

Climate Change and Hydropower, Impact and Adaptation Costs: Case Study Kenya

September 2009

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Report FutureWater: 85

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1 Introduction

It is now commonly understood that most climate change damage will be felt in developing countries (e.g. Stern, 2006, IPCC, 2007), with Africa being the continent of most concern. There are several reasons for this: many of the largest changes are projected to occur in African countries; their economies rely more on climate-sensitive activities; many operate close to environmental and climatic tolerance levels; and their ability to adapt may be limited because of technical, economic and institutional limitations (Tol et al, 2004).

In line with this, economic assessments (integrated assessment analysis) identify particularly high economic costs from climate change in Africa (see Downing et al, 2005). Conservative estimates are that African economies could be facing losses of at least 1–2% of GDP, or US\$10–20 billion annually (van Aalst et al, 2007). Evidently some sectors will be much more exposed.

Hydropower will be hit severe by changes in climate given the non-linear nature of rainfall-runoff processes. A 10% reduction in rainfall can easily result in a loss of hydropower generation by 25 to 50%. Simultaneously an increase in temperature of a few degrees might result in substantially higher evapotranspiration having a severe impact on hydropower as well. Finally, increases in year to year climate variability may well lead to a lower energy security in general.

DFID and DANIDA initiated a project entitled “Economic Impacts of Climate Change in Burundi, Kenya and Rwanda” which is executed by an international consortium. Focus of the project will be on the economics of adaptation strategies. FutureWater was asked by SEI-Oxford to perform a rapid assessment on the impact of climate change on hydropower generation in the Tana basin in Kenya using the WEAP (Water Evaluation And Planning tool) approach. Given the limited time to undertake the assessment, this report should be considered as a working paper rather than a full report. The developed WEAP model is available to undertake more detailed and/or additional analysis.



2 WEAP model

2.1 General

WEAP is short for Water Evaluation and Planning System. It is a computer tool for integrated water resources planning. It provides a comprehensive, flexible and user-friendly framework for policy analysis. WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP is a laboratory for examining alternative water development and management strategies (SEI, 2005).

WEAP is operating on the basic principles of a water balance. The analyst represents the system in terms of its various supply sources (e.g. rivers, creeks, groundwater, and reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The data structure and level of detail may be easily customised to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data.

Operating on these basic principles WEAP is applicable to many scales; municipal and agricultural systems, single catchments or complex transboundary river systems. WEAP does not only incorporate water allocation but also water quality and ecosystem preservation modules. This makes the model suitable for simulating many of the fresh water problems that exist in the world nowadays.

WEAP applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The Current Accounts, which can be viewed as a calibration step in the development of an application, provide a snapshot of the actual water demand, pollution loads, resources and supplies for the system. Key assumptions may be built into the Current Accounts to represent policies, costs and factors that affect demand, pollution, supply and hydrology. Scenarios build on the Current Accounts and allow one to explore the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

WEAP calculates a water and pollution mass balance for every node and link in the system. Water is dispatched to meet stream and consumptive requirements, subject to demand priorities, supply preferences, mass balance and other constraints. Point loads of pollution into receiving bodies of water are computed, and stream concentrations of polluting elements are calculated.

WEAP operates on a monthly time step, from the first month of the Current Accounts year through the last month of the last scenario year. Each month is independent of the previous month, except for reservoir and aquifer storage. Thus, all of the water entering the system in a month (e.g. head flow, groundwater recharge, or runoff into reaches) is either stored in an aquifer or reservoir, or leaves the system by the end of the month (e.g. outflow from end of river, demand site consumption, reservoir or river reach evaporation, transmission and return flow link losses). Because the time scale is relatively long (monthly), all flows are assumed to occur instantaneously. Thus, a demand site can withdraw water from the river, consume some, return the rest to a wastewater treatment plant that treats it and returns it to the river. This return flow is available for use in the same month to downstream demands (SEI, 2005).



Each month the calculations (algorithms) follow this order (SEI, 2005):

1. Annual demand and monthly supply requirements for each demand site and flow requirement.
2. Runoff and infiltration from catchments, assuming no irrigation inflow (yet).
3. Inflows and outflows of water for every node and link in the system. This includes calculating withdrawals from supply sources to meet demand, and dispatching reservoirs. This step is solved by a linear program (LP), which attempts to optimise coverage of demand site and instream flow requirements, subject to demand priorities, supply preferences, mass balance and other constraints.
4. Pollution generation by demand sites, flows and treatment of pollutants, and loadings on receiving bodies, concentrations in rivers.
5. Hydropower generation.
6. Capital and operating costs and revenues.

Further details about WEAP are beyond the scope of this report, but can be found in various literature, and especially on the WEAP website and manuals (<http://www.weap21.org/>). Details how WEAP compares to other modeling tools has been described elsewhere (Droogers et al., 2006a)

2.2 Previous WEAP Tana models

Two WEAP models were developed over the last years for Tana. The first one was constructed in the context of the Green Water Credits project and is described by Hoff et al. (2007) and Droogers et al. (2007).

Based on this earlier version a revised version of the WEAP model was developed putting more emphasize on water demand from irrigation and urban water supply (Petz and Minca, 2008).

However, both WEAP models focused on the demand site only, while water resources originated from the hydrological model SWAT (Kauffman, et al, 2007; Droogers, et al. 2006). Although it is widely acknowledged that SWAT performs better to simulate the entire hydrological cycle, it has weaknesses in hydropower generation and lacks an economic evaluation. Moreover, a very user-friendly and comprehensive scenario analysis options is one of the main strengths of WEAP. It was therefore decided to reconstruct the original WEAP-Tana model to include water resources processes as well.

2.3 WEAP Tana

2.3.1 Setting up model

The basis for the new WEAP model is the catchment approach. The Upper and Middle Tana basin (up to the proposed location of the Fourth-Fork dam) have been divided into nine catchments (Figure 1). Each catchment provides water resources through a rainfall-runoff process. These catchments are similar to the delineation used by the Kenyan Ministry of Water and Irrigation and the Tana Water Resources Management Authority (WRMA). A screenshot of the updated model can be seen in Figure 2.

For each Catchment the most important characteristics included are:



- Total area in ha
- Land cover in percentage for:
 - Forest
 - Agriculture rainfed
 - Coffee
 - Tea
 - Irrigated agriculture
 - Rangeland
 - Open water
- Land cover characteristics
 - Crop coefficient
 - Effective precipitation
- Climate
 - Precipitation
 - Potential evapotranspiration

Other important features included in the model are:

- Towns
 - Population
 - Water requirements
 - Water return flows
- Reservoirs
 - Storage capacity
 - Hydropower generation
 - Cost / benefit hydropower

A detailed description of the value of each of these variables has been included in the Appendix.

With this setup the WEAP model can be used as an integrated framework including water supply, water demand and hydropower cost/benefit analysis. It should be emphasized that this is a significant extension of the two previous WEAP-Tana models. First of all water supply is now included in an integrated way so that changes in climate, land cover, or land/farm management can be analyzed directly without the need to obtain this information from other models/sources. Secondly, cost and benefits of hydropower will directly depend on changes (scenarios) that are analyzed.

The developed model is available to be used for further applications and/or further refinements.



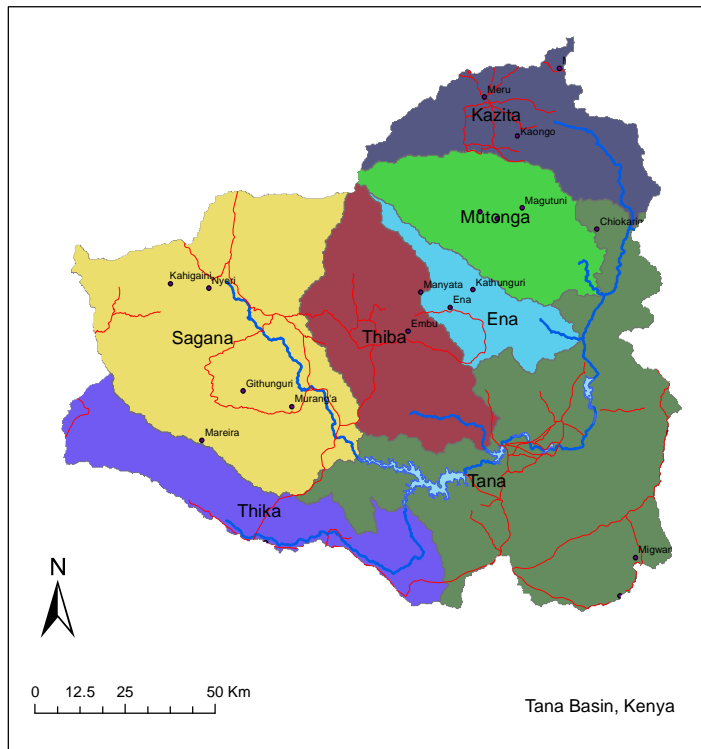


Figure 1. Upper Tana catchments.

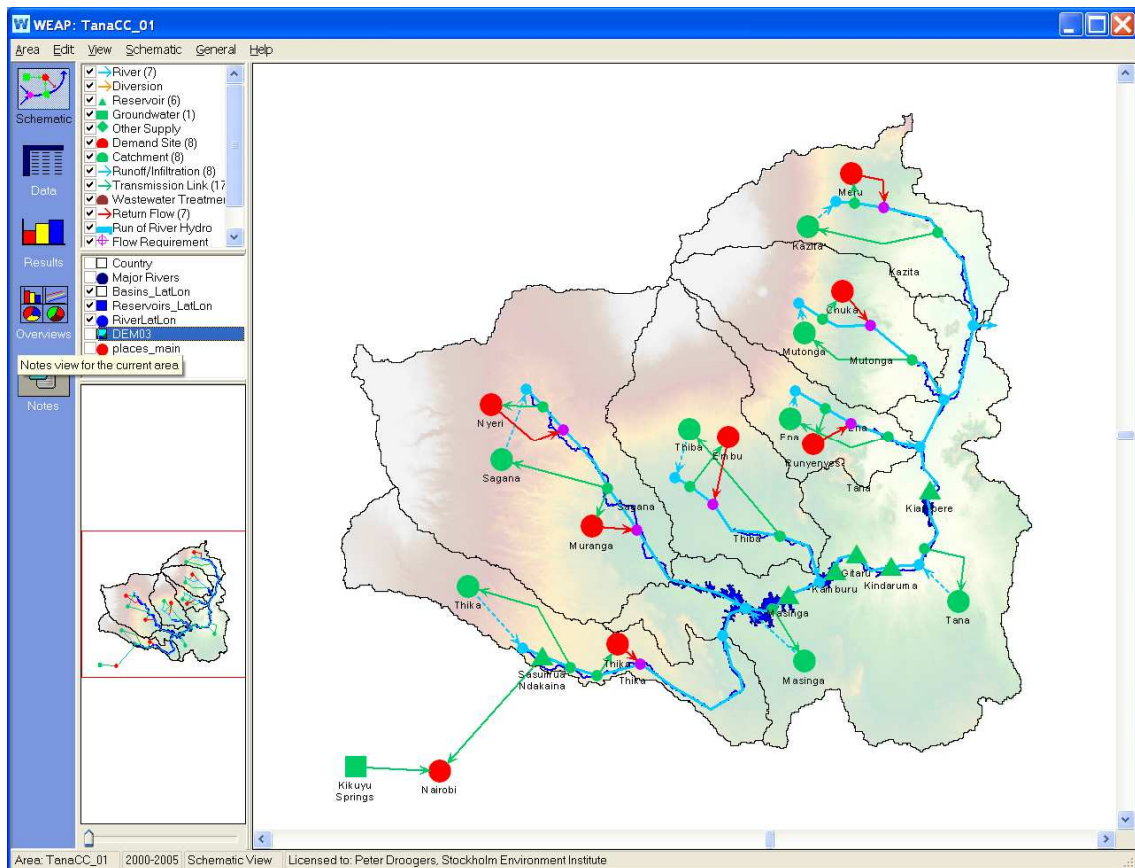


Figure 2. Overview of the newly developed WEAP model.



2.3.2 Calibration and validation of model

Observed and simulated inflows into the Masinga Reservoir are plotted in Figure 3. Based on this figure it can be concluded that the model is performing very well in simulating streamflow. Observed annual average inflow into Masinga is 2131 MCM over these five years, while simulated inflow is 2189 MCM.

For the five main reservoirs in the area observed outflows were available and were compared with simulated ones. Table 1 indicates that simulated outflows from the five reservoirs match reasonable well the observed ones for the years 2001 to 2004. For the years 2002 and 2003 simulated outflows are slightly higher than observed ones. The main reason for this are two peak runoff events (Figure 4) for Kindaruma Reservoir. It is not completely clear what the reason for this mismatch is. Rainfall might be incorrect, but given the correct simulation of inflow into Masinga (Figure 3) this is unlikely. Given the fact that in WEAP rainfall-runoff processes are conceptual defined rather than physical, this might cause some errors. However, for most other months the model is performing very well. Another explanation might be that observations on outflow of the reservoirs do not include flows over the spill-way. In many reservoirs only water through the turbines is monitored and spill-way flows are often not monitored or recorded (This argument is confirmed when comparing with the recorded and simulated hydropower generation, see hereafter).

A last validation of the model performance is done by comparing reported hydropower generation to simulated hydropower by WEAP (Figure 5). It is surprising how close these two are if one considers the many factors that determine hydropower generation such as: discharge, rating characteristics, minimum and maximum turbine flow, tailwater elevation, plant factor, etc.

Obviously, further calibration/validation could be performed to increase the accuracy of the model within the range of limitations given the conceptual nature of WEAP. However, based on the various comparisons between observed and simulated data as presented here, it can be concluded that the model is performing very well and can be used to undertake scenario analysis. Moreover, in the context of scenario analysis one should realize that relative accuracy of models is more important than absolute accuracy (Droogers et al. 2008).

Table 1. Observed and simulated outflows for the main reservoirs in Tana Basin.

OUTFLOW	MCM	MCM
Masinga	Observed	Simulated
2001	1012	924
2002	2031	2561
2003	2909	3447
2004	1892	1709
Kamburu		
2001	1438	1395
2002	2804	3521
2003	3619	4381
2004	2247	1891
Gitaru		
2001	1530	1382
2002	2888	3518
2003	3576	4386
2004	2151	1892
Kindaruma		



2001	1366	1370
2002	2688	3514
2003	3336	4391
2004	2157	1893
Kiambere		
2001	1283	1564
2002	3101	4479
2003	3754	5593
2004	2436	2425

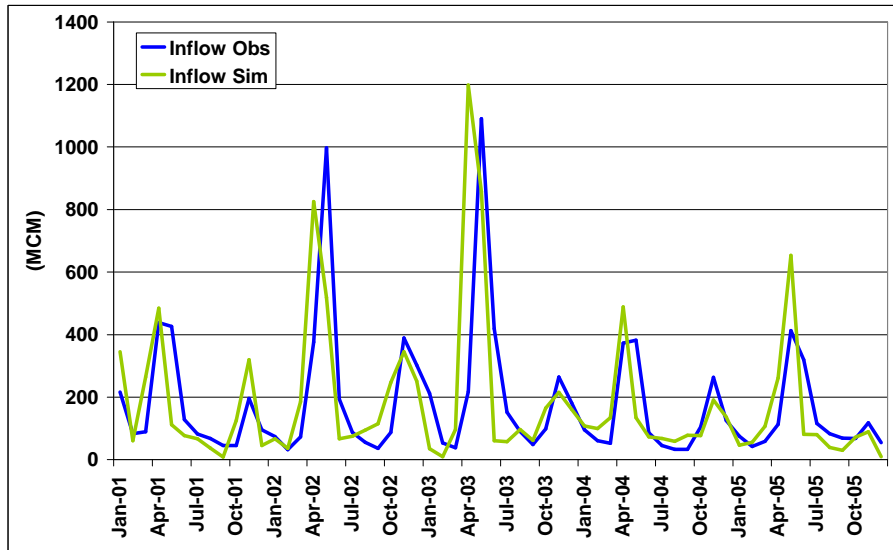


Figure 3. Observed and simulated inflow in Masinga Reservoir.

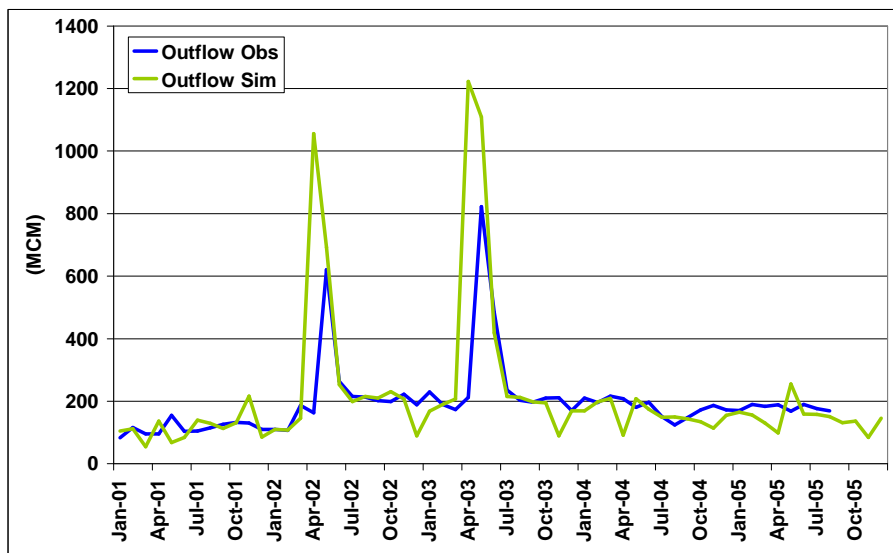


Figure 4. Observed and simulated outflow for Kindaruma Reservoir.



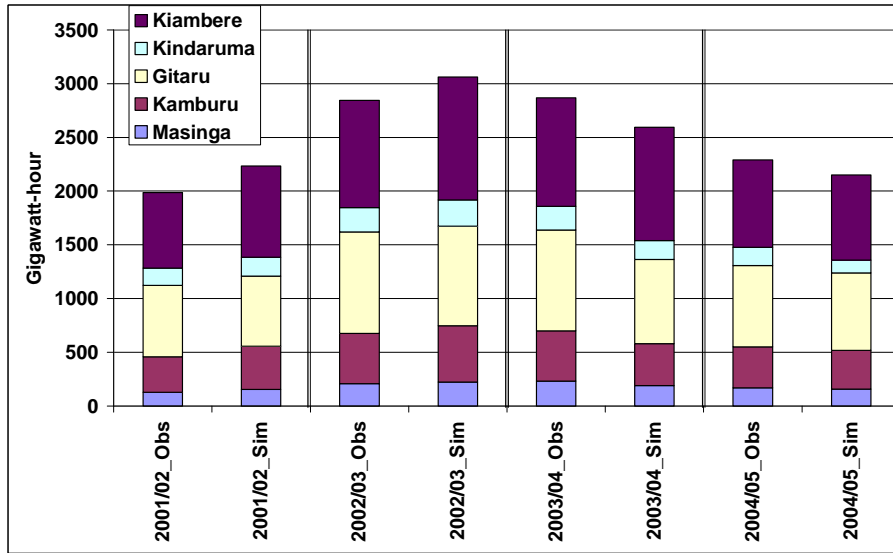


Figure 5. Reported and simulated hydropower generation.



3 Projections and Scenarios

3.1 General

The main reason to apply models is their ability to explore different scenarios. These scenarios can capture aspects that cannot directly be influenced, such as population growth and climate change (Droogers and Aerts, 2005). These are often referred to as projections. Contrary to this are the adaptation measures (or management scenarios or interventions) where water managers and policy makers can make decisions that will have a direct impact. Examples are changes in reservoir operation rules, water allocation between sectors, investment in infrastructure such as water treatment or desalinization plants, and agricultural/irrigation practices. In other words: models enable to change focus from a re-active towards a pro-active approach (Figure 6).

The so-called robust decision making (RDM) process to support policy making has been advocated recently (weAdapt, 2009). In the context of this study it was selected to explore a limited set of adaptation strategies, based on two climate change projections. The developed model can be used subsequently in a RDM process, or, given the strength of WEAP, in an interactive stakeholder setting. The latter can be performed easily as scenario analysis in WEAP can be performed on the fly.

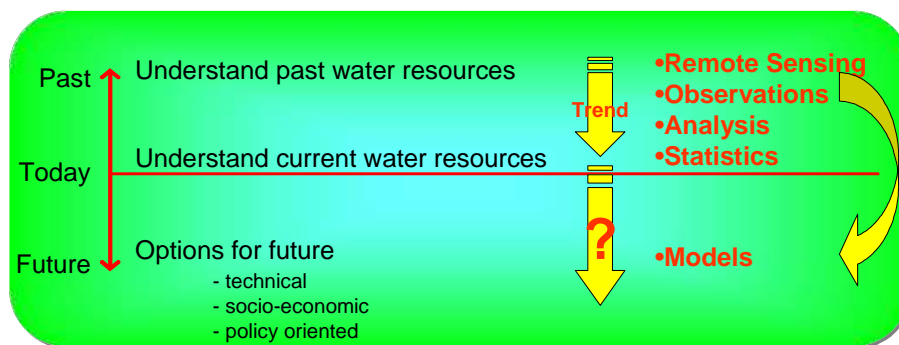


Figure 6. The concept of using simulation models in scenario analysis (source: Droogers and Perry, 2008).

3.2 Climate change scenarios

For this specific project climate projections are derived from the Climate Change Explorer (http://wikiadapt.org/index.php?title=The_Climate_Change_Explorer_Tool). Projections for the period 2045-2065 in minimum temperature, maximum temperature and precipitation for the station Meru have been used to correct the model meteorological input. Projections were extracted for the following nine GCMs:

- cccma_cgcm3_1; Canadian Centre for Climate Modeling and Analysis, the third generation coupled global climate model (CGCM3.1 Model, T47).
- cnrm_cm3; Meteo-France, Centre National de Recherches Meteorologiques, the third version of the ocean-atmosphere model (CM3 Model)
- csiro_mk3_5; CSIRO Atmospheric Research, Australia, MK3.5 Model
- gfdl_cm2_0; NOAA Geophysical Fluid Dynamics Laboratory, CM2.0 coupled climate model
- giss_model_e_r; NASA Goddard Institute for Space Studies, Model E20/Russell.



- ipsl_cm4; IPSL/LMD/LSCE, France, CM4V1 Model
- miub_echo_g; Meteorological Institute of the University of Bonn (Germany), Institute of KMA (Korea), and Model and Data Group. ECHO-G model
- mpi_echam5; Max Planck Institute for Meteorology, Germany, ECHAM5 / MPI OM
- mri_cgcm2_3_2a; Meteorological Research Institute, Japan Meteorological Agency, Japan, MRI-CGCM2.3.2a model

For each month the lowest (less extreme) and highest (most extreme) projections of those nine GCMs have been determined (Figure 8 and Figure 7). Based on this, two climate projections were constructed. The first one will be referred to as “low” and consists out of the lowest increase in temperature and the highest increase in precipitation. The second one, referred to as “high”, includes the highest increase in temperature and the highest decrease in precipitation.

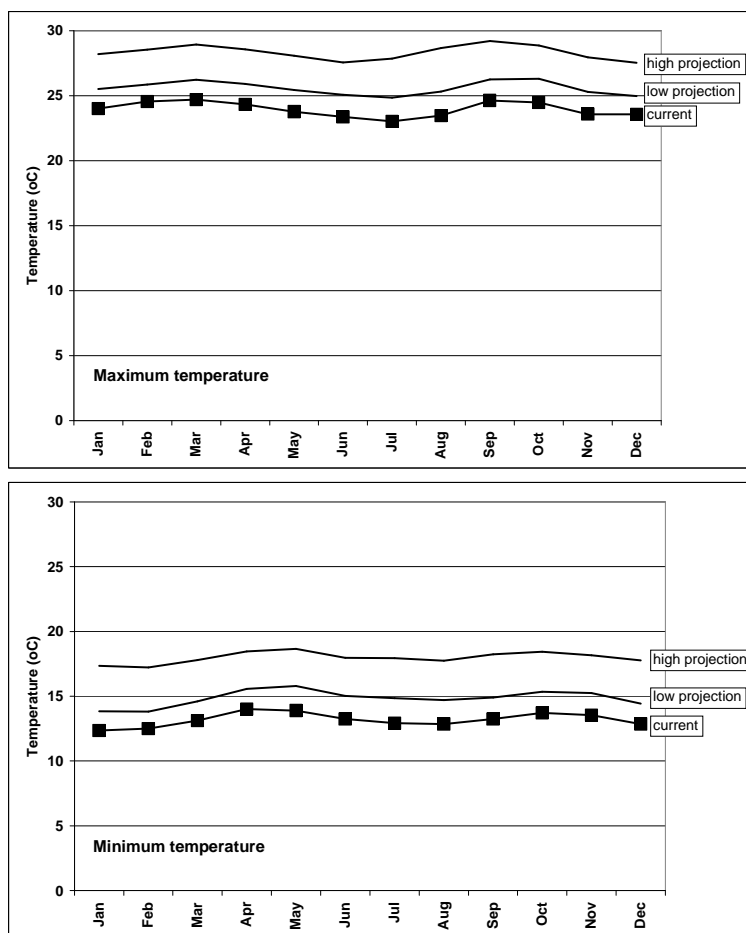


Figure 7. Projections for temperature for the 2045-2065 (in oC) based on nine GCMs.



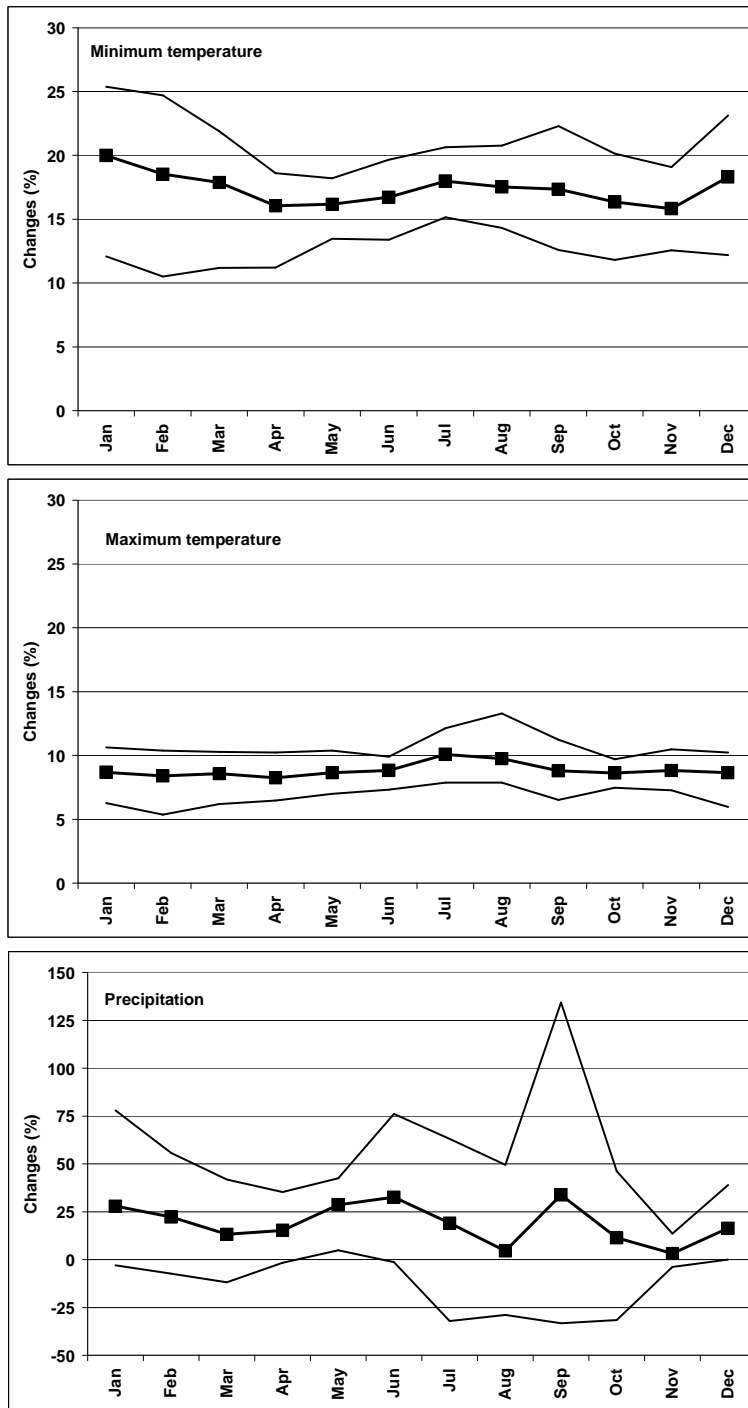


Figure 8. Projections for temperature and precipitation change for 2045-2065 (in %). Lines indicate the minimum, maximum and average changes based on nine GCMs.

3.3 Socio/economic scenarios

Besides these changes in climate the following two projections were included in the model as well for the period around 2050:

- Increase in population by 20%
- Reduction of reservoir capacity by 30% due to siltation

Population growth has been estimated based on the following references:



- Population in 2050 will be between 44 million and 80 million, depending on the success of family planning services and HIV/AIDS programs (Porritt, 2008)
- Depending on the focus on family planning, the projected population in 2050 will be between 54 million and 83 million (Allbäck, 2009)
- Population Keya: 35 million 2005; 65 million 2050 (IDB, 2009)

Siltation of reservoirs has been estimated based on:

- Loss of reservoir capacity between 2000 and 2030: 20% (Hoff et al., 2007)

3.4 Adaptation strategies

A coherent set of four adaptation strategies have been defined to be evaluated:

- 1) Demand-side management: e.g. improved irrigation and other end-use efficiency improvements across demand nodes
- 2) Supply-side management: e.g. application of water harvesting technologies to mitigate over-abstraction, or perhaps "harder" options such as reservoir construction.
- 3) Ecosystem protection: e.g. sustainable land management (SLM) interventions in upstream agriculture to reduce soil erosion and dam siltation, improve electricity production efficiency, etc.
- 4) "Full sectoral protection": Implementing all of the above activities in the basin.

Within WEAP these scenarios are implemented in the model by the following parameters:

1) Demand-side management is implemented by:

- Improved irrigation is implemented in the model by changing the crop coefficient K_c for irrigation from 1.3 to 1.1. This implies a reduction in water requirements while maintaining the same crop yield. In practice this can be achieved by a reduction in non-beneficial soil and open water evaporation and/or changing to improved crop varieties.
- Improved urban water consumption by reducing the water supply from 14 m³ per capita per year to 10 m³ and by increasing the consumption from 30% to 40%.

2) Supply-side management is implemented by:

- Assuming a higher water storage capacity. In the model this is achieved by assuming an increase in storage capacity of the reservoirs by 50%. In practice this can be achieved by a set of measures including constructing additional reservoirs (Four Lakes), improved management of groundwater resources, and/or expanding current reservoir storage capacity.

3) Ecosystem protection is implemented by:

- Erosion control so that siltation of reservoirs will be reduced from the current 30% in 2050 to only 10%. In practice this can be achieved by various sets of interventions such as mulching, contour tillage, terracing, contour strips and ridges.
- Improved rainfed agriculture by increasing the effective use of precipitation from 65% to 75% and at the same time reduce non-beneficial evaporation by changing the crop coefficient K_c from 0.9 to 0.8. This implies a reduction in water requirements while maintaining the same crop yield. In practice this can be achieved by a reduction in non-beneficial soil and open water evaporation and/or changing to improved crop varieties.

4) Full adaptation is implemented by:

- The combination of the previous three adaptation strategies.



Figure 9 shows how these two projections and the four adaptation strategies are included in the WEAP model.

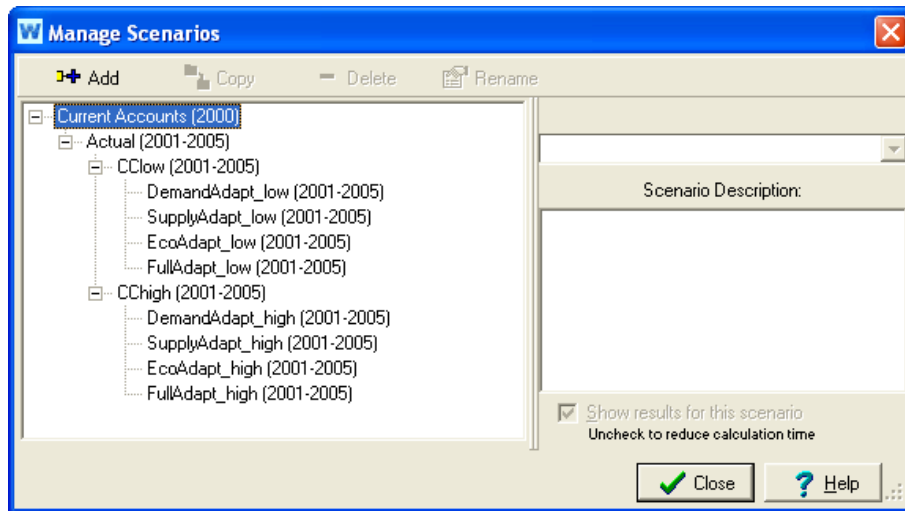


Figure 9. Management of scenarios in WEAP.



4.1 Introduction

The model as developed and presented in Chapter 2 and the projections and adaptation strategies as described in Chapter 3 will result in the following eleven cases:

1. Current, the situation as described by the years 2001-2005
2. Impact low and no adaptation. Lowest projected increase in temperature and highest projected increase in precipitation. This is described for a five years period around year 2050.
3. Impact high and no adaptation. Highest projected increase in temperature and highest projected decrease in precipitation. This is described for a five years period around year 2050.
4. Demand-side adaptation for CClow
5. Supply-side adaptation for CClow
6. Ecosystem adaptation for CClow
7. Full adaptation for CClow
8. Demand-side adaptation for CChigh
9. Supply-side adaptation for CChigh
10. Ecosystem adaptation for CChigh
11. Full adaptation for CChigh

Each of these 11 sets was evaluated using a five years period to ensure that natural changes in year-to-year weather conditions are also included. Also, an initial year was simulated before this period of five years to ensure that initial conditions are realistic. This approach is often referred to as a “warming-up” year for the model. For the current situation actual conditions of the years 2001 to 2005 were used. For the climate change projections these five years were used again, but now altered using the projections as described in the previous chapter.

In order to evaluate the impact of these projections and adaptation measures a set of indicators have been defined:

- Hydropower generation
- Irrigation water shortage
- Rainfed agriculture shortage
- Urban water shortage

Output capabilities of the WEAP model are virtually unlimited. Output can be provided as graphs, tables and maps. In this report only some of the key output components of the model will be shown, while the model itself is available to undertake a more in-depth exploration.

4.2 Impact of Climate Change

The projected changes in climate, population and siltation of reservoirs are imposed on the model, assuming no adaptation will take place. A first rough estimate of the financial consequences has been made as well, based on the following assumptions:

- Changes in hydropower generation using a fixed revenue price of US\$0.04 per kWh (KenGen, 2009)
- Costs of unmet urban water supply at a fixed price of US\$ 0.25 per m³. (Costs vary between 0.19 and 0.44 US\$ / m³, Porras 2001)



- Costs of unmet irrigation water supply at a fixed price of US\$ 0.10 per m³. (Average water productivity, Zwart 2004).

Some important output of the impact of climate change will be presented here for the low projection and the high projection bullet-wise:

- Water demand, defined as the total water that should be abstracted from a source, will increase between 15% and 28% for the low and high projection, respectively. In the current situation water demand is on average 684 MCM per year, for the low and high projection this will be 781 and 873 MCM.
- The major water demander is the irrigation sector, while urban demand is relatively low in comparison (Figure 10).
- Total demand from natural surfaces (evapotranspiration) is substantially higher compared to the need for domestic and irrigation (Figure 11). This total demand will increase by 11% to 22% for the low and high projection, respectively.
- Average hydropower generation will reduce substantially from 2,253 Gigawatt-Hour per year to levels between 1763 and 2144 GWhr / yr.
- Average revenues from hydropower electricity are currently US\$ 90 million per year. Under climate change this will reduce to revenues between US\$86 and US\$71 million for the low and high projection, respectively. In percentages this translates to a reduction between 5 and 22%.

The overall impact of the two climate change projections using the performance indicators is presented in Table 2. For the low projection (= lowest increase in temperature and highest increase in precipitation) climate change will have a modest positive impact. Unmet demand for urban and irrigation is somewhat lower and hydropower generation is only slightly lower, leading to a small positive impact at an overall value of about US\$ 2 million. However, the high projection is having a very negative impact with increasing water shortages for urban and irrigation and a substantial loss in hydropower.

Table 2. Impact of the two climate change scenarios, assuming no adaptation measure will be taken.

	Actual	CCLow	CChigh
Hydropower (GWh)	2,253	2,144	1,763
Unmet urban (MCM)	207	190	340
Unmet irrigation (MCM)	195	177	323
Hydropower (million \$)	90	86	71
Unmet urban (million \$)	-52	-48	-85
Unmet irrigation (million \$)	-19	-18	-32
Impact climate change (m \$)		2	-66



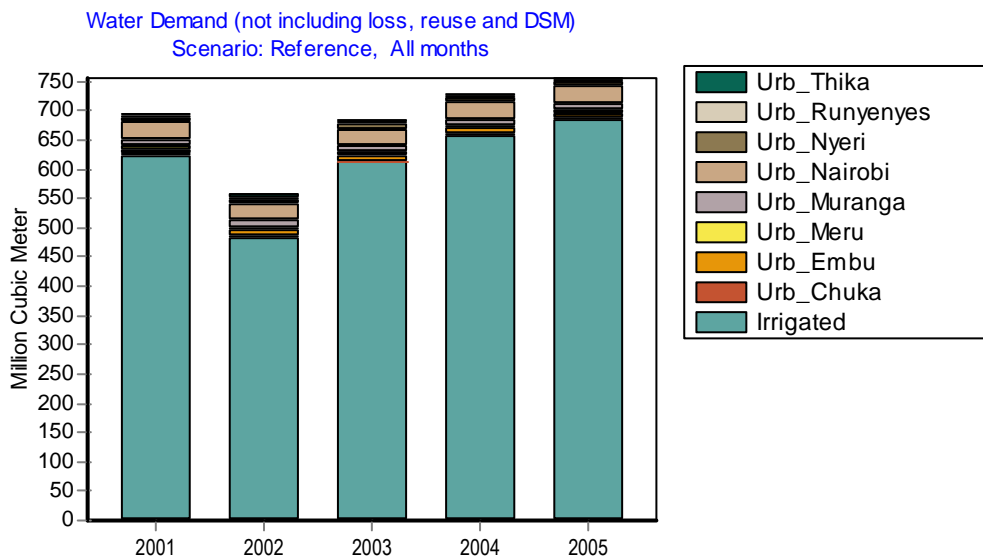


Figure 10. Water demand for domestic and irrigated agriculture for the current situation.
Note: The scenario years should be read as five random years around 2050.

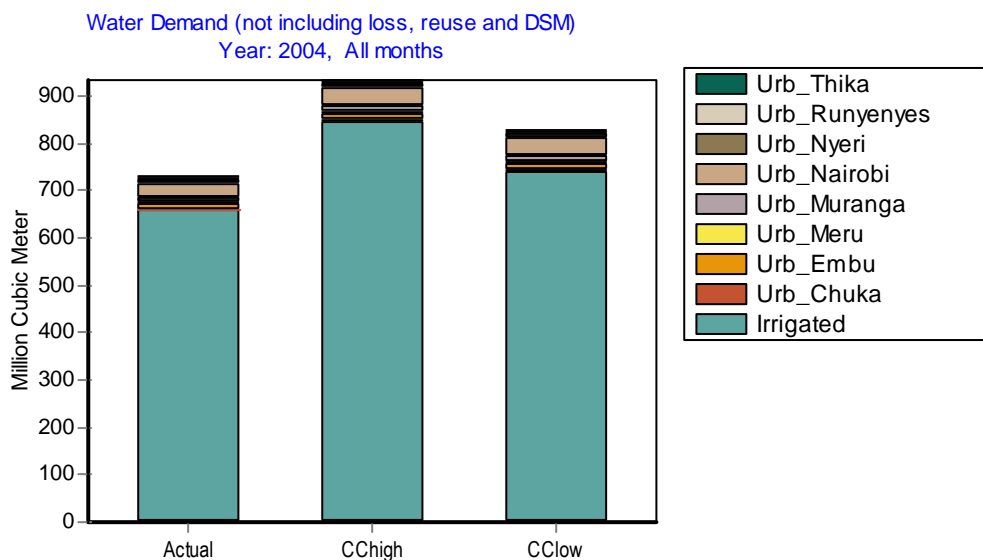


Figure 11. Changes in water demand for domestic and irrigated agriculture for the current situation and the two projections around 2050.

Note: Figure is based on data for one representative year (2004).



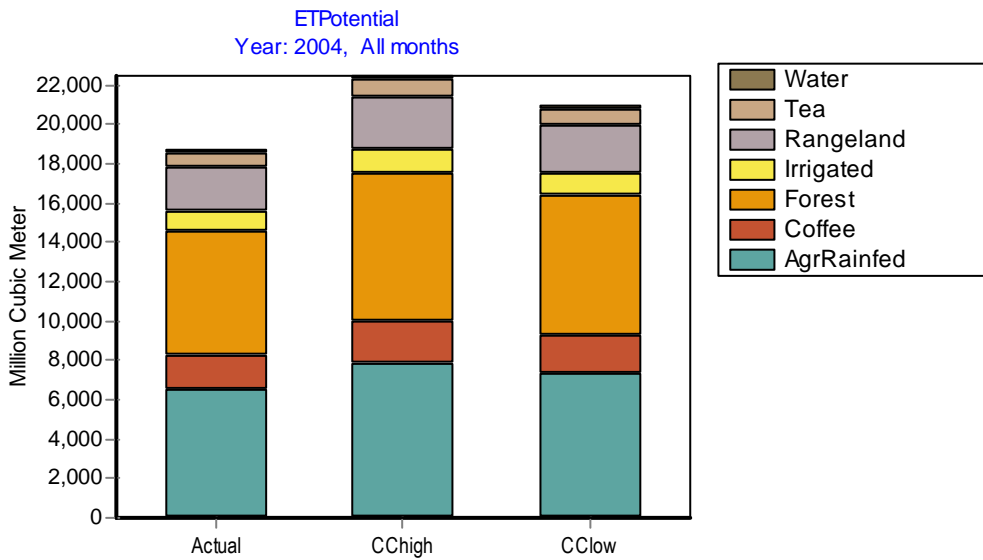


Figure 12. Water demand for land for the current situation and the two projections around 2050.

Note: Figure is based on data for one representative year (2004).

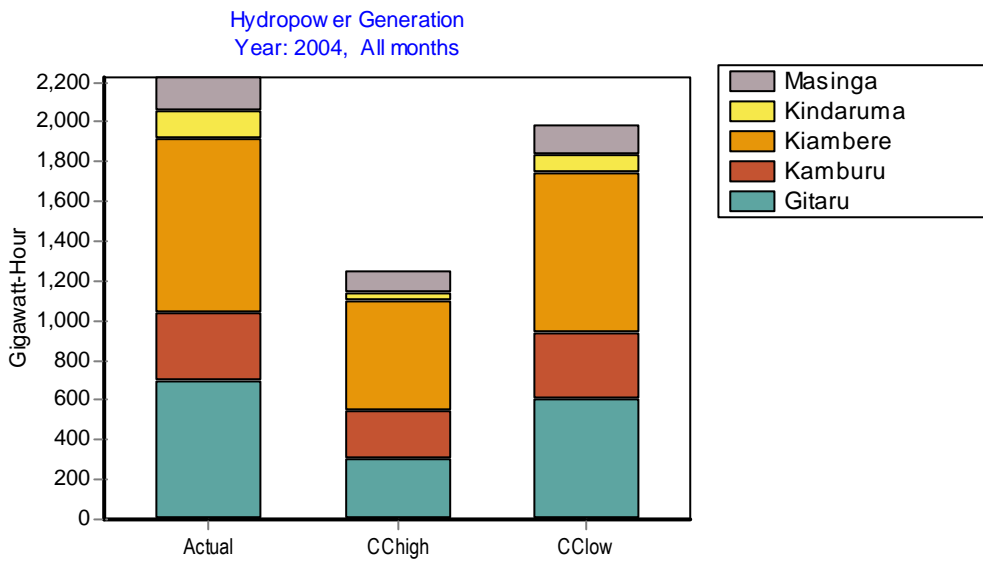


Figure 13. Hydropower generation for the current situation and the two projections around 2050.

Note: Figure is based on data for one representative year (2004).

4.3 Costs of adaptation

A rough estimate of costs of the various adaptation measures has been made. An overview is shown in Table 3. This table was created based on the following assumptions (Dent and Kauffman, 2007):



- Costs of improving the irrigated agriculture (such as reduction of non-beneficial soil evaporation, changing to improved crop varieties, farmer education) is roughly estimated at US\$ 500 per ha.
- Improving urban water supply is estimated at US\$ 10 per capita.
- Costs of expanding water storage by constructing new reservoirs are difficult to estimate. In general, investment costs are between US\$ 1 million and US\$ 5 million per MCM, although this is very location specific. Desiltation of reservoirs might be a factor 10 to 20 cheaper. For this specific study we assume a mixture of new reservoirs and desiltation with average costs of US\$ 0.5 million per MCM.
- Erosion control is estimated to cost about US\$ 50 per ha.

Table 3. Estimated costs of adaptation strategies.

Adaptation costs	Unit	Unit costs	mUS\$	
			Total	Per year
Irrigation	71,295 ha	500	35.6	3.6
Urban Supply	2.10E+06 capita	10	21.0	2.1
Supply	1,167 MCM	500,000	583.5	19.5
Erosion control	677,455 ha	50	33.9	3.4

4.4 Adaptation

The previous sections describe the impact of the two climate change projections for the period around the year 2050. Based on the analysis it was concluded that the lowest projection has an overall small positive impact and the highest projection a substantial negative impact. Policy makers are now confronted whether and which adaptation measures should be considered.

One could argue that since the low climate change projection has no negative impact adaptation measures are not required. However, since the low projection provides additional opportunities (more rainfall) it would nevertheless be interesting to explore adaptation strategies as well to see how this additional water can be fully exploited.

As typical output of WEAP hydropower generation is plotted in Figure 14 and Figure 15, for the low and the high climate change projection, respectively. For the low projection slightly less electricity is produced under climate change. Although rainfall is higher, evapotranspiration is even higher, leading to a slightly lower inflow into the reservoirs. However, two adaptation strategies, supply-side and full adaptation, can generate even more electricity compared to the current situation. For the more extreme climate change projection impact on generated hydropower is severe and electricity production is expected to reduce substantially (Figure 15), but again appropriate adaptation strategies might overcome this negative impact.

However, adaptation strategies have a cost and the main question is whether adaptation should be considered. Table 4 summarizes the impact of the four adaptation strategies (compared to the no adaptation in the first column) and costs associated to implement the given adaptation. Implementation of, for example, the demand-side adaptation will have a positive impact of about US\$ 17 million. Costs of implementing this adaptation are estimated at about US\$ 6 million so one could conclude that this adaptation strategy is feasible to implement. Costs of the other three adaptation strategies are higher than the expected benefits and are therefore not recommended. There are also non-economic considerations such as for example poverty alleviation, that may justify implementation of these adaptation strategies as well.



However, for other non-market benefits that aren't captured here such an adaptation strategy might be considered.

If we consider the high climate change projection (Table 5) all four adaptation strategies are cost effective, e.g. the adaptation costs are lower than benefits after implementing the adaptation. Especially the demand-side and the full adaptation strategies are interesting options to consider.

Based on these results policy makers are confronted with uncertainty in the climate change projections and therefore in actions to be taken. In fact one could follow two approaches. The first one, sometimes referred to as "no-regret" approach, makes it clear that demand-side adaptation strategies are always attractive even if climate change will develop along the least extreme projections. On the other hand, if climate change will be more severe, negative impact will be substantial and one could argue that all possible measures should be implemented to reverse this trend.

Table 4. Four adaptation strategies imposed on the low climate change projection.

	CClow	Demand	Supply	Ecosystem	Full
Hydropower (GWh)	2,144	2,179	2,319	2,237	2,334
Unmet urban (MCM)	190	146	190	200	154
Unmet irrigation (MCM)	177	136	177	185	143
Hydropower (million \$)	86	87	93	89	93
Unmet urban (million \$)	-48	-36	-48	-50	-38
Unmet irrigation (million \$)	-18	-14	-18	-19	-14
Impact adaptation (m \$)		17	7	0	20
Adaptation costs (m \$)		-6	-19	-3	-29
Benefits of adaptation (m \$)		11	-12	-3	-9

Table 5. Four adaptation strategies imposed on the high climate change projection.

	CChigh	Demand	Supply	Ecosystem	Full
Hydropower (GWh)	1,763	1,843	2,197	1,935	2,231
Unmet urban (MCM)	340	248	297	328	238
Unmet irrigation (MCM)	323	237	280	310	225
Hydropower (million \$)	71	74	88	77	89
Unmet urban (million \$)	-85	-62	-74	-82	-59
Unmet irrigation (million \$)	-32	-24	-28	-31	-23
Impact adaptation (m \$)		35	32	11	54
Adaptation costs (m \$)		-6	-19	-3	-29
Benefits of adaptation (m \$)		29	13	8	25



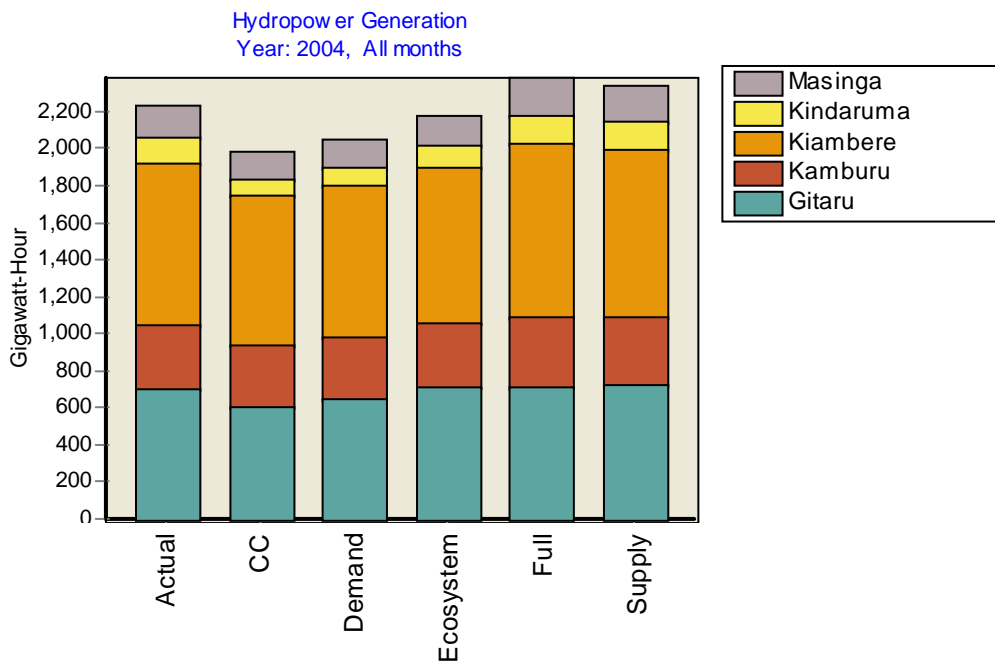


Figure 14. Hydropower generation for the current situation and the low climate change projections as well as the four adaptation strategies.

Note: Figure is based on data for one representative year (2004).

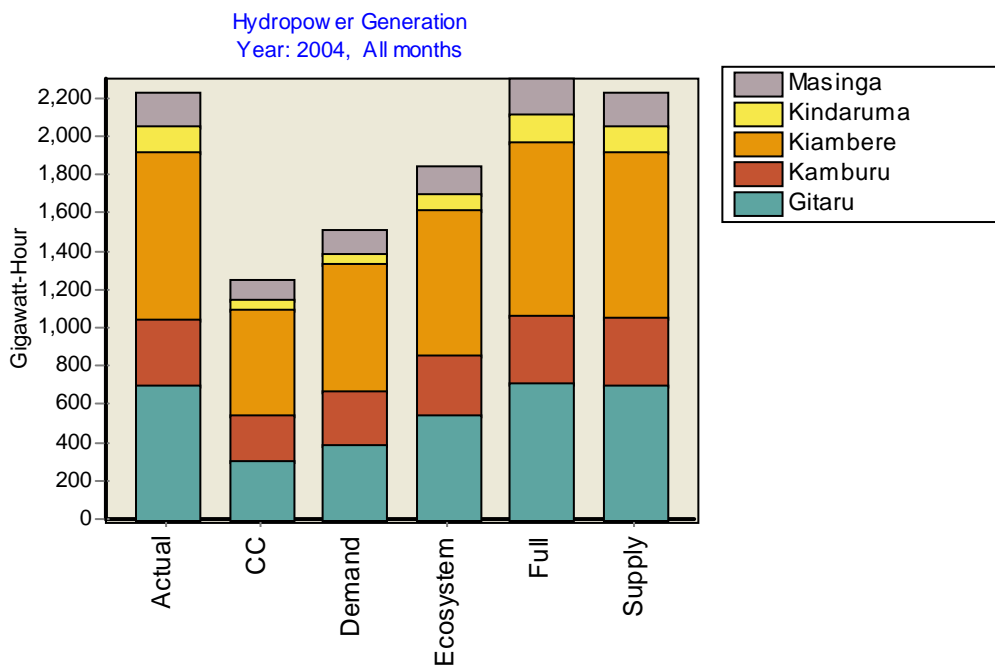


Figure 15. Hydropower generation for the current situation and the high climate change projections as well as the four adaptation strategies.

Note: Figure is based on data for one representative year (2004).



5 Conclusions / Recommendations

The overall objective of the study was to undertake a rapid assessment on the impact of climate change on hydropower generation in Tana basin in Kenya using the WEAP (Water Evaluation And Planning tool) approach.

In the context of this study a limited set of two climate change projections and four adaptation strategies were evaluated, leading to a total of 11 combinations to be evaluated and compared. The developed approach can be used subsequently in a RDM (robust decision making) process, or, given the strength of WEAP, in an interactive stakeholder setting.

The approach applied here to use a minimum and maximum climate change projection, provide decision makers with a range of options on which policies should be developed. The analysis showed that the impact of climate change without any adaptation strategies ranges from a positive US\$ 2 million to a cost of US\$ 66 million for the hydropower, irrigation and drinking water sector.

Taking into account the costs and benefits of adaptation strategies the so-called demand-side measures are always positive ranging from US\$ 11 million to US\$ 29 million for the low and high climate projection, respectively. The supply-side and ecosystem adaptations are only profitable if the climate will evolve in the direction of the high projection.

The study as presented can be further refined:

- The WEAP model is developed as a scenario-based interactive tool. In a stakeholder setting additional adaptation strategies and/or refined assumptions can be discussed.
- The following refinement in the model itself can be considered: (i) inclusion of groundwater, (ii) profits from rainfed agriculture, (iii) profits from grasslands and forests, and (iv) inclusion of livestock water requirements.
- Results presented here reflect the situation around the year 2050, using the natural variation in climate of five years. This could be expanded to 30 years to be able to provide confidence intervals on the results.



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7 Appendix: Model input

In this appendix some notes regarding input data of WEAP will be discussed.

7.1 Hydropower

Revenues US\$ 0.04 /kWh. KenGen annual report 2005.

7.2 Rainfall

Daily estimates of rainfall at a high spatial temporal resolution were obtained from FEWS-PRECIP. FEWS (Famine Early Warning System Network) information is an operational product released by the Climate Prediction Center (CPC) for the United States Agency for International Development (USAID).

Although the excellent spatial resolution (0.1 degree ~ 10 km) and the one day temporal resolution total annual observations are systematically 25 to 30% lower than ground station records (Hunink et al., 2009). Therefore, precipitation records from FEWS were multiplied by 1.3.

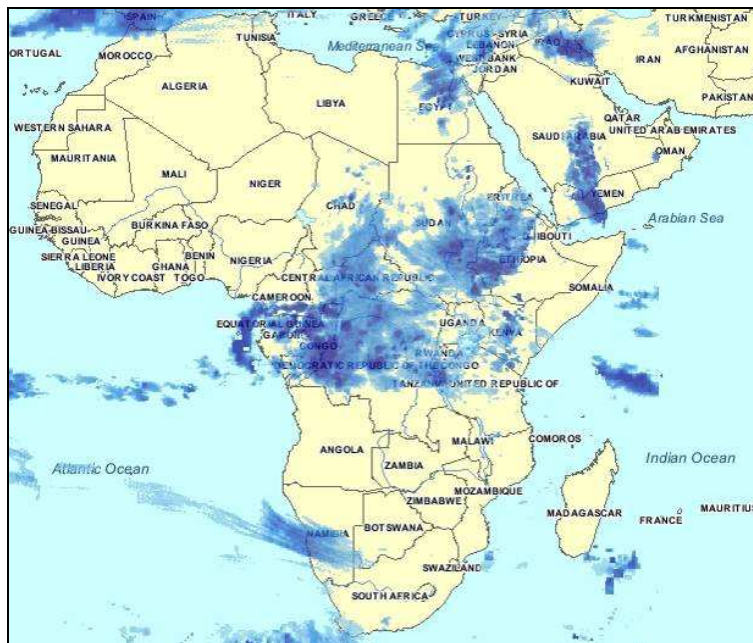


Figure 16. Typical example of rainfall estimates obtained from the FEWS network (24/11/2000).

7.3 Land cover

The so-called AfriCover land cover data set has been used. (Di Grigorio and Jansen 2000). This study, covering ten East African countries, recognizes over 50 land cover classes in the Upper Tana catchment (FAO 2000b). For this study these classes have been generalized into 7



classes. The original map has been developed by the Kenya Department of Resource Surveys and Remote Sensing (DRSRS).

7.4 Various issues

- The current model does not include groundwater flows and therefore baseflow might not be simulated correctly. This baseflow is therefore introduced by including flow requirements at low values at the end of a catchment.
- Changes in reference evapotranspiration are based on the change in minimum and maximum temperature. An often applied rule is that every one degree increase in temperature will increase the reference evapotranspiration by 5% (HBV model)
- Costs of erosion control have been described by Shiferaw and Holden (2001). They considered loss of area as the most expensive component. Given the situation in Kenya this cost factor has been ignored.

