significant changes in total basin income. The income of Sudan and Egypt is only slightly reduced in favor of more upstream countries. A preference for agricultural investments does reduce total basin income. Especially cancelling large (and costly) hydropower development in Ethiopia has a large impact on the income of this country.

The climate proofing showed that the biggest investments, mainly in hydropower, are robust under the used climate scenarios.

Future

The technical methodology of linking spatial planning and land use change with water management has been demonstrated. The possibilities of WaterWise have been acknowledged by the technical experts consulted.

The objective to apply the tool in a real stakeholder setting to guide the negotiation process has not yet been realized. Consultation with Nile Basin Initiative model experts indicated two major areas for improvement:

- Agriculture (its economic parameters) is not sufficiently represented in the current version
- The underlying biophysical data and models need further enhancement.

In addition, longer weather data series (more than 1 year, with variation within and between years) and spatially more diverse climate scenarios should be used. Future cooperation with developers of models and databases within the Nile region is vital to improve the current WaterWise Nile prototype to a powerful tool which can be used outside the scientific domain as well.

1 Introduction

Among the many events facing humankind climate change and socio-economic change create an uncertain future. To reduce possible negative impacts and to make use of opportunities, adaptive (water) management is a strategy that involves a continuous learning process and a proactive disposition, anticipating change with all its uncertainties.

Part of the Newater project specifically focuses on the interaction between adaptive water management and land use and spatial planning, the spatial adaptation. This spatial adaptation includes local, specific options, like finding space for flood mitigation or decisions on the location of buildings and construction. But in a broader sense it also relates to the way land is used, which crops are planted or where nature is preserved. Land use is directly linked to management of water and vice versa, as land cover and land use control supply and demand of this vital resource.

Land use patterns and changes are most often based on many 'small' decisions of farmers and local land owners. Together these small-scale decisions can have a large impact on the availability of water resources downstream. Also on a larger scale land use is planned and changed. Examples are the large scale development of irrigation in arid and semi-arid regions or the conversion of inland lakes and peatlands into agriculture in the Netherlands. They require long term planning and often high investment costs.

In the face of climate and rapid socio-economic change a wise investment in a different but sustainable land and water use is becoming more complicated. Integrating land use planning in adaptive water management raises several questions: "To what extent is it possible to actively manage land use, to use it as an adaptation option within the context of Integrated Water Resources Management? What are the options; what are the consequences? Will there be synergy between climate change adaptation and socio-economic drivers of land and water use decisions?". In addition, it is interesting to see what possibilities governments and stakeholders actually have to influence local decisions for the sake of overall regional, national or basin improvement.

The Nile region forms an interesting case study to find out how land use change is perceived as an adaptation option. In the Nile basin critical pressures are population growth, a high dependency on agriculture and a highly variable climate resulting in poverty, floods and droughts. Country adaptation plans have been developed in recent years, which were used as background material in this study.

To assess effects of various adaptation and investment plans, a Nile version prototype of the existing WaterWise tool was developed. This tool has been linked to a simple hydrological model and has been used to define sectoral and spatial trade-offs in land and water management at the basin scale.
This study aims to pull the climate change and water related discussion into a broader perspective, using the Nile basin as an example. It not only links climate change adaptation and its effect on the hydrological cycle to land use and land use changes but also incorporates energy (hydropower) and food security. Some of the scenarios include aspects of international cooperation and trade. In broadening the discussion this study hopes to visualize alternative, integrative and sustainable solutions and thereby contribute to a more adaptive management.

2 The Nile basin

2.1 Changes and challenges

In the past, water resources have been adequate to meet existing and emerging demands from the various economic sectors of the Nile Basin countries. Population pressure, the use of marginal lands in upstream countries and the expansion of irrigated areas in the along the river have gradually caused increasing tensions between the Nile countries. Each Nile country is planning and expecting different benefits from the control and management of the Nile water resources. Water is a main strategic factor in many facets of the complex economic, social and cultural diverse situation in the Nile Basin.

Critical pressures are population growth, a high dependency on subsistence agriculture and a highly variable climate. This increases pressure on the water resources through increased storage and diversion of surface water, in order to serve the increasing energy and agricultural demands. Effects include ecological consequences, like lowering stream flows leading to the gradual disappearance of riparian habitats. In the upstream countries forests are cut down and wetlands drained. Soils are eroded, resulting in reduced crop yields and non-sustainable livelihoods. Groundwater recharge is reduced and levels lowered, river flows become more flashy and downstream flood and drought impacts are enhanced.

The Nile passes international boundaries and involves many decision makers. This, coupled with climatic variability, the changing spatial and temporal distribution of the water resources and the complex social, political, economic status, creates challenges to sustainable development and is a potential source of conflict. The present dialogue between the riparian countries focuses on water allocation, which is a source of debate and litigation rather than a forum for cooperation. Sharing the Nile waters gives rise to debate among users with conflicting demands and management preferences. The control of river flows has long been a source of tension and dispute and an issue of sovereignty, strategic necessity, and territorial integrity. Such tensions in the Nile basin are obstacles to growth and constrain the regional political economy and avoid that resources are sustainably used.

A large potential for conflicts over water use is therefore evident, which is why achieving an integrated regional development of water resources on a sustainable basis is a critical condition for the socio-economic development of the Nile countries. To date, efforts to promote a water agreement between all Nile Basin countries have failed to materialize due to several factors. <u>One is the lack of a clear basin-wide water resources development strategy due to the absence of a reliable tool for accurately evaluating different Nile water development options and projects</u>. Hilhorst *et al.* (2008) argue that the hydro-political dialogue in the Nile Basin is a zero-sum game that needs to be widened to include other potential cooperation activities between the Nile countries. The most important opportunity that they identified through extensive stakeholder consultations was the promotion of international agricultural trade. In this spatial planning and development context, tools to provide transparency to such opportunities are crucial for supporting the hydro-political debate. Such a tool is of crucial importance since it would enable the countries of the Nile region to evaluate different water development scenarios with a relative high degree of confidence and thus help find generally acceptable solutions. (Olet *et al*., 2005).

2.2 Land use changes and the effect on the hydrology in the Nile Basin

In a quick scan of literature on land use effects on water resources Kirsch (2000) gives an overview of the land-use impacts on the hydrological and chemical regime within river basins. He concludes that in general land-use induced changes of the hydrologic regime and sediment load decrease with the size of the river basin. Depending on the size of river basin, the land-use impact can become less important because of offset effects, such as de-synchronisation (e.g. in the case of floods), storage capacity of the river bed (sedimentation) or the self-cleaning capacity of the river (organic pollution).

However, even in a large basin, effects in sub-basins will be important for certain stakeholders and may still be important for the basin as a whole. This is especially the case when changes occur on a large scale over longer periods of time. The desynchronisation or storage effects which decrease the effect of land use change in large basins as identified by the literature study by Kirsch (2000) become then less relevant. Regarding the Nile basin, there are several well documented cases in literature with regard to the impact of changing land use on hydrology:

- the decrease in stream flow in the Blue Nile related to a change in land cover, most notably a large-scale deforestation;
- the high water loss due to evapotranspiration and stream flow buffering of the Sudd swamps in Southern Sudan which could be reduced by creating the Jonglei canal;
- the increase in demand from large scale irrigation in Egypt and Sudan and in the future possibly more upstream countries like Ethiopia, directly affecting downstream runoff.

The Ethiopian highlands are the source of the Blue Nile which constitutes the largest amount of runoff to the Nile Basin, though its contribution has decreased from 65% to 55% over the recent decades (Suthcliffe and Parks, 1999). This shift is a result of an increase in runoff from the White Nile, but also a decrease in runoff from the Blue Nile itself. During this period rainfall did hardly change. Conway and Hulme (1993) question these precipitation data. Suthcliffe and Parks (1999) mention an increased irrigation abstraction as a contributing factor. However, many others see the main cause in the change in land use, mainly deforestation in the Ethiopian highlands in the last decades. Several studies in different sub-catchments (Bewket and Sterk, 2005, Hurni et al. 2005) report a link between land-use change and changes in runoff, with precipitation being rather stable. Zelek and Hurni (2001) show that in one catchment forest cover reduced from 27% in 1957 to 2% in 1982 and only 0.3% in 1995. Bewket and Sterk (2005) highlight two factors for the decrease in streamflow in their study in the Chemoga catchment in the Blue Nile: the changes in land cover and land use and degradation of the watershed, and the increased dry-season water abstraction.

As a means to adapt, Bewket and Sterk (2005) propose a set of measures aimed at reducing magnitudes of surface runoff generation and increasing groundwater recharge to sustain the water resource and maintain a balanced dry-season flow in the watershed. Hurni *et al*. (2005) assume that soil and water conservation measures aiming at ensuring long-term livelihoods in the humid to sub-humid highlands will, on the one hand, barely affect overall catchment runoff to the downstream areas, though they will considerably reduce surface runoff and soil loss on slopes and thus lower river sedimentation rates. On the other hand, in a semi-arid catchment where intensive soil and water conservation was carried out, reduction in runoff rates was more pronounced. Nyssen *et al*. (2004) state that impact assessments show clear benefits of the soil conservation measures in controlling runoff and soil erosion. They indicate that investment in soil and water conservation or catchment improvement might not always be profitable at farm level, although benefits for society are positive. More coordinated action and public support is necessary. An increased awareness or even the creation of water-space partnerships between upstream farmers and downstream water users would be an interesting option to consider.

A second well known example where land use change is expected to impact runoff are the Sudd swamps in Southern Sudan. It is estimated that some 50% of the White Nile flows are evaporating in these swamps, i.e. some 12-14 billion m3/yr (Abu Zeid, 1995, Kwadijk, 2007). Even higher amounts in recent decades of some 30 billion m3/yr due to the higher levels of Lake Victoria and corresponding higher discharge of the White Nile are mentioned by Suthcliffe and Parks (1999) and Mohamed *et al.* (2004). To reduce the swamp area, and thereby a significant part of this water loss, the construction of the Jonglei[1] canal was proposed. The construction of this canal was supposed to increase Egypt's share from the river to be used for irrigation by at least 2.0 billion m3/yr (Abu Zeid, 1995). However, apart from an impact on the hydrology of the Nile there are concerns about the social and environmental impact of the Jonglei Canal. Its construction would greatly affect the seasonally flooded land which provides dry season grazing to cattle and wildlife, while the permanent swamp provides a refuge to wildlife (Suthcliffe and Parks 1999).

An third and very obvious form of land use change which directly affects the hydrology of the Nile basin is the development of (large scale) irrigation. The irrigation has reduced the outflow of the Nile to the Mediterranean to only several billion m3/yr, a fraction of the estimated total available water resources of some 84 billion m3/yr flowing into Lake Nasser. According to the 1959 Nile Waters Agreement between Egypt and Sudan water is shared between the two countries, but this agreement did not reserve water for upstream riparians - notably, Ethiopia. In these upstream countries there is a strong interest to increase the area under irrigation to increase food production and develop agriculture (Awulachew *et al*., 2007; Block *et al*., 2007). Envisaged infrastructure encompasses both multiple small scale projects as well as the large proposed irrigation project, especially in combination with construction of reservoirs for hydropower in the Blue Nile (Whittington et al, 2005). This could have a significant affect on the hydrology of the Nile and the possibilities for downstream water users, e.g. Sudan and Egypt.

In addition to the above described impacts, regional climate changes in the form of changing rainfall amounts and patterns may affect land use and thereby also runoff. The impact of an increase in irrigated area, deforestation or a change in cropping patterns due to climate change will be addressed in chapter 4.

[1] The first stage of the project includes the construction of a canal of 360 km long which will form a shortcut along the upstream Nile from the Bahr el Jebel part to the White Nile part. The canal capacity at this stage will be 30 million m3/day. The second phase of this project includes the construction of a dam at the exit of the Albert Lake to increase the storage capacity of the Equatorial Lakes. The Jonglei Canal capacity will increase to 43 million m3/day. The implementation of the project started in 1978. However, work stopped in 1983 due to political problems in the south of Sudan after the contractor has completed 75% of the earth work within 270 km of the canal length. It was planned to complete the first stage in 1985, which was supposed to increase Egypt's share from the river by 2.0 billion m3/yr (Abu Zeid, 1995). Today, with the new political and socio-economic situation in Southern Sudan there is no indication that the project will be completed.

3 Adaptation plans of the Nile countries

3.1 Introduction

Adaptation to climate change within the rapidly changing socio-economic context in the Nile basin can consist of a range of methods from using low water use crops to switching to an increase in off farm labor or promoting the use of LPG for cooking instead of using firewood and thus conserving forests. In this study we focused on one set of measures, i.e. spatial adaptation options in land and water use. These are the measures related to the use of the land, the agricultural practices and related water management. This is only part of the solution, but a vital one.

Several sources of information are used. Firstly, the National Adaptation Plans (NAPA), which each Least Developed Country (LDC) has prepared give an insight in the options each country considers worthwhile. Secondly, the projects as proposed by the Nile Basin Initiative (NBI) were listed.

3.2 National Adaptation Programs of Action

To identify and prioritize the adaptation needs the National Adaptation Programs of Action (NAPAs) of various Nile countries[2] have been compared. They draw on existing information and community-level input to identify adaptation projects required now in order to enable these countries to cope with the immediate impacts of climate change. The following groups were distinguished (see Table 1):

- Spatial adaptation options which can be subdivided into rangeland conservation, preserving or extending a certain land use or promoting certain water and land management options, like erosion control on agricultural lands. (there is a grey area between management options like cultivating drought resistant forest species which on a larger scale could also be perceived as a land use change);
- Hydrologically related adaptation options. Hydropower is considered a separate group;
- 'Other', like investing in health care, financial options like insurance programs or other adaptation options like training and extension work, supporting the switch to other livelihoods.

A quick scan reveals that many proposed adaptation measures consist of small-scale local water and land use management improvements. These relate mostly to the use of drought resistant crops and water harvesting and erosion control measures. A third measure given high priority in many countries and related to a preservation of a certain land use is reforestation or, on a smaller scale the planting of trees on and around farmlands or homesteads.

[2] The NAPAs are created under the coordination of the UNFCCC for the 39 least developed countries in the world. Egypt and Kenia are not included.

Table 1 Overview of priorities in adaptation options

	Spatial			**Hydrological**		**other**		
	Rangeland conservation	Land use change or preservation	Water and land management options	Controlling rivers, forecasting	Hydropower	Health	Financial	Training, other livelihoods
Burundi		iii	iiiii	ii	i			iii
Rwanda		i	iii	i				ii
Sudan	ii	iii	iiiii	ii		iiii		iii
Ethiopia	ii	iii	ii	ii		i	i	iii
Tanzania		iii	iiiii					iiiiiii
Uganda			iiiii	ii		i		iiiiiiiiii
Eritrea	ii	i	ii					

Erosion control and reforestation will not only help to adapt to drought but can also have an important effect on flood mitigation during periods of heavy rainfall. The different climate scenarios (IS-CPW/UNESCO-IHE, 2007) show that impacts in the Nile basin vary. Especially in the Great Lakes area there is a high probability of a strong increase in rainfall. Erosion control measures are seen as essential in these upstream countries. In addition, especially in Sudan, the construction of larger scale infrastructure to control the river flow is proposed. In Burundi, small scale hydropower is promoted. In many countries early forecasting systems are mentioned. There is also the urgent need to disconnect the energy production from the widespread use of wood in Rwanda.

3.3 Nile Basin Initiative

The Nile Basin Initiative (NBI) is a partnership initiated and led by the riparian states of the Nile River through the Council of Ministers of Water Affairs of the Nile Basin states. The NBI seeks to develop the river in a cooperative manner, share substantial socio-economic benefits, and promote regional peace and security. Its vision is "to achieve sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile Basin water resources" (www.nilebasin.org).

The NBI has a Shared Vision Program (SVP) for cooperative action to build confidence and capacity throughout the basin. Simultaneously, it tries to pursue cooperative development opportunities to realize physical investments and tangible results through sub-basin activities in the Eastern Nile and the Nile Equatorial Lakes regions, the so called Subsidiary Action Programs (SAP).

Table 2 shows an overview of the current SAPs. Similar to he NAPAs this gives an indication of pressing issues. A difference is ,however, that the NAPAs are national programs whereas the NBI Action Programs strive for cooperation and must include at least two of the Nile riparian countries. Within these SAPs there are two clear main groups: integrated water resources management and hydropower. Connecting the power grids is an issue in both the Eastern Nile and Equatorial Lakes region. Interestingly, hydropower development itself is only a central issue in the Equatorial Lake region and not the Eastern Nile region. The large scale hydropower development plans in the Ethiopian part of the Blue Nile are not included in the NBI Subsidiary Action Plans, possibly because of their controversy. As could also be found in the NAPAs, there is a strong emphasis on erosion control in the Eastern Nile region. Large scale irrigation development is a strong issue here as well in contrast to the focus on more small scale irrigation in the Equatorial Lakes region.

Table 2 NBI Subsidiary Action Programs

Eastern Nile region Subsidiary Action Programs (ENSAP)

- Flood preparedness and early warning
- Irrigation and drainage development: 747600 ha in Sudan and 43370 ha in Ethiopia. Feasibility study on 7500 ha in each country.
- Integration of Ethiopian and Sudan power system
- Water management project: focuses on land degradation prevention and erosion control

Nile Equatorial Lakes region Subsidiary Action Programs (NELSAP)

- Enhanced Agriculture Productivity through Rainwater Harvesting, Small Scale Irrigation, and livestock Management
- Fisheries Project for Lake Albert and Lake Edward
- Development of a Framework for Cooperative Management of the Water Resources of the Mara River Basin
- Kagera River Basin Integrated Water Resources Management
- Development of a Framework for Cooperative Management of the Water Resources of the Malakisi-Malaba-Sio River Basins
- Water Hyacinth Abatement in the Kagera River Basin.

- Rusumo Falls Hydroelectric Power Development
- Ranking and Feasibility Study of Hydroelectric Power in the Nile Equatorial Lakes Region
- Power grid interconnections between; Kenya and Uganda, Burundi; DRC and Rwanda; Burundi and Rwanda; and Rwanda and Uganda.

4 Exploring options for trade offs in water allocation and spatial adaptation

4.1 Introduction

Water and land use are inextricably linked. External pressures, like climate change, thus result in chains of impacts and responses that are intertwined and interactive. Recognizing this, the development of methods for integrated design of water and land management systems is seen as one of the key elements in *Adaptive Water Management (AWM)*. To facilitate investigations into a system as complex as the Nile Basin and to structure the process of trans-disciplinary stakeholder consultation, models can be used to show the impact of climate change, the effect of measures or to simply get better insight in critical components of the system.

In this study the analyses are done with WaterWise (Van Walsum, 2009), which is an integrated model linking hydrology, economy and ecology. WaterWise is a holistic biophysical-economical model and method to explore consequences of changes in land and water use in a catchment in a spatially explicit way. The ability of WaterWise is to use spatial relationships between sub-basins and then make suggestions for spatially varied patterns of measures that make best use of the available land and water resources. Thus the model solves a problem involving economic scarcity, with the use of a certain local measures having direct consequences for the physical possibility of an option elsewhere. It thereby provides a framework for answering policy questions ('objectives') and at the same take various types of stakeholder preferences into account ('constraints'). It creates the possibility to highlight the consequences of people's preferences and claims on land and water use on the water quantity, water quality and ecosystems as well as other (economic) indicators. WaterWise has the ability to combine knowledge options from different sectors and different knowledge tools and to define sectoral and spatial trade-offs. By supporting an integrated discussion on land and water use it aims to support the creation of durable water-space partnerships.

WaterWise provides an integrated modeling platform for exploring a range of strategies and innovative ideas with respect to the socio-economic development in the context of the Nile basin. The results can be understood in conventional economic terms and also in terms of their effects on ecosystem services and human welfare. Results are not only visible for the Nile Basin as a whole, but also for the different riparian countries to support discussions and negotiations on acceptable solutions for spatial planning and water management.

4.2 Modeling tradeoffs in land use and water allocation

As the Nile is one of the most studied basins in the World not only several hydrological models exist describing the hydrology of the Nile, but there are also a number of optimization models linking hydrology to economy. The Investment Model for Planning Ethiopian Nile Development (IMPEND) (Block *et al*., 2007) weighs the trade off value of hydropower and water for irrigation. As its acronym suggests, it focuses on the Ethiopian part of the Blue Nile and investigates the effects of four proposed hydropower dams. The model uses as input the stream flow and net evaporation at the different dams. Due to its simple setup it is capable of quickly assessing the impact of different reservoir management options and of stochastically modeling various change scenarios. Its focus is however only on the Blue Nile region in Ethiopian and thus not oriented towards the basin as a whole.

The Nile Economic Optimization Model (NEOM) developed by Whittington *et al.* (2005) does describe the whole Nile basin. It is designed to maximize the sum of economic benefits from irrigated agriculture and hydropower generation. It includes all existing reservoirs and irrigation schemes in the basin as well as eight new reservoirs and 13 new irrigation schemes. The analysis focuses on the tradeoffs resulting from the following economic ‘pressures’:
– i)use water for irrigation upstream to reduce evapotranspiration;
– ii) use water downstream to take full advantage of hydropower;
– iii) store water upstream to reduce evapotranspiration losses and;
– iv) use water where its value is the most profound.

Whittington et al. show that cooperation between the different Nile countries for an optimum use of water will give a far greater economic value than the current status quo with fixed allocations will.

WaterWise closely resembles the NEOM model in several aspects. It also describes the whole Nile basin. All the existing irrigation schemes and hydropower reservoirs are included as are most of the proposed plans. The economic parameters are similar. However the NEOM model primarily addresses the allocation side, with irrigated area as the only land use related water consumer. Water input into the system, stream flow, is fixed, based on prior calculations. WaterWise adds to this concept the supply side, by modeling the land use as an endogenous variable within the whole catchment (i.e. not only the irrigated areas), thus covering the complete hydrological cycle WaterWise incorporates processes in the Soil-Vegetation-Atmosphere column at pixel scale and then calculates the resultant stream flow which is dependent on the choice of land use. Land use and land use changes are thereby integrated in the approach. This broadens the optimization from a river oriented to a more comprehensive land water oriented approach. As the Comprehensive Assessment on water management in Agriculture (2007) and others (Snellen, 2006) state, thinking differently about water is essential for ensuring food security, reducing poverty, and conserving ecosystems. It argues that instead of a narrow focus on rivers and groundwater, rain should be viewed as the ultimate source of water that can be managed. WaterWise does exactly this and thereby aims to integrate water management with land use planning.

In addition to the hydropower and irrigation tradeoff studies by Whittington *et al*. (2005) and Block *et al*. (2007), the integrative land and water use oriented approach of WaterWise broadens the discussion on cooperation versus individual optimization into two new areas:

- Achieving food self-sufficiency, i.e. evaluate the agricultural production of the entire basin, both rainfed and irrigated;
- Adapting to climate change and climate variability in rainfed agriculture, irrigated agriculte and hydropower.

This creates the possibility to investigate whether individual countries will be able to maintain their own food self-sufficiency and how much can be gained from total cooperation within the Nile basin. This links to a recent vision study undertaken by FAO and NBI (Hilhorst et al., 2008). The interesting outcome of this vision study was the notion that a shift is needed from a discussion on water to a discussion on the use of land-and-water. If trade between the basin countries could be increased, several of the most pressing problems regarding the sharing and use of water could be solved.

Assessing the integrative impact of climate change and associated uncertainties is the second extended feature. Climate change and variability will not only affect irrigated agriculture and evapotranspiration in hydropower reservoirs, but will also have an impact on upstream rainfed agriculture, forests and shrub lands. As a result, land use patterns may change resulting in a different runoff and stream flow. This again may interact with food security targets or hydropower yields. In addition, climate change and variability introduce the issue of uncertainty. WaterWise has the ability to optimize based on multiple climate runs. This yields suggestions for spatial patterns of measures that have been based on more than one possible future climate. This increases the robustness of the chosen options.

4.3 General model schematization

The Nile Basin application of Waterwise has been constructed around a simplified hydrological model. Some 120 sub-basins of the Nile have been integrated. At a more detailed level there are 1371 so-called hydrotopes, which in turn are comprised of 3 million 1 km^2 pixels. The schematization includes an aggregation to the level of the 10 riparian countries. Presenting results for and having the possibility of inserting constraints at this level (e.g. minimum agricultural production for a certain country) is a crucial element in the interface between the model and the stakeholders.

The 1371 hydrotopes are formed by overlaying sub-catchments, soils and land use. The sub-catchments were delineated with AVSWAT (Luzio *et al.*, 2001) using a Digital Elevation Model (DEM) of the Shuttle Radar Topography Mission (SRTM) *(see http://srtm.usgs.gov/*). AVSWAT also generates the main surface water system. All the major rivers are included as well as the main lakes and reservoirs (Figure 1).

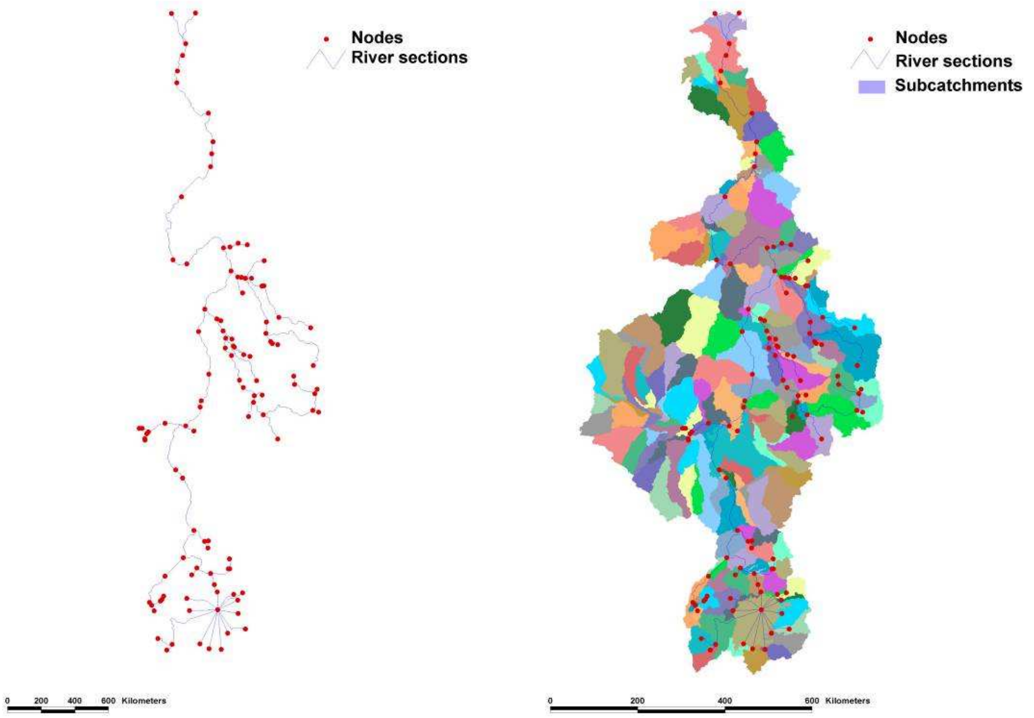


Figure 1 Surface water schematization (a) and catchment delineation (b)

The land use is derived from a FAO Land Use Systems of the World map for Sub-Saharan Africa (www.fao.org/geonetwork). A more detailed mapping of the irrigated areas was achieved by a supervised classification of Landsat images (glcfapp.umiacs.umd.edu) in combination with a FAO map indicating regions with a certain percentage of irrigation (Occurrence of irrigated areas (FGGD) www.fao.org/geonetwork) (Figure 2a). The general agricultural land use types of the FAO classification were further specified using country information on the main cropping patterns (see also paragraph 4.4). This resulted in the main land use types as shown in Figure 2b.

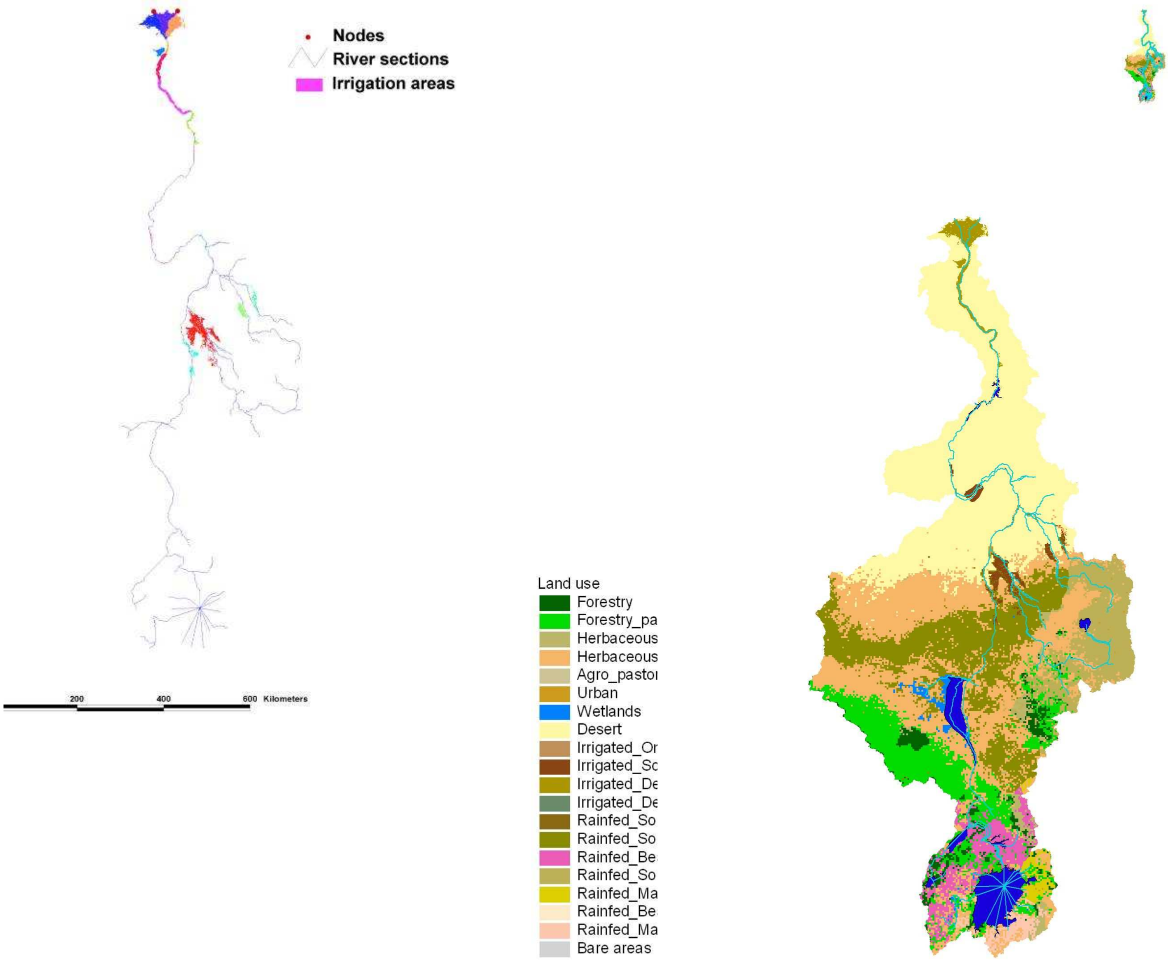


Figure 2 Supervised classification of major irrigation areas (a) combined with FAO land use regions map (b).

Soils were based on the FAO-UNESCO 1974 Soil Map of the World (1:5,000,000). For several countries more detailed soil maps are available, but not for all. And not all use the same legend to which cross-references to the Wise 1.1 soil properties database (Batjes, 2002) could be made, making it difficult to derive a consistent set of parameters for each soil class for the whole Nile basin. The current, very simple classification is based on a combination of maximum soil moisture content and surface slope (Figure 3 and paragraph 4.4).

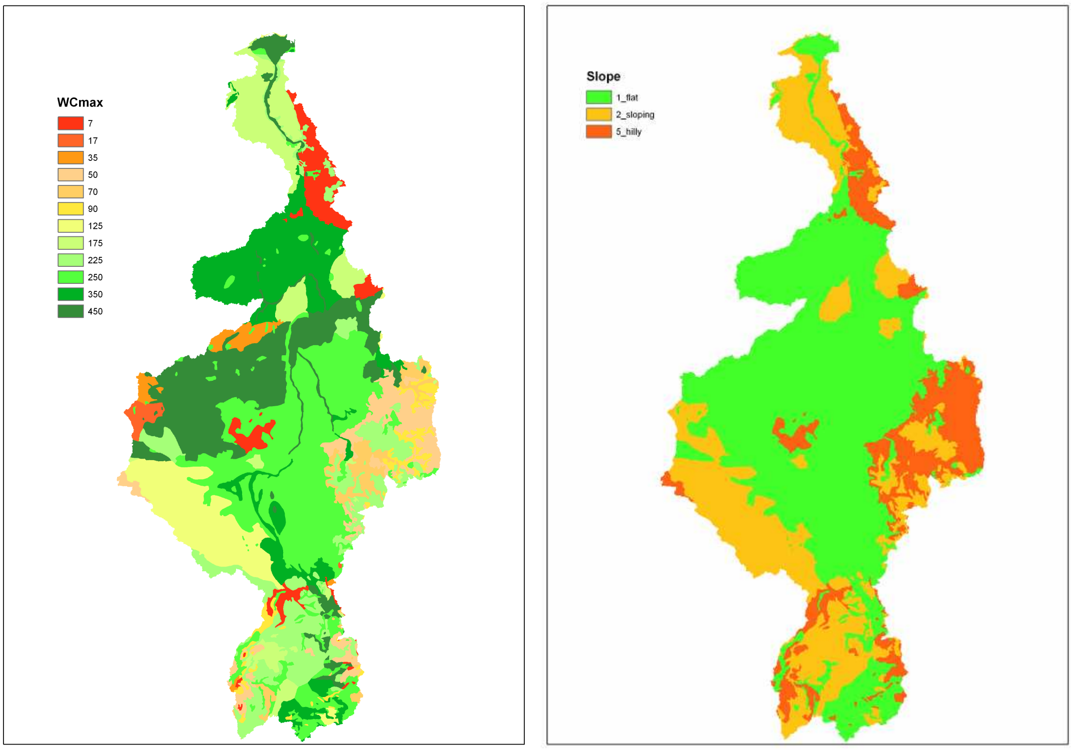


Figure 3a maximum Water Content (WCmax in mm) and b Slope fraction

A special feature form the meteorological regions. Meteorological regions are based on a combination of ECMWF (http://www.ecmwf.int/) and DWD data (http://www.dwd.de/) for the reference evapotranspiration. TRMM data (http://trmm.gsfc.nasa.gov/) are used for daily precipitation values per 0.25 degree pixels. The meteorological regions themselves were not used to derive the hydrotopes. The hydrotopes have, in this study, been determined as the result of a gridding and overlay procedure involving soil, land use and sub-basins. However, meteorology is used to determine in each hydrotope the possible extent of a certain land use type: A minimum 'Actual Evapotranspiration/Potential Evapotranspiration' cutoff value is demanded for each type, and the number of pixels that fulfill this condition are added up. These totals are used as constraints in defining the decision space of the model. In this way land use cannot extend beyond a certain meteorological range within a hydrotope.

For each 1 km^2 pixel a basic water balance is computed. Water in each cell can contribute to runoff, drainage or to its local groundwater storage. When activated, runoff and drainage can temporarily be stored in the local surface water system of each catchment. Potentiall, a cell can draw water from three sources:
- i) its own local groundwater storage;
- ii) the local surface water storage of each sub-catchment and;
- (iii) irrigation water from the main water courses itself, if available (Nile, Atbara etc.) (Figure 4).

In WaterWise these options will be activated based on investment costs and returns on investment, if not limited by water-related constraints. For example, only the main irrigation regions can demand water from the Nile itself. All other land uses can demand water only from groundwater and local surface water. But they will only do so if enough water is available in the local surface water system and the increase in crop yields will outweigh the investment costs of activating this option. For a more detailed description see Van Walsum (2009).

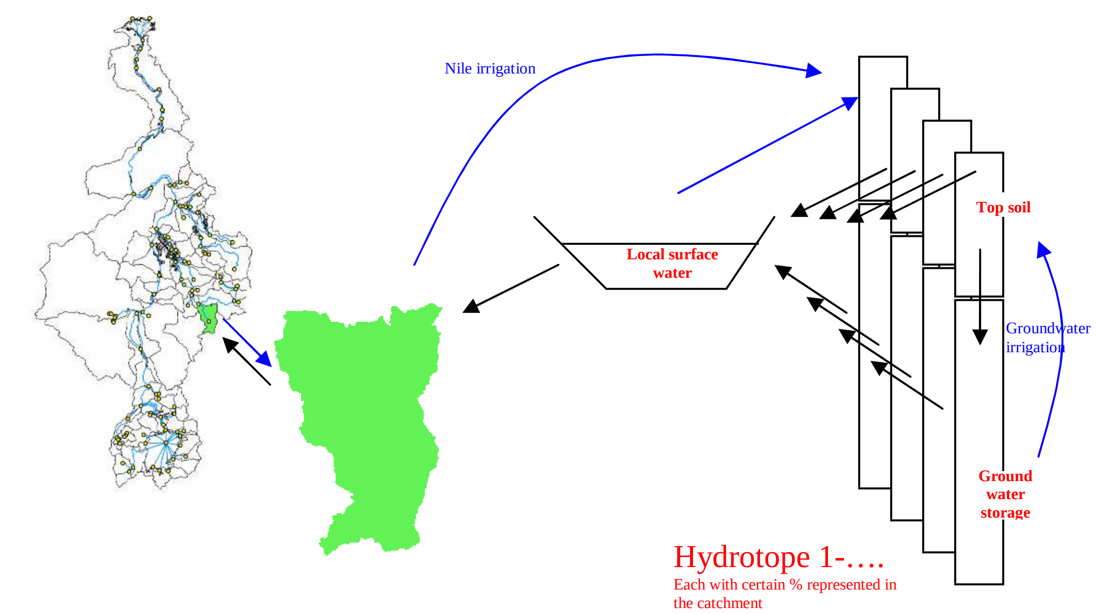


Figure 4 Subcatchment – hydrotope interaction and water flows

4.4 General model parameterization

Soils

The FAO-UNESCO 1974 Soil Map of the World (1:5,000,000) has been used as the basic soil map. In order to obtain soil properties a link was made with the Wise 1.1 database (Batjes, 2002). To stay in line with the simple setup of the hydrological model, three entry keys were selected for the soil classification: soil slope, profile depth, and soil texture. Soil slope gives an indication for runoff capacity, while profile depth and texture give a measure for soil water storage and infiltration capacity. Table 3 shows the subdivisions per entry key leading to the 12 basic soils identified (see also Figure 3).

Table 3 Description of the 12 soil classes and major soil physical properties

Soil nr.	Slope	Profile depth	Soil texture	Surface Storage (mm)	Infiltration Capacity (mm/d)	Water Storage Capacity Topsoil (mm)	Water Storage Capacity Profile (mm)	Dead Storage Capacity Profile (mm)	Drainage Resistance (d)
1	flat	deep	medium	25	200	35	9847	9550	500
2	sloping	intermediate	medium	15	100	35	347	0	500
3	hilly	shallow	medium	10	50	35	47	0	100
4	flat	deep	fine	25	100	250	10138	9550	500
5	sloping	intermediate	fine-medium	15	100	250	638	0	500
6	hilly	shallow	medium	10	50	250	338	0	100
7	flat	deep	medium	25	200	350	10273	9550	500
8	sloping	intermediate	medium	15	100	350	773	0	500
9	hilly	shallow	medium	10	50	350	473	0	100
10	flat	deep	medium-coarse	25	300	450	10322	9550	500
11	sloping	intermediate	fine-coarse	15	100	450	822	0	500
12	hilly	shallow	fine-coarse	10	50	450	522	0	100

These descriptions in combination with the Wise database and some expert judgment were used to derive the basic soil physical properties required for hydrological modeling. The most important values are presented in Table 3. 'Surface storage' is used to define a threshold value above which runoff will start. For irrigated areas these values are replaced by a value of 100 mm in order to correctly represent ponding conditions. Crops and natural vegetation can use the water stored in the topsoil for their transpiration. Part of the remaining water stored in the (total) profile can be drained to surface waters and/or pumped for irrigation, provided this option is available.

Land use and cropping patterns

For the WaterWise application in the Nile Region initially agriculture and hydropower will be the two main economic activities that will compete for water. For the agricultural sector key indicators need to be determined to be used in the optimization algorithms.

In FAOSTAT the cropping data for eight of the ten Nile riparian countries for the last 10 years (1997/2006) have been extracted. The data are areas grown (ha) and production (ton). The countries are Burundi, Rwanda, Tanzania, Uganda, Kenya, Ethiopia, Sudan and Egypt. DR Congo and Eritrea have been left out because these countries have only a very small percentage of their area within the Nile Basin.

The total number of crops distinguished in FAOSTAT in these countries is 109. The data have been consolidated to the 13 main crops present in the area. Only crops that occupy at least 5% of the area in any of the countries has been considered as a main crop. As an example the cropping pattern of Burundi is given below in Table 4.

Table 4 Burundi cropping pattern data (FAOSTAT)

Crops	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
Bananas	26	26	27	28	26	26	26	27	27	27	26
Beans, dry	29	29	26	25	26	27	27	26	25	25	27
Clover	0	0	0	0	0	0	0	0	0	0	0
Coffee, green	3	3	4	4	4	4	4	4	4	4	4
Cotton lint	0	0	0	0	0	0	0	0	0	0	0
Fruit trees	2	2	2	2	2	2	2	2	2	2	2
Groundnuts, with sh	1	1	1	1	1	1	1	1	1	1	1
Maize	10	10	11	11	10	10	10	10	10	10	10
Rice, paddy	2	1	2	2	2	2	2	2	2	2	2
Sorghum	6	6	5	5	6	6	6	6	6	6	6
Sweet potatoes	18	17	19	19	19	19	19	20	20	20	19
Vegetables	3	3	3	3	3	3	3	3	3	3	3
Wheat	1	1	1	1	1	1	1	1	1	1	1
Total	100	100	100	100	100	100	100	100	100	100	100

The data on areas grown (with consolidated crops) and production have been used to calculate the crop yields per ha. In the further analysis only average data on cropping pattern and production have been used. In order to further simplify analysis and exclude data on minor crops, only main crops (generally more than 10% in the cropping pattern) have been used in the ensuing analyses. In order to derive meaningful relations between rainfall, irrigation and crop yield, another consideration to maintain a crop in the cropping pattern was that the crop should be present in at least five countries. That resulted in seven remaining main crops only: bananas, beans, maize, sorghum, sweet potatoes, vegetables and wheat. The importance of groundnuts for Sudanese agriculture and rice for Egyptian agriculture resulted in adding these two crops again. Alexandrian clover (also known as 'berseem' in Arabic agriculture) should also have been added based on these considerations, but the absence of price information for this crop in the FAO database resulted in the decision to neglect it (occurs in Egypt only). The resulting simplified average cropping pattern is given below in

Table 5.

Table 5 Simplified average (1997/2006) cropping pattern for the 8 major Nile countries

Percentages	Country							
Crop	Burundi	Egypt	Ethiopia	Kenya	Rwanda	Sudan	Tanzania	Uganda
Bananas	31				27		5	32
Beans, dry	33		12	34	27	15	13	24
Groundnuts, with shell						12		
Maize	12	23	17	45			42	13
Rice		11						
Sorghum			39		13	71	15	13
Sweet potatoes	23			4	23		18	18
Vegetables		26	10	13	10		6	
Wheat	1	33	23	5		2	1	

The crop yields for these major crops are given below in Table 6.

Table 6 Average (1997/2006) crop yields of major crops in the eight main Nile countries (FAOSTAT data)

	Crop yield (ton/ha)								
Country	Bananas	Beans	Groundnut	Maize	Rice	Sorghum	Sweet pot	Vegetables	Wheat
Burundi	5.14	0.90		1.10			7.18		0.81
Egypt				7.61	9.39			24.76	6.07
Ethiopia		0.89		1.78		1.01		2.59	1.27
Kenya		0.43		1.62			9.10	8.53	2.14
Rwanda	6.67	0.64				1.00	5.40	7.59	
Sudan		0.26	0.69			0.02			0.05
Tanzania	2.18	0.57		1.13		0.94	6.57	4.13	
Uganda	5.71	0.67		1.61		1.48	7.53		1.30

One of the main optimization criteria in WaterWise is the economic performance of different alternatives. Data on production costs (inputs) and revenues resulting in generated income need therefore be collected. For the revenues data from FAO PRICESTAT on producer prices for the crops identified for the countries studied have been collected for the period 2001/2005. These prices have been averaged over the period and weighted with the average production volumes (period 1997/2006) in the countries (based on FAOSTAT). The data in FAO PRICESTAT are quite incomplete and generally data for only 3 to 5 of the eight main Nile Basin countries were found.

Data on production costs of the crops distinguished are currently not available in the FAO database. Therefore, through a Google exercise, some sparse data on production costs of the main crops in these countries were collected from several PhD theses (Bagamba, 2007; Darwish, 1992) and other studies available on the internet (Gurmani et al., 2006; Lust et al., 2009; Kudi and Abdulsalam, 2008; www.biotech-monitor.nl/; www.fapri.missouri.edu/; ressources.ciheam.org/). These basic data per crop are given in Table 7, together with the production volume weighted average for the price and the area weighted average for the production cost.

Table 7 Basic economic crop data (price/ton and cost/ha) for the main crops in the Nile Basin region and average prices and costs for the cropping patterns of the eight main Nile basin countries.

Crop	Price (US$/ton)	Cost US$/ha
Bananas	321	300
Beans, dry	489	42
Groundnuts	306	143
Maize	142	112
Rice	175	261
Sorghum	152	14
Sweet potatoes	125	64
Vegetables	102	385
Wheat	152	121
Average	162	105

	Average	
Country	Price (US$/ton)	Cost US$/ha
Burundi	240	137
Egypt	124	210
Ethiopia	167	94
Kenya	143	121
Rwanda	223	149
Sudan	342	36
Tanzania	149	105
Uganda	239	134
Average	162	105

Surface Water

The river system has been modeled with a node-arc architecture. The flow and storage processes are modeled with two types of arcs:

- river trajectories, with the focus on modeling translation time and losses;
- lakes and reservoirs, with the focus on storage and release, operational management, hydropower, and atmospheric losses and gains.

For the translation time modeling use has been made of the unit hydrograph (UH) method embedded in the optimization model. The used time step is in the order of 5 days. Losses are taken into account by using UH's that do not add up to the unit. In the White Nile trajectories between the ouflow of Sudd and the confluence with the Blue Nile a total of 12% is lost in this way. Between the confluence and the delta another 18% is in the same manner. The UH's have been based on a wave-celerity of 60 km per day.

For the reservoir modeling nonlinear relationships between head and surface area have been implemented, and also between head and discharge. Depending on the type of reservoir, the discharge can be 'natural' or managed. In the latter case the discharge relationship serves as an upper bound on the release. The (variable) area of the reservoir determines the interaction with the atmosphere. The storage changes in the reservoirs have been modeled at a time step of year-quarters; computational experiments showed that using a shorter time step did not yield significantly different results.

An off-take of irrigation water can either be from a node or from a trajectory, whichever is the most appropriate for modeling the local situation. Return flows enter the river via the nodes. A number of river links have been modeled as discrete (0/1) decision variables; this concerns the options for new major and local reservoirs and for the completion of the Jonglei canal. It is up to the model user to enable the links in the model (or to forcefully implement them).

Hydropower

The income of hydropower per m^3 discharge is calculated for the main dams by combining the maximum discharge with the maximum capacity and a price per kWh. Based on the actual discharge a total income per dam can be calculated. The price per kWh is set for all hydropower stations at 0.10 USD/kWh, in the same range as the price of 0.8 USD/kWh by Whittington et al. (2005).

In Table 7 three categories of hydropower dams are distinguished: in operation, under construction, and planned. For each dam the relevant parameters are presented. Kalagala and Bujagali are excluding each other, which means that if one of them is built the other becomes irrelevant because the reservoirs influence each others head difference too much. Ayago North, Ayago South and Murchison Fall are combined as one option as are the proposed dams in the Blue Nile in Ethiopia. This simplification will not drastically alter the upstream-downstream relationships and trade-offs, but will alter intersectoral optimizations. Block *et al*. (2007) describe the exact properties of the proposed dams in Ethiopia in more detail.

Table 8 Hydropower parameters[3]

	Country	*Maximum discharge (m3/s)*	*Capacity (MW)*	*Price (#/kWh)*	*Income (#/m3)*	*Investment (M#)*
Owen Falls Extension (Kiira)	Uganda	1800	300	0.1	0.00463	existing
Bujagali	Uganda	1316	250	0.1	0.00528	730
Kalagala	Uganda	1344	315	0.1	0.00651	680
Karuma Falls	Uganda	577	200	0.1	0.00963	450
Ayago North	Uganda	410	143	0.1	0.00969	1000
Ayago South	Uganda	371	234	0.1	0.01752	
Murchison Fall	Uganda	421	222	0.1	0.01465	
Tana (Tis Abbay I&II)	Ethiopia	180	84.4	0.1	0.01302	existing
Aswan	Egypt	4152	2100	0.1	0.01405	existing
Roseires	Sudan	1689	210	0.1	0.00345	existing
Merowe	Sudan	3600	1250	0.1	0.00965	1700
Ethiopia dams combined	Ethiopia	1750	5300	0.1	0.08413	6900

4.5 Options

The WaterWise tool has the option to attach weights to the different components of the over-all yield function. The two main components are yield of land use and yield of hydropower. It is also possible to leave out a certain component altogether (weight of zero) and instead use a constraint specifying a minimum value for it. The land use yield has a specific spatial dimension and influences crop yields, runoff and irrigation water demand. Yield of hydropower relates more to the surface water system where reservoirs can be built and storage increased to receive optimum power generation. However, both types of yield are highly interlinked. In the best case there is full synergy: land use can then be optimized so that there is also optimum discharge for hydropower generation. Seen from the opposite perspective, hydropower reservoirs can in the case of full synergy provide a storage which is also beneficial for the development of large scale irrigation. But usually there is a certain degree of antagonism between the two objectives, because upstream use of water for irrigation can limit the profitability of downstream hydro-power development.

[3] Sources: Block et al. (2005); Database of African Dams; Suthcliffe and Parks (1999); Shahin (1985); Bleeker at www.unu.edu; www.mowr.gov.et

4.5.1 Land use change and watershed improvement

The introduction of local watershed improvement is identified in the National Adaptation Plans as an important option within the Nile basin. The WaterWise model has the possibility to choose several options, like irrigation from local groundwater or regional surface water reservoirs and/or to increase infiltration capacity. These options have initial investment costs, fixed annual costs and variable maintenance and operational costs that depend on the actual use. The model can also convert land use and will do so if the increased yields are higher than the costs of conversion and other maintenance/operational costs. In addition also large scale options like new irrigation projects can be implemented.

Land use change

Land use change can influence both the discharge side of water (different runoff and drainage rates) and the demand side of water (through a change in irrigation amount). Table 9 shows changes that are allowed in the current version. Various irrigation schemes have been defined, with one crop (one season) or multiple crops per year and different fallow percentages for the irrigated areas in Sudan (Irrigated_south) and Egypt (Irrigated_Delta and Irrigated_DeltaLessIntensive).

Table 9 Allowed land use changes

	From	*To*	*Vice versa*
All countries	Agro_pastoralism	Agriculture (rainfed)	n
	Herbaceous	Agriculture (rainfed)	n
	Herbaceous_pastoralism	Agriculture (rainfed)	n
	Forestry	Agriculture (rainfed)	n
	Forestry_pastoralism	Agriculture (rainfed)	n
Large irrigated areas	Irrigated_OneSeason	Irrigated_South (Sudan)	y
	Irrigated_OneSeason	Irrigated_DeltaLessIntensive (Egypt)	y
	Irrigated_OneSeason	Irrigated_Delta (Egypt)	y

n= no , y = yes

Watershed improvement options

Watershed improvement consists of three options;

- Local groundwater irrigation
- Local surface water irrigation
- Increase in infiltration capacity (i.e. field management)

Local groundwater or surface water irrigation can be activated separately or in combination with each other. The increase in the infiltration capacity is linked to the irrigation options, but could also have been separately enabled. It is assumed that when investments are made for irrigation there will be simultaneous improvements in field management so that the extra water applied is used with a higher efficiency. Table 10 gives the costs for the different options.

Table 10 Investment costs

option	*type*	*Cost # per ha*
Watershed improvement	supply from local reservoirs	750
	irrigation from local groundwater	100
Irrigation development		3500
Extension of agricultural land		7500

Large scale irrigation

The development of large scale irrigation is a special option in WaterWise. Unlike the other land use conversions, this land use change is coupled to a certain predefined area. The high initial investments in large scale infrastructure distinguish this option from the other more diffuse land use changes. In the current version, the existing irrigated areas in Egypt and Sudan are modeled as a standard option. Two large new irrigation areas, one near the new Merowe dam in North Sudan and one in the Blue Nile region in Ethiopia, have been defined (Table 11). They can be activated against certain costs (see Table 10). WaterWise can choose out of different irrigated cropping regimes (single or double cropped, certain % of bare area). Additional groundwater use is an option as well.

Table 11 Some characteristics of large scale irrigation projects in WaterWise

	existing	*efficient*	*Land use change investment*	*Water management investment (fixed)*	*Water management investment (variable)*	*Potential Evapotranspiration*
Egypt (Delta and Valley)	y	y	n	n	y	Medium - Very High
Sudan (Blue Nile and Atbara)	y	n	n	n	y	High – Very High
Sudan (Merowe)	n	y/n	y	y	y	Very High
Ethiopia (Blue Nile)	n	y/n	y	y	y	Medium – Very High

n= no , y = yes

4.5.2 Hydropower and reservoirs

WaterWise can optimize water storage and runoff for hydropower production and choose to invest in new hydropower stations and reservoirs. The completion of the Jonglei canal is also included in the model as a special option. Table 8 gives the investment costs and capacities of the different hydropower stations.

4.6 Multiple climate optimization

A special feature of WaterWise that was developed during the Newater Nile-case project is the multiple climate optimization. Adaptation has to take place under an uncertain future. With WaterWise (sub)optimum solutions can be sought within the boundaries of a single climate scenario or by taking into account multiple climate scenarios/possibilities at the same time. This will highlight options that are robust under different circumstances and can show the extra costs of decisions based on only the current climatic conditions or a single climate scenario if the future reality turns out different (or the extra gains when one has betted on the right climate scenario).

To test the multiple climate optimization the following climate changes, based on data from Kwadijk (2007), were combined:

- All regions: Average Potential Evapotranspiration +10%
- White Nile: Average Precipitation + 25%
- Blue Nile: Average Precipitation +15% or Average Precipitation -15%

This resulted in two alternate climates: a ‘dry’ and a ‘wet’. The difference between these climate scenarios is concentrated in the Blue Nile region, which contributes most to the total Nile discharge. It is expected that it will become warmer over the whole basin resulting in a higher evaporative demand. In the upstream part of the White Nile all scenarios point to an increase in precipitation.

The changes were imposed on a relatively dry climatological year of the standard run, 2000-2001. The timing of precipitation events was not changed.

4.7 Results

The different levels of data aggregation (basin, country, hydrotope) and stakeholder focus (agriculture/hydropower) in WaterWise provide the opportunity to present results in numerous ways, depending on request. Paragraph 4.7.1 will look at choices and income at different investments levels for the basin as a whole and for different countries. Paragraph 4.7.2 will show the choices and changes in land use. Paragraph 4.7.3 will highlight the effect of taking into account more than just the current climate and how to evaluate the robustness of different options.

Monetary values will be expressed in # or million #, instead of USD or Euro to create clear distinction between modeled value and yields and reality.

Secondary effects such as a distortion of market prices due to (local) over-production for agricultural products are not included. It is assumed that there is a market for energy and agricultural products so that prices remain at the same level.

The current production is taken as a reference situation. A better use of water can increase production, but ‘external’ effects such as a higher fertilizer or pesticide use are not taken into account (but could be introduced via a higher yield/prices at a certain investment cost). The animal sector was not included in the model.

4.7.1 Overall results

A set of 7 investments levels was applied to find out which options would give the highest income given a certain investment level. For each investment level a division in the presentation of the results has been made between investments in and income from agriculture and the total investments and income which also includes hydropower (Figure 5). Agriculture generates the highest income in the basin but its income increases only slightly with increased investments. Hydropower related income is low in the current situation but shows a high increase after investment.

Figure 5 shows the decreasing return on investments. However, even with an investment of 50,000 million # there are still options to convert non-productive land into agricultural lands even though climate, soil and water and water availability conditions become more and more sub-optimal.

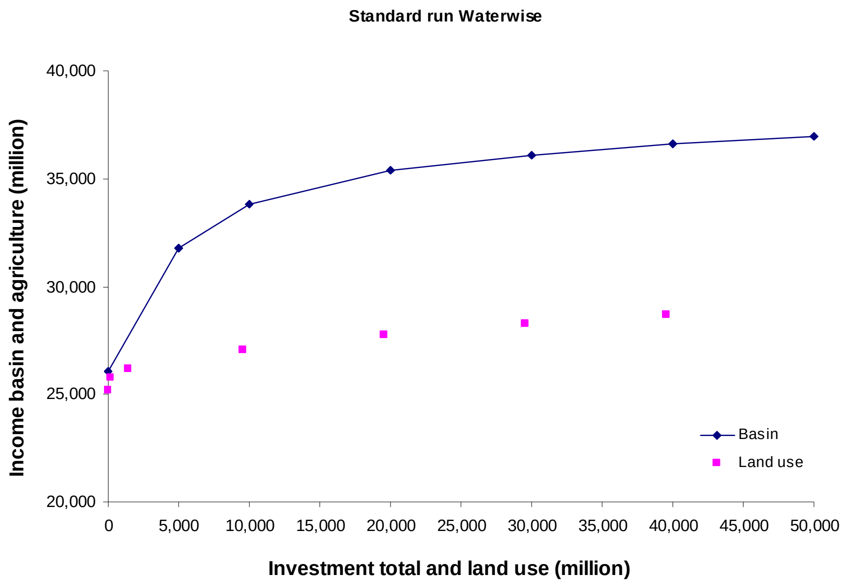
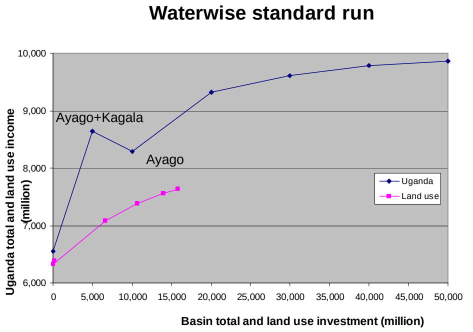


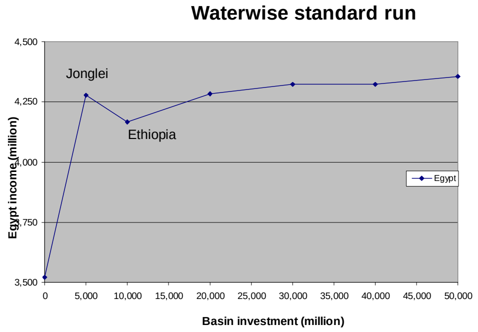
Figure 5 Annual income as a function of investment for agriculture and the total basin

Figure 6 shows the income for several of the different countries. The biggest changes occur during the initial investments of 5, 10 and 20 billion #; after that the most profitable investments have been made and the increase in income is mainly due to watershed improvement or land use changes. Egypt is the only country where there is no investment in agriculture. The current setup of WaterWise assumes the irrigation potential of Egypt is already fully used. The investment in the Jonglei canal, however, increases water availability and thereby the income from irrigated agriculture and hydropower. Interestingly, in the 10 billion # investment run, the Jonglei canal is not included anymore. With 10 billion of investments it becomes possible to build the Ethiopian hydropower dams which cost a total of 6900 million #. Adding an additional investment in hydropower in Uganda makes it become infeasible to build the Jonglei (at this level of total investement) and thus income in Egypt decreases. A similar dynamic can be seen in Uganda where in the 5 billion # run it is possible to complete two hydropower projects (Ayago and Kagala) but in the 10 billion # run only Ayago.

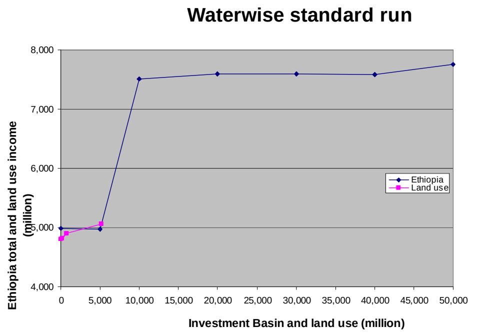
Figure 6 also shows that only in Sudan there is a significant investment in land use, up to 15 billion #. Within the climatic conditions there is a large potential to convert shrub land into agricultural land and improve production.



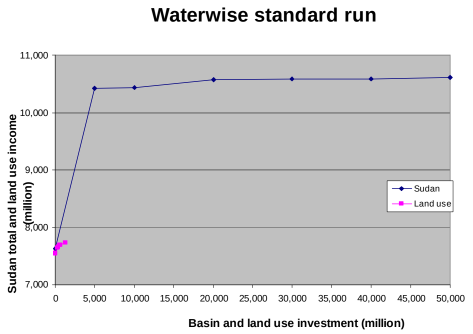
Uganda



Egypt



Ethiopia



Sudan

Figure 6 Return on investments for different countries

In the standard run WaterWise optimizes land and water use to achieve the highest economic returns for the whole basin without prejudice between countries or sectors. An interesting question would be, however, what happens if upstream countries (poorer) get priority from big investors like the World Bank. Or what would happen if food production (as part of the Millennium Development Goals, to reduce hunger and poverty) gets higher priority than industry (e.g. hydropower).

The results are shown in Table 12 and Figure 7. Clearly in the agriculture scenario Ethiopia is most affected as it 'loses' its income from the hydropower dams, which are not built because of the lower priority. These changes are however relative to the 'standard' 20 billiard # investment scenario in which Ethiopias income increase by more than 3.5 billiard #. This is in the agricultural scenario reduced to an increase of about 1 billiard #. Giving agriculture a strict priority over other developments also clearly influences total basin income as Table 12 shows.

In the upstream priority scenario changes are relatively small. As expected the income of Egypt and Sudan is somewhat reduced to the benefit of several upstream countries.

Table 12 Change in sector income and investments compared to the standard situation for the upstream and agriculture priority scenarios

20 B# runs				
Item	Reference	Standard	Upstream	Agriculture
Basin income (B#)	26.09	35.15	35.11	32.49
Agriculture (B#)	24.97	26.33	26.32	26.82
Hydropower (B#)	1.11	8.82	8.79	5.67
Investment hydropower (B#)		10.28	10.28	2.70
New agriculture (Mha)		1.09	1.17	2.06
Watershed improvement (Mha)		1.83	1.02	2.24

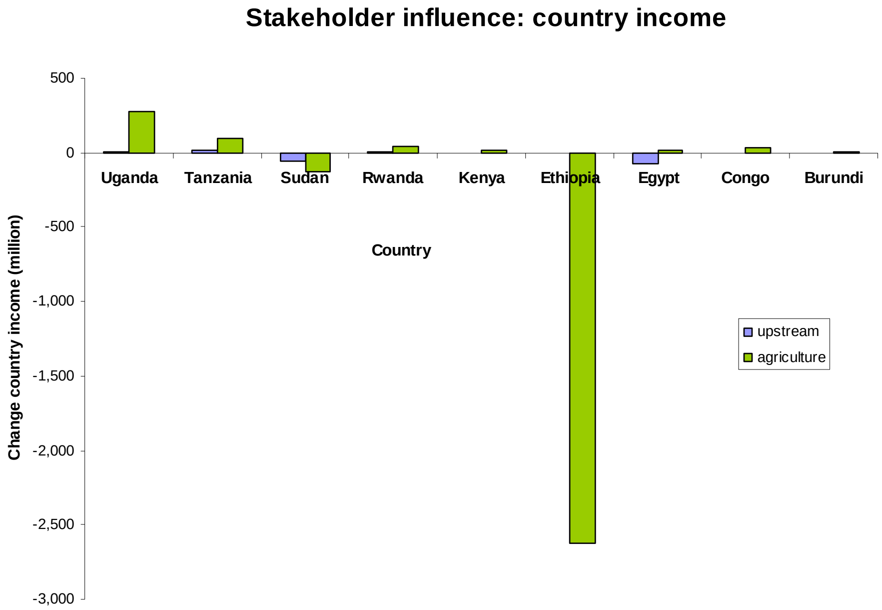


Figure 7 Change in country income compared to the standard 20 B# investment situation for the upstream and agriculture priority scenarios

4.7.2 Spatial adaptation

Figure 8 shows land use changes in the 20 billion # scenario compared to the standard run. As can be seen throughout the whole basin there is not drastic change in land use. This is not surprising as the present land use has developed within the biophysical possibilities, which have not changed. A large part of the basin receives such a low amount of rainfall and has such a high evaporative demand that conversion to agriculture is unlikely.

However, there are several countries where land use change and investment in watershed improvements play an important role in increasing the income from agriculture. As Figure 6 shows Uganda is one of them. Agricultural land use types, in Rwanda and Uganda dominated by beans and bananas, increase at the expense of herbaceous pastoralism land use.

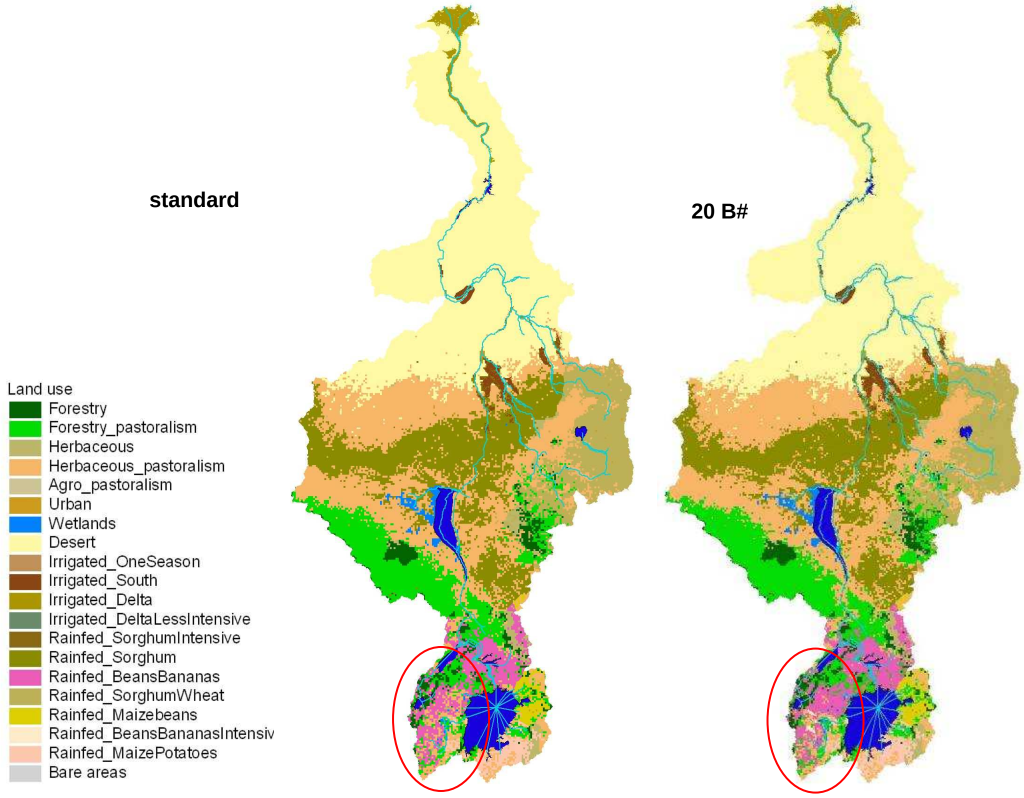


Figure 8 changes is land use between the standard and the 20 B# investment scenario

The water management options show big changes in southern Sudan (Figure 9). Here investment in the additional use of groundwater becomes profitable according to the model. In the upstream parts of the Blue Nile in Ethiopia also local surface water is used. Large scale irrigation in Egypt is active in both scenarios, which is not surprising given the intensive irrigated agriculture and thus (relative) high income. Furthermore, as they are already existing no investments will be needed. Interestingly, irrigated agriculture in Sudan, which is less efficient, is not profitable enough and therefore not active.

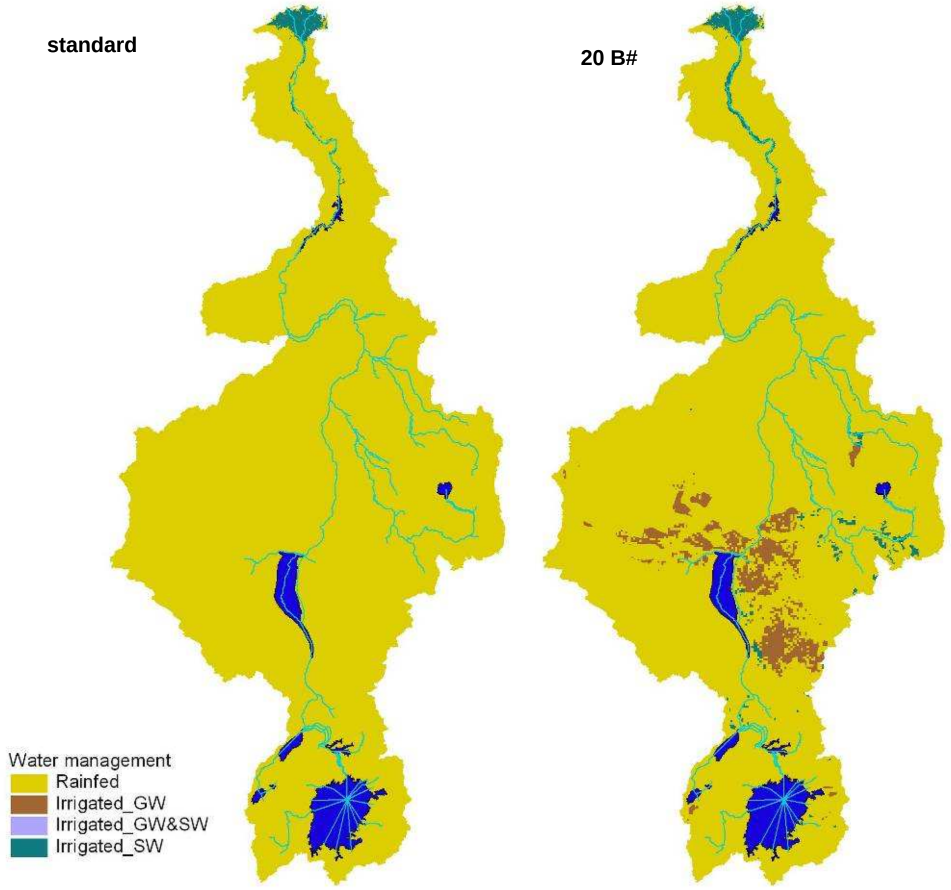


Figure 9 Changes is water management options between the standard and the 20 B# investment scenario

4.7.3 Climate change

Downscaled results of Global Circulation Models (GCMs), showing the past and present climate as well as indications for future changes, are conflicting for the major precipitation zones in the Nile Basin and should hence be interpreted with caution (LNFDC/ICC, 2007). So the question is; "How to account for this in investment planning?" A (Water)Wise option would be to select those investments first that perform well under all scenario's and take calculated risks. Thereto the following rationale was tested:

1. Base investments on a drier climate scenario and calculate outcome also under wetter conditions and calculate average;

2. Base investments on a wetter climate scenario and calculate outcome also under drier conditions and calculate average;

3. Base investments on both wetter and drier climate scenarios simultaneously ("climate proof")).

Results are shown in Table 13. As can be seen in this table results are rather trivial. Total Basin income decreases in all three scenarios compared to the Standard (current) climate scenario. As expected the Dry/Wet scenario, so the robust scenario, has a (very slightly) higher Basin income than the Dry and Wet scenario which only take one future climate condition into account. But differences are small. The main difference in the agriculture income can be found in the Dry scenario. Investment in hydropower is with the current constraints and objectives not an issue and takes place in all scenarios.

Table 13 Change in sector income and investments with investments based on different climate assumptions

20 B# runs		Investments based on:		
Item	Standard	Dry	Wet	Dry/wet
Basin income (B#)	35.15	33.15	34.27	34.29
Agriculture (B#)	26.33	24.34	25.34	25.36
Hydropower (B#)	8.82	8.81	8.94	8.94
Investment hydropower (B#)	10.28	10.28	10.28	10.28
New agriculture (Mha)	1.09	1.15	1.13	1.15
Watershed improvement (Mha)	1.83	1.17	1.43	1.22

5 Conclusions and discussion

5.1 Spatial adaptation and planning

There is a need for further study on the impact of land use change at different levels of scale. Climate adaptation is a process of decades rather than years or months. Large, basin wide changes do take place which could significantly change the land and water use within a basin and thereby affect its hydrology. Literature on this respect however is limited and contradictory.

The National Adaptation Programmes of Action (NAPAs) and transboundary NBI subsidiary action programs show resemblance in the type of projects or development they propose. A further analysis of their interconnected effects could help in prioritizing their implementation. It would be interesting to investigate what are the options and obstacles of putting them into practice at both the local and basin scale. This study has made an attempt to show the different interactions and effects of several proposed strategies.

The NAPAs provide a path to prioritize urgent adaptation needs for the Least Developed Countries. They draw on existing information and community-level input to identify adaptation projects required now in order to enable these countries to cope with the immediate impacts of climate change. The process of creating the NAPAs should be identical for all countries which makes it an interesting source of information to compare the perceived priorities of the different countries. Care should be taken however in interpreting the NAPAs as they are donor driven and do not necessarily reflect government policy, but more whishes of individual countries.

Another open question remains if and how, in practice, land use change and watershed improvement can become a spatial planning option for the catchment scale, or if it remains a more or less autonomous process, based only on individual local small scale reactions to change. This study and the WaterWise tool more in general attempt to bring more awareness to the possibilities of managing land use as an adaptation option.

5.2 To be WaterWise.....

Both IWRM as well as land use changes and spatial planning are complex processes that cannot be studied in isolation. With this study and the development of WaterWise tool for the Nile the intention was to help broaden the current discourse on water sharing and division. The discussion in the Nile basin should not only focus on water, but also on food security (and food self-sufficiency considering present infrastructure), environment, climate change and energy. This relates strongly to the FAO-NBI vision approach of Hillhorst *et al.* (2009) and the value of cooperation as described by Whittington *et al.* (2005)

The WaterWise tool was developed and works well for the three tests done:

- Investment decisions with stakeholders' priorities
- Decisions on climate change uncertainty
- Decisions on future food security

Results in investments show interesting differences. The climate change and food security show, at first sight, more trivial results. Changes are smaller, choices more logical. This however is an outcome as well. A controlling factor is the high agriculture production in downstream Egypt. Any agricultural development more upstream, at the expence of Egypts production, is under this situation not profitable. This dominance in profitability, however, could change in the future with upstream countries improving their agriculture.

Different investments lead to different priorities within the basin. Hydropower needs high investments but brings also instant revenues. The model shows that for certain countries there is still space for extension of agricultural lands. Watershed improvement is effective mainly in combination with intensification of agriculture.

Prioritising investments to upstream countries does not show significant changes in total basin income. The income of Sudan and Egypt is slightly reduced in favor of more upstream countries. A preference for agricultural investments does reduce total basin income. Especially the cancelling of large (and costly) hydropower development in Ehtiopia has a large impact on the income of this country.

The climate proofing was tested with a Standard 20 billiard # investment, so without any further constraint and enough investments to activate the most important hydropower investments. Results are logical but not spectacular. It would be interesting to combine the climate proofing with the upstream-downstream or agriculture preferences scenario to evaluate the effect. But to get a better insight, first of all, a longer climate period (more than 1 year, with variation within and between years) and spatially more diverse climate scenarios should be used. Due to computational and data limitations this was not possible in the current study.

Results should be compared in relative terms. In general one has to be carful in assessing economic data and interpreting results in absolute monetary values. Prices of crops and hydropower can change by the day. This cannot be simulated by the model. Secondary effects on market prices, like a decrease in price with an increase in yield, are not included. It is expected that additional hydropower or higher yields will have no effect on pricing.

5.3 Future

The technical approach and methodology of linking spatial planning and land use change with water management with WaterWise has been demonstrated. Its possibilities have been acknowledged by the technical experts consulted. The objective to apply the tool in a real stakeholder settings to guide the negotiation process has however not been realized. It is important to know in which way WaterWise can by applied in any process of stakeholders, targeting on different goals like awareness, assessment, scenario development, negotiations and reflection. It remains questionable whether the use of such a tool in stakeholder negotiations would be suitable as it may disturb the process by making effects of decisions (too) transparent.

However the current study was a pilot and there is still much scope and much need for improvement. Consultation with Nile Basin Initiative model experts indicated two major areas for improvement:

1. Agriculture is not sufficiently represented with only FAO data.
2. The underlying biophysical data and models need further enhancement.

Ad 1). It is very difficult to set up a consistent set of agricultural/agronomic parameters for all countries. FAO data refers to average yields, costs and cropped area for the whole country. This makes it difficult to apply the data to countries which have a significant part outside the Nile basin like Kenya or Tanzania, in most cases a very different agro-ecological zone. Averages won’t be sufficient then. In further development more local agronomist should be consulted. Integrating better statistics with a better, more local, land use classification based on the latest remote sensing data could also improve the schematization. Furthermore current crop-yield relationships could be replaced by a more specific agro-ecological model.

Ad 2). It was not within the scope of this research to develop a state of the art biophysical Nile model. To be able to create realistic WaterWise scenarios a simplified hydrological model was created. This can be improved or replaced by existing models or new models to be developed for example as under the coordination of the NBI. A better representation of the agro-hydrological system, with more detailed effects of land-use changes on the hydrology will greatly enhance the possibilities and acceptability of the WaterWise tool.

In addition, a longer climate period (more than 1 year, with variation within and between years) and spatially more diverse climate scenarios should be used.

The Nile Basin itself, with ten riparian countries, with spatial planning processes taking place in all these countries with different pace and priorities was advised as too complex for the objective of stakeholder support at present. In the Nile Basin the transboundary aspects of land use changes related to water management are politically sensitive. A much longer process with involvement of partners from the Nile Basin itself is needed to be able to test the tools in practice. Future research would better concentrate on the sub-basin level with only a few countries involved. In this case the focus could be put on poverty alleviation, vulnerability reduction and upstream – downstream interactions. With more trust and knowledge in results the discussion could then be extrapolated to the whole river basin.

Future cooperation with developers of models and databases within the Nile region is vital to improve the current WaterWise Nile prototype to a powerful tool which can be used outside also the scientific domain. Underlying data and models need to be shockproof when applied when there is a lack of consensus on important issues like climate change or the impact of certain developments.

A start has been made in broadening the discussion from water to land, water and energy. With improved data and models there is much scope for testing new hypotheses and exploring alternative ways to adapt to climate and socio-economic changes.

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