Green Water Credits

Water use and demand in the Tana Basin:

Analysis using the Water Evaluation and Planning tool (WEAP)

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Green Water Credits is a mechanism to pay rural people for specified land and water management activities that determine all fresh water resources at source. These activities are presently unrecognised and unrewarded. This proof-of-concept project is supported by the International Fund for Agricultural Development (IFAD) and the Swiss Agency for Development and Cooperation (SDC)

Series editor: David Dent

Authors:
Holger Hoff
Stacey Noel
Peter Droogers

Contributions from:
Eric Odada
Mary Wanjiru
Sjef Kauffman
David Dent

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Contact:
Sjef Kauffman
ISRIC - World Soil Information
PO Box 353
6700 AJ Wageningen
Netherlands
E-mail: sjef.kauffman@wur.nl

MAIN 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 un-met demand, costs and benefits.

In the Tana Basin, all water users (hydro-power, municipal water utilities and irrigation) have substantial, un-met water demands. For hydro-power, 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 is supplied at present and climate change is likely to further increase water demands for irrigation.

Immediate and nationally-significant gains in power generation and urban water supply may be realised by arresting the siltation of reservoirs. For instance, The Masinga may have lost some 30 per cent of its capacity over 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.

Given the incentive of Green Water Credits, green water management can arrest soil erosion and siltation of reservoirs, and make a significant contribution to un-met water demands. The financial benefits from improved water supply largely cover the costs of effective soil and water conservation packages.

ACKNOWLEDGEMENTS

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Abbreviations

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
WEAP	Water Evaluation and Planning tool
WRMA	Water Resources Management Authority

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 management*[1] in the Upper Tana basin, Kenya, for the proof-of-concept for Green Water Credits. The Water Evaluation and Planning tool (WEAP) has been developed specifically to integrate the data from these diverse fields of information.

For the proof-of-concept, 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 have been built up solely from this information, making plausible assumptions about future trends after discussions with key parties. Forthcoming detailed 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* and *blue* 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. Beyond 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 decentralize 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 Credits program, e.g. in terms of adoption potential for different water management measures.

[1] Green water management is defined in Green Water Credits Report 3 (Kauffman and others 2007). It embraces a variety of soil and water conservation practices, tailored to the local situation, that increase the infiltration of rainfall into the soil and cut unproductive evaporation - thereby increasing *green water* resources, groundwater recharge and stream base flow and cutting runoff, soil erosion and floods.

1.2 The need for information

With 650m^3 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 as:

> *'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 per cent 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 per cent 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.'*

In addressing water management, the Government of Kenya (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, excluding the needs of hydro-power generation.

Management options include the reduction of illegal water abstraction, provision of new reservoir storage and, also, improved land and water management in the catchment. To develop and to evaluate these options, it is necessary to consider both demand and supply, and to value the benefits and negative effects of 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 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 2006–2008 (Govt Kenya 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.'*

The Draft Rules and Forms seek to provide equitable access, sustainable use, and efficient water use to optimize social and economic benefits. They categorize 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. Other users will be assessed charges according to the type of activity and the levels of abstraction they require (Table 1).

Table 1: Provisional water-use charges

User	*Criteria*	*Rate*
Domestic, public, livestock	Domestic, public, and livestock purposes up to the limit of the water allocated on the permit	50 cents/m^3
Hydro-power generation	Amount of energy generated	15 cents/ kWh
Irrigation, agriculture, pisiculture	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/m3
	Any water in excess of 300 m^3/day	100 cents/m3
Bottled drinking water		100 cents/m^3
Effluent discharge		100 cents/m^3

The Green Water Credits process supports the water reforms by comparing development alternatives, including green water management in the catchment, both for their hydrological effects and, also, their costs. This information may 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) 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, catchment and administrative political boundaries (Yates and others 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 optimization 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 only a short 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 organizations 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 with any time step where routing is not a consideration; for the proof-of-concept in the Tana Basin, a monthly time step is 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 some other 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 in 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 put into the model through the WEAP interface.

Water allocation: The problem is to distribute the supply remaining after satisfaction of catchment demand (the *Reserve* mentioned in the Water Act); the objective to maximize 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 with a number in parentheses (from 1, having the highest priority, and 99, the lowest). The program 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 per cent. 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 by groundwater recharge which feeds river base flow. The SWAT model simulates the cumulative effects of these measures on runoff, erosion, groundwater recharge, stream flow, 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, hydro-power 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, water management scenarios are based on the actual surface-water availability for the period 1989-2004, measured at gauging stations on the main tributaries in the Upper Tana (Kauffman and others 2007). For the forthcoming 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).

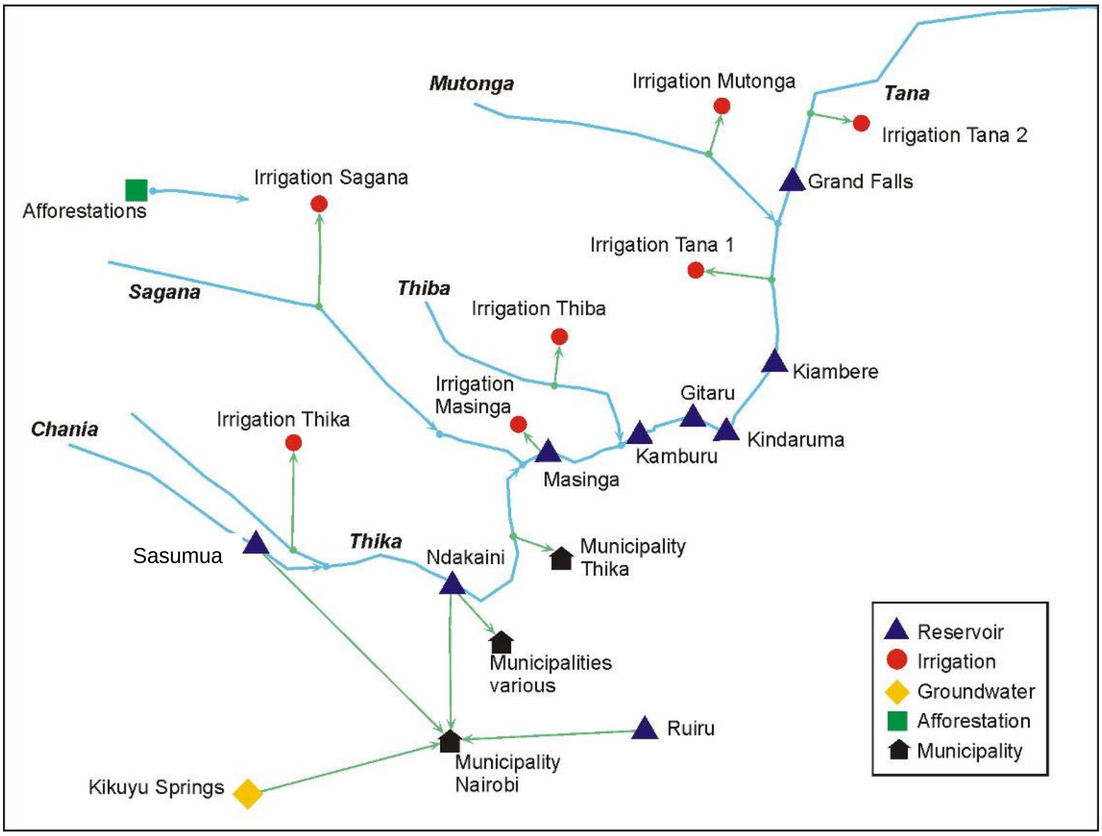


Figure 1: WEAP representation of the Upper and Middle Tana

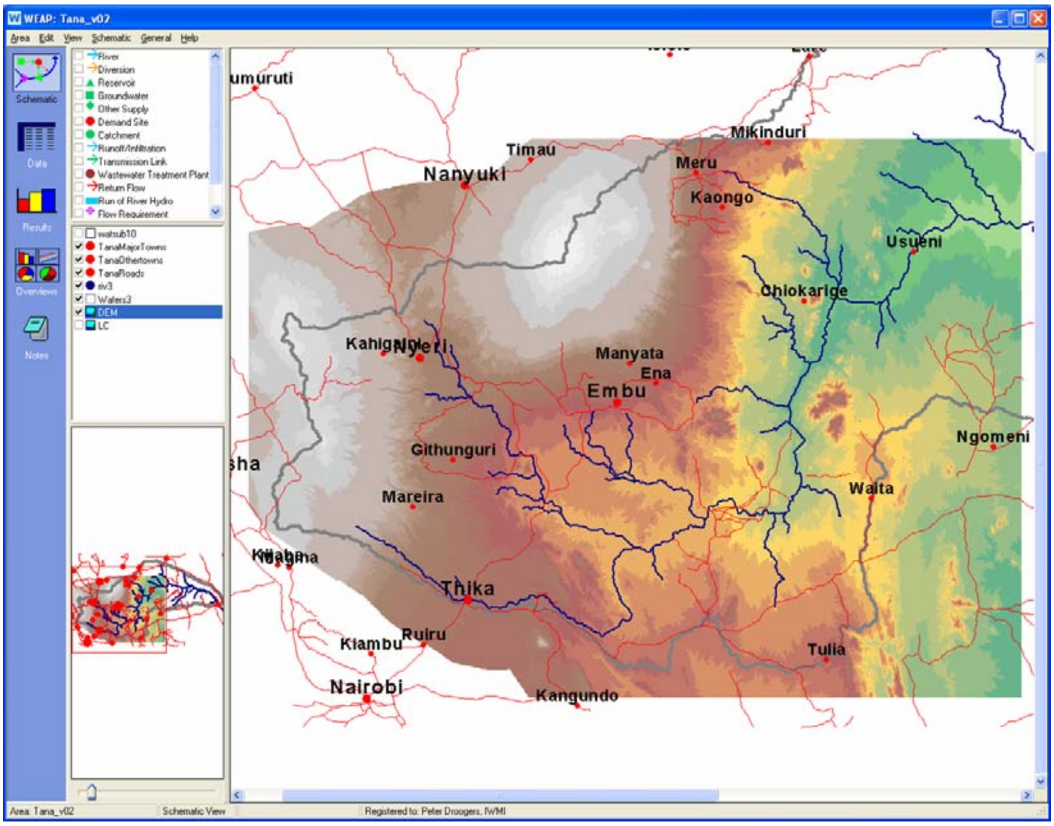


Figure 2: Upper Tana, terrain (digital elevation model) in WEAP

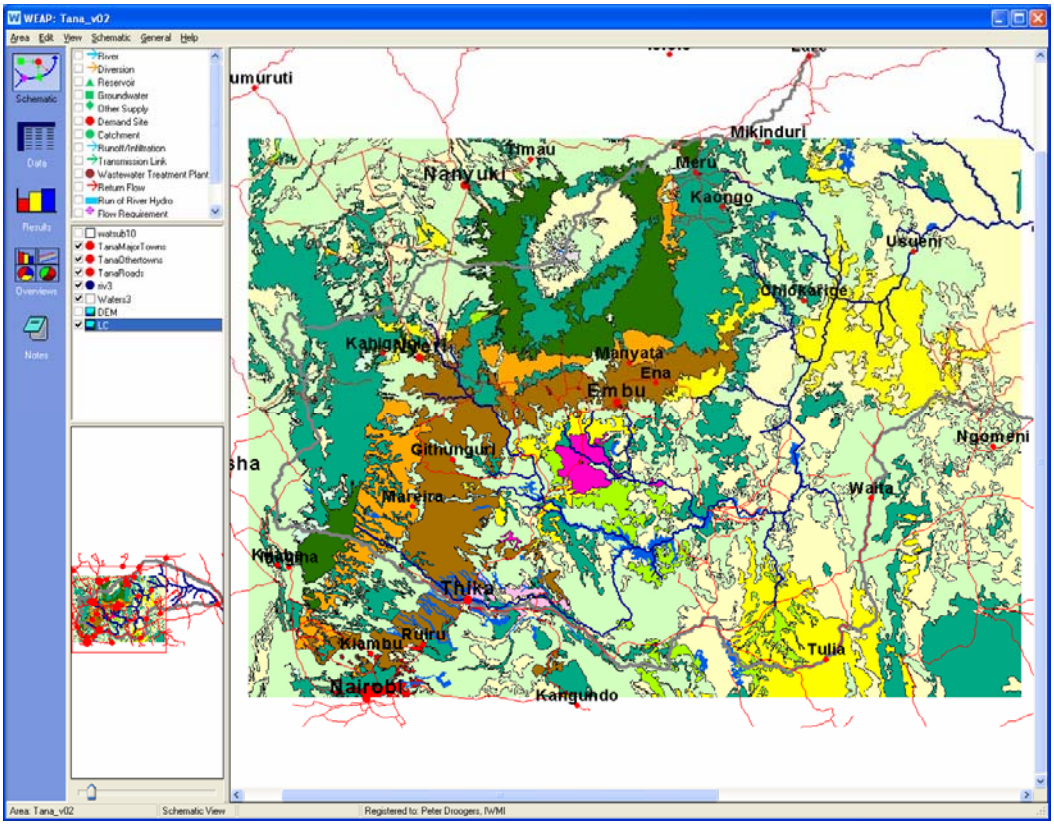
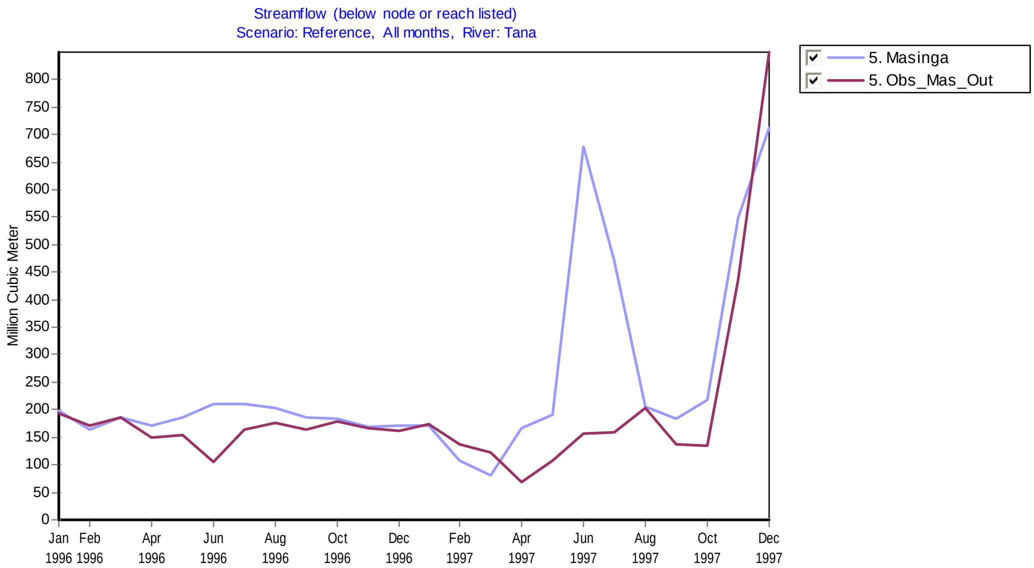


Figure 3: Upper Tana, land cover in WEAP

2.2.3 *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 is used for allocations and reservoirs; comparison was done 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 never observed. Further analysis on this discrepancy should be done, but is most likely due to input inaccuracies. Overall, the model is performing well.



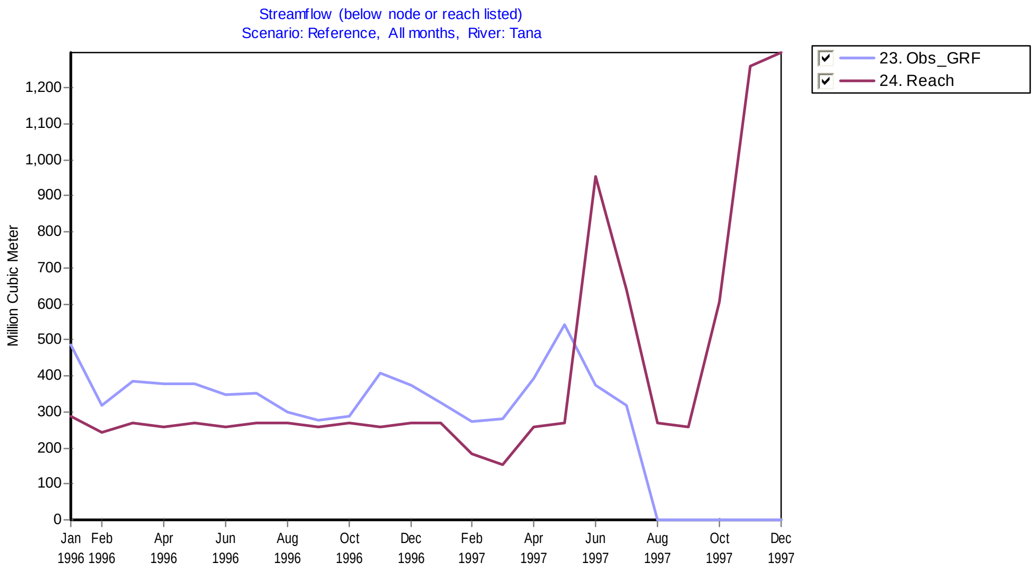
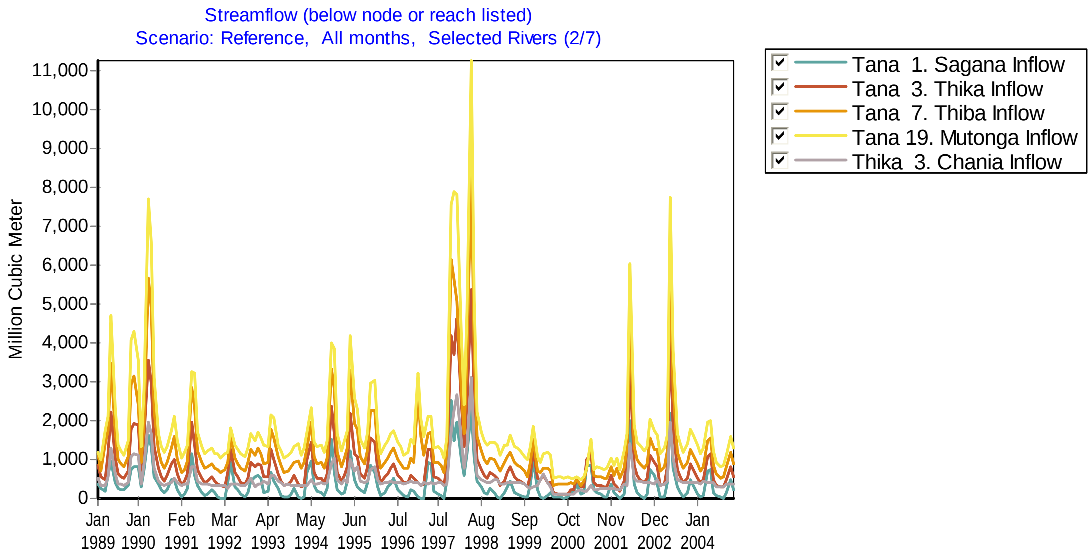


Figure 4: Observed and simulated stream flow below Masinga and Grand Falls
No observations were available for Grand Falls (bottom) after July 1997

Figure 5 shows monthly variation of runoff in the main tributaries of the Tana for the period 1989-2004, based upon gauging-station data from 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.



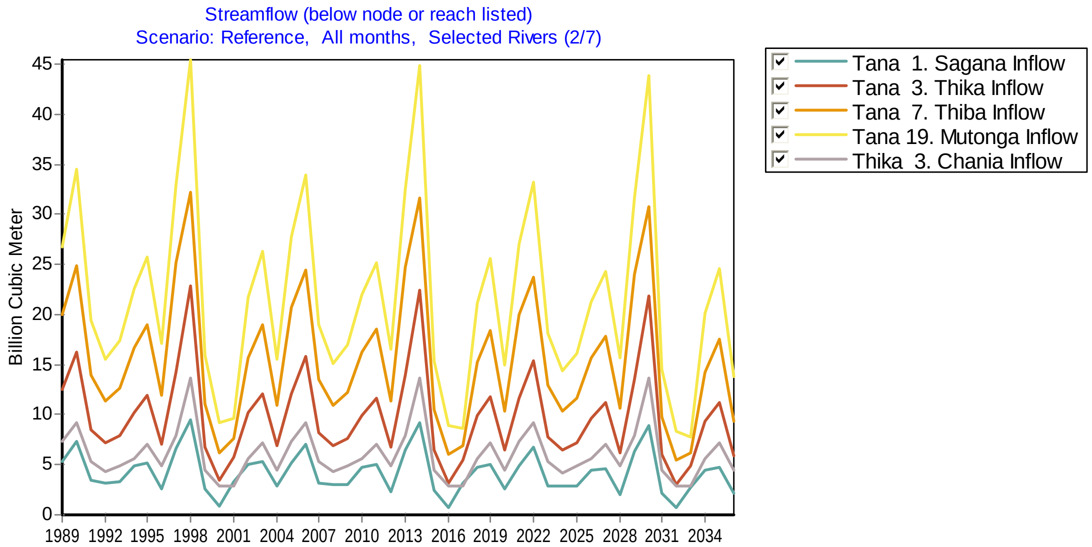


Figure 5: Upper Tana, monthly stream flow (top) and annual totals (bottom)

3 Long term trends

3.1 Municipal water supply

3.1.1 Demand and supply

Nairobi gets 70-80 per cent 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 (Govt Kenya 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 growing at 6 per cent annually and industrial water demand projected to grow from some 220 000 to more than 280 000 m^3/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 m^3/day but only some 456 000 m^3/day was abstracted (384 000 m^3/day from Ndakaini), a shortfall of 20 per cent. Water storage per person has not kept up with population growth which is one of the highest in Africa (Mogaka and others 2006). NWC anticipates a 3-5 per cent annual increase in demand, so un-met demand continues to be a serious issue.

Under the WRMA Draft Rules, NWC should pay 0.50 KES/m^3 for water abstraction and 1 KES/m^3 for discharging effluent (Table 1). Since the company's consumer rate structure fixed, NWC may not be able to cover these charges opposes the imposition of tariffs.

3.1.2 Economic gains from increased blue water flows

NWC has pressing need for increased water flows; under business-as-usual, 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 and others 2006);
- *Plugging leaks and illegal connections:* NWC estimates that it loses at least 30 per cent of its water supply within Nairobi city, Foster and Tuinhoff (2005) suggest losses of up to 50 per cent; in the Nairobi slum of Kibera, 40

per cent 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; $50 000 annually was spent digging silt out of the Sasumua reservoirs between 2003 and 2006; water purification is a further significant cost that might reduced by effective action against agricultural contamination of the water supply (Ngari pers. comm.). NWC is fully seized 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 $50 000 annually in the catchments to combat sedimentation of its reservoirs.

3.1.3 Potential contribution of Green Water Credits

Figure 6 gives a WEAP forecast for the increased un-met demand under a business-as-usual scenario; the increase in demand from population growth has been included but water consumption per person has been kept constant at a hypothetical value of 70 m^3/year. NWC also supplies 20 000 m^3/day to Thika municipality and 5 000 m^3/day to communities located between its treatment plants and Nairobi. These demands are included using the same per caput volumes and growth rates as Nairobi (current population of Thika is taken as 500 000).

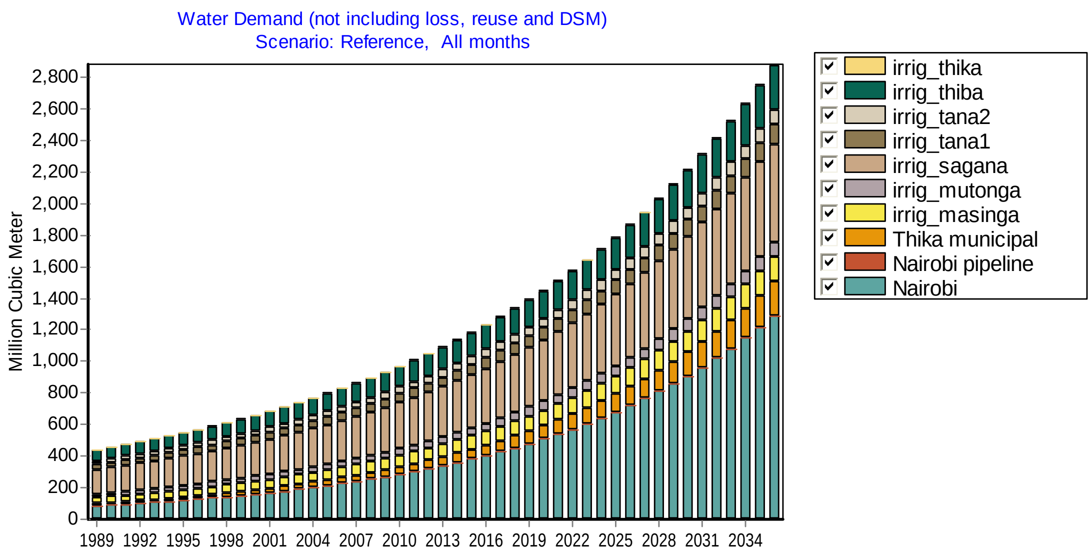


Figure 6: Tana Basin water demand to 2036, business-as-usual scenario applying a 6% annual increase in municipal demand and 3 per cent increase in irrigation demand

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 farms (Del Monte, Kakuzi), public schemes (Mwea, Bura, Hola), and community-based smallholder schemes (Yatta canal). Demand greatly outstrips supply. Currently there are 68 700 ha under irrigation but there are more than 205 000 ha of irrigable land. Interviews with irrigators from large commercial operations to smallholders raised many complaints about insufficient supplies, and 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:

(i) 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

(ii) Identifying the suitable water saving technology and the efficient production level.'

Certainly, there are many water-saving technologies available for both irrigated and rain-fed agriculture. This proof-of-concept examines just three simple green water management practices that can improve water management in rain-fed farming.

3.2.2 Demand for irrigation water

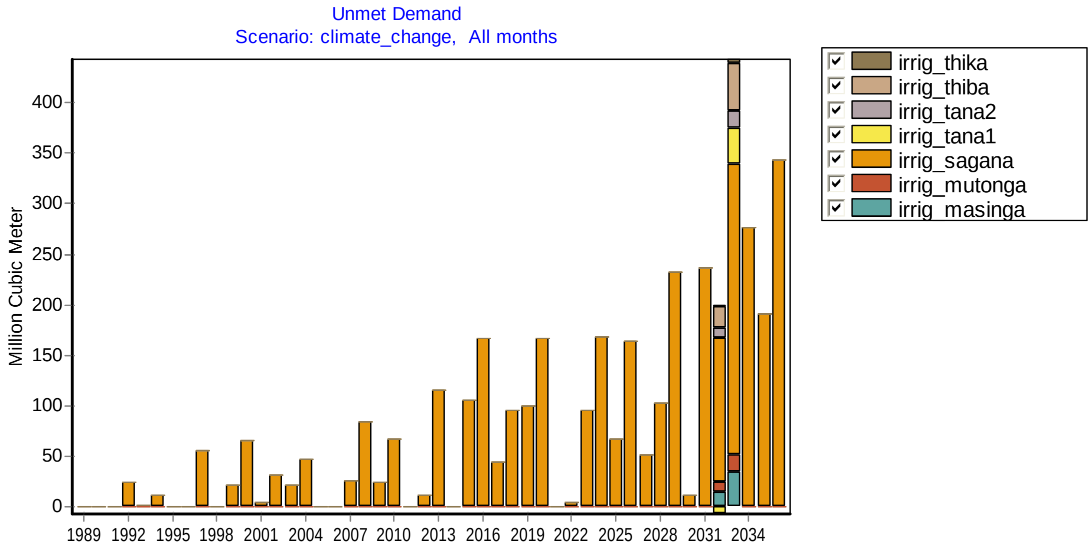


Figure 7: Increase in un-met demands in irrigation for a climate-change scenario

In the Tana WEAP model (Figure 6), irrigation-demand data from TARDA (Willis, pers. comm.) are aggregated to monthly values for each sub-basin and a demand-growth rate is set at 3 per cent for area increase. Figure 7 depicts a climate-change scenario in which crop water requirements are assumed to increase by 10 per cent (from 7777 to 8555 m^3 per ha) in response to the predicted rise in temperature and the resulting increased evapo-transpiration, and accessible blue water flows are assumed to decrease by 20 per cent in line with an assessment by Strzepek and others (2001) for the Nile basin.

3.3 Hydro-power

3.3.1 Capacity and demand

Hydro-power is strategically important to Kenya; it provides 50-80 per cent of the country's electricity, depending on rainfall (Oludhe 2003), and 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' (Govt Kenya 2006a). Installed capacity is 650 MW/year; technically exploitable capability may be 9 TWh/year (UNESCO 2006). Some 80 per cent of hydro-power power is generated from five dams on the Tana (Figure 8 and Table 2). In addition, there are two smaller hydro-power 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
Source: KenGen (www.kengen.co.ke)

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

The Tana River power stations are owned and operated by Kenya Electricity Generating Company Limited (KenGen) instituted in 1997 as part of energy sector reforms which 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 7.9 per cent - that is 27.7 million people did not have access to electricity (UN Millennium Project 2004); the Government of Kenya estimates that access is now 15 per cent. Annual increase in demand averaged 9 per cent during the 1960s and '70s, 7 per cent during the 1980s, 5% during the 1990s (Oludhe undated) and is spurting again; both electricity generation and consumption rose by 6.8 per cent in 2005 (Govt Kenya 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 2025/26 (www.kplc.co.ke).

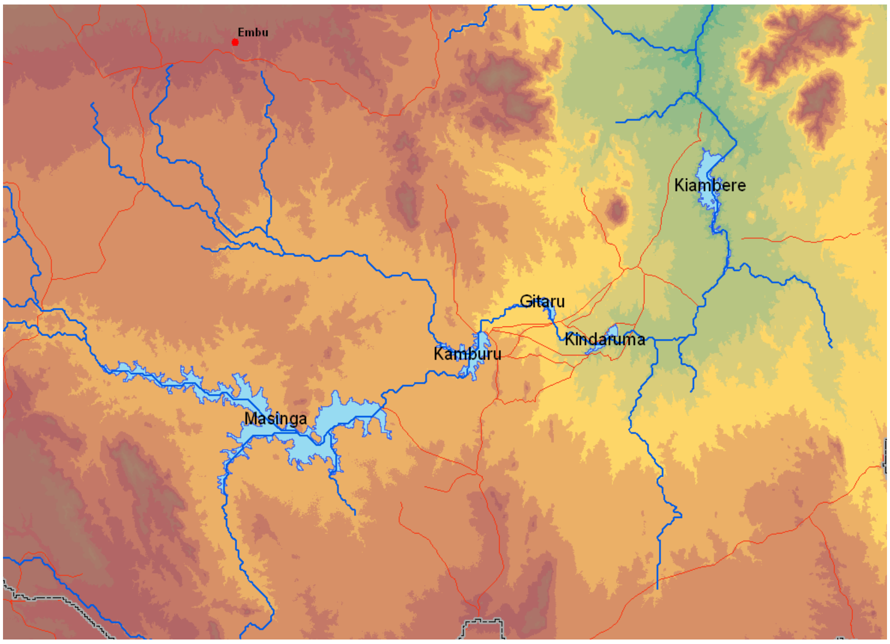


Figure 8: Tana River, main reservoirs for hydro-power

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 (Govt Kenya 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 versions are being considered: the Low Dam, would have 1.6 billion m^3 of storage and focus on hydro-power development only, at an estimated cost of $US 378.3 million; the High Dam would have a 6.5 billion m^3 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 hydro-power industry. Therefore, upstream land management practices that result in better regulation of river flow would bring direct financial benefits. During the 1999-2000 drought, hydro-power generation fell by 41 per cent (from 3 000 to 1 800 GWh), monthly losses to the hydro-power industry are estimated at $US 68 million, lost industrial production $1.4 billion, and some companies relocated to neighbouring countries with more secure power supply (Mogaka and others 2006). Any significant rainfall event, particular high-intensity rainfall, brings floods and soil erosion and siltation that affect hydro-power infrastructure through the loss of reservoir storage capacity, and damage to turbines that requires 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 may be illustrated by the Masinga reservoir: when it was designed, sediment input was estimated at 3 million m^3/yr; recent estimates indicate an input of 11 million m^3/yr (Bobotti 2000) or even higher; WWAP (UN Water 2006) reckoned that in the 20 years before 2002, the reservoir suffered a loss of 460 million m^3 volume. The latter figure (29 per cent loss of storage 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.

Hydro-power 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 per cent across reduction in soil erosion and siltation of the reservoirs. This is conservative; Wanyonyi (2002) records improvements of 80 per cent after adoption of soil and water conservation measures around the Tungabhada reservoir in India, and the average reduction of erosion by all Kenyan WOCAT measures is 76 per cent.

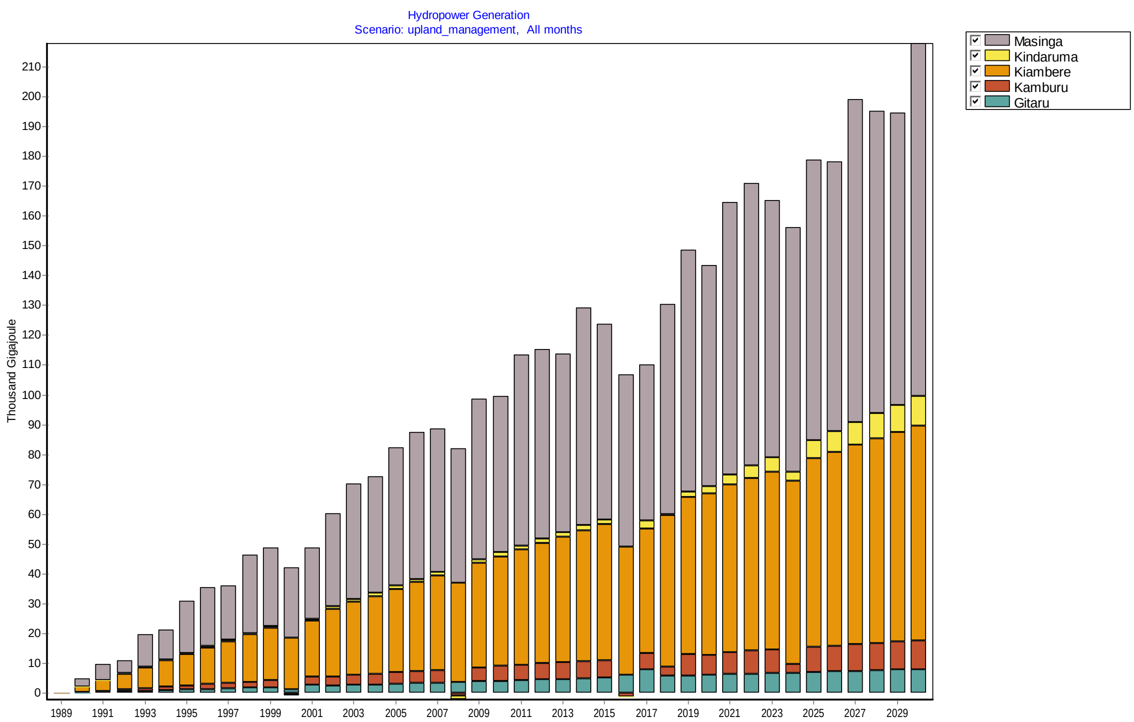


Figure 9: Increase in hydro-power production for a green water management scenario compared to the business as usual

The purpose of these proof-of-concept scenarios is simply to demonstrate the potential of green water management. A priority in the forthcoming project- design stage will be to establish, with all partner institutions, 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 takes 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 and, also, coastal and marine ecosystems at the river mouth, particularly mangrove and reef systems near the Kiunga Marine National Reserve where forest officials report that the quality and quantity of water from the river was damaging the mangroves – which play many roles including erosion control, protection against floods and severe storms, maintenance of water quality, fish nurseries and sustaining coral ecosystems, so mangrove degradation has an impact on an important source of biodiversity and a major international tourist attraction (see also Abuodha and Kairo 2001). UNEP (2006) claims that sediment input into the Indian Ocean has been reduced by 50 per cent after construction of the Tana reservoirs.

Protected areas in the basin include the Tana River Primate National Reserve on the upper delta - home to the endangered Mangabey and the Tana River Red Colobus primates; Arawale National Reserve designated to protect the rare Hunter's Antelope; Mwea National Reserve, northwest of Kamburu Dam– with Elephant, Rothschild Giraffes, Common Zebras, Warthog, Hippopotamus, Crocodile, Buffalo, and over 150 species of birds -, also a recreation area taking advantage of access to nearby dams; a string of national reserves located along the Tana banks, comprising the Meru, Kora, Mwingi and Bisanadi conservation area - a wildlife dispersal area 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 (Govt Kenya 2006c), of which 70 per cent (l per cent of GDP) is attributed to wildlife -which 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 basic needs, kitchen gardens, stock water and production of food and drink. In rural areas especially, livelihoods often depend directly on forest products, fish and other marine products (ADB and others 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 questions 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 easily identified), an approach would be to define the demand as international, and look to organizations that already recognize and value the link between water resources management and ecosystem sustainability.

One possibility is a *debt-for-nature swap*, successfully accomplished by several countries. This might be attractive to the Government of Kenya as a way to retire national debt[1], 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.

1 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. It has been refined to evaluate specific green water management practices, three of these are appraised in this proof-of-concept: permanent vegetative contour strips, mulching, and tied ridges. These three scenarios are compared for a dry year (1996) and a wet year (1997) in respect of:

- Hydropower generation
- Agricultural production from irrigated areas
- Downstream flows.

The following refinements have been made to the WEAP model:

Financial calculations

- Variable revenue for irrigation systems is based on the concept of water productivity, taking a mean value for the Tana of $US 0.15/$m^3$
- Revenues from drinking water supply are set at $0.10/$m^3$ and consumer prices of drinking water are set at $0.50/$m^3$
- Revenues from electricity are set at $ 0.04/ kWh (based on KenGen annual report, revenues are 2.36 KES/kWh, consumer prices are around $0.50/ kWh at an exchange rate of KES 1 ~ $US 0.015)

Water resources

- Head flows from the four main rivers (Thika, Thiba, Sagana, and Mutonga) are substituted by flows calculated by SWAT. First, because insufficient observation data are available; SWAT uses all available data. Secondly, head flow data are not ideal for inflow to reservoirs; abstractions and supplies along the course of the rivers should be taken into account, as in SWAT
- In the long-term WEAP analysis, a steadily diminishing reservoir capacity was assumed. Since we focus only on a dry year and a wet year, the reference situation was defined as: top of buffer = 25 per cent of storage capacity; buffer coefficient = 0.5; storage capacity = 70 per cent of original

Water demand

- Actual irrigated area is 68 700 ha (Chapter 3). Land cover analysis from Landsat satellite data indicate a similar figure (71 000 ha – Kauffman and others 2007). The WEAP version used for the long-term trends assumed an area of 44 000 ha and this was adjusted to 70 000 for the green water management scenarios
- On top of the demand for irrigated areas (7 777 m^3/ha), it was assumed that 25 per cent was lost to drainage (which should be considered as used elsewhere rather than an absolute loss), leading to an increase in demand
- The irrigation demand of 7 777 m^3/ha used in the long-term analysis is for an average year; 1996 was dry so it was assumed that demand would be 10 000 m^3/ha (1000 mm)
- A maximum supply capacity to irrigation systems of 5 mm/d is assumed

General
- To ensure constancy and transparent model alteration, many of the parameters described above were put into the so-called Key Assumptions
- To demonstrate the flexibility and user-friendliness of WEAP, some layers of background information were included

4.2 Siltation of reservoirs

There is no consensus on the current rate of siltation of the reservoirs; three different figures from the literature are in the previous chapter (in brackets, the conversion to mm soil loss if this were derived equally over the catchment):
- 3 million m^3/y (0.4 mm/ ha/y)
- 11 million m^3/y (1.5 mm/ha/y)
- 23 million m^3/y (3.1 mm/ha/y)

The SWAT results for input to the reservoir, based on a volumetric weight of erosion product of 1.65 tonne/m^3 are lower:
- 0.6 million m^3 (0.1 mm/ ha) for a dry year
- 3.5 million m^3 (0.5 mm/ ha) for a wet year

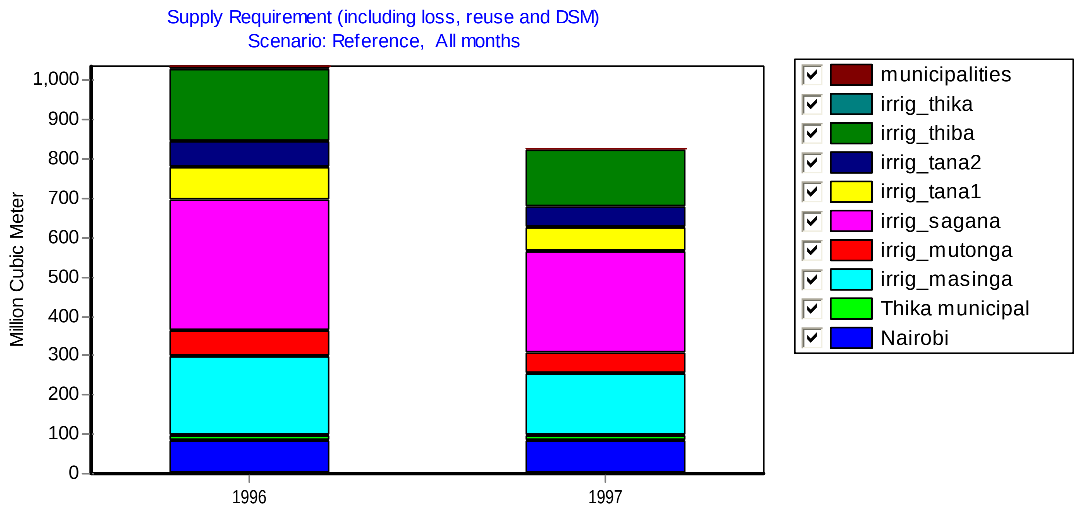
These figures include sedimentation within the river channel but not include bank erosion - both complex process and, since data were lacking, probably not very reliably represented in the preliminary SWAT model. If we consider only erosion from maize, tea and coffee, as simulated by SWAT, the following values are:
- 0.8 million m^3 (0.2 mm/ ha) for a dry year
- 11 million m^3/y (2.3 mm/ ha) for a wet year

For this proof-of-concept, an average annual rate of siltation of 10 million m^3 is assumed. Since Masinga reservoir was completed in 1980, a loss in capacity of 270 million m^3 (~ 20 per cent of its design capacity) was assumed for the reference situation (1996 and 1997).

4.3 Current situation

4.3.1 Demand and supply

WEAP outputs are presented for a dry year (1996) and wet year (1997). Figure 10 shows the total water demand from all users. Demand for irrigation outstrips demands for urban use; irrigation demand is much higher for the dry year and there is a significant seasonal variation. Not all the demand is met (Figure 11). Water supply to Nairobi is given priority so its un-met demand is quite constant. For irrigation, shortages build up from August 1996, rising to 80 million m^3/month in March 1997



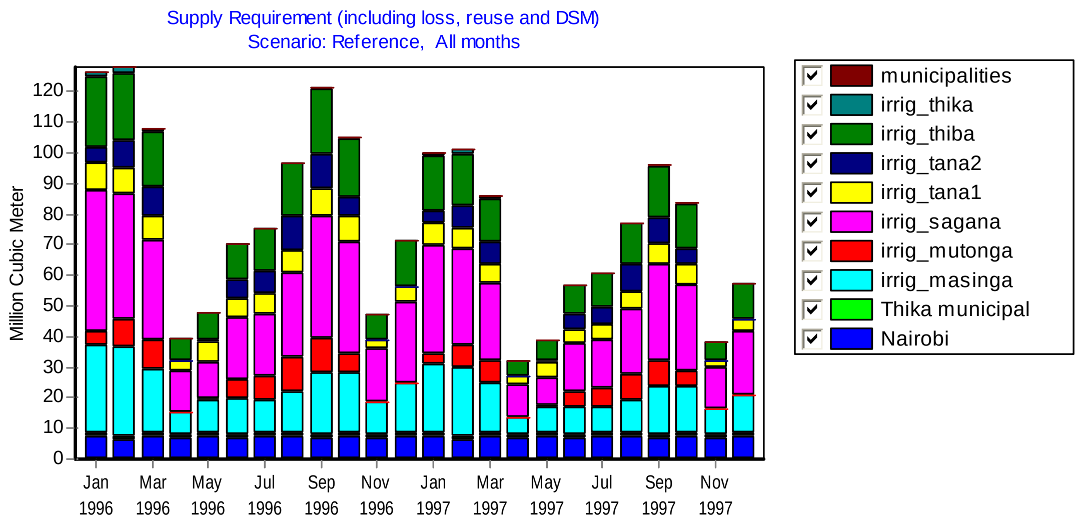


Figure 10: Total water demand, 1996-1997

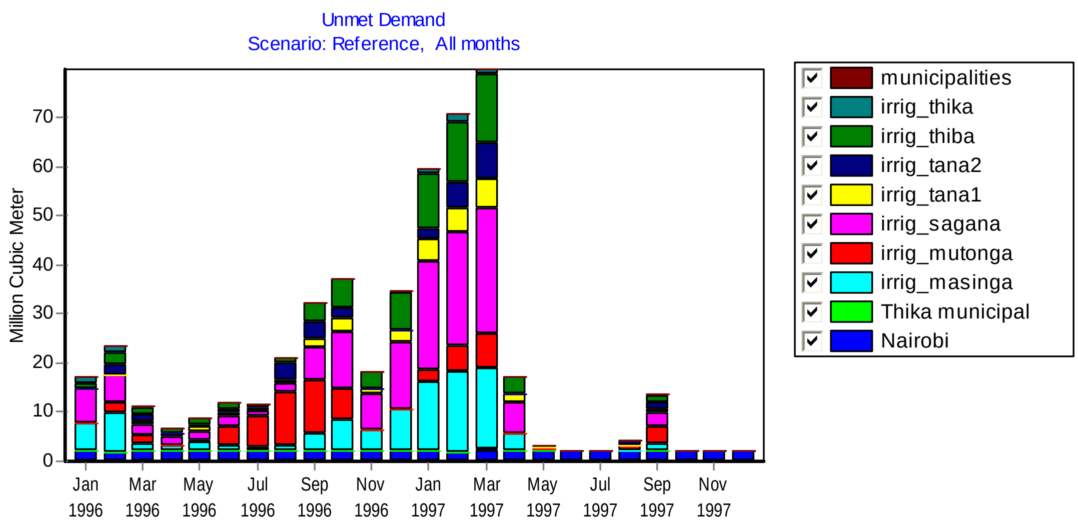


Figure 11: Un-met water demand, 1996-1997

Most of the water is drawn from reservoirs. Starting from August 1996, they are depleted at an alarming rate (Figure 12), only re-filling with the rains of March 1997.

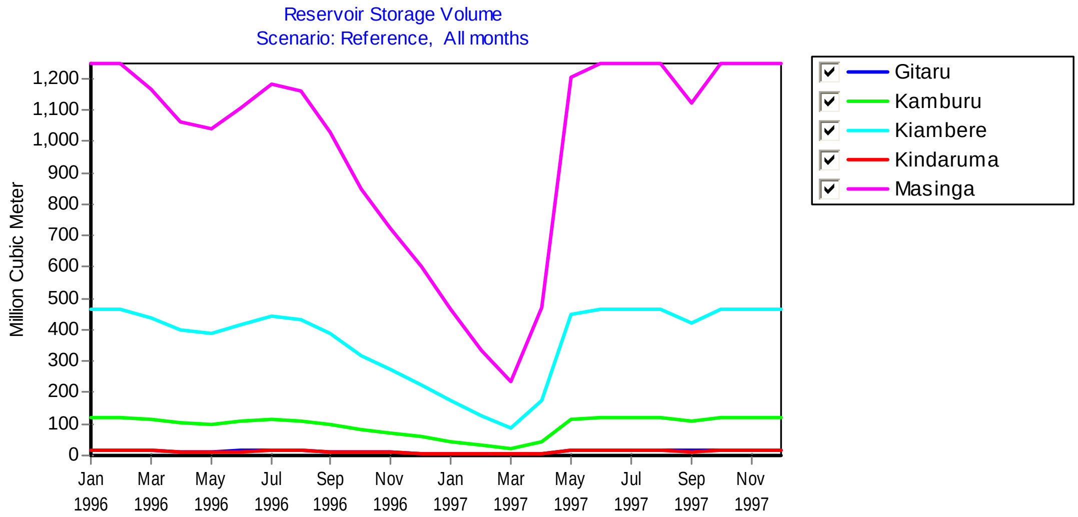


Figure 12: Reservoir storage, 1997-1997

4.3.2 The worth of water

Different scenarios may be compared using the total gross water benefits (Figure **13**) The costs to obtain these benefits have not been included in the analysis but can be included easily if data are available. Averaged over the two years, total revenues are around $US 180 million:

- Hydropower 101 million
- Irrigation 74 million
- Urban 7 million

Hydro-power is clearly the greatest financial benefit, however total revenues are a crude indicator; costs should also be considered and the worth of urban water supply is surely underestimated because the price of water is currently fixed for social reasons.

Annual revenues are not very different between the two years, although 1996 was much dryer than 1997. This is because the drought extended into 1997 and most of the 1966 water supply was provided by depleting the reservoirs. The same applies to hydro-power (Figure 14), where generation was lowest at the beginning of 1997.

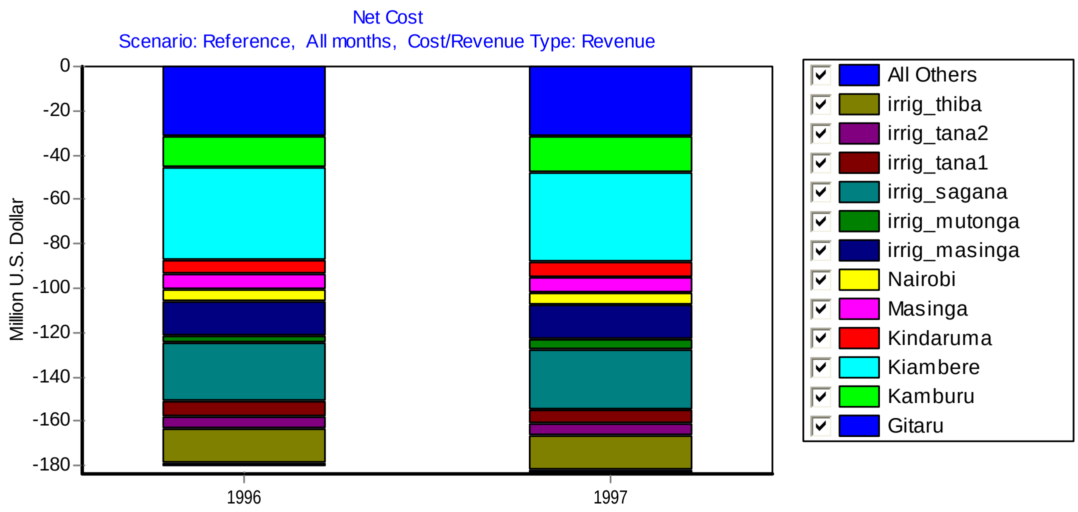


Figure 13: Annual revenues of all water users
Note: WEAP displays revenues as negative costs

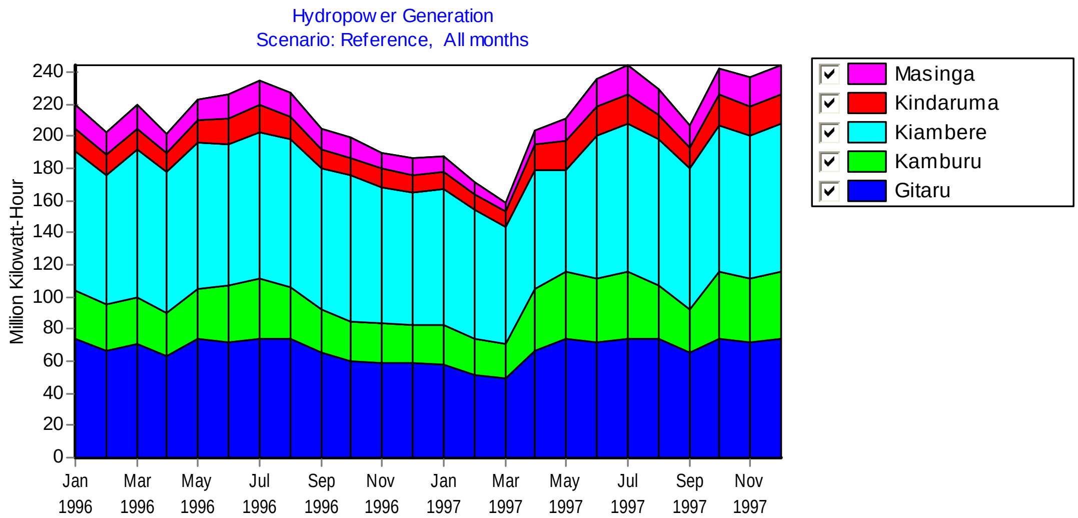


Figure 14: Hydro-power generation, 1966-1967
Note: Calculations make assumptions about turbine characteristics

4.4 Green water credits scenarios

4.4.1 Green water management packages

Three green water management packages were defined:

- Grassed contour strips - to intercept runoff and eroded soil, and increase infiltration of rainwater;
- Mulching - to reduce evaporation from the soil surface, increase infiltration and reduce soil erosion;
- Tied ridges – to increase infiltration and reduce runoff and erosion.

The hydrological impacts of these packages were evaluated using the WOFOST and SWAT models (Kauffman and others 2007). Table 3 shows changes in key indicators assuming application of each package individually on all cropland across the Upper Tana.

Table 3: Change compared to baseline, per cent, for green water management scenarios
1996 is a dry year, 1997 is wet. Data from Kauffman and others 2007

Management practice	*Contour Strips*		*Mulch*		*Tied Ridges*	
	1996	*1997*	*1996*	*1997*	*1996*	*1997*
Inflow Masinga	1	-1	5	-1	3	-3
Groundwater recharge	5	6	12	13	11	16
Soil loss	-47	-33	-71	-46	-82	-49

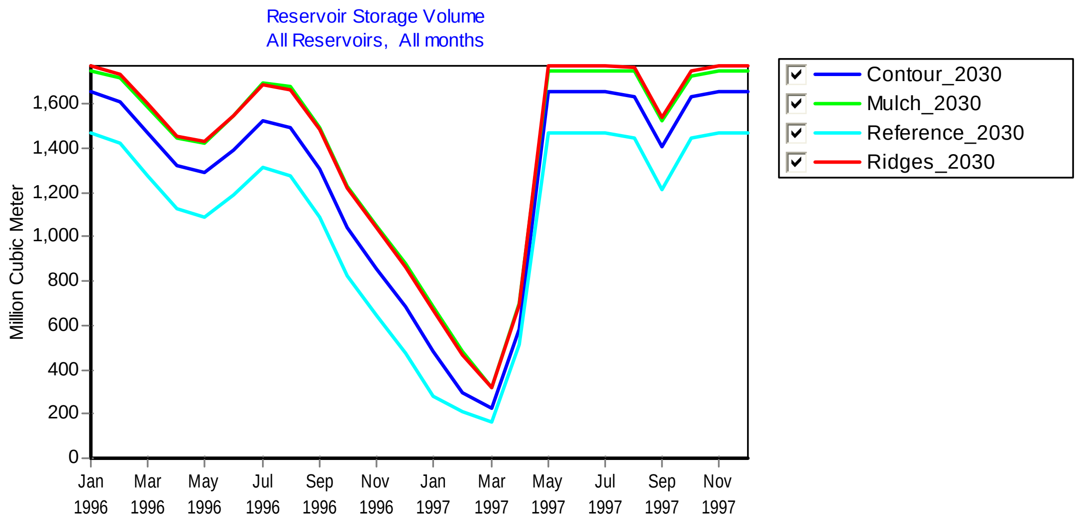
Translating soil loss to a reduction in siltation, reservoir capacity would be reduced from the design level by 500 million m^3 (40 per cent) by 2030 without green water management; the loss of reservoir storage would be much less if green water management practices were implemented. Results of the SWAT analysis are used in WEAP (Table 4) to evaluate four scenarios:

- *Reference 2030:* loss of 40 per cent (20 up till now and a further 20 per cent over the next 20 years)
- *Contour strips:* erosion reduced by 40 per cent, so total loss of capacity by 2030 is 32 per cent (20 + 20 x (1-40%))
- *Mulch:* erosion reduced by 58 per cent, so total loss in 2030 is 28 per cent (20 + 20 x (1-58%))
- *Tied ridges:* erosion reduced by 65 per cent, so total loss in 2030 is 27 per cent (20 + 20 x (1-65%)).

Table 4: Changes in WEAP input to evaluate green water management scenarios

	Reference	*Contour strip*	*Mulch*	*Ridges*
Head flows	no change	+1%	+5%	+3%
Reservoir capacity	60%	68%	72%	73%
Blue water flow	no change	-5%	-12%	-13%

Figure 15 shows WEAP outputs for reservoir storage and un-met water demand, respectively. The positive impacts of green water management are due mainly to reduction of siltation but improved *blue* water flow due to improved groundwater recharge is also significant, especially for mulch (Figure 18).



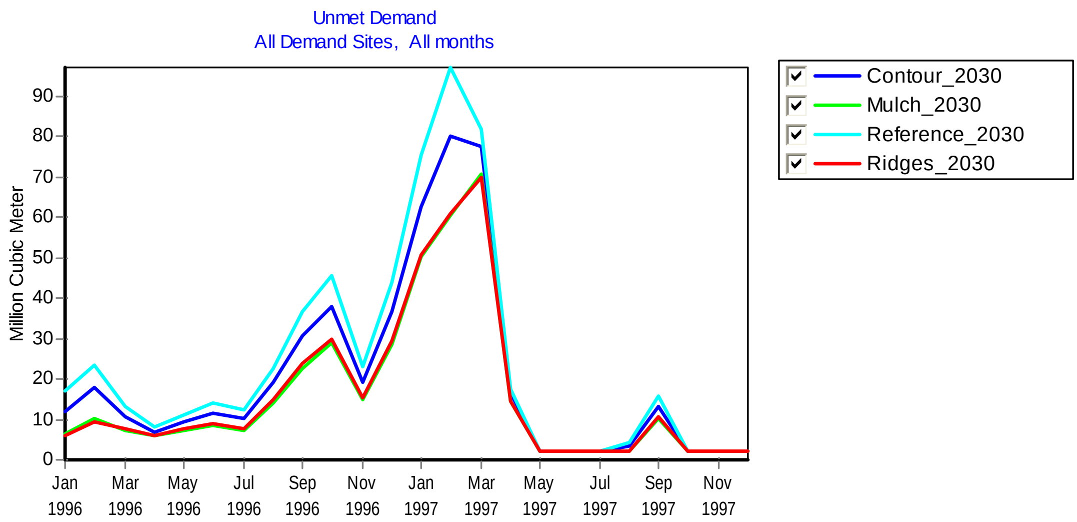


Figure 15: Reservoir storage volumes and un-met demand for different green water management scenarios

The impact of the different scenarios is estimated using key indicators. In Table 5, the first column, *Reference,* is the current situation already described in Section 4.3; scenario *Ref 2030* describes the situation in 2030 at constant prices if no green water management measures are taken - so the capacity of the reservoirs will be reduced by a further 20 per cent; the following three scenarios show the situation in 2030 with green water management measures in place, again assuming constant prices. With green water management, the negative trend will be reversed.

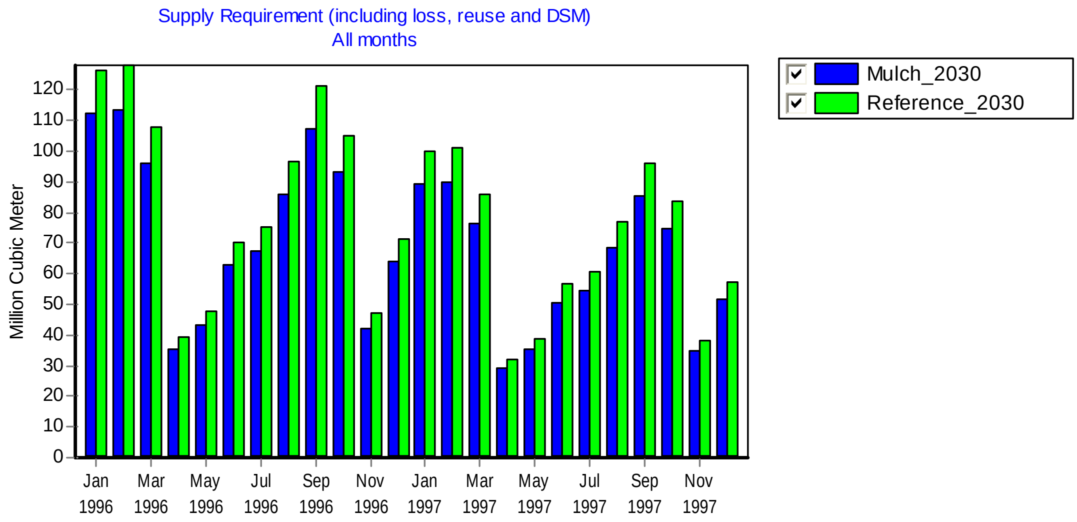


Figure 16: Changes in demand for all irrigation systems for the reference and mulching scenarios

Table 5: Key indicators to evaluate Green Water Credits scenarios

	Reference	*Ref 2030*	*Contour2030*	*Mulch2030*	*Ridges2030*
Un-met demand m^3 million	247	287	244	192	194
Revenues $ million	182	173	179	187	186
Hydro- power $ million	101	97	100	102	102
Irrigation $million	74	69	72	77	77
Urban $million	7	7	7	7	7
Hydro-power kWh million	2556	2453	2513	2580	2567

Table 6 compares the impact of green water management compared with business-as-usual (*Ref 2030)*. Mulching and tied ridges have a substantial positive impact: a decrease in un-met water demand of 33 per cent (Figure 18), increase in hydro-power generation of about 5 per cent, and an increase in gross revenues of as much as $US 14 million per year.

These projections are based on modelling; some of the input data are only best estimates but inaccuracies in the data and model assumptions are reflected in all scenarios, so that relative differences between scenarios are likely to be robust.

Table 6: Impact of green water management compared with business-as-usual

	Contour2030	*Mulch2030*	*Ridges2030*
Un-met demand, m^3million (%)	-43 (-15)	-96 (-33)	-94 (-33)
Revenue, $million (%)	6 (3.6)	14 (7.9)	13 (7.3)
Hydro-power, $million	2 (2.5)	5 (5.2)	4 (4.6)
Irrigation, $million	4 (5.3)	8 (12.3)	8 (11.5)
Urban, $million	0 (1.5)	0 (2.5)	0 (2.4)
Hydro-power, kWhmillion	61 (2.5)	128 (5.2)	114 (4.6)

The above scenarios assume green water management across all cropland in the Upper Tana. This will not happen. Green Water Credits Report 3 (Kauffman and others 2007) also estimated the effects of partial adoption of green water management: as a rule of thumb, implementation over 20 per cent of the area would result in about 50 per cent of the gains. The gain in terms of reduced siltation of reservoirs will be much higher than this if areas adjacent to the waterways are targeted.

Table 7 provides a first estimate of the costs of green water management, taking the area of conservation benefit as the total area under coffee-based and maize-based systems (394 200 ha). Two scenarios are considered: 100 per cent and 20 per cent adoption of green water management. For grassed contour strips, costs are derived from Shiferaw & Holden, 2001 (see Green Water Credits Report 5, Porras and others 2007) using the mean slope of cropland (7-10 per cent), writing off the cost of construction ($8/ha) over 5 years, annual maintenance of $1.5/ha, and assuming that land taken up by the grass strips represents a total loss of production - *which is not necessarily the case*. For tied ridges, an annual cost of $50/ha is applied. For mulching, $25/ha as the cost of bringing and spreading 1-5 tonnes/ha.

Table 7: Annual costs of green water management

	Contour strips 100%	*Tied ridges 100%*	*Mulch 100%*	*Contour strips 20%*	*Tied ridges 20%*	*Mulch 20%*
Area, ha	394 200	394 200	394 200	78 800	78 800	78 800
Construction/ maintenance, $million	1.2	19.7	9.8	0.2	3.9	2.0
Area loss, $million	41.3	nil	nil	8.3	nil	nil
Total, $million	42,5	19.7	9.8	8.5	3.9	2.0

For the 100 per cent-adoption scenario, annual costs are in the range $US 10-42 million: generally greater than the water benefits, except for mulch. Under the 20 per cent-adoption scenario, annual costs will be in the range $US 2-8.5 million, against annual water benefits of the order of $US 3-7 million. These calculations are clouded by the uncertainty about the current costs of green water management under local conditions. However, it appears that the worth of targeted green water management, in terms of water gains alone, can exceed the total cost of the management packages.

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GWC 5	*Farmers' adoption of soil and water conservation: the potential role of payments for watershed services*	Porras I and others 2007
GWC 6	*Political, institutional and financial framework for Green Water Credits in Kenya*	Meijerink G and others 2007
GWC 7	*The spark has jumped the gap. Green Water Credits proof of concept*	Dent DL and JH Kauffman 2007