

Costs and Benefits of Land Management Options in the Upper Tana, Kenya Using the Water Evaluation and Planning system - WEAP



World Soil Information

Green Water Credits Report 14



P. Droogers, J.E. Hunink, J.H. Kauffman and G.W.J. van Lynden



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Green Water Credits Report 14

Foreword

ISRIC – World Soil Information has the mandate to create and increase the awareness and understanding of the role of soils in major global issues. As an international institution, ISRIC informs a wide audience about the multiple roles of soils in our daily lives; this requires scientific analysis of sound soil information.

The source of all fresh water is rainfall received and delivered by the soil. Soil properties and soil management, in combination with vegetation type, determine how rain will be divided into surface runoff, infiltration, storage in the soil and deep percolation to the groundwater. Improper soil management can result in high losses of rainwater by surface runoff or evaporation and may in turn lead to water scarcity, land degradation, and food insecurity. Nonetheless, markets pay farmers for their crops and livestock but not for their water management. The latter would entail the development of a reward for providing a good and a service. The Green Water Credits (GWC) programme, coordinated by ISRIC – World Soil information and supported by the International Fund for Agricultural Development (IFAD) and the Swiss Agency for Development and Cooperation (SDC), addresses this opportunity by bridging the incentive gap.

Much work has been carried out in the Upper Tana catchment, Kenya, where target areas for GWC intervention have been assessed using a range of biophysical databases, analysed using crop growth and hydrological modelling.

This report presents the results of the use of the Water Evaluation And Planning tool (WEAP). WEAP was developed for water management planning and water allocation, integrating information on water supply, demand and cost. This powerful but easy-to-use, computer-based system can be employed in developing and testing options for matching water supply and water demand, and assessing the upstream-downstream links for different options terms of water sufficiency or unmet demand, costs and benefits.

The tool helps to demonstrate that, given the incentive of Green Water Credits, *green water* management can arrest soil erosion and siltation of reservoirs, and make a significant contribution to unmet water demands. The financial benefits from improved water supply largely cover the costs of effective *green water* management packages.

Dr ir Prem Bindraban
Director, ISRIC – World Soil Information

Key Points

- The Water Evaluation And Planning tool (WEAP) has been developed for water management planning and water allocation, integrating information on water supply, demand and cost. This powerful but easy-to-use, computer-based system may be used for developing and testing options for matching water supply and water demand, and assessing the upstream-downstream links for different options terms of water sufficiency or unmet demand, costs and benefits.
- In the Tana basin, all water users (hydropower, municipal water utilities and irrigation) have substantial, unmet water demands. For hydropower, key issues are low reservoir levels and high silt loads that significantly shorten the life of the reservoirs and turbines.
- Most of Nairobi’s water is drawn from the Tana basin and demand is projected to increase steeply. Only one-third of irrigable land receives water at present and climate change is likely to further increase water demands for irrigation.
- Municipal water demand is growing strongly, with the population of Nairobi increasing by 6% annually, and industrial water requirements burgeoning. Presently water demands can barely be met and shortages occur during dry seasons: for example in 2006 a shortfall of 20% was experienced over a four-month period.
- Given the incentive of Green Water Credits, *green water* management can arrest soil erosion and siltation of reservoirs, and make a significant contribution to unmet water demands. The financial benefits from improved water supply largely cover the costs of effective *green water* management – that is soil and water conservation - packages.
- *Green water* management can increase water productivity by reducing unproductive evaporation losses, storm runoff and soil erosion, and by increasing water storage in soils and aquifers. And consequently siltation of reservoirs can be reduced by 50% or more.
- Ecosystem services also depend on improved *green water* management: these services include river regulation, groundwater recharge, protection from landslides and carbon sequestration. Loss of environmental flows damage wetlands and aquatic ecosystems: once again benefits will accrue from better management of land and water upstream.
- Immediate and nationally-significant gains in power generation and urban water supply will be realised by arresting the siltation of reservoirs. For instance, the Masinga reservoir may have lost some 10% of its capacity over the 20 years up to 2002. Targeting siltation involves relatively small areas and few farmers; resources and managerial capacity are already available for pilot operation of Green Water Credits in the reservoir catchments.
- The impact of implementation of *green water* management was evaluated using the WEAP model, assuming 20% of the land covered with associated measures. Revenues could be up to a total of US\$ 8 million every year from the four sectors of rainfed farming, irrigation, domestic water use and hydropower.

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Acronyms and Abbreviations

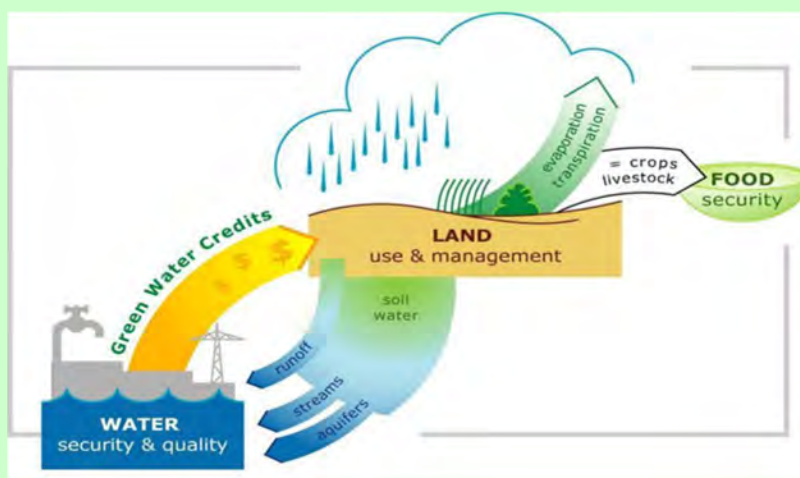
ADB	African Development Bank
CIDA	Canadian International Development Agency
DANIDA	Danish International Development Agency
EC	European Commission
ETH	Swiss Federal Institute of Technology
FAO	Food and Agriculture Organisation of the United Nations
GoK	Government of Kenya
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
ISRIC	World Soil Information
IUCN	International Union for Conservation of Nature
KARI	Kenya Agricultural Research Institute
KenGen	Kenya Electricity Generation Company Ltd.
KFS	Kenya Forest Service
KPLC	Kenya Power and Lighting Company
NWC	Nairobi Water Company
NWRMS	National Water Resource Management Strategy
SDC	Swiss Development Cooperation
SEI	Stockholm Environmental Institute
Sida	Swedish International Development Agency
SIWI	Stockholm International Water Institute
SWAT	Soil and Water Conservation Tool
TARDA	Tana and Athi River Development Authority
UN	United Nations
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme
UNESCO	United Nations Education, Scientific and Cultural Organisation
WEAP	Water Evaluation And Planning tool
WHO	World Health Organisation
WOCAT	World Overview of Conservation Approaches and Technologies
WRMA	Water Resources Management Authority
WWAP	World Water Assessment Programme

Green Water Credits: the concepts

Green water, Blue water, and the GWC mechanism

Green water is moisture held in the soil. Green water flow refers to its return as vapour to the atmosphere through transpiration by plants or from the soil surface through evaporation. *Green water* normally represents the largest component of precipitation, and can only be used *in situ*. It is managed by farmers, foresters, and pasture or rangeland users.

Blue water includes surface runoff, groundwater, stream flow and ponded water that is used elsewhere - for domestic and stock supplies, irrigation, industrial and urban consumption. It also supports aquatic and wetland ecosystems. *Blue water* flow and resources, in quantity and quality, are closely determined by the management practices of upstream land users.



Green water management comprises effective soil and water conservation practices put in place by land users. These practices address sustainable water resource utilisation in a catchment, or a river basin. *Green water* management increases productive transpiration, reduces soil surface evaporation, controls runoff, encourages groundwater recharge and decreases flooding. It links water that falls on rainfed land, and is used there, to the water resources of rivers, lakes and groundwater: *green water* management aims to optimise the partitioning between *green* and *blue water* to generate benefits both for upstream land users and downstream consumers.

Green Water Credits (GWC) is a financial mechanism that supports upstream farmers to invest in improved green water management practices. To achieve this, a GWC fund needs to be created by downstream private and public water-use beneficiaries. Initially, public funds may be required to bridge the gap between investments upstream and the realisation of the benefits downstream.

The concept of green water and blue water was originally proposed by Malin Falkenmark as a tool to help in the understanding of different water flows and resources - and the partitioning between the two (see Falkenmark M 1995 Land-water linkages. FAO Land and Water Bulletin 15-16, FAO, Rome).

1 Introduction

1.1 Present and future studies

This report brings together information about water demand, water supply and the costs and benefits of *green water* management¹ in the Upper Tana catchment, Kenya, for the Green Water Credits programme. The Water Evaluation and Planning tool (WEAP) has been developed specifically to integrate this type of data from these diverse fields of information.

For the Proof-of-Concept phase of GWC, data on water availability (in terms of surface water flows) and water demands for power, irrigation and municipal supply were collated from all accessible sources. Scenarios were built up solely from this information, making plausible assumptions about future trends, after discussions with key parties. Forthcoming design studies will construct detailed water-flow scenarios in WEAP using new data from field, and basin, hydrological modelling, validated by in-field measurements. These further studies will provide more precise data for *green*¹ and *blue*¹ water yields, soil erosion and sediment transport, with and without *green water* management practices, as well as more reliable cost estimates for these and other water management measures.

The WEAP scenarios provide a starting point for dialogue with interested parties about the various options for allocation of water resources. Following on from this, determination of the unit costs of providing additional water may provide a basis for water charges and permits. The Ministry of Water and Irrigation, and the Water Resources Management Authority have expressed the need for this kind of information under the water reforms that value water as an economic good, introduce user water charges and permits, and decentralise water resources management to the catchment level. The catchment management strategies now being drawn up for each of the six main basins in Kenya may also make use of the eco-hydrological, hydro-economic and socio-cultural information generated by the Green Water Credits¹ programme: for example in terms of adoption potential for different water management measures.

1.2 The need for information

With 650m³ fresh water per person per year, Kenya is classified a water-scarce country. The World Water Development Report (UNESCO 2006) sums up the current situation in Kenya:

“Demand management strategies are lacking, and water resources allocation decisions related to surface and groundwater abstractions are made without adequate data. It is estimated that more than 50 percent of water abstractions are illegal. Water metering systems are used in few projects; as a result, revenue collection is very low and corresponds to just 55 percent of the total operation and maintenance costs.”

“The need for domestic, industrial and agricultural water supply is growing, but the absence of demand-management strategies means that the increase in demand will likely outstrip the available supply.”

¹ See Green Water Credits: The Concepts

In addressing water management, the Government of Kenya (GoK 2007) describes one of its biggest challenges as “the unaccounted-for water in our water supply infrastructure”, citing poor infrastructure and illegal connections as the two major factors. It estimates the cost of infrastructure needed up to 2010 as US\$ 2.6 billion (exchange rate: US\$ 1 = KSh 82) excluding the needs of hydropower generation.

Management options include the reduction of illegal water abstraction, provision of new reservoir storage and, also, improved land and water management in the catchments. To develop and to evaluate these options, it is necessary to consider both demand and supply, and to calculate the benefits and the negative impacts of the different options to mitigate water scarcity.

1.3 Water sector reform and water charges

The present wide-ranging reform of the water sector in Kenya stems from the Water Act of 2002. Draft rules for implementation of the act are set out in the Draft Water Resource Management Rules and Forms (WRMA 2006). The essence of the reforms is the transition from dealing with water as a *social good*, to dealing with it as an *economic good*. This is summed up by the National Water Resource Management Strategy (NWRMS) 2006–2008 (GoK 2006a):

“Current pricing policies have not significantly contributed towards the financing of the sector both for recurrent and investment purposes. Social and political considerations outweighed the economic considerations in the setting of tariffs such that water is largely considered a social good. The low tariffs for both urban and rural domestic water supplies do not promote efficient utilization of water, environmental conservation and preservation. With the increasing pressures on the water resources, the need to have a different view on the pricing of water becomes urgent. Increasingly, water is now viewed as an economic good.”

These draft rules and forms seek to provide equitable access, sustainable use, and efficient water use to optimise social and economic benefits. They categorise users according to impact on water resources:

Category A: Water use activity deemed by virtue of its scale to have a low risk of impacting the water resource

Category B: Water use activity deemed by virtue of its scale to have the potential to make a significant impact on the water resource

Category C: Water use activity deemed by virtue of its scale to have a measurable impact on the water resource

Category D: Water use activity which involves either international waters, two different catchment areas, or is of a large scale or complexity and which is deemed by virtue of its scale to have a measurable impact on the water resource

Category A users will not be required to have a permit or pay water charges. Charges for other users will be assessed according to the type of activity, and the levels of abstraction they require (Table 1).

Table 1*Provisional water-use charges*

User	Criteria	Rate (KSh)
Domestic, public, livestock	Domestic, public, and livestock purposes up to the limit of the water allocated on the permit	50 cents/m ³
Hydropower generation	Amount of energy generated	15 cents/kWh
Irrigation, agriculture, pisciculture	Up to 500 m ³ /day	50 cents/m ³
	Any water in excess of 500 m ³ /day	100 cents/m ³
Commercial	Up to 300 m ³ /day	50 cents/m ³
	Any water in excess of 300 m ³ /day	100 cents/m ³
Bottled drinking water		100 cents/m ³
Effluent discharge		100 cents/m ³

The Green Water Credits process supports these water reforms by comparing development alternatives, including *green water* management within the catchment, both for their hydrological effects, and also their costs. This information should assist in water allocation and in the setting of cost-recovery tariffs.

2 Integrated supply-and-demand scenarios

2.1 Water Evaluation and Planning tool (WEAP)

2.1.1 Overview

An easy-to-use tool is needed to match water supplies and competing demands, and to assess the upstream–downstream links for different management options in terms of their resulting water sufficiency or un-met demands, costs, and benefits. The Water Evaluation And Planning tool (WEAP) (Yates *et al.* 2005) has been developed to meet this need. It uses the basic principle of water balance accounting: total inflows equal total outflows, net of any change in storage (in reservoirs, aquifers and soil). WEAP represents a particular water system, with its main supply and demand nodes and the links between them, both numerically and graphically. Delphi Studio® programming language and MapObjects® software are employed to spatially reference catchment attributes such as river and groundwater systems, demand sites, wastewater treatment plants, and both catchment and administrative/ political boundaries (Yates *et al.* 2005).

Users specify allocation rules by assigning priorities and supply preferences for each node; these preferences are mutable, both in space and time. WEAP then employs a priority-based optimisation algorithm and the concept of “equity groups” to allocate water in times of shortage.

The simplicity of representation means that different scenarios can be quickly set up and compared, and it can be operated after a brief training period. WEAP is being developed as a standard tool in strategic planning and scenario assessment for water management in partnership between the Green Water Credits team, the Water Resources Management Authority, KenGen and the Nairobi Water Company. Licences are free for NGOs, governmental and academic organisations in developing countries.

2.1.2 Operational steps

1. The study definition sets up the time frame, spatial boundary, system components and configuration. The model can be run over any timespan where routing is not a consideration; for the Proof-of-Concept phase of GWC in the Tana basin, a monthly period was used.
2. System management is represented in terms of supply sources (surface water, groundwater, inter-basin transfer, and water re-use elements); withdrawal, transmission and wastewater treatment facilities; water demands; and pollution generated by these activities. The baseline dataset summarises actual water demand, pollution loads, resources and supplies for the system during the current year, or for another baseline year.
3. Scenarios are developed, based on assumptions about climate change, demography, development policies, costs and other factors that affect demand, supply and hydrology. The drivers may change at varying rates over the planning horizon. The time horizon for these scenarios can be set by the user.
4. Scenarios are then evaluated in respect of desired outcomes such as water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

Water supply: Using the hydrological function within WEAP, the water supply from rainfall is depleted according to the water demands of the vegetation, or transmitted as runoff and infiltration to soil water reserves, the

river network and aquifers, following a semi-distributed, parsimonious hydrologic model. These elements are linked by the user-defined water allocation components inserted into the model through the WEAP interface.

Water allocation: The challenge is to distribute the supply remaining after satisfaction of catchment demand (the *Reserve* discussed in the Water Act); the objective of maximising water delivered to various demand elements, and in-stream flow requirements - according to their ranked priority. This is accomplished using an iterative, linear programming algorithm. The demands of the same priority are referred to as “equity groups”. These equity groups are indicated in the interface by a number in parentheses (from 1, having the highest priority, to 99, the lowest). The programme is formulated to allocate equal percentages of water to the members of the same equity group when the system is supply-limited.

2.2 Application in Green Water Credits

2.2.1 Context

Green water management can increase water productivity by reducing unproductive evaporation losses, storm runoff and soil erosion, and by increasing water storage in soils and aquifers; for instance, soil erosion and the consequent siltation of reservoirs can be reduced by 50-100%. In terms of *blue water* resources, there is a trade-off between runoff, which travels directly overland to streams, and infiltration into the soil - but this may be compensated for by groundwater recharge (as a result of the latter process) which feeds river baseflow. The SWAT model simulates the cumulative effects of these measures on runoff, erosion, groundwater recharge, streamflow, and changes in reservoir storage. Possible climatic changes can also be accounted for.

WEAP integrates this information on water supply and water quality with the demands from irrigation, household supply, industry, hydropower generation and environmental flows. By integrating supply and demand with costs of different interventions, WEAP enables the analysis of the costs and benefits of different water allocation and development options. Vulnerabilities in the system, mitigation options and coping capacity may be assessed by using data from extreme years. This, in turn, can be used for cost-benefit analysis of mitigation options.

2.2.2 Application in the Tana basin

For the Proof-of-Concept phase, water management scenarios were based on the actual surface-water availability for the period 1989 to 2004, measured at gauging stations on the main tributaries within the Upper Tana (Kauffman *et al.* 2007). For the current design phase of Green Water Credits, WEAP will also be driven by SWAT model results for the effects of different land management interventions on runoff, erosion, and downstream water availability.

The schematic representation of the water supply and distribution system of the Upper Tana in WEAP is depicted in Figure 1. Within the WEAP framework, this is combined with other spatial layers such as terrain (Figure 2) and land cover (Figure 3).

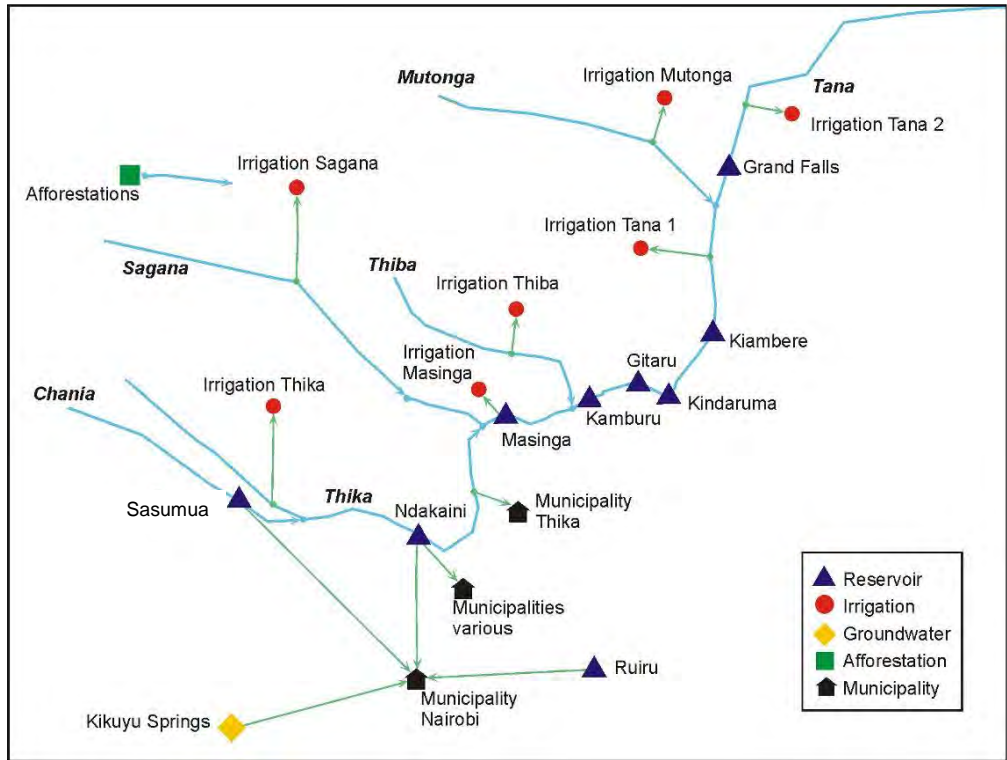


Figure 1
WEAP representation of the Upper and Middle Tana

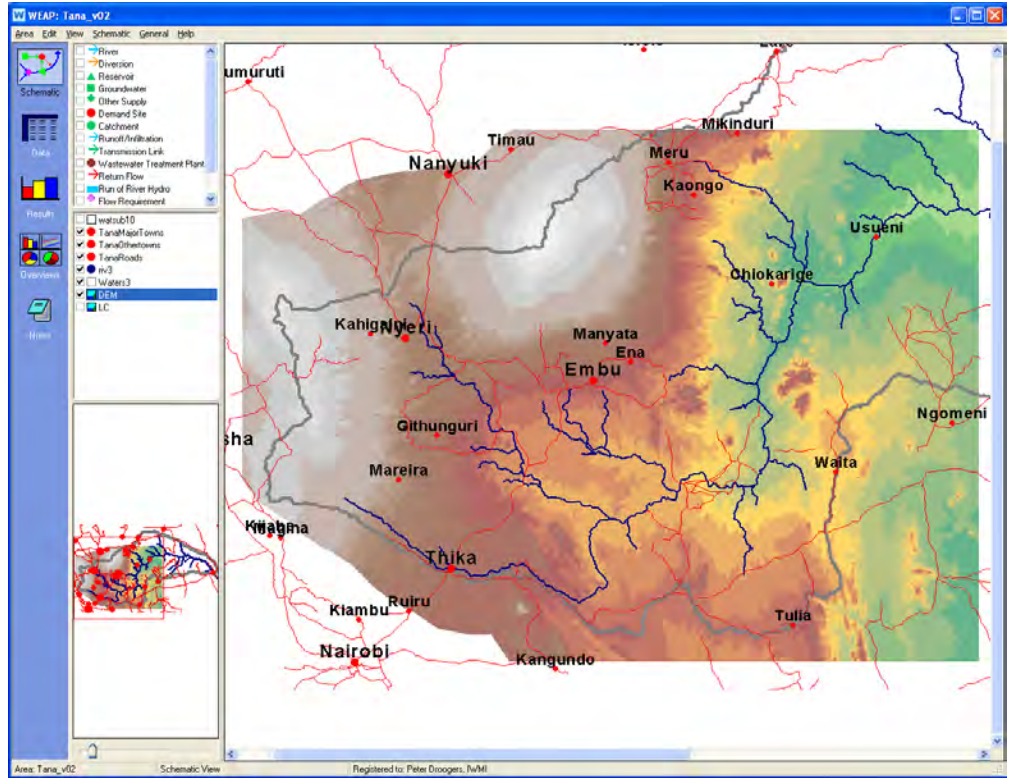


Figure 2
Upper Tana, terrain (digital elevation model) in WEAP

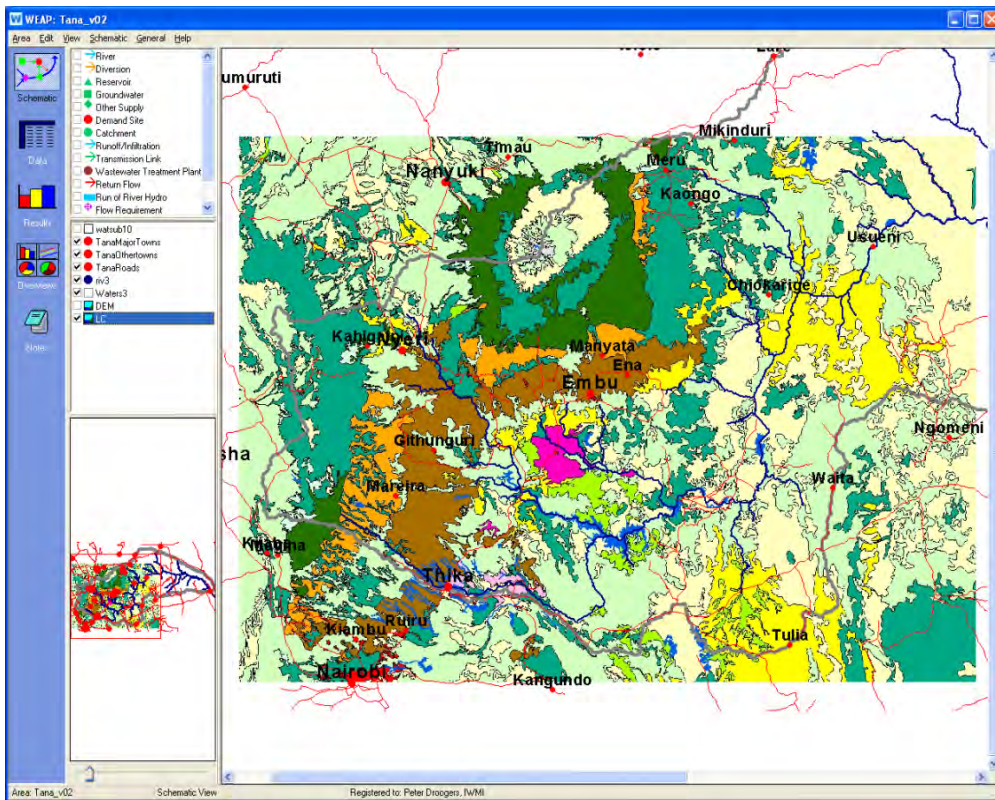


Figure 3
Upper Tana, land cover in WEAP

2.3 Model validation

The objective of modelling is to compare scenarios. The accuracy of the model is assessed by comparing observed and simulated results. However, although model inaccuracies will be present in all scenarios, they will be the same for each - so the *relative* accuracy is likely to be higher than the *absolute* accuracy. For the Proof-of-Concept, WEAP was used for allocations and reservoirs; comparison was carried out at two locations - just downstream of the Masinga reservoir and at Grand Falls. Figure 4 shows that simulated and observed flows are comparable - except for June 1997 where a peak flow was simulated but not observed. Further investigation of this discrepancy should be carried out, but is most likely due to input inaccuracies. Overall, the model performs well.

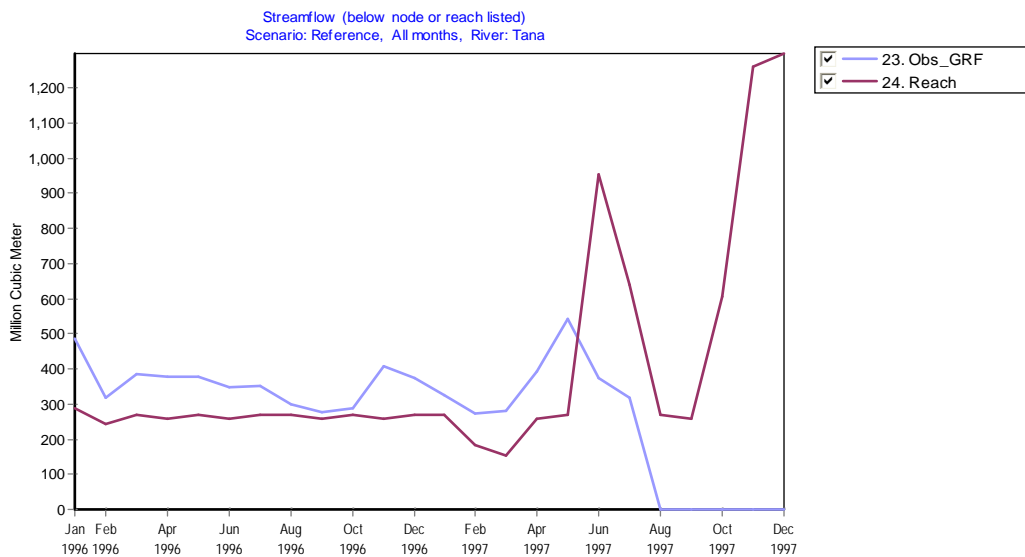
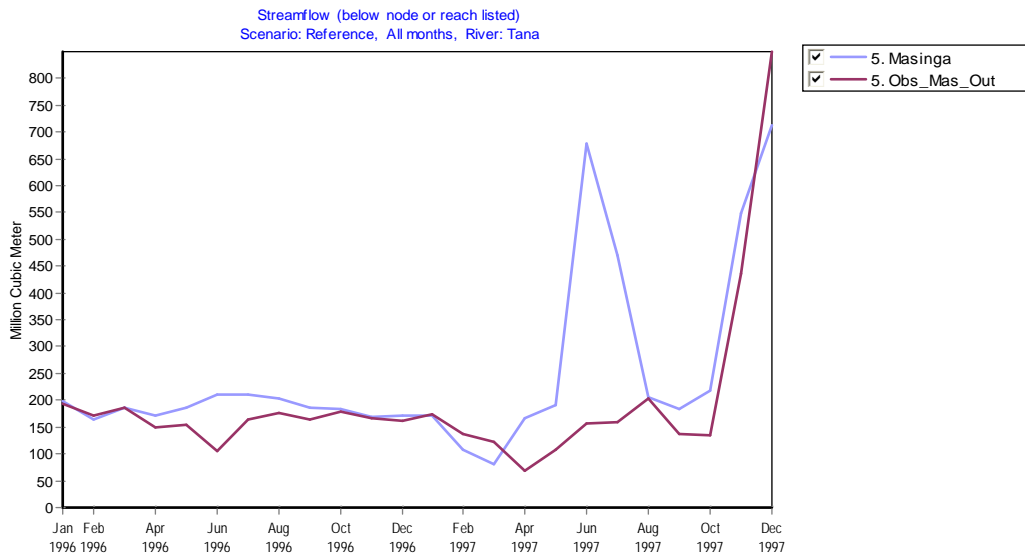


Figure 4
Observed and simulated streamflow below Masinga and Grand Falls. No observations were available for Grand Falls (bottom) after July 1997

Figure 5 shows monthly variation of runoff in the main tributaries of the Tana for the period from 1989 to 2004, based upon gauging station data from the University of Nairobi. Runoff scenarios were developed, assuming that this temporal pattern would be repeated for the period 2005-2021 and again for 2022-2036.

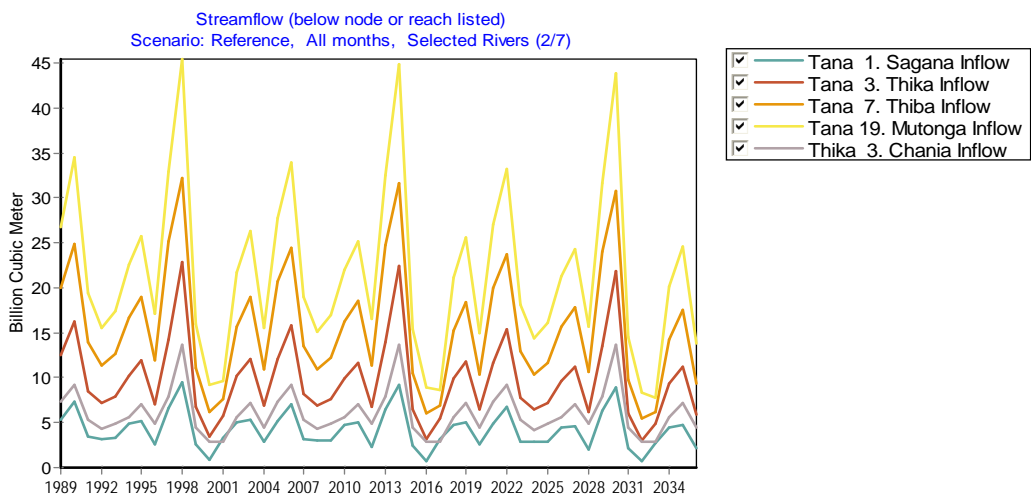
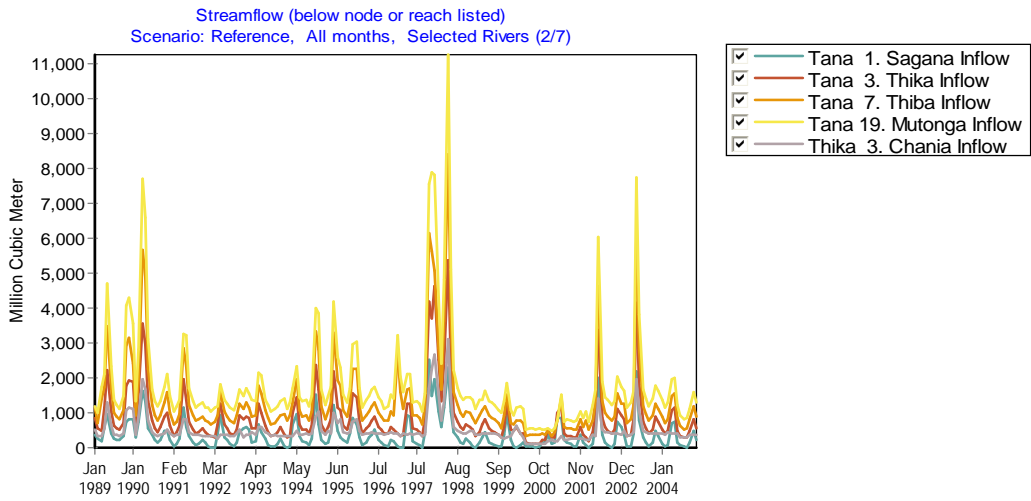


Figure 5
Upper Tana, monthly streamflow (top) and annual totals (bottom)

3 Long-term trends

3.1 Municipal water supply

3.1.1 Demand and supply

Nairobi gets 70-80% of its water from the Ndakaini reservoir in the Upper Tana, with the balance coming from the Sasumua and Ruiru reservoirs, and from wells beneath or near Nairobi. Supply is the responsibility of the Nairobi Water Company (NWC), previously the City Council Water Department, but now instituted as a subsidiary company. The National Water Resources Management Strategy (GoK 2006a) states: “*utilities operating in the water sector both at the local authority and parastatal level have to operate on commercial basis*”.

Municipal water demand is growing strongly, with the population of Nairobi increasing by 6% annually, and industrial water demand projected to grow from some 220,000 to more than 280,000 m³/day between 2000 and 2010 (UN Water 2006). Presently, NWC is unable to meet daily water demands; for example, during the June - September 2006 dry season, demand was 570,000 m³/day, but only some 456,000 m³/day was abstracted (384,000 m³/day of this from Ndakaini), a shortfall of 20%. Water storage per capita has not kept up with population growth - which is one of the highest in Africa (Mogaka *et al.* 2006). NWC anticipates a 3-5% increase in demand, so unsatisfied demand continues to be a serious issue.

Under the WRMA Draft Rules, NWC should pay KSh 0.50 /m³ for water abstraction and KSh 1.00/m³ for discharging effluent (Table 1). Since the company’s consumer rate structure is fixed, NWC may not be able to cover these charges and opposes the imposition of tariffs.

3.1.2 Economic gains from increased *blue water flows*

NWC has pressing need for increased water flows; under the “business-as-usual” scenario, it cannot meet current, let alone future demand. Options to cope with this situation include:

- *Tapping Tana water north of Ndakaini*: this would be costly and is opposed by KenGen and large commercial irrigators as it would reduce water availability for their operations;
- *Groundwater*: reliable information on groundwater use and costs has not yet been assembled, but there is general agreement among water managers that, in many parts of the basin, the sustainable yield is higher than the current rates of abstraction. However, groundwater levels around Nairobi are falling by 0.1 to 0.9 m/yr, and each year the cost of pumping water increases (Mogaka *et al.* 2006);
- *Plugging leaks and illegal connections*: NWC estimates that it loses at least 30% of its water supply within Nairobi itself: Foster and Tuinhoff (2005) suggest losses of up to 50%. In the Nairobi slum of Kibera, 40% of the water supplied by NWC is lost through leaks and illegal connections, and less than one-third of the amount billed is actually collected by the company (UNDP 2006). The relative contributions of leakage and illegal connection are not known;
- *Green water management in the catchment*: Siltation of reservoirs is a significant cost; US\$ 50,000 annually was spent de-silting the Sasumua reservoirs between 2003 and 2006; water purification is a further significant cost that might be reduced by effective action against agricultural contamination of the water supply (Ngari, *pers comm*). NWC is fully aware of the need for sustainable management of water resources and, in particular, increased water flows to meet un-met demand, and may be expected to be a

major participant in Green Water Credits; it already spends US\$ 50,000 annually in the catchments to combat sedimentation of its reservoirs.

3.1.3 Potential contribution of Green Water Credits

Figure 6 presents a WEAP forecast for the increased un-met demand under a “business-as-usual” scenario; the increase in demand through population growth has been included but water consumption per person has been kept constant at a hypothetical value of 70 m³/year. NWC also supplies 20,000 m³/day to Thika municipality and 5,000 m³/day to communities located between its treatment plants and Nairobi. These demands are included using the same per capita volumes and growth rates as Nairobi (the current population of Thika is taken as 500,000).

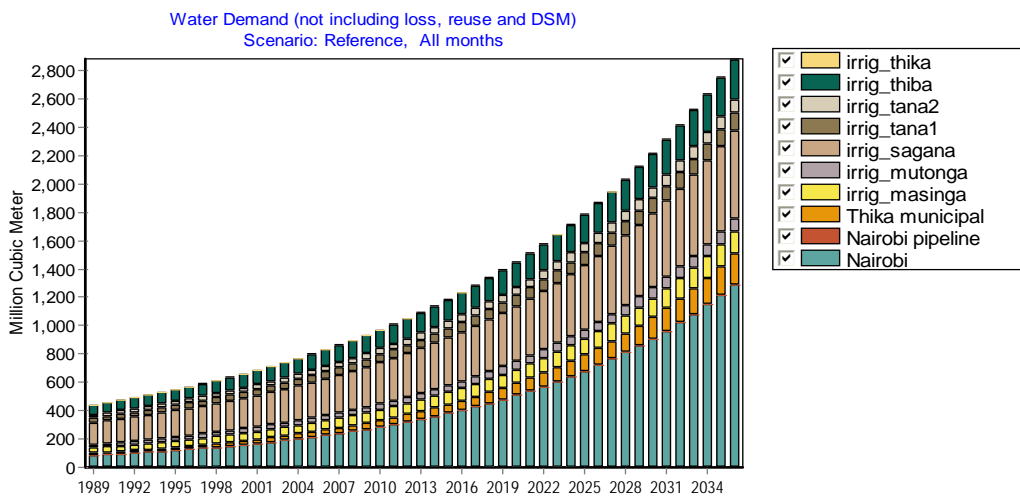


Figure 6
Tana basin water demand to 2036, business-as-usual scenario, applying a 6% annual increase in municipal demand and 3% increase in irrigation demand

WEAP could be used to assess the effects on the water system of raising customer fees, making assumptions about the price elasticity of water consumption for different sectors.

3.2 Irrigation

3.2.1 Current and projected demand

Irrigators in the Tana basin include large commercial estates (Del Monte and Kakuzi), public schemes (Mwea, Bura and Hola), and community-based smallholder schemes (Yatta canal). Demand greatly outstrips supply. Currently there are 68,700 ha under irrigation but there is a total of more than 205,000 ha of irrigable land. Interviews with irrigators - from large commercial operations to smallholders – uncovered many complaints about insufficient supplies, and a consensus that lack of water was limiting output.

The National Water Resources Management Strategy acknowledges the issue and defines how it will manage demand:

“Since the agricultural sector accounts for a large proportion of water use in Kenya, introduction of water demand management in this sector is imperative. More efficient irrigation approaches and technologies should be adopted. These include:

1. *Assessing the irrigation potential of soils in terms of water loss. This includes determining soil texture, moisture retention properties and the slope and then choosing the more water-efficient soils*
2. *Identifying the suitable water saving technology and the efficient production level.”*

Certainly, there are many water-saving technologies available for both irrigated and rainfed agriculture. The Proof-of-Concept examines just three simple *green water* management practices that can improve water management in rainfed farming.

3.2.2 Demand for irrigation water

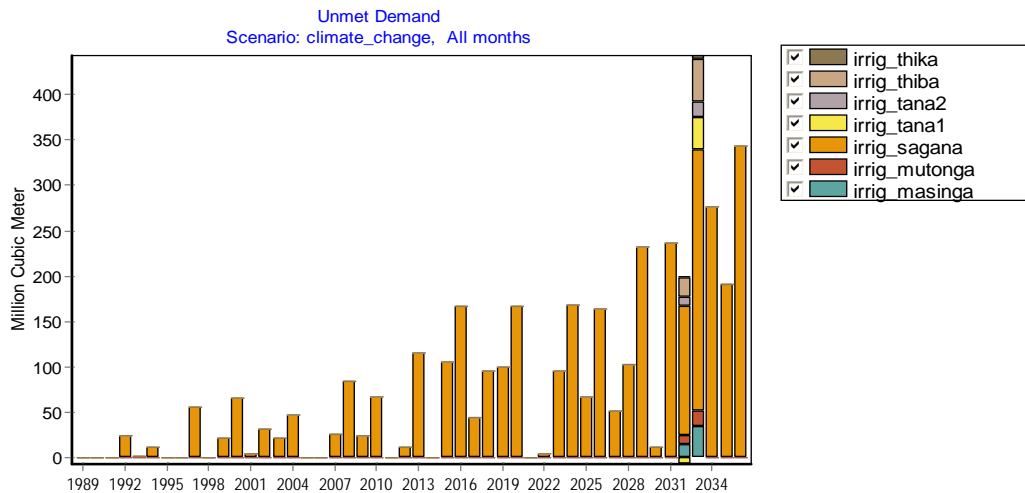


Figure 7
Increase in un-met demands in irrigation for a climate change scenario

In the Tana WEAP model (Figure 6), irrigation-demand data from TARDA (Willis, *pers comm*) are aggregated to monthly values for each sub-catchment and a demand- growth rate is set at 3% for area increase. Figure 7 depicts a climate change scenario in which crop water requirements are assumed to increase by 10% (from 7,777 to 8,555 m³ per ha) in response to the predicted rise in temperature and the resulting increased evapotranspiration, and accessible *blue water* flows are assumed to decrease by 20% in line with an assessment by Strzepek *et al.* (2001) for the Nile basin.

3.3 Hydropower

3.3.1 Capacity and demand

Hydropower is strategically important to Kenya; it provides 50-80% of the country's electricity, depending on rainfall (Oludhe 2003). When there is water scarcity “*water may be set aside for such purposes once the quantities of water available for allocation (including the Reserve) in a catchment have been made*” (GoK 2006a). Installed capacity is 650 MW/year; technically exploitable capability may be 9 TWh/year (UNESCO 2006). Some 8% of the hydropower generated comes from five dams on the Tana (Figure 8 and Table 2). In addition, there are two smaller hydropower plants upstream of Masinga: the Tana power station with 14.4 MW (commissioned 1940; additional capacity installed 1953) and the Wanji power station with 7.4 MW (commissioned 1955).

Table 2

Tana river dams

Dam	Installed capacity	Date commissioned
Kindaruma	44 MW	1968
Kamburu	94.2 MW	1974
Gitaru	225 MW	1978 (145MW), 1999 (80MW)
Kiambere	144 MW	1988
Masinga	40 MW	1981

Source: KenGen²

The Tana river power stations are owned and operated by the Kenya Electricity Generating Company Limited (KenGen) established in 1997 as part of the energy sector reforms. This separated it from the Kenya Power and Lighting Company (KPLC) which is charged with the distribution of electricity.

Kenya's population is about 34.3 million, with an annual growth rate of 2.5% (World Bank 2007). In 2004, its “electrification rate” was estimated at just 7.9%; that is 27.7 million people did not have access to electricity (UN Millennium Project 2004); the Government of Kenya estimates that current access is now 15%. Annual increase in demand averaged 9% during the 1960s and 1970s, 7% during the 1980s, 5% during the 1990s (Oludhe undated) and is surging again; both electricity generation and consumption rose by 6.8% in 2005 (GoK 2006b). KPLC forecasts that power demand will nearly triple over the next 20 years, rising from 885 MW in 2005 to 2,397 MW in 2025/26³.

² Kenya Electricity Generating Company: www.kengen.co.ke

³ Kenya Power and Lighting Company: www.kplc.co.ke

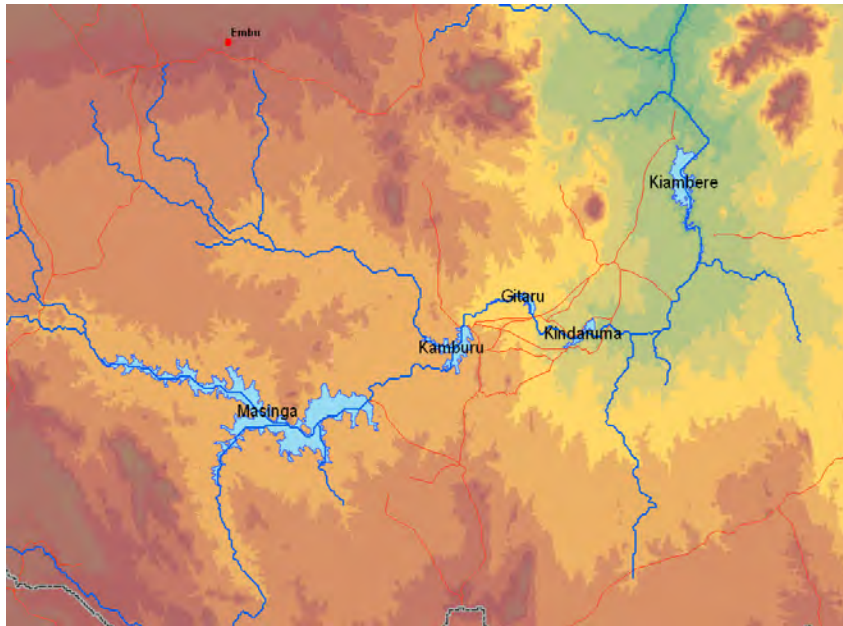


Figure 8
Tana river, main reservoirs for hydropower

Kenya has had great difficulty meeting its electricity demand. It has a bilateral agreement with Uganda for the regular provision of 30MW / year generated by the Owen Falls Dam but during the 1999-2000 drought it had to increase these imports, which stood at 189.4 MW in 2003 - though cut back to 27.9 MW by 2005 (GoK 2006c).

It is clear that with the current rate of population and economic growth, major investments in new infrastructure will be needed. The main candidate is the Grand Falls Dam project, which would be located downstream of Kiambere. Two alternatives are being considered: the Low Dam, would have 1.6 billion m³ of storage and focus on hydropower development only, at an estimated cost of US\$ 378.3 million; the High Dam would have a 6.5 billion m³ storage capacity and would also supply water for irrigation and other purposes.

3.3.2 Economic gains from river regulation

Extreme weather events are a huge risk to the hydropower industry. Therefore, upstream land management practices that result in better regulation of riverflow would bring direct financial benefits. During the 1999-2000 drought, hydropower generation fell by 41% (from 3,000 to 1,800 GWh); monthly losses to the hydropower industry are estimated at US\$ 68 million, lost industrial production US\$1.4 billion, and some companies relocated to neighbouring countries with more secure power supplies. Any significant rainfall event, especially with high-intensity rainfall, brings floods, and soil erosion and siltation that affect hydropower infrastructure through the loss of reservoir storage capacity, and damage to turbines requiring frequent repair or replacement.

Climatic and hydrological variability is represented in WEAP by the runoff time series 1989-2004 measured at various gauging stations in the Upper Tana (Wanjiru *pers. comm.*). There is consensus that climate change will bring an increase in extreme events (IPCC 2007) but, as a first approximation, future variability has been kept

constant by simply replicating the 1989-2004 seasonal and inter-annual pattern twice (for the period 2005-2020 and again for the period 2021-2036).

Siltation of hydropower reservoirs is a major issue. It can be illustrated by the Masinga reservoir: when it was designed, sediment input was estimated at 3 MCM yr⁻¹; recent estimates indicate an input of 11 million m³/yr (Bobotti 2000) or even higher; WWAP (UN Water 2006) reckoned that in the 20 years before 2002, the reservoir suffered a loss in volume of 460 million m³. The latter figure (29% loss in storage capacity over 20 years) has been used for the WEAP reference scenario for all reservoirs; however, it is not accepted by KenGen - pending confirmation of the water level from which the WWAP measurements were made.

Hydropower generation is represented by KenGen data for 1991-2004. In the absence of information on turbine flows and elevation difference between reservoir and downstream river level or operational rules for filling and draining the series of reservoirs, WEAP results were adjusted by a “plant factor” and generating efficiency. Figure 9 illustrates a hypothetical *green water* management scenario assuming a uniform 50% reduction in soil erosion and siltation of the reservoirs. This is conservative; Wanyonyi (2002) records improvements of 80% after adoption of soil and water conservation measures around the Tungbhadra reservoir in India, and the average reduction of erosion by all Kenyan WOCAT-recorded sustainable land management measures is 76%.

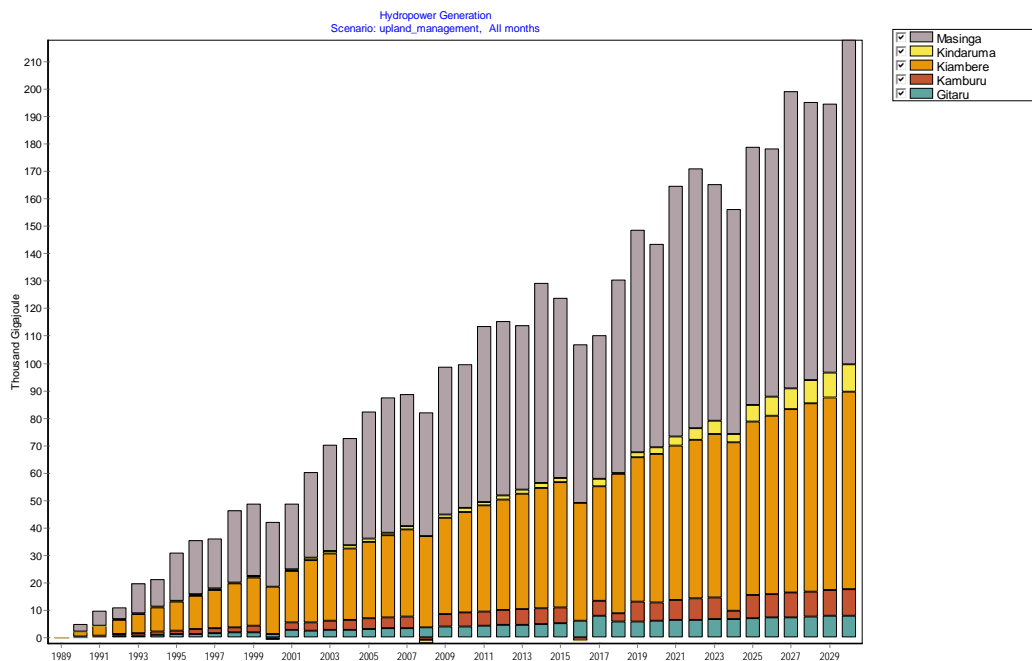


Figure 9
Increase in hydropower production for a green water management scenario compared to business-as-usual

The purpose of these Proof-of-Concept scenarios was simply to demonstrate the potential of *green water* management. A priority in the project design stage is to establish, with each partner institution, accurate values for all parameters. However, it is clear that KenGen stands to gain the most from increased *blue water* flows and from reduction in reservoir siltation, both in terms of revenue flow and from being able to delay the commissioning of the Grand Falls dam.

3.4 Ecosystems

3.4.1 Ecosystem goods and services

Ecosystem services dependent on *green water* management include river regulation, groundwater recharge, protection from landslides and siltation, carbon sequestration and climate regulation. Financial appraisal of these services is difficult because there is no market value. Rather, the National Water Resources Management Strategy has taken the precautionary approach of ring-fencing a *Reserve*, defined as water for basic human needs and for protection of aquatic ecosystems, which “*has priority over all water uses and the requirements of the Reserve must be met before water can be allocated for other uses*”. The strategy acknowledges that, in some cases, water is already allocated to other uses - in which case the Reserve will then have to be recouped progressively over time.

Loss of environmental flows and changes in siltation damage wetlands and aquatic ecosystems along the Tana river. There are also impacts on coastal and marine ecosystems at the river mouth. These particularly affect mangrove and coral reef systems near the Kiunga Marine National Reserve where forest officials report that the quality and quantity of water from the river is damaging the mangroves – which play many roles including erosion control, protection against floods and severe storms, maintenance of water quality, fish nurseries and sustaining tidal ecosystems. Thus mangrove degradation has an impact on an important source of biodiversity; furthermore mangroves constitute a major international tourist attraction (see Aboudha and Kairo 2001). UNEP (2006) claims that sediment input to the Indian Ocean has been reduced by 50% after construction of the Tana reservoirs.

Protected areas in the basin include (i) the Tana River Primate National Reserve on the upper delta - home to two endangered primates, the Mangabey, and the Tana River Red Colobus; (ii) the Arawale National Reserve, designated to protect the rare Hunter’s antelope; (iii) Mwea National Reserve, northwest of Kamburu dam– with elephant, Rothschild’s giraffe, common zebra, warthog, hippopotamus, crocodile, buffalo, and over 150 species of birds. There are also recreational areas taking advantage of access to nearby dams; a string of national reserves located along the Tana’s banks, comprising the Meru, Kora, Mwingi and Bisanadi conservation area - a wildlife dispersal zone for Meru National Park. Kora National Park is also located on the banks of the Tana river.

3.4.2 Economic benefits from ecosystem goods and services

Kenya’s receipts from tourism in 2005 were US\$ 709 million (GoK 2006c), of which 70% (1.0% of total GDP) is attributed to wildlife - which naturally depends on access to water. Ecosystem goods and services are also vital to local communities, especially the poor and most vulnerable; those without access to piped water turn to wells and streams to meet their domestic needs, as well as for kitchen gardens and livestock water. In rural and coastal areas livelihoods often depend closely on forest products, fish and other marine products (ADB *et al.* 2006).

Environmental goods and services are frequently undervalued when water allocation decisions are made; standard methods depend on markets for valuation for private goods; ecosystem valuation requires subtle and more complicated techniques. For instance, the cost-benefit analysis of the proposed Grand Falls dam did not consider its environmental impacts. The environmental impact assessment estimated net present cost of consequent economic losses from that the existing dams on the Tana river at US\$ 27 million in terms of lost production, and that the incremental cost of building a new dam involved a median present cost of almost US\$ 20 million in economic losses (IUCN 2003).

A question arising beyond the valuation of ecosystem goods and services is: *to whom do the benefits accrue?* Without a straightforward link between these goods and services and individual users, it is difficult to assign responsibility for paying for the water management services. Given the global significance of the environmental goods and services in question (wildlife and the mangrove and coral reef ecosystems are clearly in this category), one approach would be to define the demand as international, and look to organisations that already recognise and value the link between water resources management and ecosystem sustainability.

One possibility is a “debt-for-nature swap”, which has been successfully implemented by several countries. This might be attractive to the Government of Kenya as a way to reduce national debt⁴, since Kenya does not qualify for the IMF/World Bank Heavily-Indebted Poor Countries Initiative. Such an arrangement could enhance environmental protection and resolve funding issues for the Kenya Forest Service (which became semi-autonomous along the lines of the Kenya Wildlife Service in 2007) requiring it to generate its own operational funds. A model is provided by the arrangement brokered in 2001 by Nature Conservancy with the US Government for Belize, under which a new foundation was endowed to fund forest conservation work. The Belize debt-for-nature swap is noteworthy in that it involved both bilateral and commercial debt.

⁴ Kenya’s external debt in 2004 was in the range of US\$ 7 billion and annual debt service was US\$ 365 million (World Bank 2006).

4 Green Water Credit scenarios

4.1 WEAP applications

The version of WEAP presented in Chapter 3 is designed to evaluate the impact of long-term trends in water resources. In 2010/2011 an improved version of SWAT was developed (soils, land use, climate, calibration, and in more recent years simulation) in the context of Phase II of GWC (Hunink *et al.* 2011). The results from this improved SWAT version have not yet been used to evaluate the impact on downstream beneficiaries. For this an improved version of WEAP has been developed and used.

The following steps have been taken and are described in this report:

- *Model refinement.* The 2007 WEAP model has been refined based on additional data and knowledge acquired during the GWC project.
- *SWAT results included.* The output of the SWAT 2010 model has been used to feed into WEAP.
- *Validate and calibrate the WEAP model.* Validation and calibration of the original 2007 WEAP model was limited. More rigorous validated and calibrated has been undertaken.
- *Build scenarios.* The 2011 new *green water* management measures are included. SWAT results based on these new scenarios have been fed into the WEAP model.
- Output analysis.

4.2 Model set-up

4.2.1 WEAP Model 2007

In 2006 a first version of a WEAP model for the Upper and Middle Tana catchments was built and used to explore the impact of three *green water* management measures during the Proof-of-Concept phase. A detailed description of this model can be found in Hoff and Noel 2007. The overall results indicated that implementing Green Water Credits will have a positive cost-benefit balance of up to US\$ 5 million annually, assuming implementation on 20% of the fields.

These analyses were however based on a limited data and knowledge base. Much more detailed information and knowledge was gathered later, and thus required a fresh analysis. In summary, the most important changes included are:

- *Smaller area*
 - From Upper and Middle Tana to Upper Tana only
- *Simulation period*
 - From 1996-1997 to 2005-2006
- *Headflows from updated version of SWAT*
 - Improved soil map
 - Updated land use
 - Calibrated model
- *More green water management scenarios*
 - Increase from 3 to 11 scenarios

4.2.2 Set-up

Overall

The WEAP model was set up for the Upper Tana catchment in Kenya (Figure 10) based on six rivers and catchments (Figure 11) as follows:

- Chania
- Thika
- Sagana
- Thiba
- Mutonga
- Tana

For each of these sub-catchments the following information was included:

- Water availability
- Irrigated areas and water requirements
- Domestic and industrial water requirements
- Reservoirs

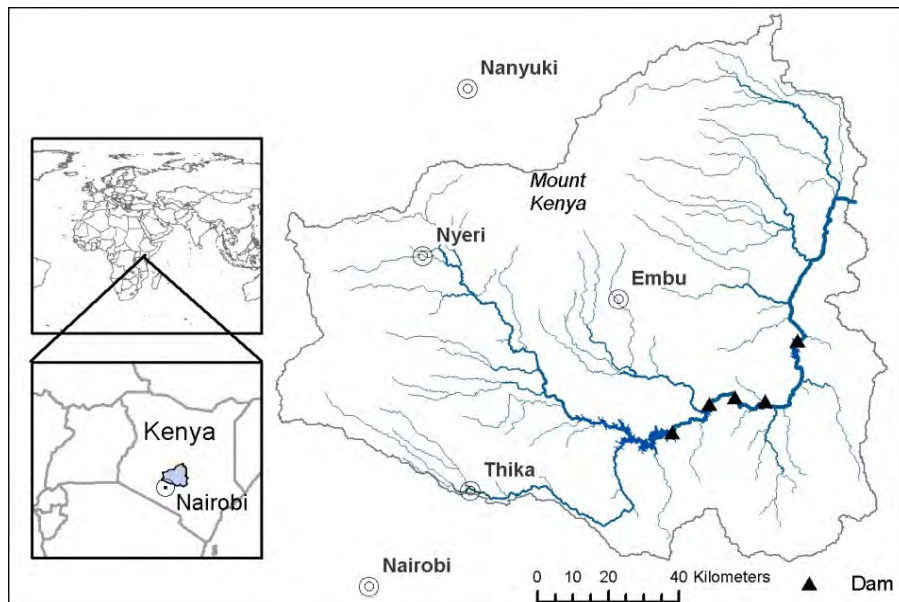


Figure 10

Location of the Upper Tana catchment, drainage network and main reservoirs

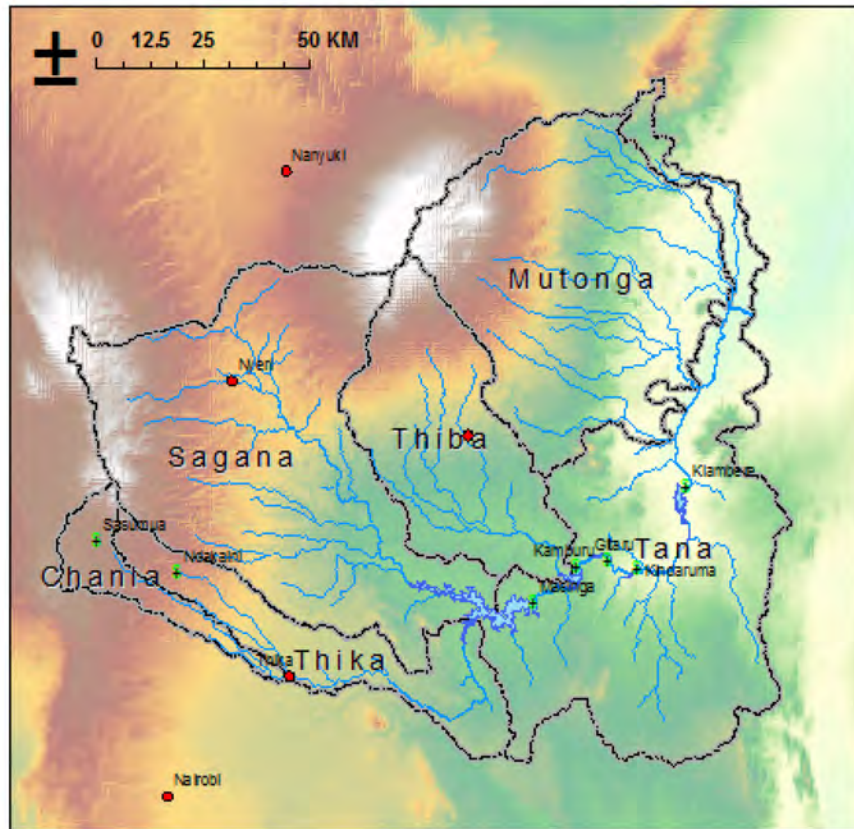


Figure 11
 Overview of sub-catchment included in model analysis

Water yield

The total amount of water available for further application is referred to as “water yield”. The water yield is the sum of water from the surface runoff, the lateral flow (drainage), and groundwater flow. Thus water yield is the same as *blue water* and can be used for hydropower, irrigation, domestic and industrial allocation and/or environment flow requirements. The water yield is derived from the SWAT analysis (Hunink *et al.* 2011). The amount of water yield depends on various interlinked factors such as the size of the sub-catchment, weather conditions, soil/land characteristics and complex hydrological processes. From Figure 12 it is clear – unsurprisingly - that during a wet year, substantially greater water yield is generated than during a dry year. Figure 13 shows that on a monthly basis Oct-Nov-Dec 2005 water yields are low, due to the limited rainfall in this wet season.

It is also interesting that the Mutonga contributes most to the water yield in a wet year, while the Sagana produces most during a dry year. This is mainly a result of the runoff coefficient - the fraction of rainfall that reaches streams, as shown in Figure 14. The runoff coefficient is around 0.2 in a dry year while in a wet year it is about 0.35. The difference in runoff coefficient between a dry and a wet year is relatively small for Sagana compared to the other sub-catchments. This can be explained by the different bio-physical characteristics of the sub-catchments.

Finally, another important factor relevant to the water yield is the fraction of the total generated by surface runoff. Figure 15 demonstrates that this fraction of fast surface runoff is obviously higher during a wet year, but is also very variable across the sub-catchments. This fast surface runoff is in general considered to be

harmful as it generates high peak runoff with the risk of flooding, and is also likely to generate substantial erosion.

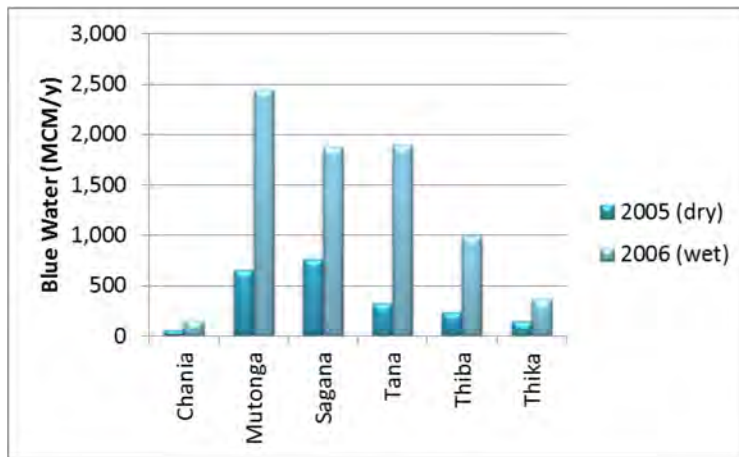


Figure 12
Blue water (water yield) for the six sub-catchments

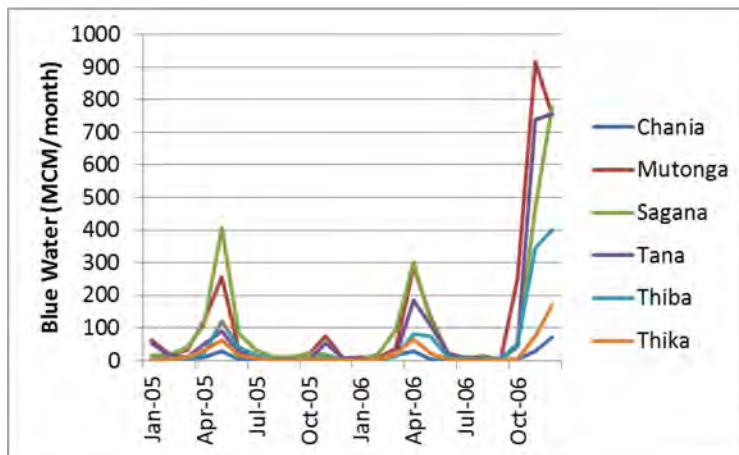


Figure 13
Blue water (water yield) for the six sub-catchments

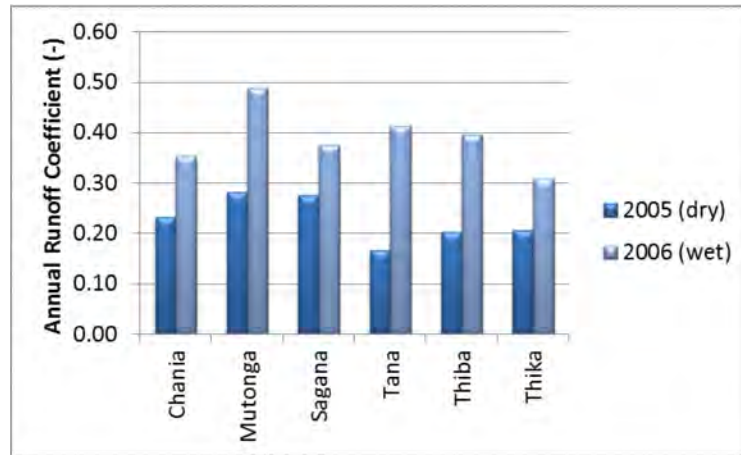


Figure 14
Annual runoff coefficient for the six sub-catchments

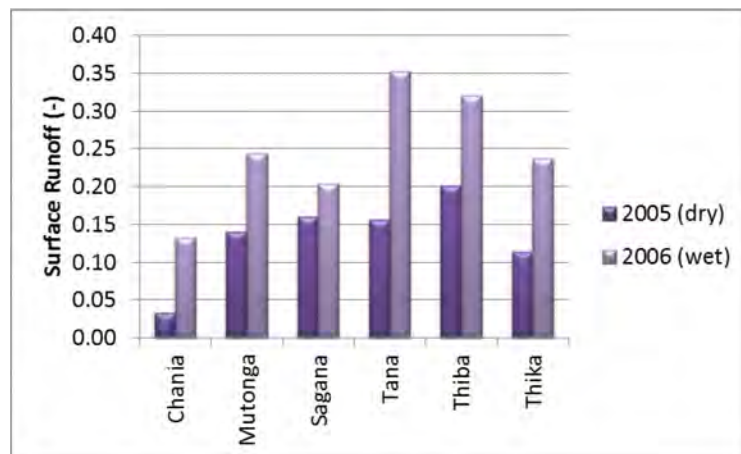


Figure 15
Surface runoff as fraction of total water yield for the six sub-catchments

Irrigated areas

The total irrigated area for the entire Upper Tana, based on the Wilschut (2010) land use map was 13,956 ha. For this study the Wilschut dataset was used as reference (since it was also used for the SWAT analysis), but we corrected the irrigated areas according to the Africover dataset. The following irrigated areas were used for each sub-catchment:

- Chania: 504 ha
- Thika: 2,677 ha
- Sagana: 4,734 ha
- Thiba: 10,603 ha
- Mutonga: 7,951 ha
- Tana: 49,475 ha

Water requirements for irrigation were set as 500 mm per year (= 5000 m³ / ha / year).

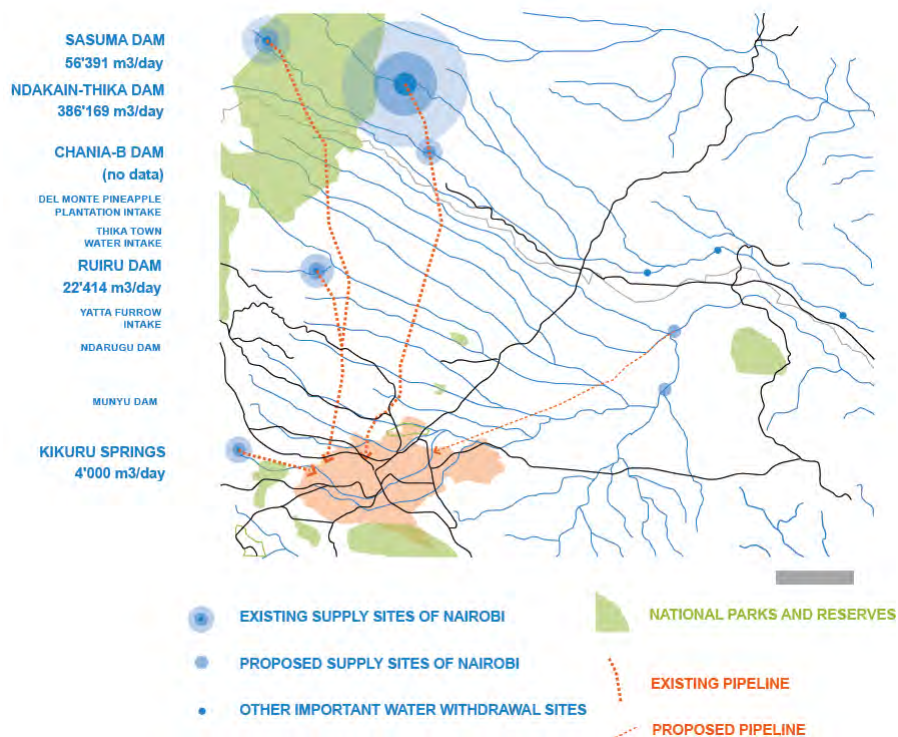


Figure 16
Nairobi water supply (source ETH 2008)

Domestic and industrial water requirements

Domestic water requirements are determined by assuming a water allocation of 150 litres per person per day, based on numbers provided by Nairobi Water Supply. As industrial water requirements are relatively small in the area, it was assumed that this is included in the 150 litres. The exact population of the six sub-catchments is unknown and it was therefore decided to use the total population of the Mount Kenya sub-catchment of 1.1 million and divide this proportionately according to the size of the various sub-catchments:

- Chania: 30,000 ha
- Mutonga: 250,000 ha
- Sagana: 300,000 ha
- Tana: 300,000 ha
- Thiba: 135,000 ha
- Thika: 85,000 ha

Nairobi obtains water from various sources (Figure 16). The four most relevant sources with their estimated supply capacity are:

- Sasuma reservoir: 56,000 m³ / day
- Ndakain-Thika reservoir⁵: 386,000 m³ / day
- Ruiru reservoir: 22,000 m³ / day
- Kikuru springs: 4,000 m³ / day

⁵ According to design documents 260,000 m³ / day (www.karolakgmbh.de/pdf/Major_Projects.pdf).

The total of these four sources is 468,000 m³ /day. The population of Nairobi is estimated at about 3.2 million, which means that supply capacity equates to about 150 litres per person per day. However, during dry periods the actual supply is lower than the installed capacity and severe water shortages occur frequently.

Reservoirs

A total of eight reservoirs have been included in the model (Table 3). Seven of these reservoirs are within the Upper Tana; one reservoir (Ruiru) is outside but is included as it plays an important role in Nairobi's water supply (see list above).

Table 3

Key characteristics of main reservoirs

Station	Max. storage (mcm)	dead storage (mcm)	Spill level (masl)	FSL(m)	MOL(m)	TWL (m)	HLoss (m)
Masinga	1560.0	193.0	1056.5	1056.5	1035.0	1008.0	1
Kamburu	151.0	23.0	1006.5	1006.5	990.0	925.5	5
Gitaru	19.4	7.5	924.5	924.5	919.0	780.0	10
Kindaruma	19.0	11.0	781.0	780.5	776.8	743.4	2
Kiambere	585.0	108.0	700.0	700.0	665.0	542.0	9
Ndakain-Thika	70.0	1.0					
Ruiru	3.0						
Sasuma	13.3						

mcm = million cubic meters

masl = meters above sea level

FSL = Full Supply Level

MOL = Minimum Operating Level

TWL = Tail Water Level

Hloss = Head Loss is the difference between Total Head and Effective Head and it is as a result of frictional forces or turbulence in the penstock.

Economics

To undertake a cost-benefit analysis the following assumptions have been included in the model:

- Value of agricultural production in rainfed systems is based on the concept of Water Productivity. Each m³ of water used for transpiration in rainfed farming has a value ranging from US\$ 0.05 to 0.10 m³. The higher value is used for the additional water becoming available through *green water* management measures.
- Value of irrigation water is between US\$ 0.15 and 0.30 m³. The higher value is used for the additional water becoming available through *green water* management measures.
- Revenues from drinking water supply is set between US\$ 0.30 and 0.60 m³. The higher value is used for the additional water becoming available through *green water* management measures.
- Revenues from electricity were set between US\$ 34,000 and 50,000 GWH. The higher value is used for the additional water becoming available through GWC measures. These numbers are based on KenGen annual report revenues; exchange rate: US\$ 1 = KSh 82):
 - 3596 GWH sold (including also non hydropower)
 - energy income KenGen: 10*10⁹ KSh
 - so: 2.8*10⁶ KSh/GWH ~ 34,000 US\$/GWH ~ 0.03 US\$ / kWh

Costs for the implementation of the various GWC measures are discussed in the next chapter.

4.2.3 Model Validation

The final schematisation of the model as built in WEAP can be seen in Figure 17. The model was validated using observed inflow and outflow data from the main reservoirs. In Figure 18 the results of this validation are shown. Overall, the model performs very well in simulating the observed inflows and outflows of the reservoirs. Moreover, since the model will be used to compare the baseline with the *green water* management measures, model/ data errors will be reflected in both results. In other words, relative model errors will be much smaller than absolute errors (Droogers *et al.* 2008).

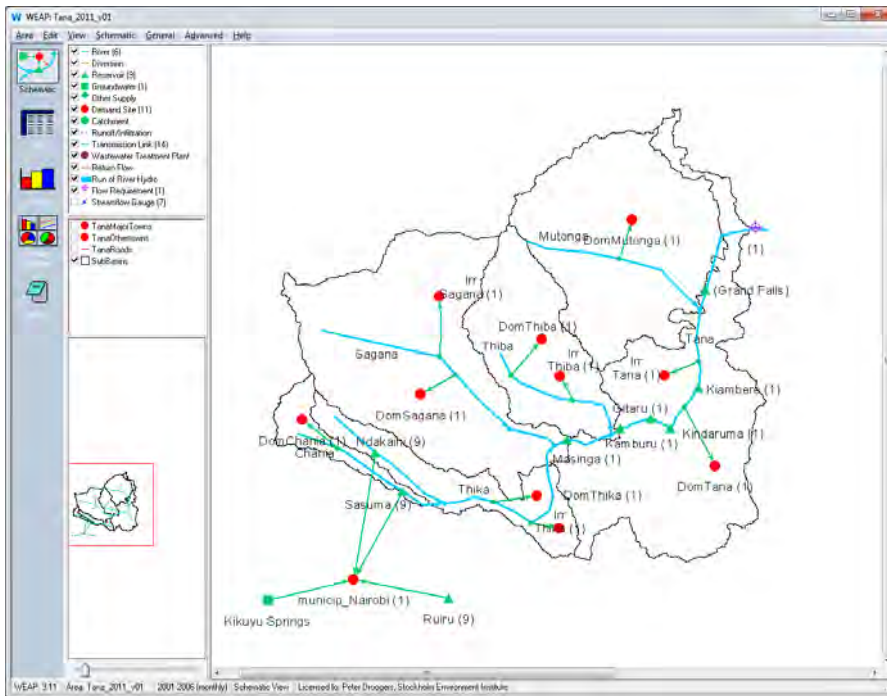


Figure 17
Schematic view of Upper Tana catchment as implemented in WEAP

The model was also validated using hydropower generated as reported by KenGen. However, only annual data, based on years running from July to June were available. The observed and modelled hydropower are shown in Figure . It is clear that the non-calibrated model shows hydropower generation being reasonable good, despite many factors that determine hydropower being unknown. Given the importance of hydropower, it was decided to undertake a model calibration. The most important unknown factors that determine hydropower generation are:

- Volume-elevation curve (partly known)
- Maximum turbine flow (data available)
- Tailwater elevation (partly known)
- Plant factor (data available)
- Generating efficiency (unknown)

In most cases one would select the generating efficiency as the calibration factor. However, the non-calibrated model simulated too low a level of hydropower, while the efficiency factor was fixed at 100%. Thus it was decided that the Volume-Elevation curve and/or the Tailwater elevation must be corrected. The original estimated Tailwater Elevation and its correction factor are (in meters):

Table 4
Details of Reservoirs

Reservoir	masl	Calibration
Masinga	1,008	-5
Kamburu	925	-20
Gitaru	780	-50
Kindaruma	743	-10
Kiambere	542	-40

The comparison between observed and simulated hydropower generation indicate that the model is a good representation of reality (Figure 19).

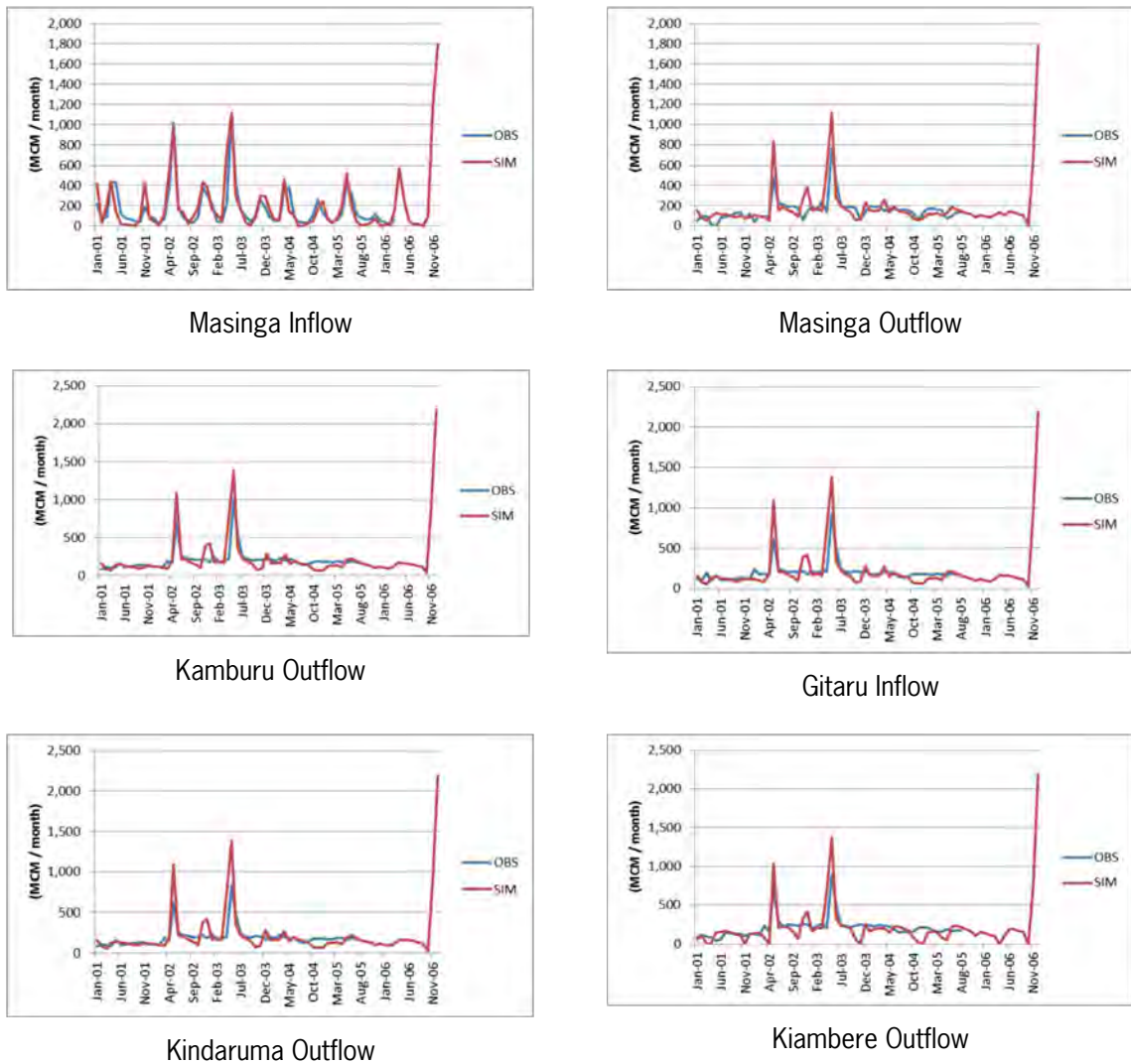


Figure 18
Validation of the WEAP model

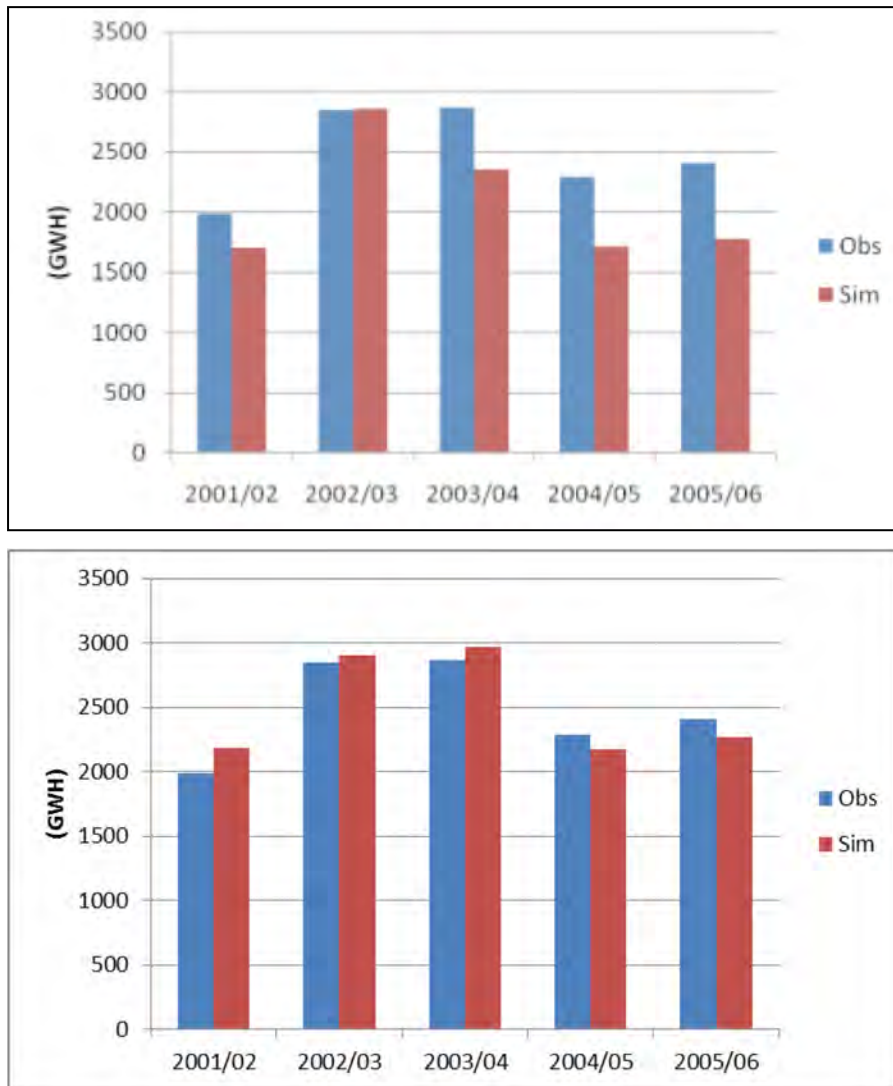


Figure 19
Observed and simulated hydropower for the non-calibrated model (top) and the calibrated one (bottom)

Green water management options

A total of 11 **green water management** measures were identified and the impact of these measures then explored using the WEAP model. These scenarios are:

- 0 Baseline
- 1 Bench terraces
- 2 Conservation tillage
- 3 Contour tillage
- 4 *Fanya juu* terraces and variations
- 5 Grass strips
- 6 Microcatchments for planting fruit trees
- 7 Mulching
- 8 Rangelands
- 9 Ridging
- 10 Riverine protection
- 11 Trash lines

A more detailed description of these scenarios can be found in the GWC Report (Hunink *et al.* 2011). It should be emphasised here that the 11 measures were evaluated in isolation. In reality a mixture of measures will be implemented, where local specific conditions will determine the most effective combinations. Results presented here will be therefore very conservative.

Results from the SWAT analysis of the 11 *green water* management measures were introduced into the WEAP model. The major output that is used as input for WEAP includes changes in:

- Rainfed crop transpiration
- Streamflow
- Inflow into reservoirs
- Erosion and sedimentation

Based on this WEAP calculates:

- Rainfed agricultural production value
- Irrigated agricultural production value
- Domestic water value
- Hydropower value

Some additional assumptions are required to undertake the cost-benefit analysis:

- Sediment inflow will reduce the capacity of the reservoirs. It was assumed that specific mass of sediment is 1.65 t/ m³, so that sedimentation of 1 million tonnes per year will reduce reservoir capacity by 18 MCM after 30 years.
- Erosion will have a major impact on crop production. Fertile soil will be lost and will reduce crop production. Since precise numbers on the impact are closely dependent on many factors (crop, soil, fertilizer, management), the assumption has been made that for every tonne of erosion per hectare, yields will be reduced by 5%. Again a period of 30 years was chosen. This is implemented in WEAP by reducing the Water Productivity value.

4.3 Results

4.3.1 Baseline

Some typical output of the analysis will be presented here to demonstrate the capabilities of the model.

Figure 20 shows the water demand, the water delivered, and the unmet demand for irrigation in the six sub-catchments and domestic water. Demand is more or less constant for domestic use, but irrigation demands vary per month.

Figure 21 shows the amount of water available from runoff, drainage and baseflow for the sub-catchments. It is clear that 2005 was much wetter than 2006. The two rainy seasons can be observed distinctly. Note that these headflows are different from the rainfall as all complex hydrological processes, such as evapotranspiration and delays, are included by using the results from the SWAT model.

Figure 22 emphasises again the differences in streamflow between the various seasons. In this figure the visual comparison has been displayed in the map capabilities that WEAP offers.

Figure 23 displays the volume of the reservoirs in the study area. It is clear that during the beginning of 2006 and taking into consideration the dead storage of the reservoirs, levels were becoming critical low.

Figure 24 shows the amount of hydropower generated by the reservoirs. It is evident that Kiambere and Gitaru are the dominant producers of hydropower.

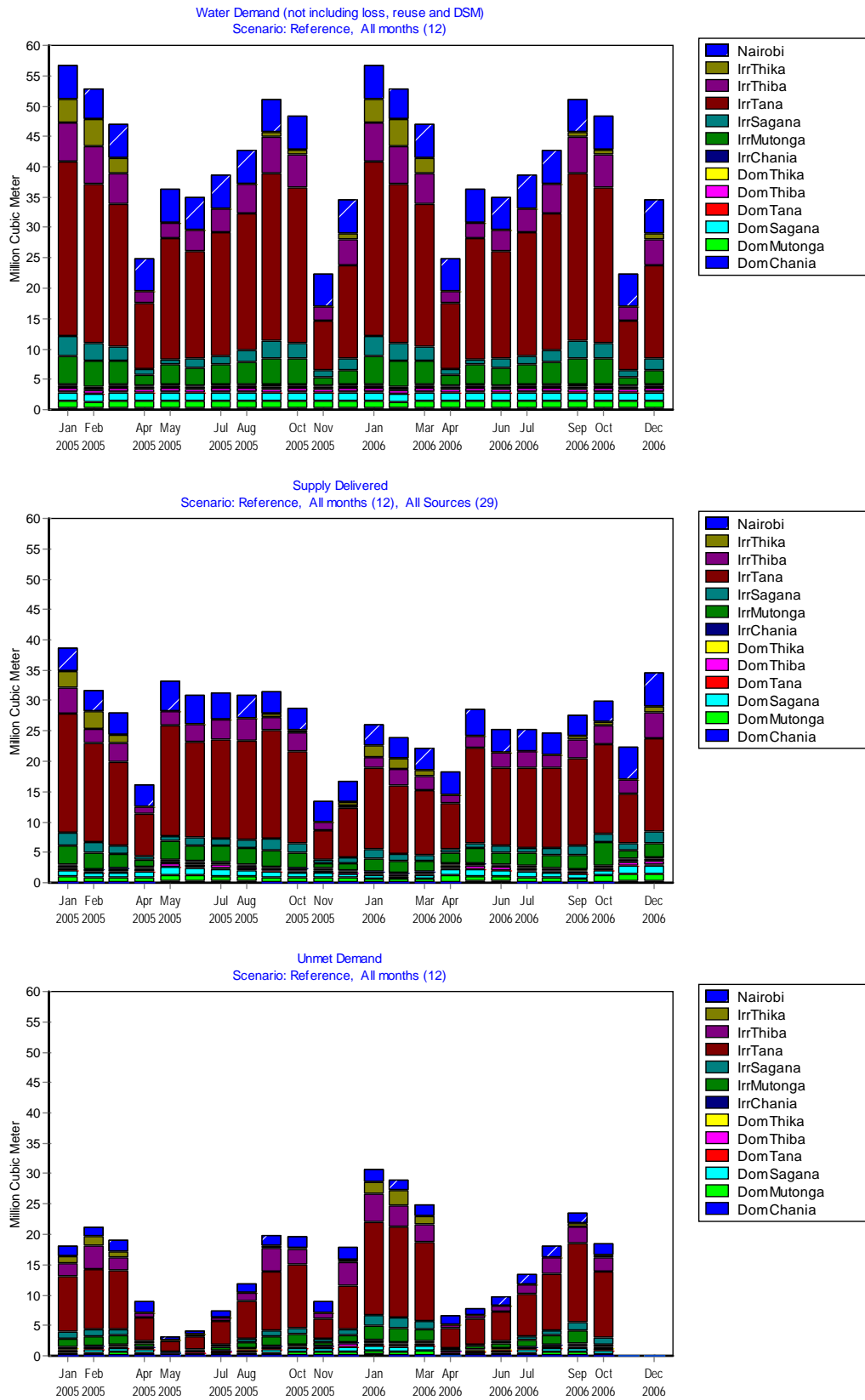


Figure 20
Water demand, supply and un-met demand for the baseline

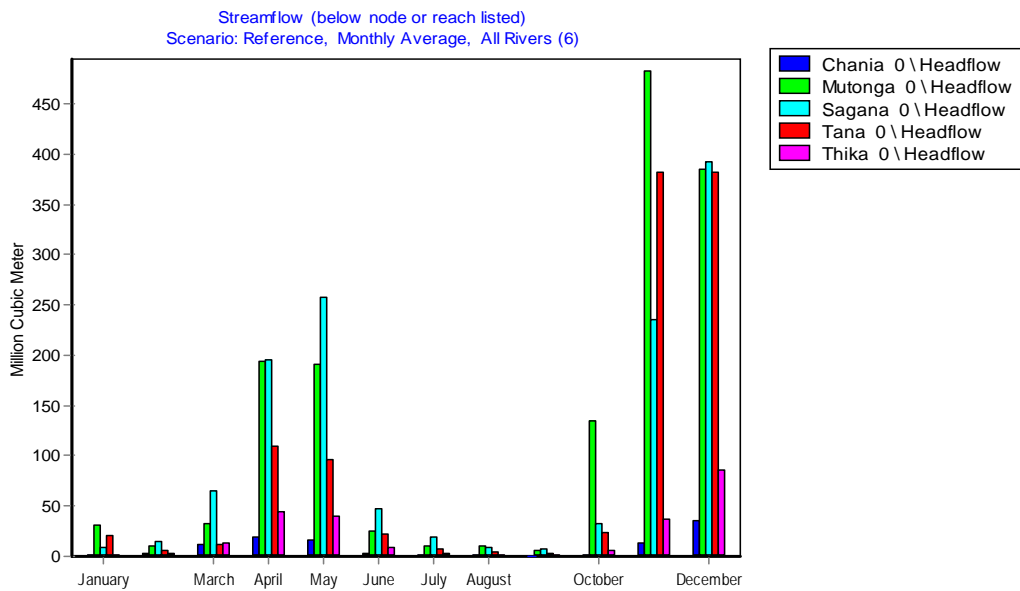
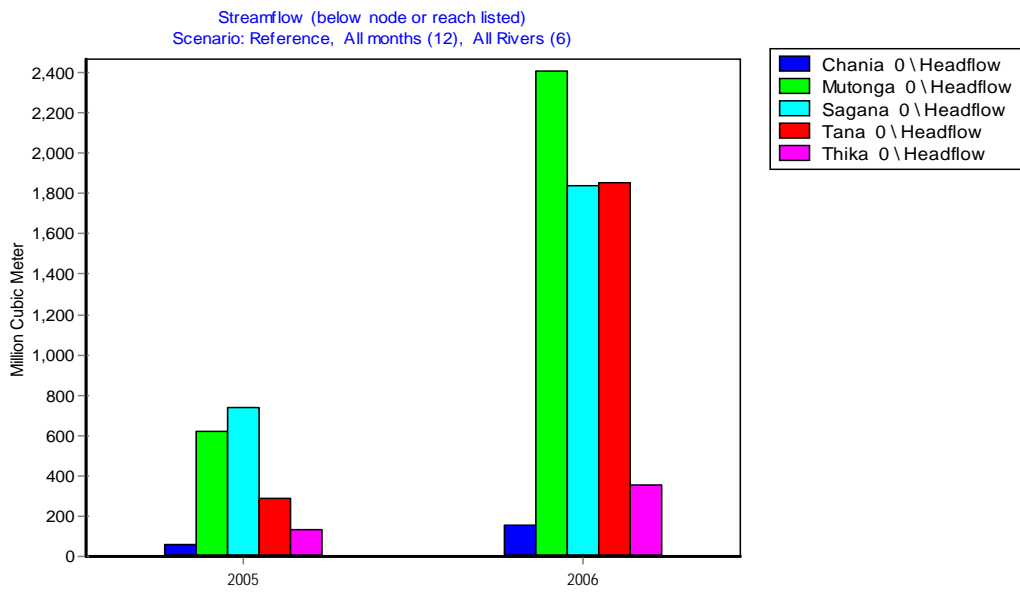


Figure 21
Headflow for the two years (top) and average per month (bottom) for the baseline

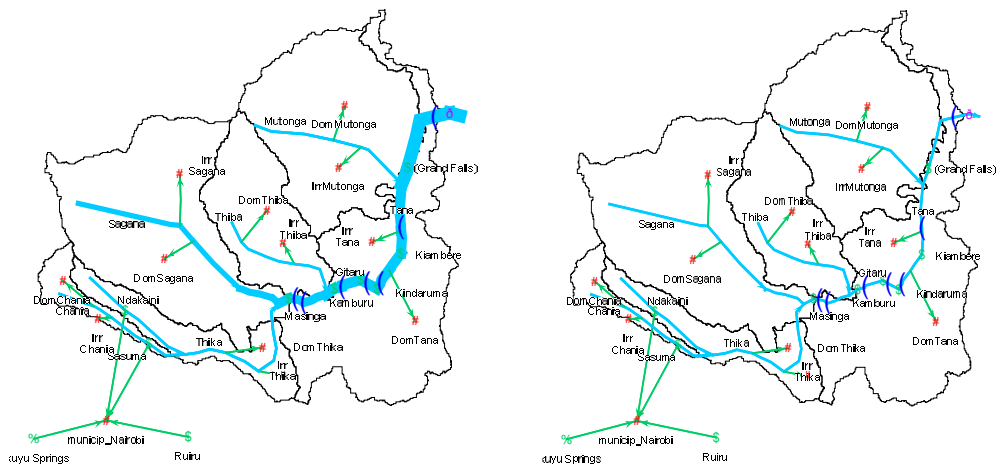


Figure 22
 Riverflow May-2003 (left) and Jul-2003 (right) for the baseline

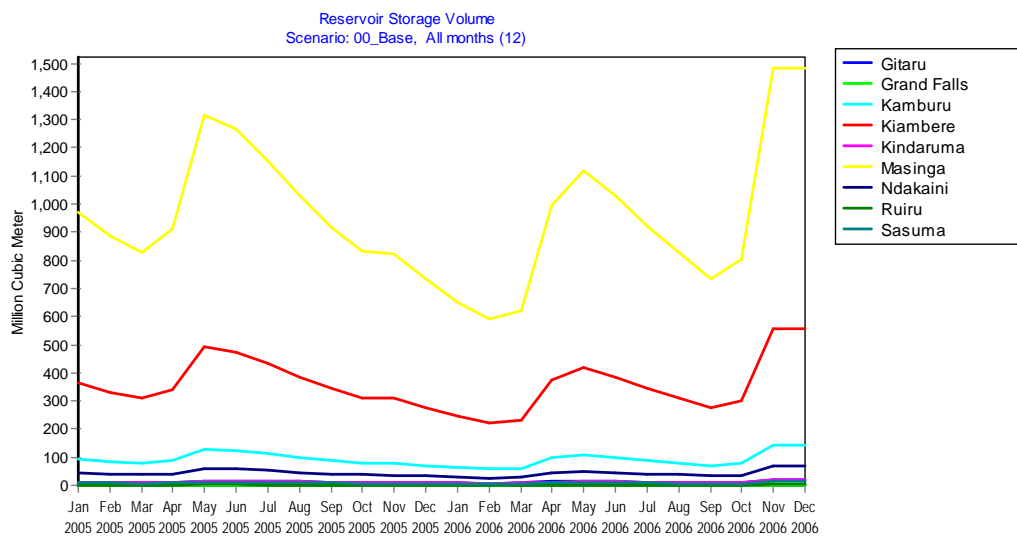


Figure 23
 Reservoir storage volume for the baseline

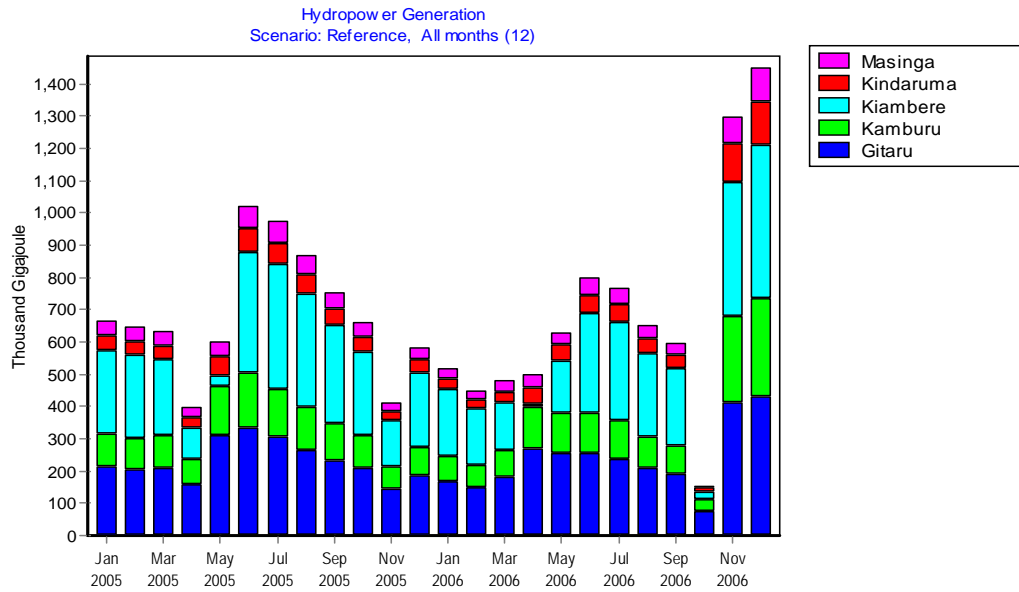


Figure 24
Hydropower generation for the baseline

4.3.2 Green water management measures

The impact of implementation of *green water* management measures was evaluated using the WEAP model. The assumption was that these measures would be implemented on 20% of the area. This is more or less equivalent to the focal area of 100,000 ha that the new NRM-P project is aiming at. It is clear that all scenarios have the effect of reducing water shortage (Figure 25), increasing reservoir volume (Figure 26) and enhancing hydropower generation (Figure 27).

Revenues, expressed in million US\$, for the four main sectors (rainfed agriculture, irrigation, domestic and hydropower) are shown in Figure 28. It is clear that increases in revenues can be up to US\$ 8 million every year. It is interesting is that for most of the *green water* management measures, increases in rainfed agricultural production provide significant benefits: these can be mainly attributed to the reduced loss of fertile soil by erosion. Obviously, for the three *green water* management scenarios which do not take place within the rainfed farming fields (microcatchments for fruit trees, rangeland improvement, and riverine protection), no substantial revenues can be expected.

A first estimate of costs of implementation of the *green water* management measures has been made as well. These estimates are based on a combination of a publication by Shiferaw and Holden (2001), earlier GWC work and expert estimates. More work is required to be carried out on these costs. The assumptions underpinning these cost estimates are that construction costs will be depreciated in ten years and that for most scenarios there will be annual maintenance costs.

The final cost-benefit analysis can be seen in

Table 4. The assumption of this cost-benefit analysis (as mentioned before) is that implementation will take place on 20% of the area - which covers the target group of the NRM-P project that is focusing on about 100,000 smallholders (and is about 100,000 ha).

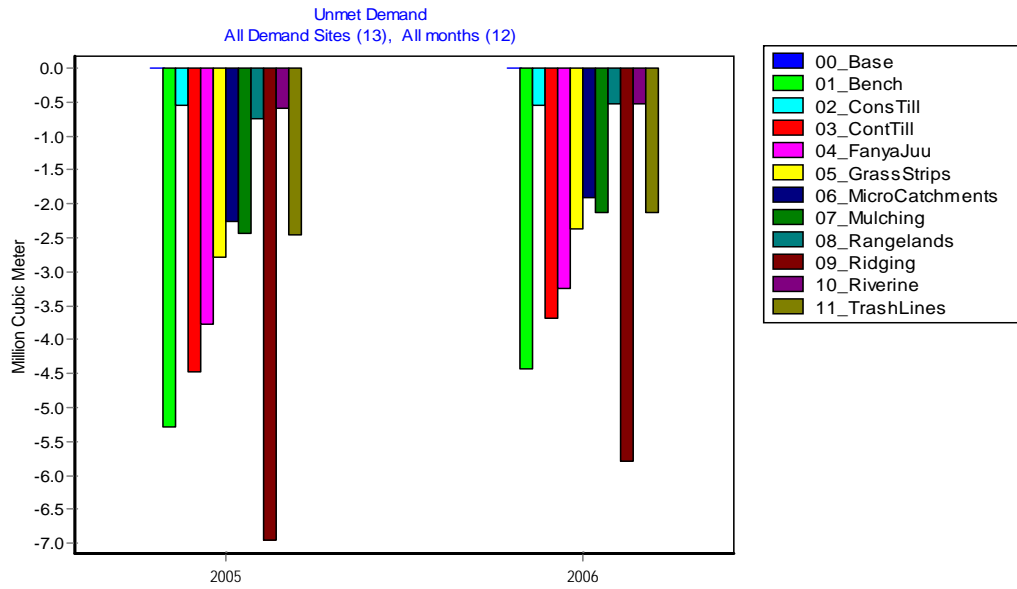


Figure 25
Reduction in water shortage for the two years and the 11 green water management scenarios. Note that all scenarios are plotted relative to the baseline (no green water management measures)

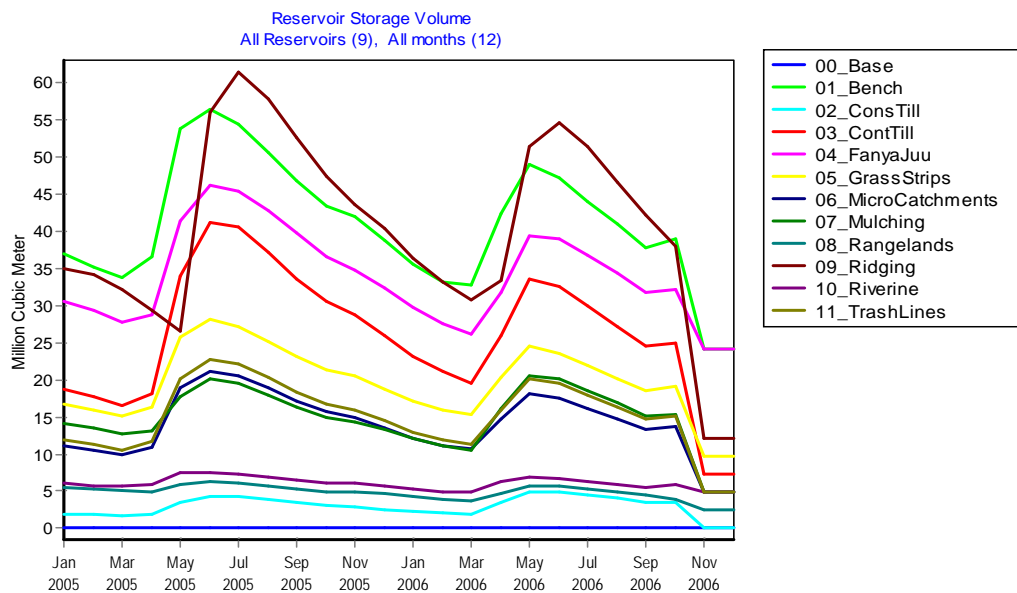


Figure 26
Changes reservoir storage for the 11 green water management scenarios. Note that all scenarios are plotted relative to the baseline (no green water management measures)

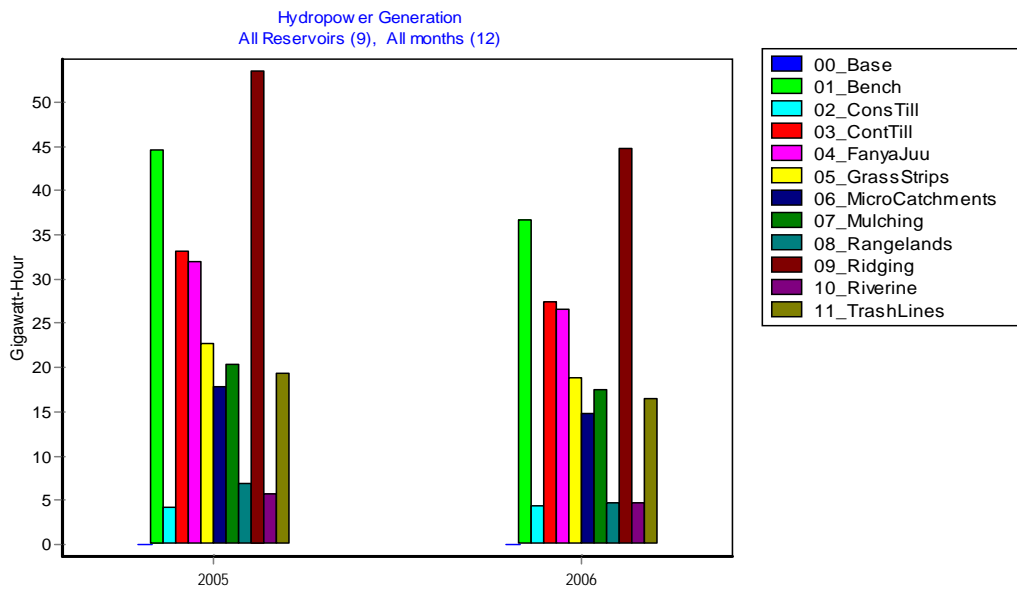


Figure 27

Changes in hydropower generation for the 11 GWC scenarios. Note that all scenarios are plotted relative to the Baseline (no green water management measures)

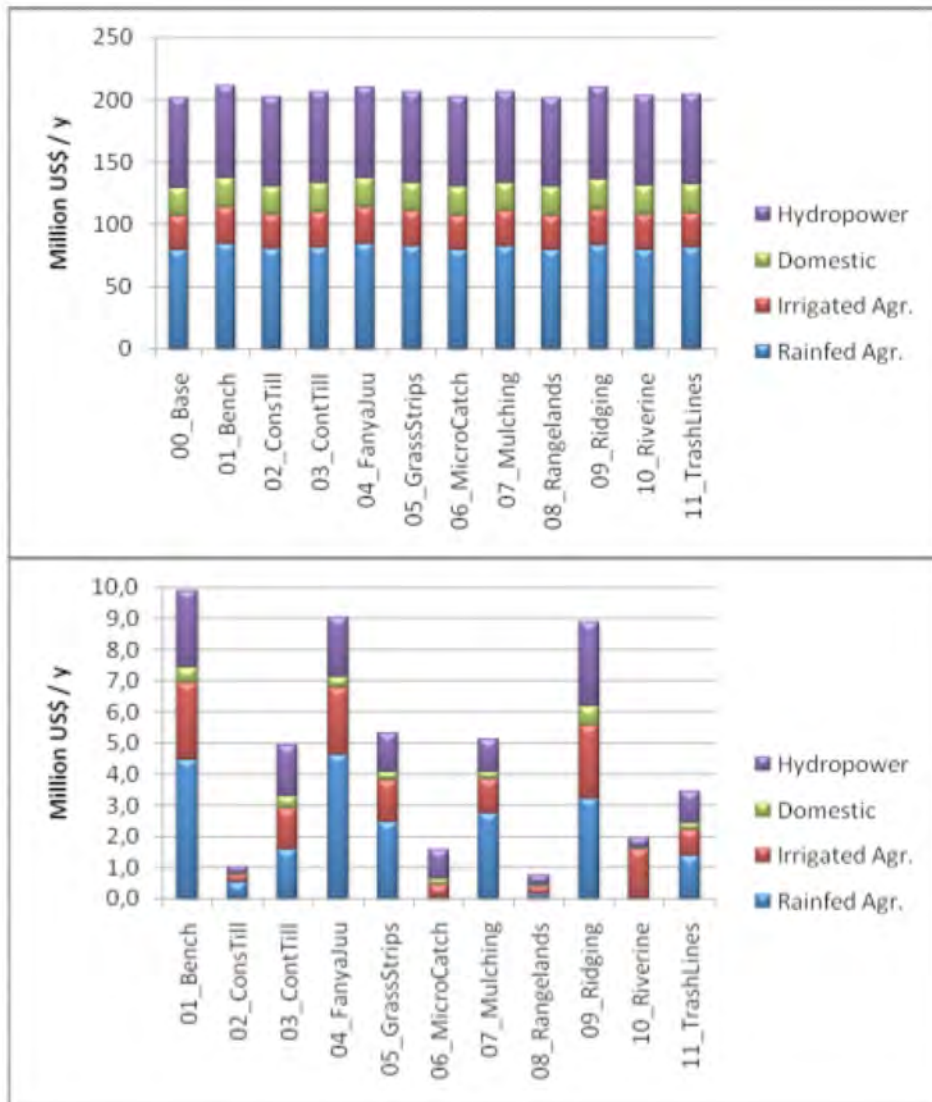


Figure 28
 Total revenues of water for the four sectors (top) and changes compared to baseline (bottom)

Table 4*Cost-benefit analysis for the 11 green water management measures*

	Benefits	Costs			B/C	
	mUS\$/yr	ha	Construction US\$/ha	Maintenance US\$/ha /yr	mUS\$/yr	mUS\$
01_Bench	9.9	92,865	100	20	2.8	7.1
02_ConsTill	1.0	52,766	0	0	0.0	1.0
03_ContTill	4.9	52,766	0	0	0.0	4.9
04_FanyaJuu	9.0	92,865	200	20	3.7	5.3
05_GrassStrips	5.3	92,865	50	20	2.3	3.0
06_MicroCatch	1.6	1,000	500	20	0.1	1.5
07_Mulching	5.1	92,865	0	0	0.0	5.1
08_Rangelands	0.8	136,916	50	0	0.7	0.1
09_Ridging	8.9	52,766	100	20	1.6	7.3
10_Riverine	2.0	10,000	100	20	0.3	1.7
11_TrashLines	3.4	92,865	50	20	2.3	1.1

4.4 Conclusions

The concept of Green Water Credits addresses the sustainable management of the water resources in a river basin at source. It links the rainwater that falls and is used (*green*) on rainfed land to the (*blue*) water resources of rivers, lakes and groundwater. The importance of proper management of soil water to the provision of the *blue water* resources is often overlooked. One of the reasons for this is the difficulty of quantifying the potential impact of these measures. By using the SWAT model in combination with the WEAP model these potential benefits can be assessed.

The WEAP model as developed during the project has been extensively validated and calibrated. The final model is able to mimic observed flows and hydropower generation. The model is therefore assumed to be useful to assess the impact of *green water* management measures.

The assumption of the 11 *green water* management measures explored during this study is that implementation will take place on 20% of the area. This was considered to be a realistic assumption and is similar to the NRM-P project that aims at about 100,000 smallholders. The 11 *green water* management measures were also explored individually while in reality a mixture of measures will be implemented based on specific local conditions. Overall, the cost-benefit analysis as presented in

Table 4 can be considered as conservative.

The most effective measures, in terms of getting additional benefits, include the labour intensive structural measures: bench terraces, *fanya juu* and ridging. The minor investment measures that are still having a clear positive impact are: contour tillage, vegetative grass strips and mulching.

Taking into consideration the costs of these measures bench terraces and ridging are the preferred measures, followed by contour tillage, *fanya juu* and mulching.

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