Water Evaluation And Planning System, Kitui – Kenya

WatManSup project

WatManSup Research Report No 2

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Preface

This report is written in the context of the WatManSup project (Integrated Water Management Support Methodologies). The project is executed in three countries: The Netherlands, Kenya and Turkey. Financial support is provided by Partners for Water. For more information on the WatManSup project see the project website: http://www.futurewater.nl/watmansup.

The Dutch consortium:

- FutureWater (Wageningen)
- Institute for Environmental Studies (Amsterdam)
- Water Board Hunze en Aa's (Veendam)

Foreign clients:

- SASOL Foundation (Kitui, Kenya)
- Soil and Water Resources Research Institutes of the Turkish Ministry of Agricultural and Rural Affairs (Menemen, Turkey)
- SUMER (Izmir, Turkey)

Additional technical support:

- the University of Nairobi (Kenya)
- EA-TEK (Izmir, Turkey)

Reports so far:

Research report No.1: Water Management Support Methodologies: State of the Art
Research report No.2: Water Evaluation and Planning System, Kitui - Kenya

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1 Introduction

The challenge to manage our water resources in a sustainable and appropriate manner is growing. Water related disasters are not accepted anymore and societies expect more and more that water is always available at the right moment and at the desired quantity and quality. Current water management practices are still focused on reacting to events occurred in the past: the re-active approach. At many international high level ministerial and scientific meetings a call for more strategic oriented water management, the pro-active approach, has been advocated. Despite these calls such a pro-active approach is hardly adopted by water managers and policy makers.

Water managers and decisions makers are aware of the necessity of this paradigm shift: from a re-active towards a pro-active approach, but are confronted with the lack of appropriate methodologies.
To be prepared for the paradigm shift Integrated Water Management Support Methodologies (IWMSM) are needed that go beyond the traditional operational support tools. Note that these IWMSM are more than only tools, but include conceptual issues, theories, combining technical and socio-economic aspects. To demonstrate and promote this new way of thinking the WatManSup (Water Management Support Tools) has been initiated. The IWMSM approach comprises three different components: a water allocation component, a physical based component and a decision support component. This report describes the water allocation component for one of the study areas included in the project: Kitui in Kenya.

The overall objective of this report is to demonstrate how the water allocation component of IWMSM, the WEAP tool, can be used to support water managers and policy makers on relatively small reservoirs in a developing country.

2 Background

2.1 The WEAP model

Water managers and policy makers are in need to have tools at their disposal that will support them in their decision-making. The WEAP tool is one of the components of IWMSM that can be implemented relatively easy to evaluate scenarios on different water allocation strategies in a user-friendly environment.

WEAP is short for Water Evaluation and Planning System and is originally developed by the Stockholm Environment Institute at Boston, USA (SEI, 2005). WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP places the demand site of the equation – water use patterns, equipment efficiencies, re-use, prices and allocation – on an equal footing with the supply site – streamflow, groundwater, reservoirs and water transfers. WEAP is a laboratory for examining alternative water development and management strategies (SEI, 2005).

WEAP 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 customized to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data.

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 (SEI, 2005).

WEAP, in contrast to many other tools, is not optimisation oriented in the sense that the optimal water allocation will be presented. The entire approach is based on scenarios (alternatives) to ensure that stakeholders, water managers and policy makers are actively involved in the entire process of planning in order to guarantee the ownership feeling of the final decisions taken.

WEAP consists of five main views: Schematic, Data, Results, Overviews and Notes (Figure 1). A typical stepwise approach will be followed to develop WEAP for a particular area: (i) create a geographic representation of the area, (ii) enter the data for the different supply and demand sites, (iii) compare results with observations and if required update data, (iv) define scenarios and (v) compare and present the results of different scenarios. In general, the first three steps will be done by technical experts like hydrologists, while for the last two steps input and exchange with stakeholders, water managers and policy makers is essential.

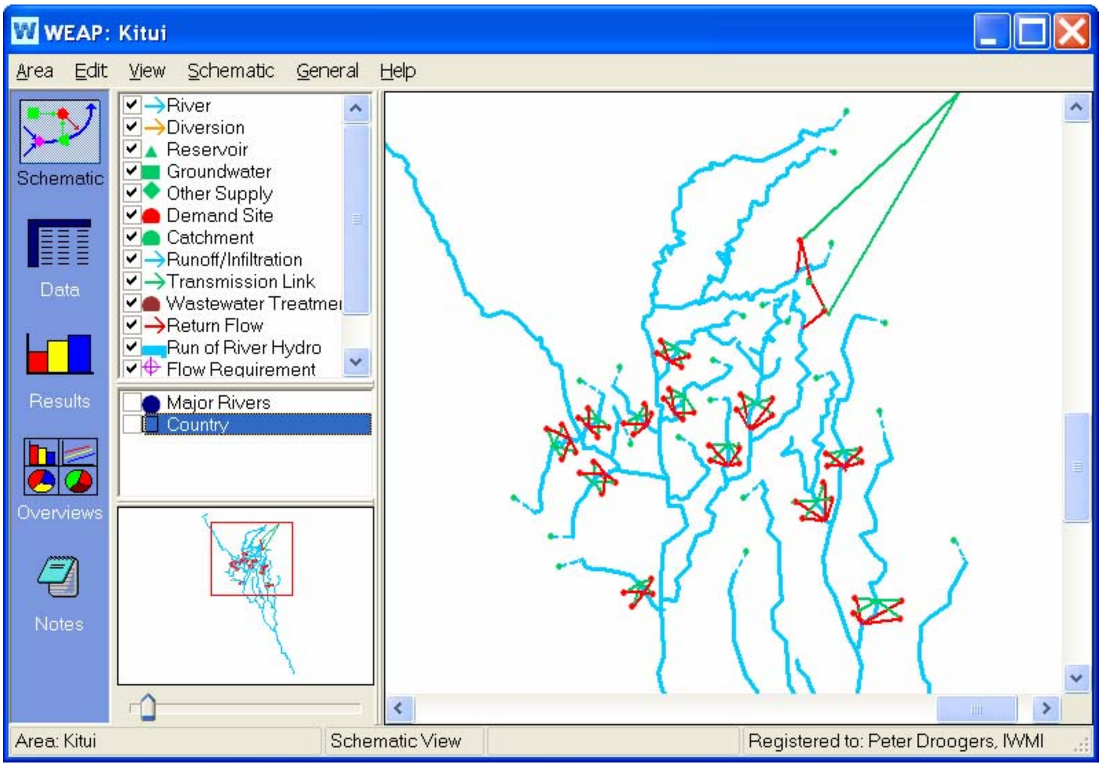

Figure 1. User interface of WEAP with on the left the five main views.

2.2 *Kitui – Kenya*

2.2.1 Regional setting

The WatManSup project aims at testing and demonstrating the IWMSM components in contrasting settings. The Kitui area is selected as it presents a typical case for a developing country with alternating wet and dry periods within one year and small-scale local human interventions on the water resource.

The Kitui District in the Easter Province of Kenya is a semi-arid region situated 150 km East of Nairobi (Figure 2). The total land area is approximately 20.000 km², including 6.400 km² of the uninhabited Tsavo National Park. The elevation of the district is between 400 and 1800 metres. The central part of the district is characterised by hilly ridges, separated by low lying areas between 600 and 900 metres above sea level. Approximately 555.000 people inhabit the district and the growth rate is 2.2 percent a year (DDP, 2002).

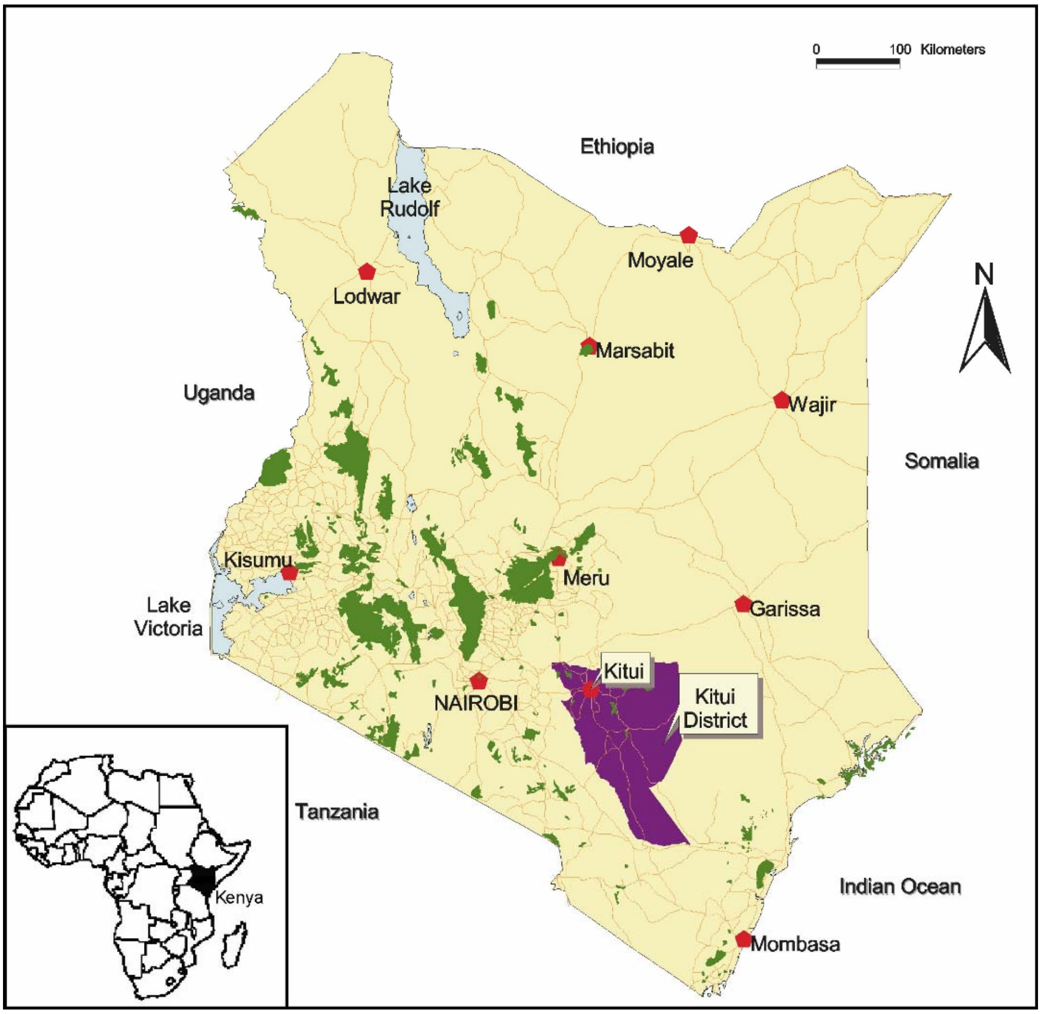

Figure 2. Map of Kenya, with the Kitui district in dark.

2.2.2 Geography and climate

The area is characterised by rainy periods that are highly erratic and unreliable. The rain usually falls in a few intensive storms (Nissen-Petersen, 1982). There are two rainy seasons, one from April to June, these are the so-called 'long rains' and one from October to December, these are the 'short rains'. On average the precipitation in the Kitui District is around 900 mm a year, but there are large local differences in amount of precipitation due to topography and other influences. The potential evaporation is high, 1800 to 2000 millimeter a year.

Virtually all of Kitui District's total area belongs to the Tana River drainage basin. Only a narrow strip along the south and southwest border drains to the Athi River. These two rivers form the northern, western and southern boundaries of the district. The Tana river is Kenya's largest river and drains the Eastern flank of the Aberdares and the Southern slopes of Mount Kenya. Both of the rivers discharge to the Indian Ocean.

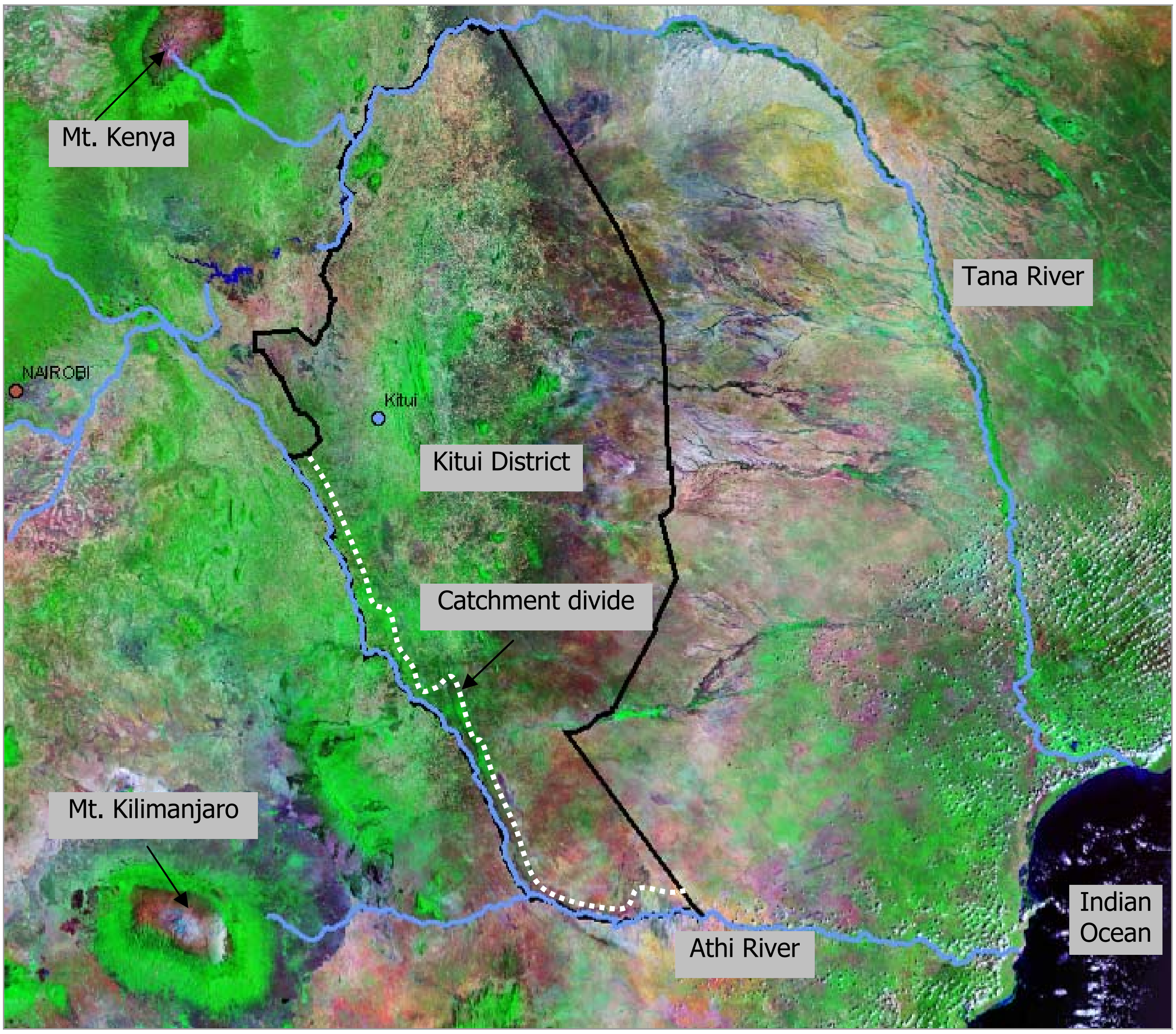

Figure 3. False colour composite satellite image of the Southern part of Kenya (source: USGS and NASA).

There are no perennial rivers in the District except the Tana River. In spite of perennial headwaters, the Athi often runs dry due to evaporation and infiltration losses. All of Kitui's rivers, including the Tana River, are strongly characterized with high flows in April-May and November-December and very low (or nil) flows in the intervening dry periods. Most of the ephemeral streams that drain into the Tana River generally become dry within one month after the rainy season. (Borst and De Haas, 2006)

2.2.3 Socio-economical data

In 1997 the income of 58 percent of the eastern districts was beneath the poverty line of 2 dollars a day (PRSP, 2001). This is one of the poorest regions of Kenya. The main economic activity is rainfed agriculture (Census, 1999). Irrigated agriculture only takes place on small plots on the river banks. During prolonged dry periods the farmers are dependent on relief food from donors. In 2004 and spring 2005 up to 50 percent of the inhabitants of Kitui received food aid (FEWS-NET). Besides farming the main economic activities are charcoal burning, brick making and basket breading.

Only 45 percent of Kenyans have access to clean water for domestic use and even fewer have access to water that is fit to drink. In the Kitui district these numbers are even lower: only 6 percent of the inhabitants has access to potable water (DDP, 2002). Water is the most essential development commodity in this area, the major sources are the ephemeral rivers. Water scarcity forces women and girls to walk up 20 kilometres in dry periods to water sources such as springs and scoopholes.

2.2.4 The Kitui sand dams

One of the successful examples of a rural water conservation programme is the construction of sand storage dams in the Kitui district in Kenya. This programme is a cooperation between the community and the Sahelian Solution Foundation (SASOL). SASOL, founded in 1992, assists Kitui communities to address household and production water scarcity through the sand storage dam technology.

The planning objective was to shorten the distances to water sources to below two kilometres whilst making water available for productive use. Typically, women walk 10-15 km to water sources in the district. To date, almost 500 dams have been constructed in central Kitui. The key success factors of the Kitui sand storage dams are firstly the high degree of community participation in the planning and construction and secondly the concept of cascades (many dams constructed in one riverbed), creating a substantial volume of storage in a small area and hence reaching a larger part of the population.

Sand storage dams are being built in the river bed, perpendicular to the flow direction. Behind these dams the river bed fills up with sand, enlarging the natural aquifer(Figure 4). During the dry season water will be stored in the area for a longer period. More water can be harvested from scoopholes and wells, providing water to the people for a longer period. (Borst and De Haas, 2006)

Figure 4. SASOL sand storage dams in Kitui (pictures field visit July 2006, P. Droogers & A. van Loon).

2.2.5 Water management and institutional aspects

The institutional framework surrounding the sand dam project in Kitui comprises several actors on various institutional levels. By means of interviews with representatives, information was gathered concerning i.e. the responsibilities, the level of cooperation and the coordination structure of the different actors. The results are presented according to the three institutional levels: NGO level, community level and government level.

In the bottom-up approach practiced by SASOL, community participation plays an important role. The organization only facilitates construction materials, knowledge and the required funding, keeping the total costs as low as possible. The 8-step methodology includes formal meetings, selection of the site and site-confirmation by SASOL. At the end of the pre-constructive phase, the community selects a dam committee who is responsible for the organization of the site and for the long-term utilization of the dam. During construction and in the post-constructive phase several trainings are given. These sub-locational training sessions cover subjects like project management, natural resource management and catchment development. In some cases, Ex-change (a Dutch NGO) cooperates with SASOL, by providing student teams to help the community with the construction of the sand dam.

At community level, the village elder and the newly formed dam committee fulfil the most important roles. Being the official spokesperson for the community, the village elder is approached first by SASOL to discuss the Sand Dam Project and its impacts. The responsibilities of the village elder are overall supervision of the site, the participants and the materials and the protection and utilization of the dam. The dam committee has very similar responsibilities, including supervision of the site, organizing the community, and managing and maintaining the sand dam. In cooperation with SASOL, the committee also sets up rules and regulations for the construction period and for utilization and maintenance of the sand dam after construction.

The highest institutional level is the Kenyan government. The various levels of government (ranging from national to district) are not only regulatory institutions, but are also active in setting up projects in sectors as agriculture, irrigation and health. This is mostly done through extension officers who visit communities and give advice on various topics. For this reason, the ministries could play a major factor in making the Sand Dam Project a success.

The Ministry of Water and Irrigation is responsible for the development of water resources, and therefore closely connected to SASOL. Although the Ministry is aware of SASOL's activities, there is little cooperation between the two parties; making the outcome of the project less effective due to insufficient support and follow-up services from the Ministry. The Water Act 2002 is a new policy concerning the management of the water resources. The act supports a minimal role of the government and greater community participation. In the near future, water user groups may become an important entity on district level and it is recommendable that these groups work together with the dam committees.

Another important actor is the District Development Committee. Since 2002 the Kitui Sand Dam Project is incorporated into the Districts Development Plan (DDP for 2002-2008). Because of an increased awareness of SASOL's activities at the government, it is expected that extension services to sand dam-communities will be better matched to their situation (proper utilisation of the resources).

3 WEAP Kitui

WEAP is an integrated water management tool that allows you to schematise a watershed and all the water related activities in that area. For the Partners for Water project in Kitui the catchment of the Tiva river was selected because it contains most sand dams of SASOL. In the catchment to the East of Tiva, the Thua catchment, also many sand dams of SASOL are located. However, this catchment drains into a completely different part of Tana river and will therefore not be considered in this study.

In this chapter the overall set-up of the model is explained, while details of data can be found in the appendices.

3.1 Schematic

In the schematic part of WEAP the watershed is delineated, and rivers, demand sites and reservoirs are specified. GIS maps of rivers and riverbasins are used to determine the exact location of the streams in WEAP. The level of detail is determined by the location of the sand dams. No smaller tributaries than those with sand dams are included in WEAP. In total 31 rivers are added to the Tiva riverbasin. Every headstream gets input from a catchment site. In that way 22 catchment sites are needed for the tributaries of Tiva river. In a catchment site a rainfall runoff method is used to generate inflow into the tributary. In this project we used the method of FAO that simply calculates the difference between precipitation and evaporation. The area of the catchment site is determined from the hydrological model SWAT (WatManSup Research Report No.3). In SWAT subbasins are defined based on the topography. The area of the subbasins along one tributary are added up to represent the area of the 22 WEAP catchment sites.

Two large towns are included in WEAP, Kitui-town and Matinyani. These towns get piped water from the Masinga reservoir. This reservoir is located in a different catchment and will only be included as a source of water for Kitui-town and Matinyani. Kitui-town also receives water from a borehole in the deeper groundwater, so a groundwater site is added to the WEAP-model. The sewage of both towns is drained off as surface water. The largest part of the sewage evaporates, the rest infiltrates into the subsurface water or reaches the river. So in WEAP two return flows are specified, one from the towns into the groundwater and one into the rivers Kalundu and Mutendea.

The 273 SASOL sand dams in the Tiva catchment are clustered into 12 representative reservoirs nodes (RRNs) with 6 to 63 dams per RRN. The location of the RRNs within the catchment and the amount of sand dams per RRN are obtained from SASOL (pers.comm. Mr. Julius). Four demand sites are located close to each RRN to represent water use from the RRNs. The four demand sites represent domestic water use, livestock water use, agricultural water use and other uses. A return flow of part of the waste water enters the river downstream of the dam.

In Figure 5 and Figure 6 an overview of the catchment is given.

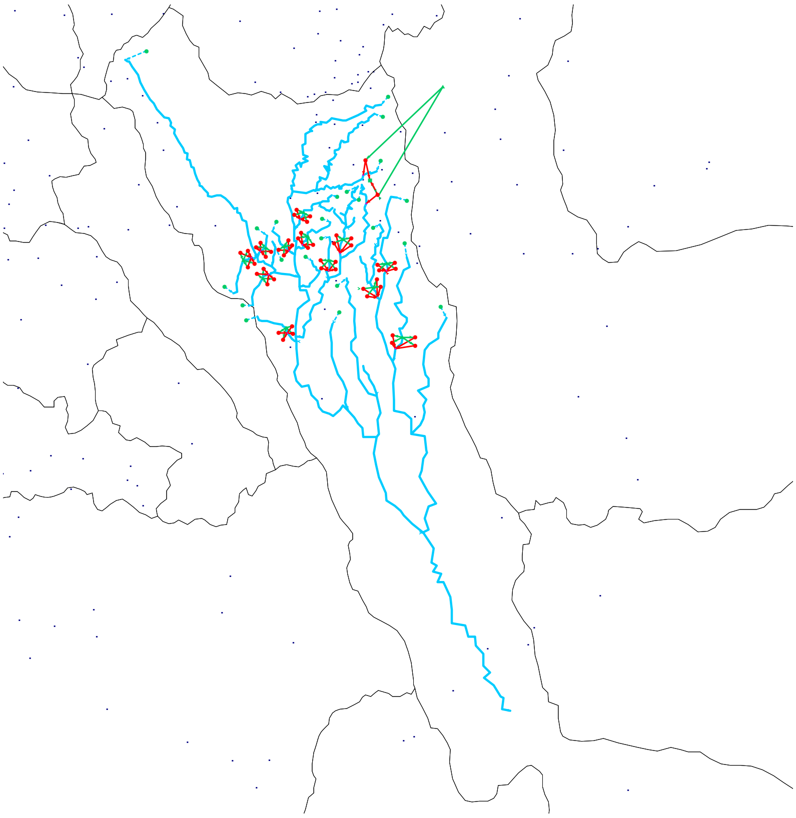

Figure 5. Scematic part of the WEAP model for Kitui.

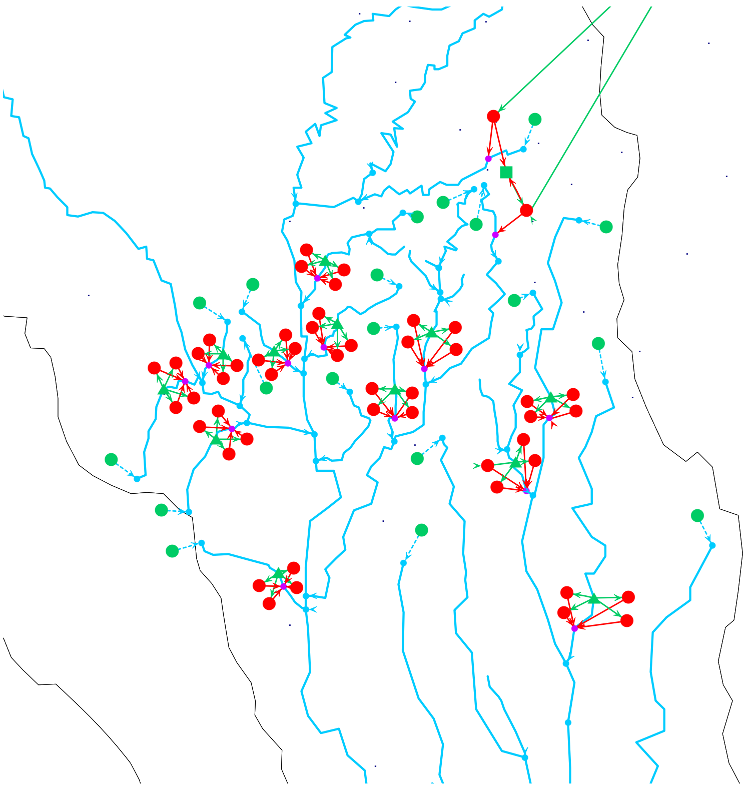

Figure 6. Schematic part of the WEAP model for Kitui (detail of Figure 5).

3.2 Baseline data

The data input in WEAP is structured according to the schematic set-up of the catchment. The following classification is used:

1. key-assumptions
2. demand sites and catchments
3. hydrology
4. supply and resources
    a. linking demands and supply
    b. runoff and infiltration
    c. river (including the reservoirs per tributary)
    d. groundwater
    e. local reservoirs
    f. return flows
5. water quality

Key-assumptions are user defined parameters that can be used throughout the WEAP model. The use of key-assumptions is especially worthwhile when the model has a large number of similar objects, for example demand sites, and when performing scenario analysis. With key-assumptions you can easily create scenarios without having to edit the data of each and every demand site – simply by changing the key-assumption value (SEI, 2005).

The use of key-assumptions is essential in this model for Kitui, because there are many RRNs and demand sites with comparable characteristics. The use of key-assumptions enables a faster set-up of the current situation and the scenarios, and simplifies changes in the characteristics of reservoirs and demand sites. This is especially useful when we present our partners with the model and they propose corrections or additions.

Water quality aspects will not be evaluated in this project because it is outside the scope of the study.

3.2.1 Current accounts and Reference scenario years

The Current Accounts is the dataset from which the scenarios are built. Scenarios explore possible changes to the system on future years after the Current Accounts year. A default scenario, the "Reference scenario" carries forward the Current Accounts data into the entire project period specified and serves as a point of comparison for the other scenarios in which changes are made to the system data (SEI, 2005).

The year 1999 is chosen as the "Current Accounts" year, or base year, for this project and the entire project period is set to 1999 to 2004. This period is regarded as representative based on data of the precipitation (Appendix A.2).

3.2.2 Catchment sites

In the WEAP model 22 catchment sites generate the input for 22 of the Tiva river tributaries (Figure 7). In a catchment site the FAO rainfall runoff method is used. For the calculations with this method the land use and climate of a catchment site need to be defined. Land use is composed of the parameters area, crop coefficient and effective precipitation, while climate is defined by the precipitation and reference evapotranspiration. The other input options of the catchment sites: 'Loss and reuse', 'Yield', 'Water quality' and 'Costs' are not taken into consideration in this project.

Land use

The area of the catchment sites is determined from an addition of the relevant subbasins of SWAT (WatManSup Research paper No. 3).

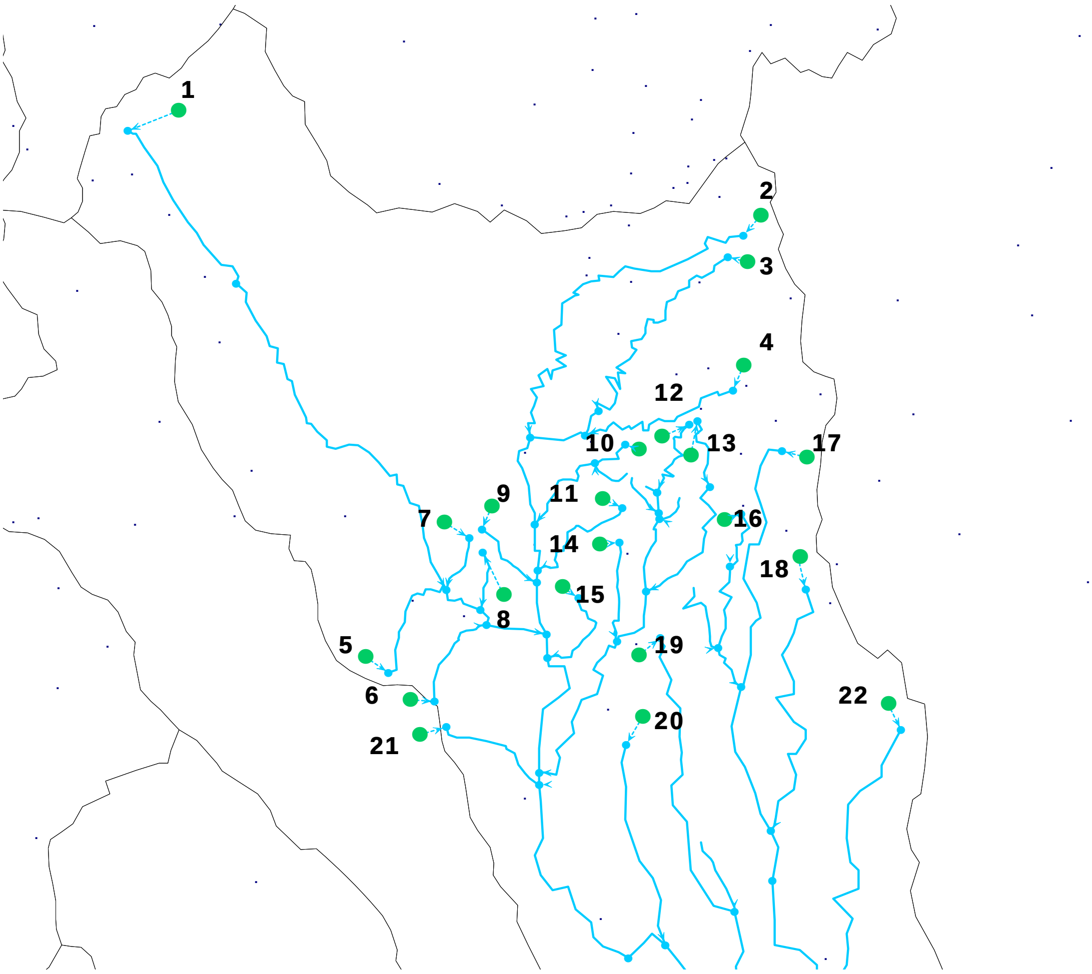

Figure 7. Catchment sites in the study area.

The land use of the Kitui district is mainly characterised as range-bushland. For the WEAP model we assume a 30% cover with (rainfed) maize and the remaining 70% other vegetation, such as fruit trees, grass and natural trees. Maize is chosen as the representative crop for the area, because it is the principal crop in Kitui.

The crop coefficient (Kc) for the "Other vegetation" is set to 1.0 and the Kc of maize is taken from Puttemans et al. (2004). Almost all the maize in Kitui is not irrigated so the data for dry maize are used. Combination of the length of the stages and the growing season and the Kc-factor (see Appendix A.1), results in the monthly variation in Table 7.

The effective precipitation is the percentage of precipitation available for evaporation. The remainder is direct runoff. In the months with peak rainfall the precipitation rate exceeds the infiltration rate of the soil. Therefore, part of the precipitation is surface runoff to streams and not available for evaporation. The data for the effective precipitation are based on Figure 4.9 of Borst and De Haas (2006) and are included as a key-assumption in WEAP (Table 7).

Climate

The precipitation data are obtained from the Institute of Environmental Issues (IVM). This dataset is assumed to be the most reliable dataset for the precipitation in Kitui district. For the potential evapotranspiration no reliable measurement data could be found. Borst and De Haas (2006) used the New LocClim data (v. 1.06, FAO, 2005). The New LocClim program uses a statistical analysis based on data from about 30,000 meteorological stations around the world to estimate climate data for any location. In this WEAP model also this dataset is used. Both precipitation and reference evapotranspiration are given in Table 7 and included in WEAP as a key-assumption.

3.2.3 Kitui town and Matinyani

Kitui town and Matinyani have a special position in the WEAP model because these two demand sites are not dependent upon water from sand dams. The towns and the surrounding villages are supplied by the Masinga reservoir and the Kitui borehole. In total 20,000 people make use of the piped water, 15,000 in Kitui-town and 5,000 in Matinyani. The total transported water is ca. 1000 m^3/d, so the annual water use rate per person is 18.25 m^3. Of the 1000 m^3/d about 50% comes from Masinga and 50% from the Kitui borehole. (pers. comm. Mr. M'ngila)

Considerable leakage occurs within the system, both in the transport from Masinga to the towns and within the towns. In total 30 to 40 percent of the water is lost. (pers.comm. Mr. M'ngila) According to Mr. M´Ngila the water loss during the transport from Masinga is more than 200 m^3/d, which is about 50% of the total amount of transported water from Masinga. The losses during the transport from Kitui borehole to Kitui town estimated at 10% because the distance much shorter. In WEAP these estimates are included in the data on the transmission links.

In Kitui town many old pipes of the colonial era are present. Only part of these cement pipes are replaced by new plastic ones, but the joints between old and new pipes cause much leakage. In WEAP the losses within a demand site result in an increase in demand. The total water use is therefore a combination of the actual water use and the losses. Only data on the total water use was available, so with an estimate for the losses (10%), the actual water use was calculated (18.25 m^3 / 1.1 = 16.6 m^3). No monthly variation is imposed for water use.

The consumption is the percentage of the inflow that is lost from the system through consumption. Consumption is estimated at 25%. As far as we know no considerable reuse of water or demand site management is done in Kitui and Matinyani.

The sewage from the towns is disposed as surface water flow. About 80% drains into river Kalundu close to Kitui town and 20% infiltrates to the groundwater. However, the loss from evaporation is very high. The key-assumption defining this loss from evaporation is based on Figure 4.9 of Borst and De Haas (2006) and the statement of Mr. M´Ngila that almost all the sewage is evaporated on the way to the river (Table 8).

3.2.4 Masinga reservoir

Masinga reservoir is the largest reservoir in Kenya. It is operated by KenGen, the national electricity generating company. Not many data are available on the in- and outflows of Masinga reservoir and its operation, so most of the input in WEAP is an estimate.

The inflow into the Masinga reservoir is taken from SWAT outputs of the Green Water Credits project (Droogres, 2006). This project only gives inflow data in the period 1995 to 1997. For WEAP these three years are used two times to cover the period 1999 to 2004 (Table 9). Inflows are highest in the rainy season when precipitation exceeds evaporation, and lowest in the dry season. However, even in the dry season there will always be inflow in Masinga reservoir, because some of the contributing rivers originate in the mountains. For example the snow melt on Mt. Kenya will give a fairly constant discharge in the rivers downstream.

According to KenGen the total storage capacity of Masinga reservoir is around 1433 million m^3. However, the siltation of Masinga reservoir is assumed to be very high. Estimates range from 10 to 30%. KenGen operates the reservoir with a siltation of 10%, so the maximum volume of water in the reservoir (parameter Top of Conservation in WEAP) is about 1290 million m^3. (pers.comm. Dr. Kimani) The initial storage is chosen at 1000 million m^3 to represent the situation in January, when just after the rainy season of November and December the storage in the reservoir is still high. The Top of Buffer stands for the level under which the releases from the reservoir are constrained. This buffer zone is estimated at 500 million m^3 with a buffer coefficient (fraction of water in the buffer zone available for release) of 0.5. Finally, the inactive zone in a reservoir is the volume of water not available for allocation. For Masinga reservoir this Top of Inactive is set at 100 million m^3. The maximum flow from Masinga reservoir to Kitui town and Matinyani is set at 800 m^3 per month.

The volume elevation curve of the Masinga reservoir is estimated based on the shape of the reservoir. The reservoir is quite shallow and very wide, resulting in a steep begin of the volume elevation curve and a flat end (Table 10). The net evaporation is composed of the key-assumptions precipitation and reference evaporation (ETref) and is calculated by subtracting the precipitation from the evaporation.

3.2.5 Kitui borehole

The Kitui borehole is the only one of five boreholes that is still in use. The borehole is made in the 1950´s and is 340 ft deep. The pumped groundwater is of good quality and not saline. The capacity of the pump is 23-36 m^3/hour. The pump is operated 22 hours a day, so 400 to 500 m^3 water is pumped daily except when the electricity fails. (pers.comm. Mr. M´ngila and Mr. Mutinda) The maximum flow from Kitui borehole to Kitui town is set at 800 m^3 per day.

The storage capacity of the Kitui aquifer is estimated at 1,000 million m^3 (Table 1). The monthly maximum withdrawal is 15,500 m^3. The estimate of the natural recharge is based on the precipitation data for Kitui. The monthly data are shown in Table 11.

Table 1. Calculation of the storage capacity of the Kitui aquifer.

Aquifer surface area	200,000 ha
Depth	5 m
Specific yield	0.10
Storage capacity	1,000 million m^3

3.2.6 SASOL sand dams

The sand dams of SASOL can not be included in WEAP separately. The model would become highly cluttered and unworkable. Therefore we clustered the sand dams in 12 RRNs of 6 to 63 dams per RRN (Figure 8).

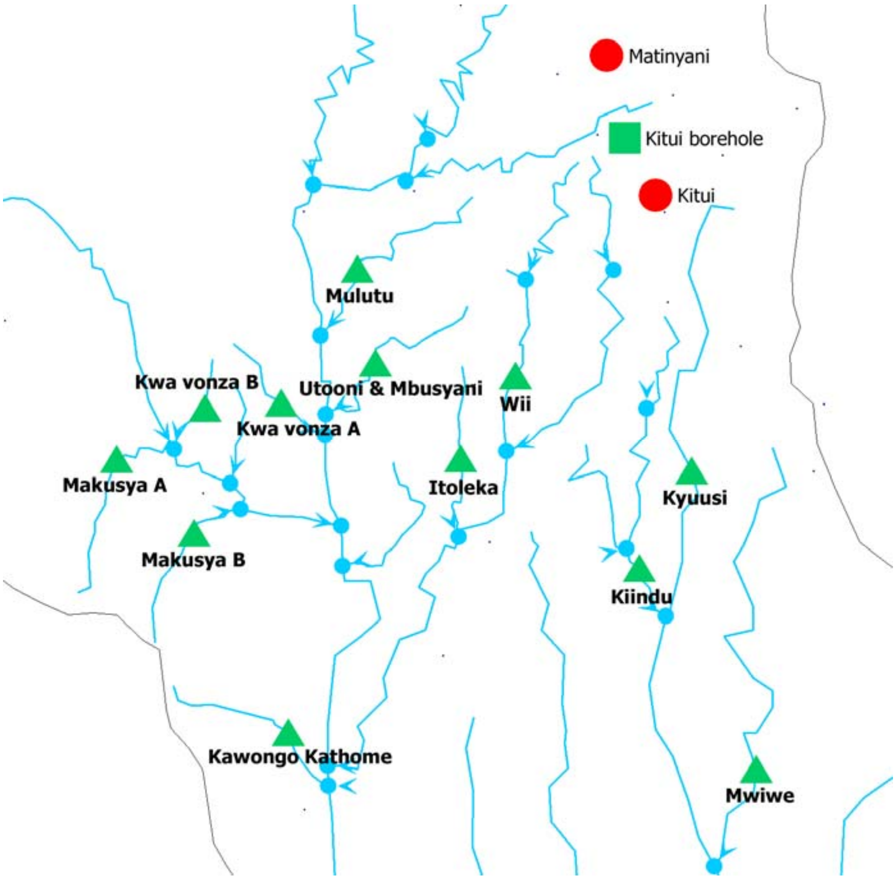

Figure 8. Schematic part of the WEAP model with names of the RRNs.

Next to the SASOL sand dams a number of natural dams are present in the catchment of a river. These natural dams are made of rock outcrops. Sand has accumulated behind the outcrop, similarly to the SASOL sand dams, and water is stored within the sand. Such a natural dam is a source of water for the people living along the river, and therefore the natural dams need to be consitered in WEAP. The number of natural dams within a river stretch is estimated to be 10% of the number of SASOL sand dams in that stretch. (pers.obs. July 2006)

Field visits to the SASOL sand dams reveal that not all of them are working properly. At four out of five dams leakage is observed underneath or around the dam. (pers.obs. July 2006) However, water is still stored in the sand behind the dam. Some of the dams are completely broken into pieces or one of the banks is severely eroded. In these cases the dam does not retain any water. According to students of Free University Amsterdam 9 out of the 95 dams they visited were completely inactive. (pers.comm. Rob and Pieter) In WEAP 10% of the SASOL sand dams in a catchment are subtracted as inactive. The total active number of dams is stored as a key-assumption, so that the figures can easily be changed.

The characteristics of the individual sand dams also need to be clustered and added. The storage capacity of one dam is estimated from its dimensions. In average, a SASOL sand dam is about 6 m wide and 2 m high. The slope of the original river is 0.2 to 4% (Ertsen and Biesbrouck, 2004) with an average of around 1%. Consequently, dams of 2 m high have an impact on sand accumulation 200 m upstream. As the distance between consecutive dams in a river stretch is 500 to 1000 m, the dams have the space to fully establish. (pers.comm. Mr. Munyoki) Calculation of the amount of sand accumulated behind a dam results in a figure of 1200 m^3, assuming a triangular shape of the sand accumulation upstream. As coarse sand has a porosity of 45% (Ertsen and Biesbrouck, 2004) the water stored behind a single dam is 540 m^3. However, the percentage of extractable water is lower, for soils with coarse sand around 35% (Ertsen and Biesbrouck, 2004). This means 420 m^3 of the water behind a SASOL sand dam can be extracted.[1] Consequently, 120 m^3 or 22% of the water in the sand dam can not be extracted. This is included in the parameter Top of Inactive. Additional to storage directly behind the sand dam, water will also be stored in the banks of the river. The strip of land directly influenced by a sand dam on one site is about half of the width of the dam. Consequently, the additional storage is estimated to be equal to the amount of water stored behind the dam, 540 m^3. The total storage then comes to 1080 m^3 and the amount of extractable water to 840 m^3 per dam.

According to Borst and de Haas (2006) the amount of extractable water from a river stretch in between two sand dams is 8372 m^3 per year. This figure is not easily comparable with the storage capacity of one sand dam in WEAP. The storage capacity of a sand dam can be extracted many times a year dependent on both input and extraction. When for example a sand dam is emptied completely about six times in a year and subsequently filled with input from precipitation, the total amount of extracted water is 6 times 840 m^3, equals 5040 m^3 per year. The difference of this amount with the amount of Borst and de Haas (2006) can also be explained by a difference in the shape of the reservoir. We assume a triangular shape, while Borst and de Haas (2006) assumed a rectangular shape of the reservoir behind a dam. Furthermore, they assumed a influence of the dam upstream up to the previous dam, while in rivers with a slope of 1% the effect of a dam with a height of 2 m is 200 m upstream. Finally, Borst and de Haas (2006) possibly overestimated the amount of groundwater storage in the aquifer underneath the sand dam.

[1] For the total amount of extractable water in an reservoir, the number of dams in that reservoir can be multiplied by the extractable water per dam.

In WEAP the parameter Top of Conservation is set at 90% to allow for leakage of the dams at high water levels. This solution does not perfectly match the real situation, because in reality leakage also occurs at low water levels. However, it is not possible to model this situation with WEAP. The Top of Buffer is estimated at 30% of the storage capacity of a sand dam. The buffer coefficient used for the sand dams is equal to that of Masinga reservoir, namely 50%.

The unit initial storage is set at 800 m^3 per dam to represent the situation in January, when just after the rainy season of November and December the storage in the reservoir behind a dam is still high. The volume elevation curve is hard to determine because a RRN is a combination of many dams. Furthermore, sand dams are not surface water dams, so the evaporation is much less and the relation between volume and elevation is completely different. Therefore the volume elevation curve has to be steep to reduce the evaporation (Table 13). Fictive elevations are used in WEAP. The volume elevation curve for each RRN goes up to the storage capacity of the RRN. The evaporation rate of a RRN is set to 50% of a surface water reservoir like Masinga.

3.2.7 Demand sites sand dams

Every RRN has four demand sites: domestic, agriculture, livestock and other uses. Domestic water use is the most important, it has the highest priority. Second important use is livestock, third is agriculture and the other uses have least priority (Table 2 and Figure 9). (pers.comm. Dr. Aerts)

Table 2. Priority demand sites.

demand	priority
domestic	1
livestock	2
agriculture	3
other uses	4

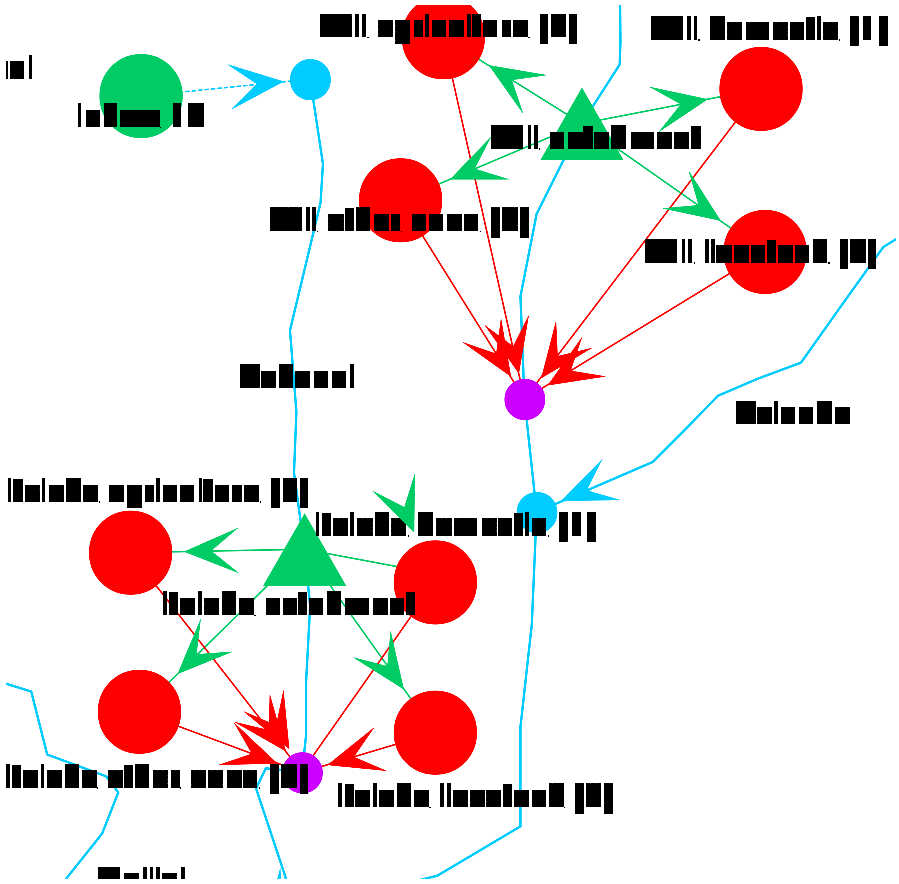

Figure 9. Scematic part of the WEAP model for two catchments: Wii catchment and Itoleka catchment, each with four demand sites: domestic, livestock, agriculture and other uses.

Domestic water use

According to Mr. Mutinda and Munyoki, one SASOL sand dam is used by 50 households of in average seven people. In WEAP this amount is multiplied by the number of SASOL dams within a catchment. The estimates of the water use of one household range from 35 to 140 l per day (Table 3). For the WEAP model an intermediate value of 80 l per household per day is used. This means 29.2 m^3 per household per year. No consiterable monthly variation was imposed.

The domestic consumption is set at 25%. The rest of the water is drained of as surface flow. A large part of this water will evaporate, part will infiltrate in the soil and part will reach the river. For the loss from evaporation the same values are used as for the return flow of Kitui town and Matinyani, as is shown in Table 8.

The loss rate is set at 0%, because in WEAP losses within a demand site result in an increase in demand. In Kitui data are available only on the amount of water abstracted from the RRN and not on the actual amount of water used.

Table 3. Water use per household, according to different sources.

source	water use (l/d)

Free University Amsterdam	35-70 l/d
Mr. Mutinda (SASOL)	50-80 l/d
Louis Berger International Inc. (1983)	140 l/d
De Bruijn and Rhebergen (2006)	90 l/d
Personal observation	80 l/d

Livestock water use

The amount of water used for livestock is dependent on the amount of households. According to (De Bruijn and Rhebergen, 2006) the percentage of households with livestock is around 50%. The water use rate of livestock is 60 l per household per day, or 21.9 m^3 per household per year (De Bruijn and Rhebergen, 2006). Again no consiterable monthly variation was imposed. The livestock consumption is set at 80%. In Kitui livestock is watered at the river, so the water that is not consumed will flow back into the river. Part of the water is lost due to evaporation (Table 8).

Agricultural water use

In Kitui, patches of irrigated land are only found close to a sand dam. The area of these patches is circa 0.1 ha and there is one on each side of the river, so in total each dam[2] has an irrigated area of 0.2 ha (De Bruijn and Rhebergen, 2006).

The crops in Kitui are only irrigated in the dry season, in the months February and March, and July, August and September. (pers.comm Mr. Munyoki) No data are available on the amount of water used for irrigation. Farmers do not know how much water they use for irrigation, because their plots are small and close to the water source. Therefore, the irrigation is calculated from the reference evapotranspiration (ET_{ref}) and the precipitation (P).

$$ET_{ref} \times K_c = ET_{crop}$$
$$ET_{crop} \times (1 + losses) = water\ demand$$
$$water\ demand - P = irrigation\ demand$$

Sukuma Wiki is the main crop for irrigated agriculture in Kitui. The crop coefficient of Sukuma Wiki is taken from Puttemans et al. (2004) (see Table 14). ET_{ref} is given in Table 7 and P in Table 5. The irrigation losses are estimated at 50%. The results of this calculation are presented in Table 15.

At the agricultural demand sites the irrigation is included as a yearly value and a monthly irrigation variation in %. This irrigation variation is included according to Table 16. The agricultural consumption is set at 100%. Losses are zero because the irrigated plots are close to the river.

Other water uses

In Kitui two other water uses are important, brick making and tree nursery. Brick making is done by 35% of the households and tree nurseries by 30% (De Bruijn and Rhebergen, 2006). Brick making is done only a few months of the year at the start of the dry season, January and June (De Bruijn and Rhebergen, 2006). During the process of brick making an enormous amount of water is used at once.

[2] including natural dams

On one day one household needs 16 times a jerrycan of 30 l water, which amounts to a water use of 0.48 m^3/HH/d. Brick making is done about 5 days a week and 4.4 weeks a month, so 10.56 m^3 of water is used per HH per month. (pers.obs. July 2006)

A tree nursery is a combined activity of a number of households. Mostly women are active in this activity, two times a day they fetch 20 l of water from the reservoir behind a sand dam. So in total 680 l of water is used per day, divided by 17 households this is 40 l per household per day. Again multiplied by 5 days a week and 4.4 weeks a month, the water use per month is 0.88 m^3 per household. (pers.obs. July 2006) Tree nurseries are principally done in the months February, July, August and September (De Bruijn and Rhebergen, 2006).

The combination of these water uses leads to the monthly variation given in Table 17. The consumption of both brick making and tree nursery is set at 100%.

3.3 Reference scenario

The WEAP model built as described in the previous section can be considered as the Reference scenario. The Reference scenario is the scenario in which the current situation (1999) is extended to the future (2000-2004). No major changes are imposed in this scenario. Only a population increase of Kitui town and Matinyani is estimated. The result is a model that mimics reality over the period 1999 to 2004, given the constraints of simplification of the model and data limitations.

3.3.1 Kitui town and Matinyani

The growth rate of Kitui town and Matinyani is estimated at 5% per year.

3.4 Other scenarios

Besides the Reference scenario three other scenarios are analysed. First scenario analysed is a situation without sand dams in Kitui, which can be considered as the case before SASOL initiated sand dam construction. Second scenario analysed is a situation with twice as much sand dams in the area and simultaneously a doubling of agriclutrual water use. Last scenario analysed is a case where storage capacity of existing dams would double, but all consumptions are similar to the Reference scenario. The only difference between the last two scenarios lies therefore only in agricultural demands.

Including scenarios in WEAP is straightforward and follows a logical tree framework. Figure 10 shows the three scenarios of the current study, that are all based on the Reference situation. Note that also scenarios themselves might have derived sub-scenarios. One can think about for example a base scenario as "Climate Change" having two sub-scenarios: "2050" and "2100" as shown in Figure 10. Note that this Climate Change scenario was not analysed in this study.

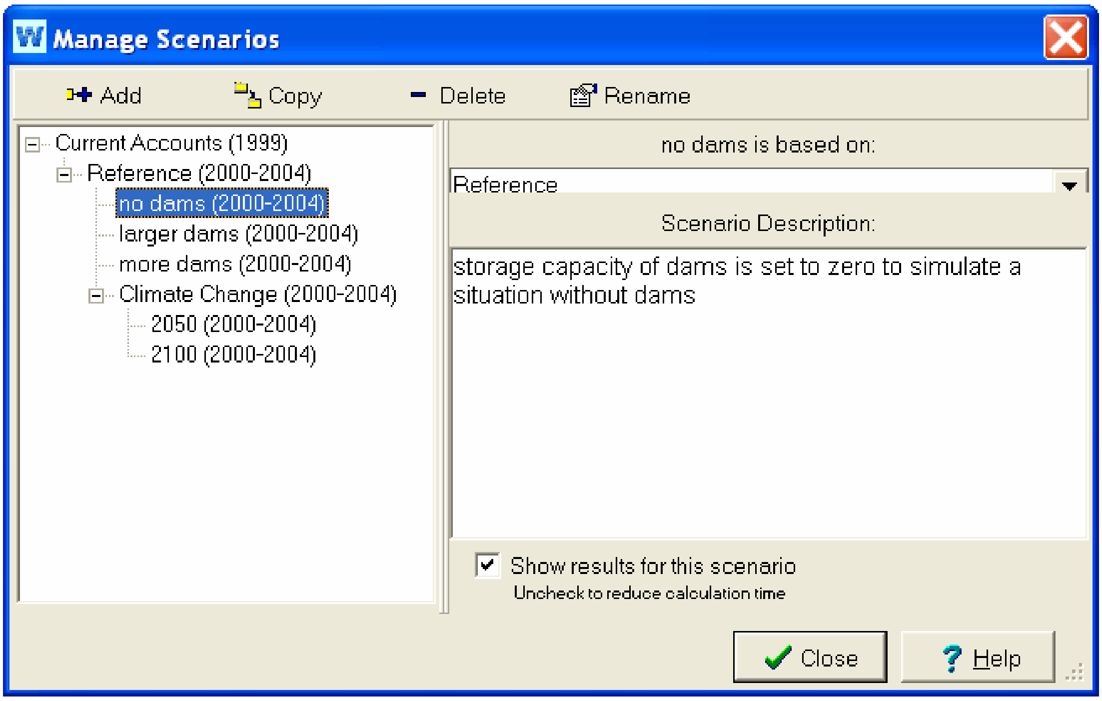

Figure 10. Example of Manage Scenarios screen in WEAP.

3.4.1 Scenario: NoDams

In the scenario without dams the key assumption percentage active dams is set to 0 and the key assumption percentage natural dams to 0.2. This results in various changes in the model. The storage capacity of the RRNs has decreased to 10% of its original value. The same decrease occurred in the parameters Top of Conservation, Top of Buffer and Top of Inactive. Consequently, the ratios between the parameters have not changed.

The water use of the demand sites is also based on the number of dams. For the domestic demand the number of households is based on the number of SASOL dams. This number is unaltered, so the number of household and the domestic water use also are unaltered. The same applies for the livestock water use and the other water uses. However, the agricultural water use is based on the number of active dams in a catchment. This number is decreased to 0, so no irrigated agriculture takes place in a situation without dams. Other parameters in the model are unchanged.

3.4.2 Scenario: MoreDams

Another scenario is one with twice as much dams as in the Reference scenario. In this scenario the key assumption percentage active dams is set to 2. Accordingly, the calculation of the number of dams including natural sand dams is changed too. Due to these changes the storage capacity of the RRNs has doubled. The same increase occurred in the parameters Top of Conservation, Top of Buffer and Top of Inactive. Consequently, the ratios between the parameters have not changed.

Due to the increase in the number of active dams, the irrigated agricultural area has also doubled. Consequently, the agricultural water use has increased significantly in this scenario. Other parameters in the model are unchanged.

3.4.3 Scenario: LargerDams

In the third scenario the number of dams is unchanged. Only the Unit storage capacity of a single sand dam is doubled, resulting in an increase in storage capacity of the RRNs. Contrary to the MoreDams-scenario, the agricultural water use is unchanged in this scenario.

In Table 4 a summary is presented of the parameters changed under the scenarios.

Table 4. Parameters changed to mimic the different scenarios.

	Parameters changed		**Resulting changes**
Scenario	**Percentage active dams**	**Unit storage capacity (m3)**	**Agricultural water use**
Reference	0.9	1080	100%
NoDams	0	1080	0%
MoreDams	2	1080	200%
LargerDams	0.9	2160	100%

4 Results

One of the strong components of WEAP is the way results can be presented and combined in graphs, tables or maps. Multiple options exist to aggregate data in time, space or per hydrological component. Moreover different scenarios can be compared easily. Additionally, data can be exported to Excel for further analysis. The most important features to display output will be presented in this chapter while detailed output is shown in the Appendices. Focus will be on results for the Current accounts, the Reference scenario and the other scenarios.

4.1 Reference Scenario

The Reference scenario (1999 to 2004) contains the same data and structure as the Current accounts year (1999). The only difference between 1999 and the following years 2000 to 2004, is the population growth in Kitui town. Obviously, also meteorological data (measured precipitation and potential evapotranspiration) are different for the five years. Current accounts for Kitui area were based on 1999 data and results are presented on: (i) availability of water, (ii) demand and demand coverage, and (iii) streamflow. Focus in this chapter will be on the options WEAP offers to present results, while detailed results regarding Kitui are presented in the Appendices.

4.1.1 Water availability

The first component to focus on is the amount of water available for further use. As explained before, WEAP is not a straightforward rainfall-runoff model but provides several options to deal with water supply / water availability. In earlier versions of WEAP water availability / supply could be included only as a fixed amount flowing into the study area as so-called headflows. However, the WEAP version used for this study has a new node component called Catchments, which considers simplified rainfall-runoff processes.

Processes in Catchment nodes include precipitation as input, and losses by evaporation that are based on the potential evaporation and the water availability. The difference between precipitation and actual evapotranspiration is than the available water that can be used downstream.

As an example of WEAP's capability to present results at different levels of detail and aggregation, the following figures are presented for the Catchments. Figure 11 shows the annual runoff from the Catchments indicating clearly that large annual variation in runoff exist. Especially in 2000 runoff was only some 60% of the year before, demonstrating that the Kitui area is sensitive to year-to-year variation. Water resources measures should therefore include options to overcome this year-to-year variation, such as large reservoirs or groundwater use as buffer. The figure also shows that Catchment 1 generates a substantial amount of runoff. This is due to the large surface area of this Catchment node (Figure 7 and Table 6).

WEAP offers the opportunity to explore runoff and associated streamflow in a comprehensive way as shown in Figure 12. These kind of figures are essential in understanding quickly what processes are taking place in which part of the study area. Also in terms of communication with stakeholders such as water managers and policy makers these kind of graphs are very useful.

In order to understand better the hydrological situation and the water availability of the Kitui area, monthly graphs of runoff can be produced (Figure 13). Two rainy seasons clearly reflect the two periods when runoff is generated: November to January and March to May. This graph indicates also the most critical period in the year when runoff is almost zero and provision for additional water storage should be available.

Finally, it should be evaluated which land cover is generating most runoff. In WEAP this can be evaluated by presenting results at another aggregation level. Figure 14 shows that Other Vegetation is generating somewhat more runoff compared to the maize areas in the Catchments.

Another relatively small supply is water originating from aquifers, the so-called Kitui borehole, and supply from Masinga reservoir. These supplies are for domestic use in Kitui and Matinyani. Although exact figures on total supply of these sources is lacking, personal communication from Mr. M'Ngila indicates that normally no water shortages occur in Kitui and Matinyani. Figure 15 shows the supply, consumption and return flows of the two major towns in the area. The normal pattern for urban water that only a small amount of supply is actually consumed can be seen here as well. The return flows can be considered as supply that can be added to the river system, but it is of too low quality to be stored in the sand dams and used. Note that this amount is less than 1% in the study area.

Detailed output for the Kitui area of these rainfall-runoff processes and the amount of water generated to supply the sand dams is given in Appendix A.3.

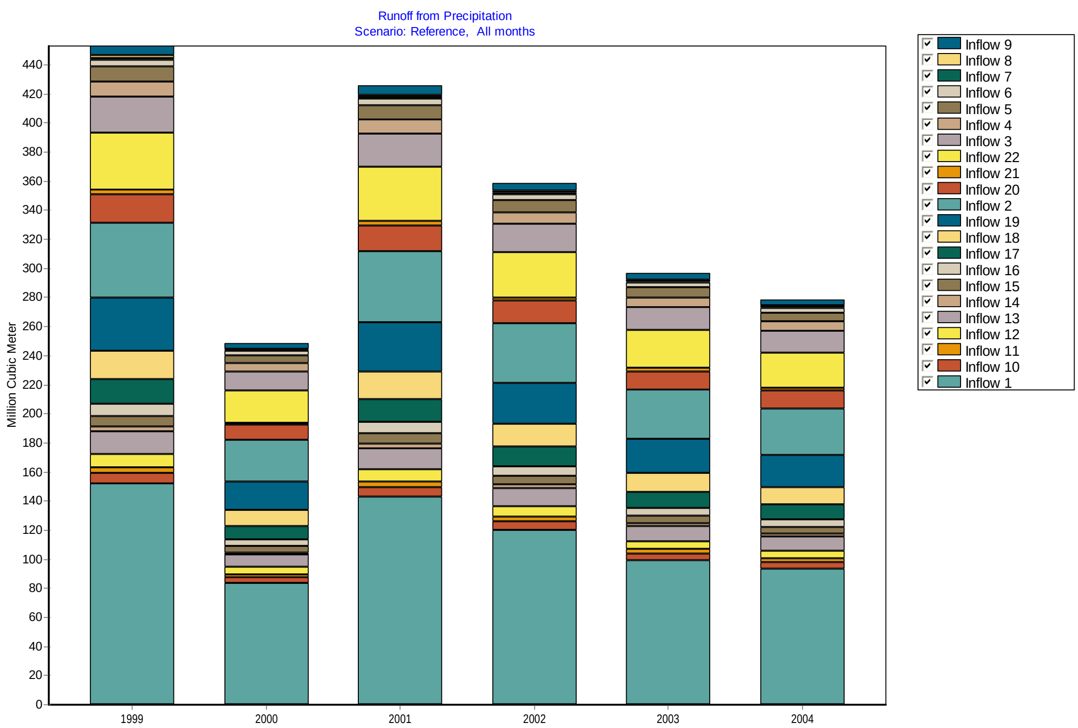

Figure 11. Annual runoff from the 22 catchments.

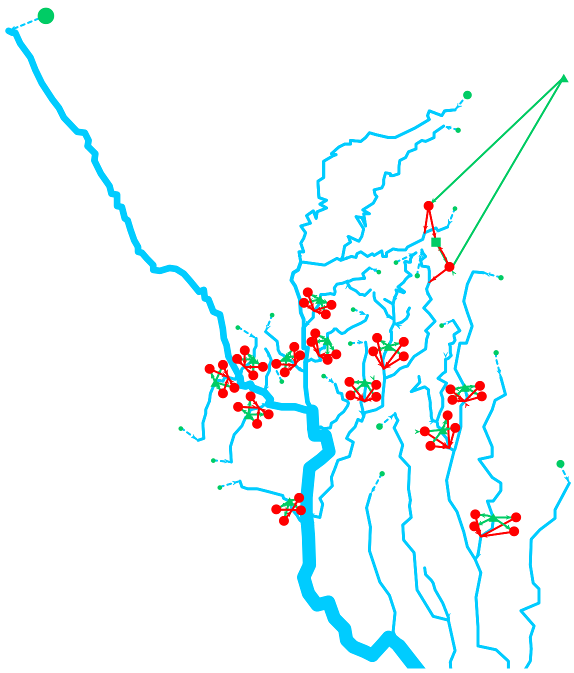

Figure 12. Catchment runoff and streamflow displayed as relative sizes for 1999.

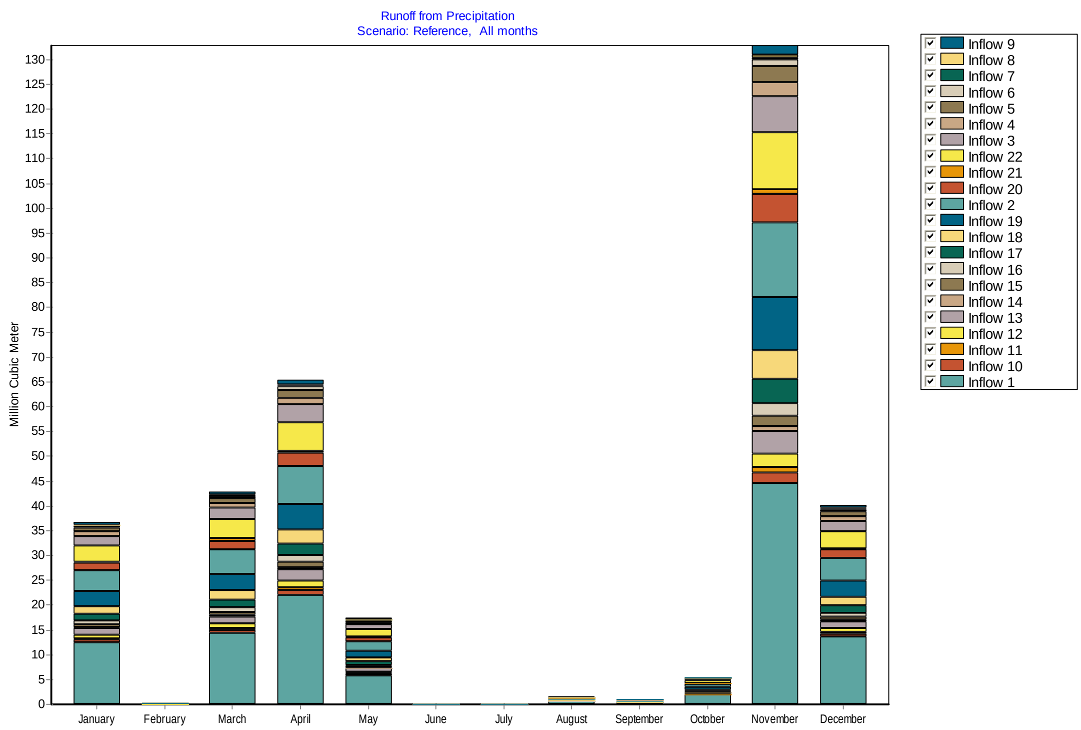

Figure 13. Average monthly runoff from the 22 catchments for six years (1999 to 2004).

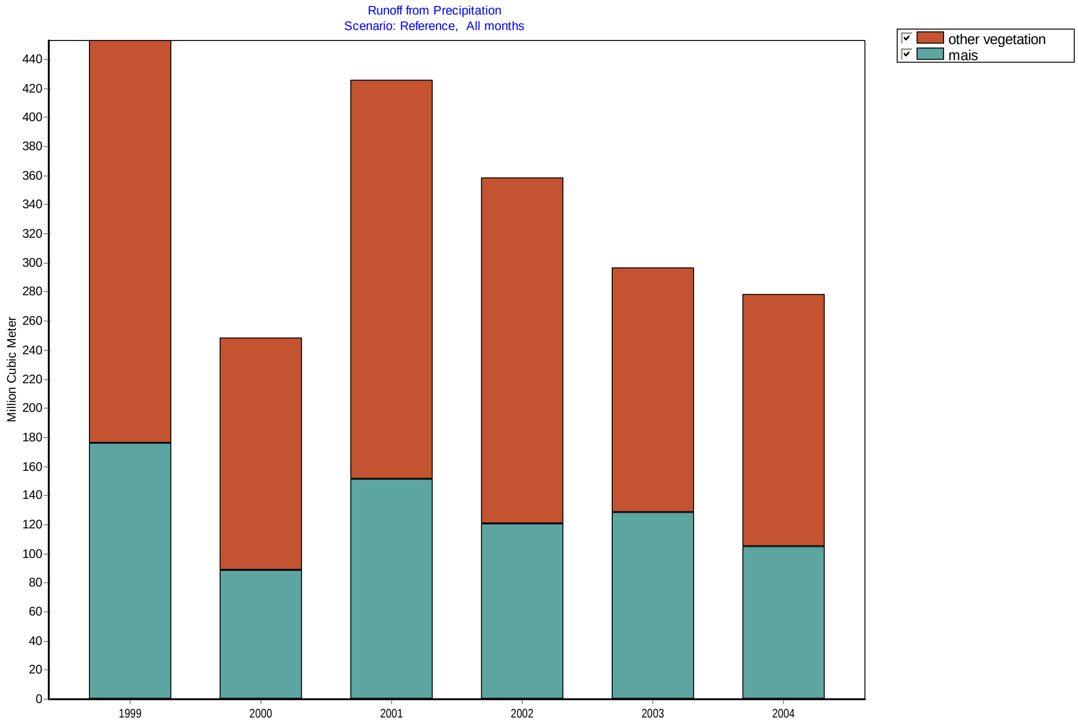

Figure 14. Annual runoff from the 22 catchments for the two landcovers considered.

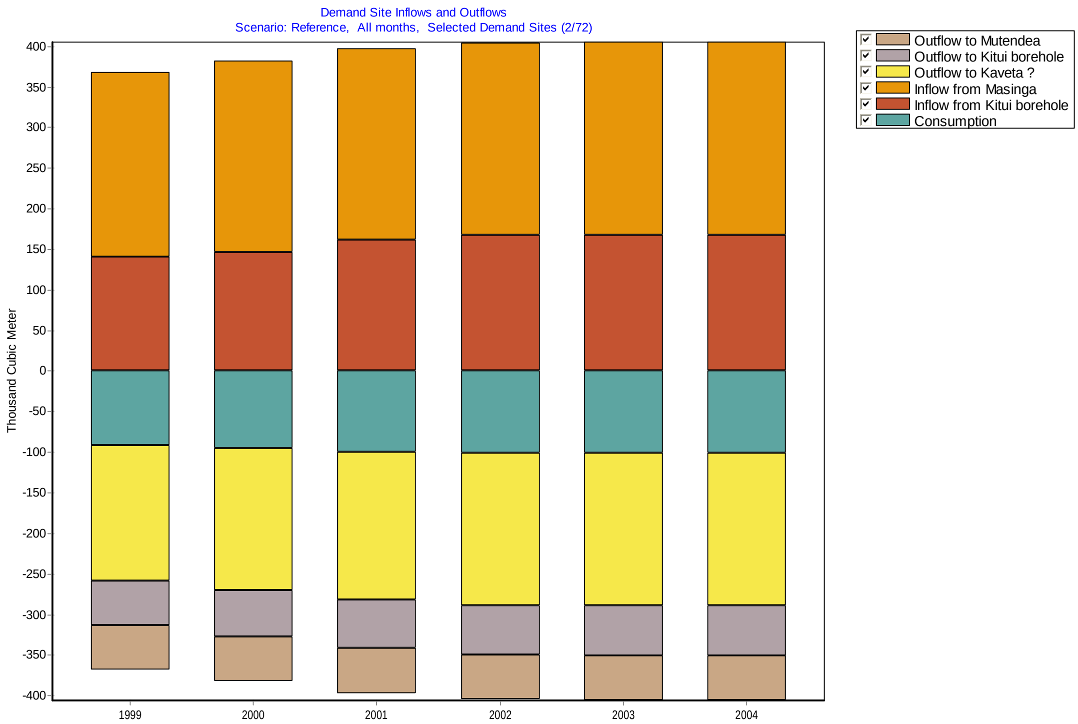

Figure 15. Supply, consumption and return flows for the towns of Kitui and Matinyani.

4.1.2 Demand and demand coverage

The main focus of WEAP is supply management of demand sites. In this paragraph, the results of the five reference years (1999 to 2004) regarding the demand, supply and coverage of the demand sites are displayed and analysed. Special emphasis will be put on the RRNs (Representative Reservoir Nodes) as they are the base for this WEAP model. As mentioned earlier a RRN is a cluster of sand dams on which four different demands are coupled: agriculture, domestic, livestock and others. Focus will be on the options WEAP offers to analyse demand and demand coverage, while detailed results are presented in the Appendix A.3.

First we explored what is the actual demand is for the various demand sites. Figure 16 shows that the biggest demand is from Kitui domestic. However, Kitui receives water from Masinga as well as from Kitui bore hole for which storage is sufficient, so no shortages occur. WEAP offers the opportunity to present the unmet demand (water shortage) in a graphical way that is extremely powerful to understand the system. Figure 17 confirms that no unmet demand can be seen for Kitui. However, there are a few demand sites where a high unmet demand can be seen. As mentioned earlier all demand sites have four components: agriculture, domestic, livestock and others. For these four components is the agricultural demand the biggest with about 55% of total demand, followed by domestic demand of 28%. Livestock (10%) and other (7%) demands are relatively low. It should also be considered that especially domestic demand has the highest priority. This option is done straightforward in WEAP by specifying the demand priorities.

The result of this priority setting can be clearly seen in Figure 18. For the dry period, July to September, the coverage for domestic is much higher than for the other components. This unmet demand is a result of water shortage in the sand dams as displayed in Figure 19.

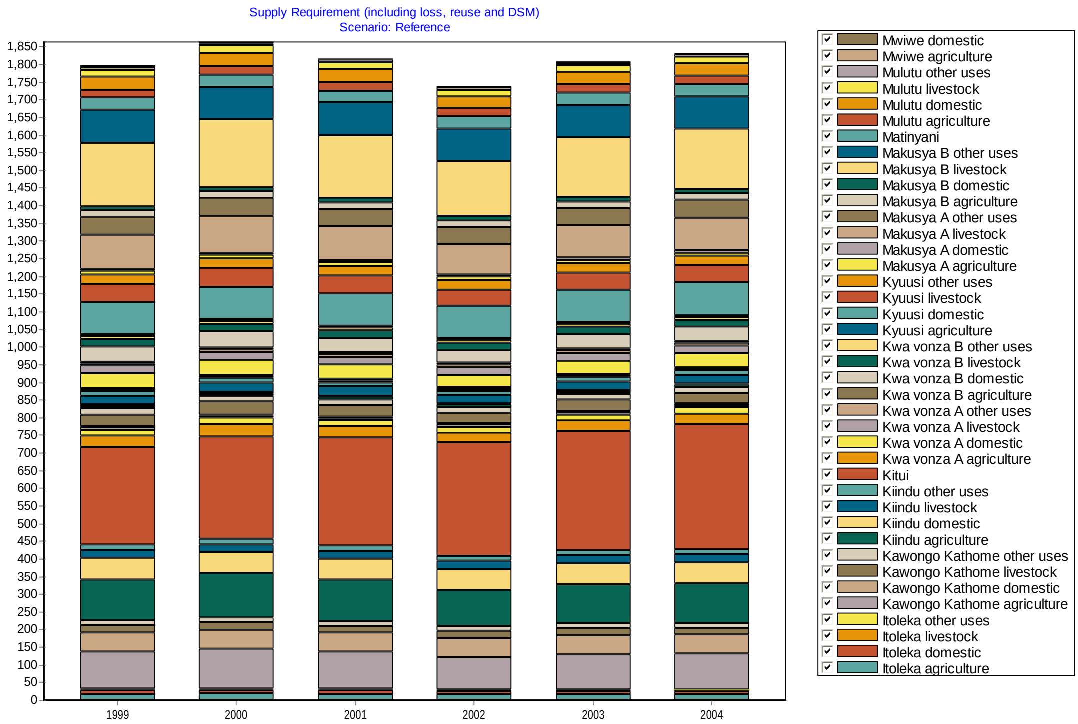

Figure 16. Total demand for all demand sites.

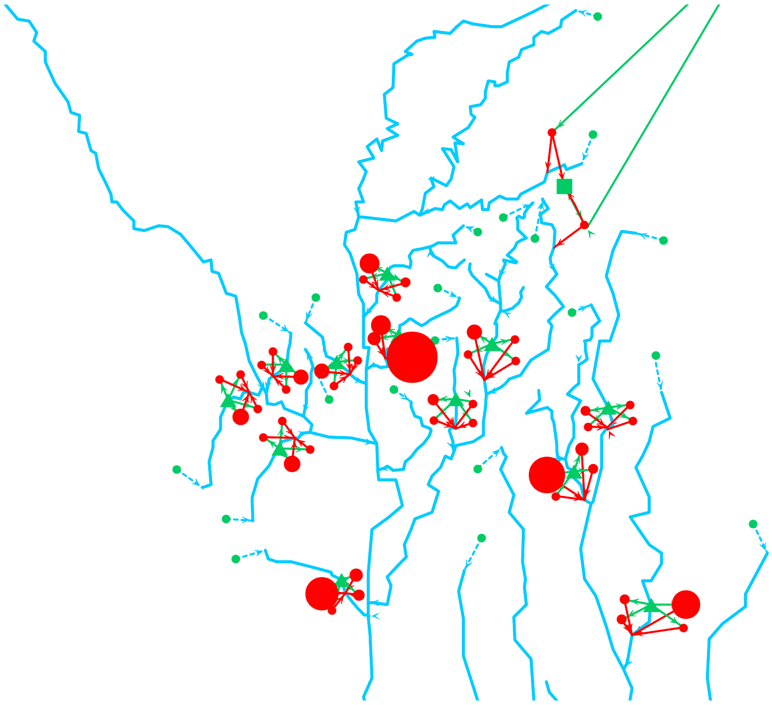

Figure 17. Unmet demand for 1999.

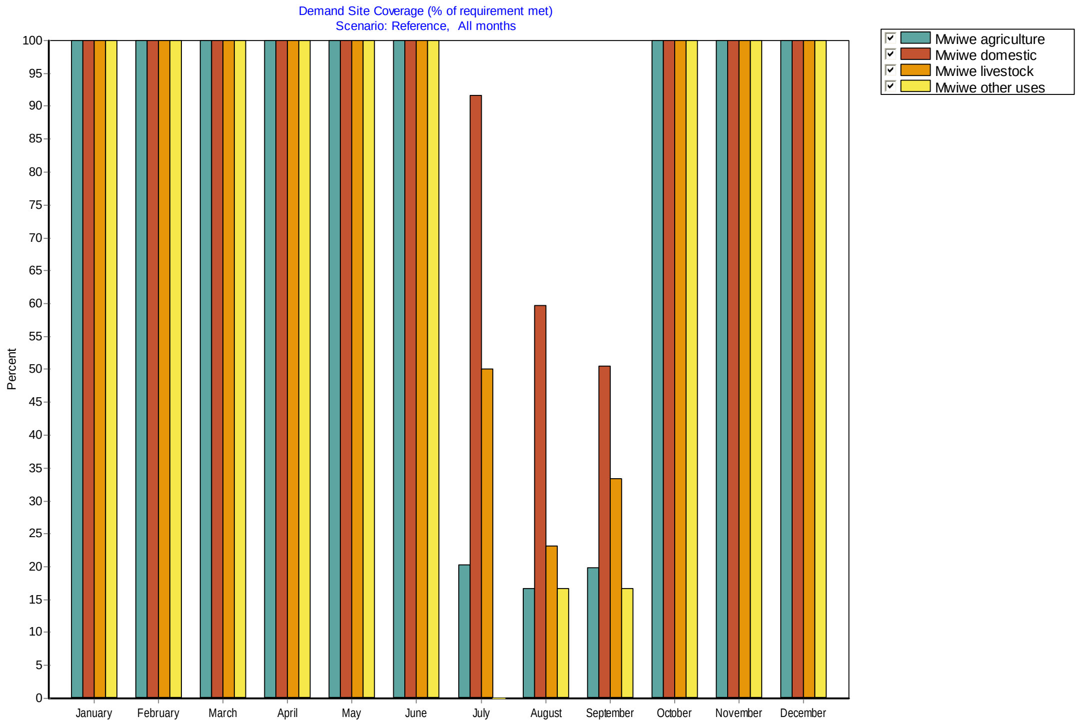

Figure 18. Demand coverage for the four demand components in Mwiwe region.

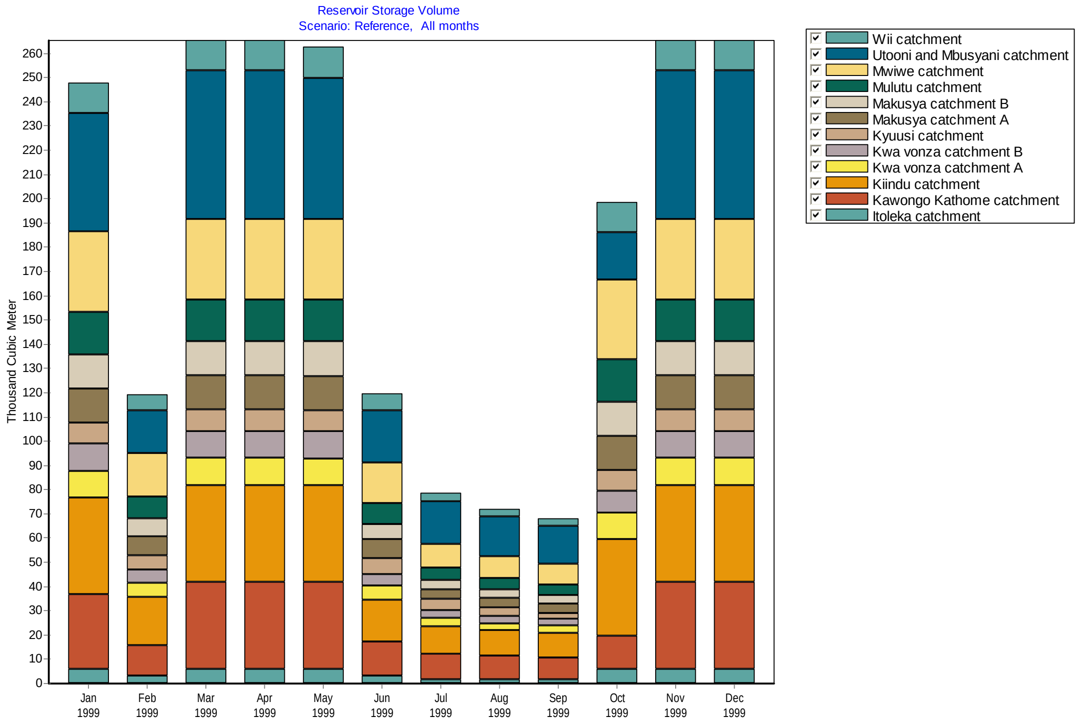

Figure 19. Storage in the sand dams presented for the RNNs.

4.1.3 Streamflow and sand dams

Discharge at the outlet of the Tiva river system follows the pattern of the inflow from the catchments Figure 20). Downstream discharge is about 1 Mm^3 lower than the inflow into the system, due to the supply of water to the demand sites in the basin. This less than one percent of total discharge. Also in Figure 20 the two rainy seasons are clearly visible in the discharge of Tiva river.

WEAP offers the option to evaluate quickly where most water is flowing (Figure 21). Most of the water discharges through the main Tiva river and some of the largest tributaries, as can be seen from the example of November 1999. The smaller tributaries, where the SASOL sand dams are located, have a very small contribution to the discharge. Table 20 shows that in total 74.9 Mm^3 flows from the catchments upstream of an RRN into the river system. That is 16.5 % of the total contribution of the catchments (453.1 Mm^3).

The difference between the inflow and outflow of the RRNs is relatively small, indicating that total amount of water supplied to the demand sites is also relatively small compared to total flows in the rivers. The storage of the RRNs is displayed in Figure 22. Due to the high inflow the storage is highest in the two rainy seasons. In the dry seasons the storage will not go to zero because part of the water stored in a sand dam is not extractable.

The three figures presented in this section are only a small subset of the output WEAP can generate to analyse water resources issues. Output can be presented for every single stream in the area at each aggregation level as required (month, year).

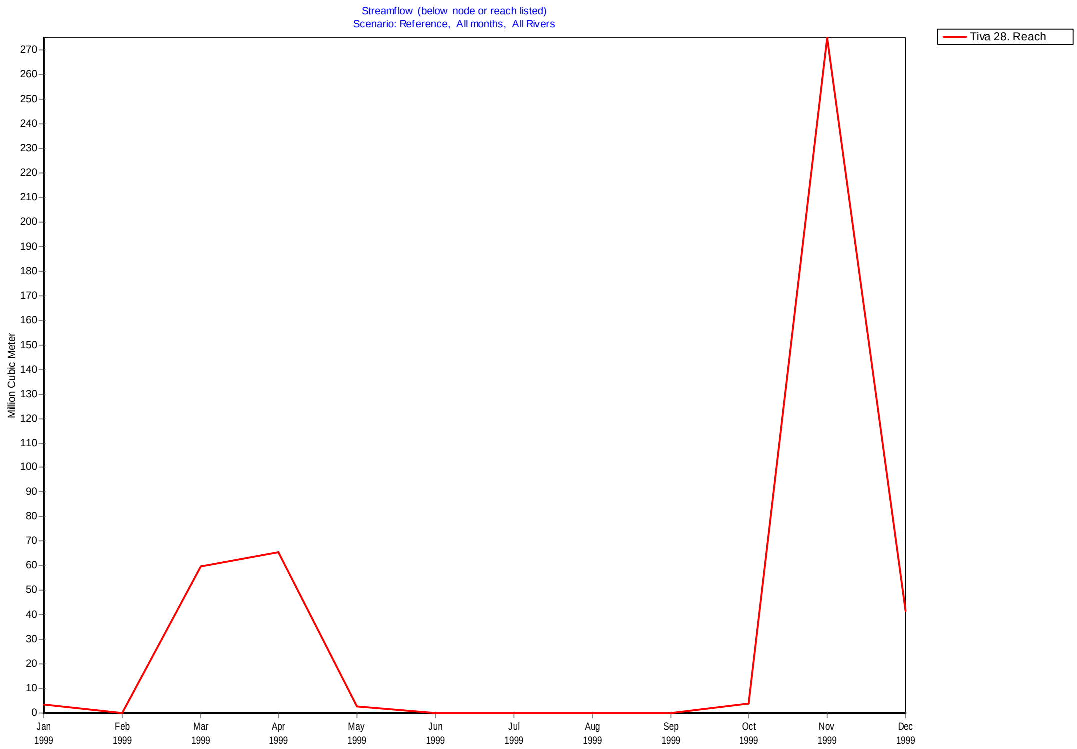

Figure 20. Discharge river Tiva at the outlet of the study area.

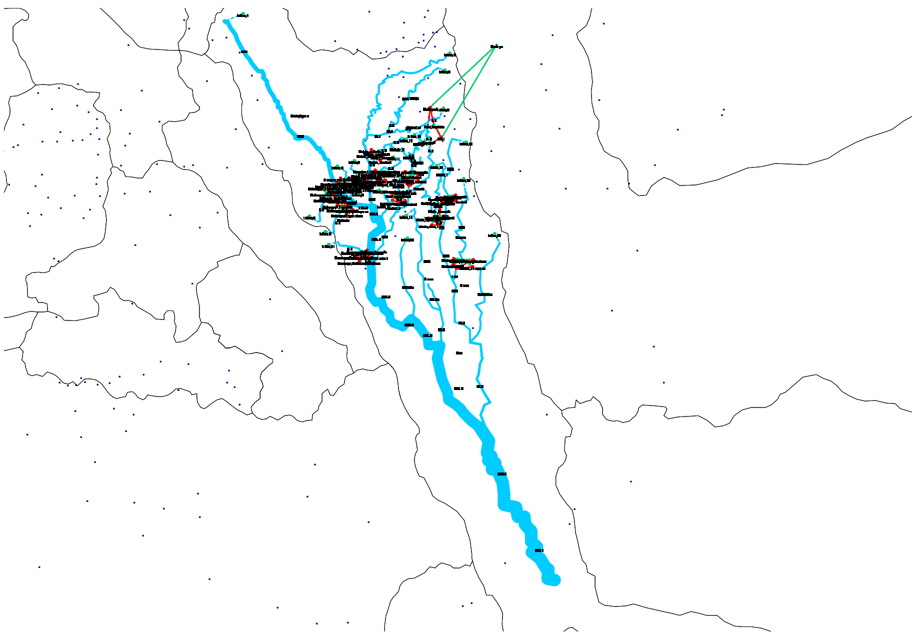

Figure 21. Streamflow November 1999.

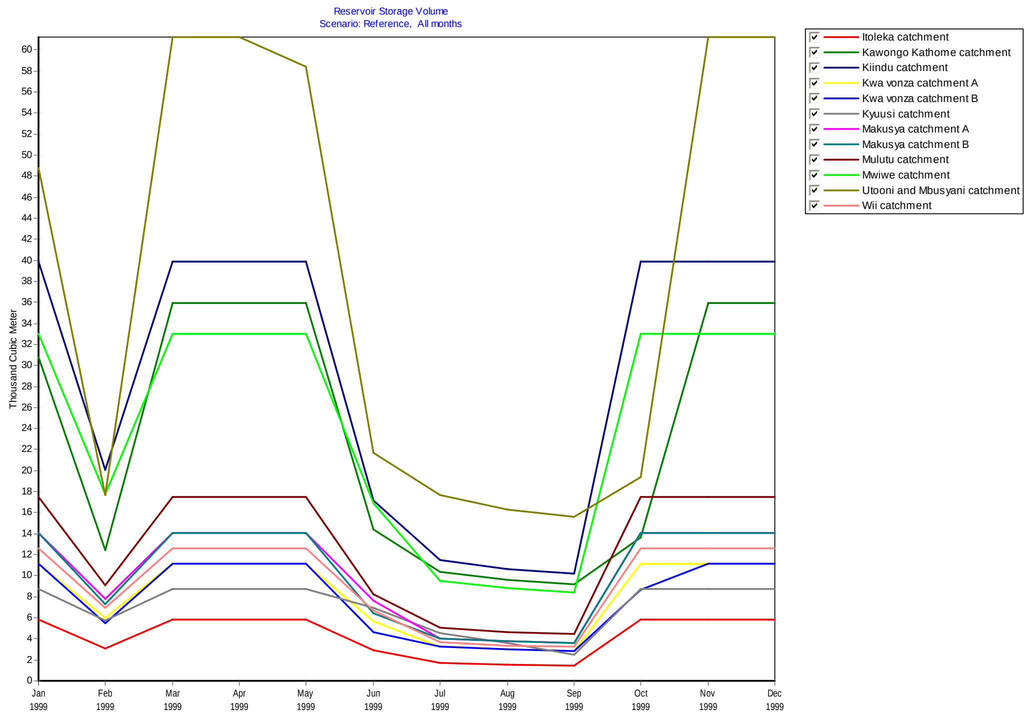

Figure 22. Actual storage in the sand dams presented for the RNNs.

4.2 Scenario: NoDams

The first scenario analysed can be considered as the situation before SASOL started to initiate dam construction. In the NoDams-scenario there are no active dams and the (irrigated) agriculture is set to zero. Furthermore, the NoDams-scenario contains exactly the same data and structure as the Reference scenario described in the previous section.

Water demand under the NoDams-scenario has been reduced drastically as it was assumed that no water from the remaining natural dams was used for agriculture. Only water for domestic, livestock and other uses is assumed to be extracted from these natural dams and rivers. Figure 23 shows that there is a substantial reduction in demand between about 650 and 800 x 10^3 m^3 per year. This is about 50% of demand in the reference case.

Interesting is also looking at how this demand for the three remaining uses is covered if no sand dams are present. For all years but 2003, coverage is better and less shortage exists under the NoDams-scenario (Figure 24). This is a somewhat surprising result as one would expect that sand dams would reduce water shortages. However, these results are somewhat biased since under the Reference scenario shortages are bigger due to the irrigated agriculture. It is therefore more realistic to consider only the coverage for domestic, livestock and other uses which is displayed in Figure 25.

Figure 26 confirms results presented in Figure 25 where the monthly average unmet demand is shown. The sand dams (Reference scenario) have a lower unmet demand if only domestic, livestock and other uses are considered. Striking is that especially the period in which water shortages occurred under Reference has gone down from 5 months a year to 3 months a year.

Finally, it is expected that discharge downstream of the Kitui area in the Tiva river would be somewhat higher in the NoDams-scenario, due to less storage capacity and less consumption. Figure 27 shows that flows are indeed higher under the NoDams-scenario, but, given the average annual discharge of about 300 MCM, this increase is lower than 1%. Interesting of Figure 27 is that flows in July are lower under the NoDams-scenario, showing the effect of return flows from water extracted out of the dams. However, since this amount is relatively small (about 20,000 m^3 per month which is less than 10 l s^{-1}) positive impact for downstream users can be neglected.

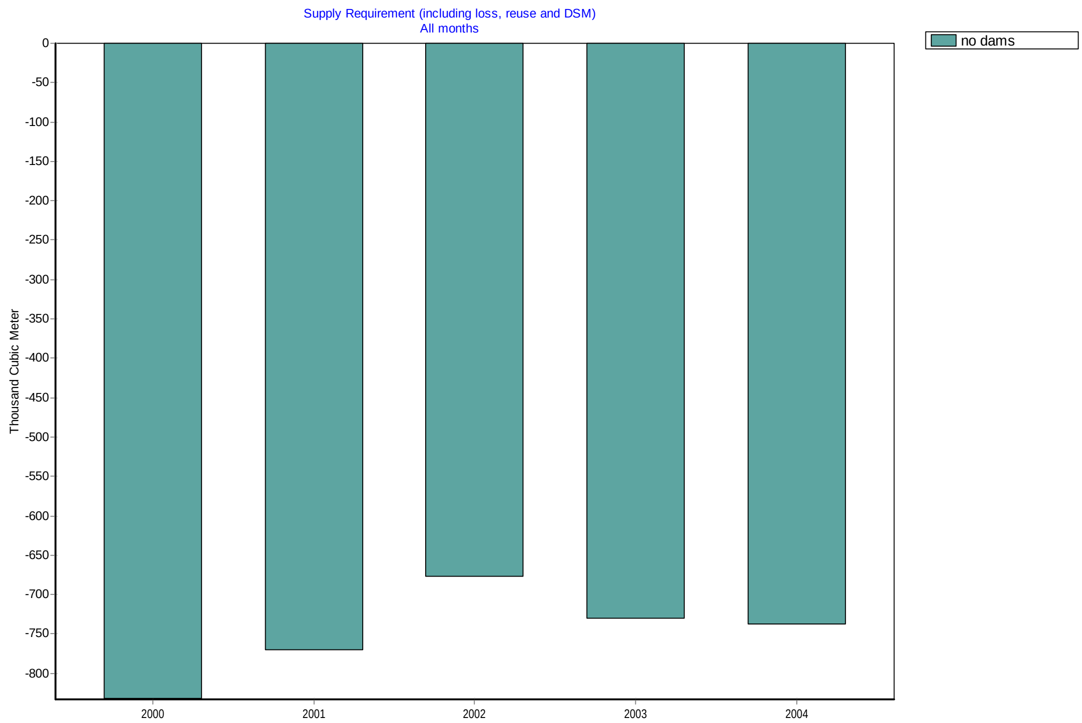

Figure 23. Reduction in demand for the NoDams-scenario.

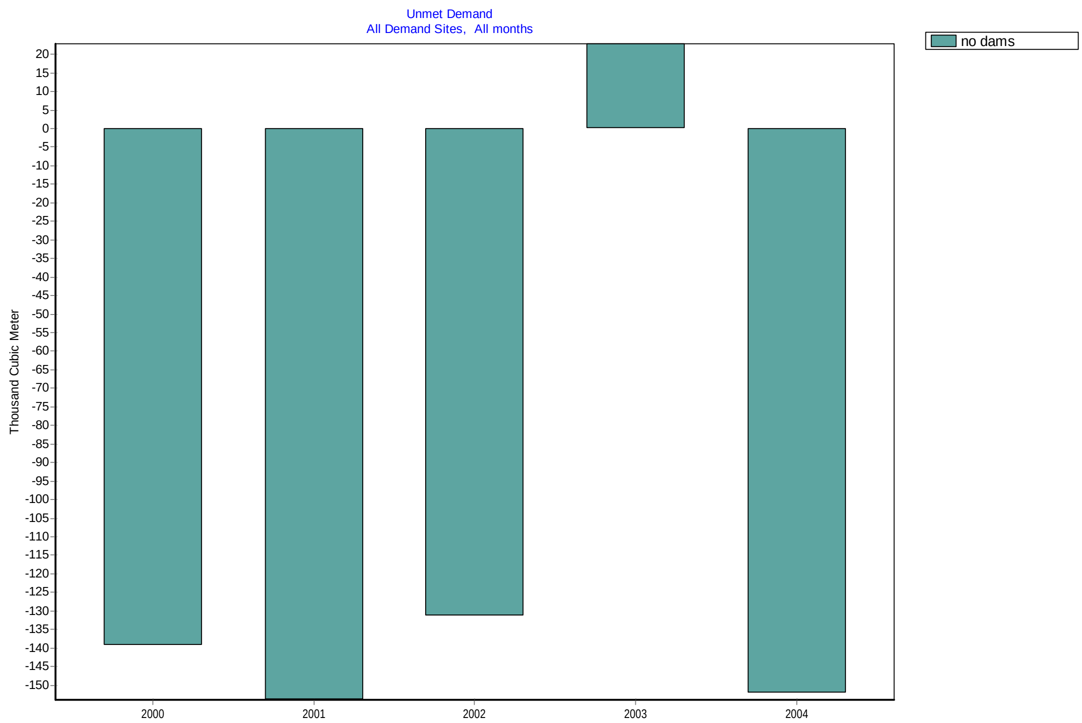

Figure 24. Changes in the unmet demand for the NoDams-scenario. Negative indicates less shortages under the NoDams-scenario.

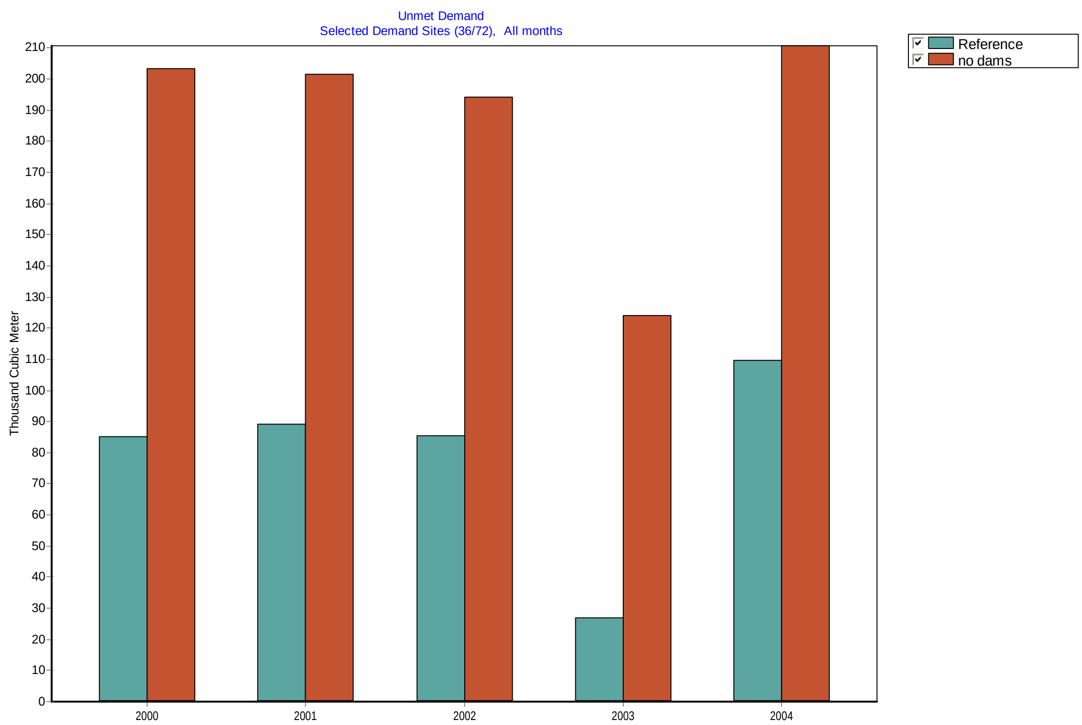

Figure 25. Unmet demand for the Reference and the NoDams-scenario. Only unmet demand for domestic, livestock and other uses are shown.

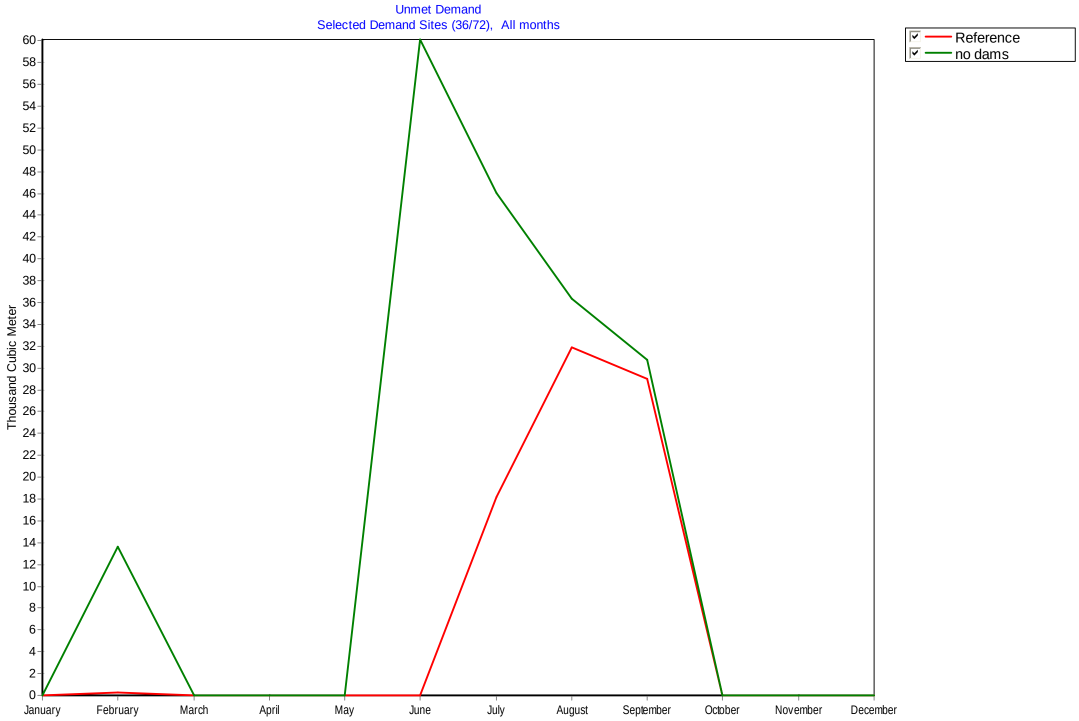

Figure 26. Monthly average (2000-2004) unmet demand for the Reference and the NoDams-scenario. Only unmet demand for domestic, livestock and other uses are shown.

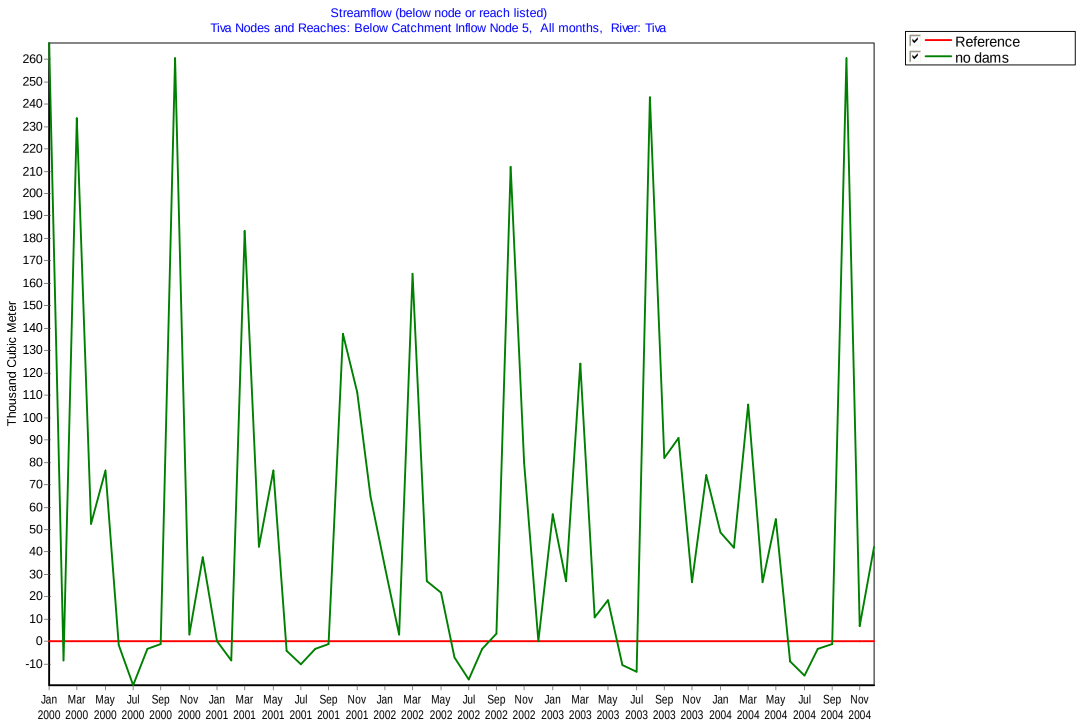

Figure 27. Changes (NoDams minus Reference) in streamflow below the Kitui area in Tiva river.

4.3 All scenarios

In the previous sections the Reference as well as the NoDams-scenario have been discussed in some detail, with special emphasis on how WEAP can be used to understand the system. In this section a comparison between Reference and the three scenarios (NoDams, MoreDams, LargerDams) will be presented.

First, it will be explored what the impact is of changes in dams on the discharge out of the Kitui region. According to Figure 28 almost no difference in outflow can be seen on an annual base, whatever scenario is considered. If we look at monthly differences, compared to the Reference situation, some interesting differences appear (Figure 29). As discussed before, the NoDams will generate somewhat more streamflow except for the month July. LargerDams and especially MoreDams will reduce streamflow especially during March and October. Since discharge in March is normally quite high, this will have no impact on downstream users. However, flows in October are relatively low and some impact, although low, might be considered.

This relative small impact on outflows has a positive impact on the Kitui area itself. More water is delivered under the LargerDams and MoreDams scenarios (Figure 30). Unmet demand (water shortage) seems to be higher under the MoreDams scenario (Figure 31) but this is mainly due to the expansion of irrigated agriculture associated to this. A close look at only domestic, livestock and other demands indicate that MoreDams and LargerDams are indeed positive in overcoming water shortages (Figure 32). Finally, Figure 33 shows that the number of months with water shortages (defined as an unmet demand larger than 5,000 m^3 per month) is five under NoDams and reduces to three months at the current situation (Reference scenario). Under LargerDams this reduces even further to only one month per year on average.

These analyses are all based on the entire system and the question remains whether smaller scale impacts occur. As discussed before, differences in discharge of Tiva river are negligible and the differences in coverage of water demand are very small and almost completely caused by differences in agricultural demand. So, do sand dams have no influence at all? A detailed look at discharges of rivers just downstream of the RRNs some striking differences appear. The months in the rainy season show very high discharges in all scenarios, and the months in the dry season have a discharge of zero in all scenarios. However, in some months, in between the rainy season and the dry season, the differences between the scenarios are considerable. For example the month January 2000 as shown in Figure 34 indicates that the discharge downstream the RNNs is very high in the NoDams (the far right of the graph) and almost zero in the MoreDams scenario (second scenario from the right). The discharge in the NoDams scenario is more then 2 times as high as the discharge in the Reference scenario. And the discharge in the MoreDams scenario is only about 20% of the discharge in the Reference scenario. These differences show the impact of the dams directly downstream during some months of the year.

Discussions and figures presented here show the strengths of WEAP in evaluating water supply and demand. Comparing different scenarios is unique in WEAP and can not be found in any other water resources analysis tool.

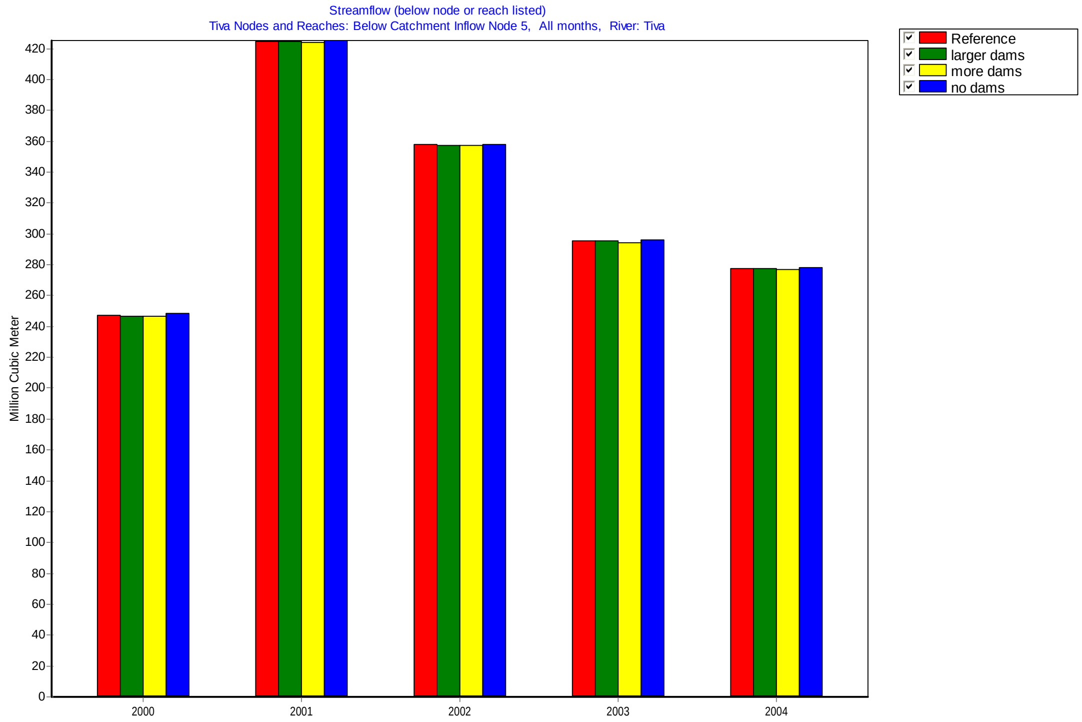

Figure 28. Annual discharge below the Kitui area in Tiva river.

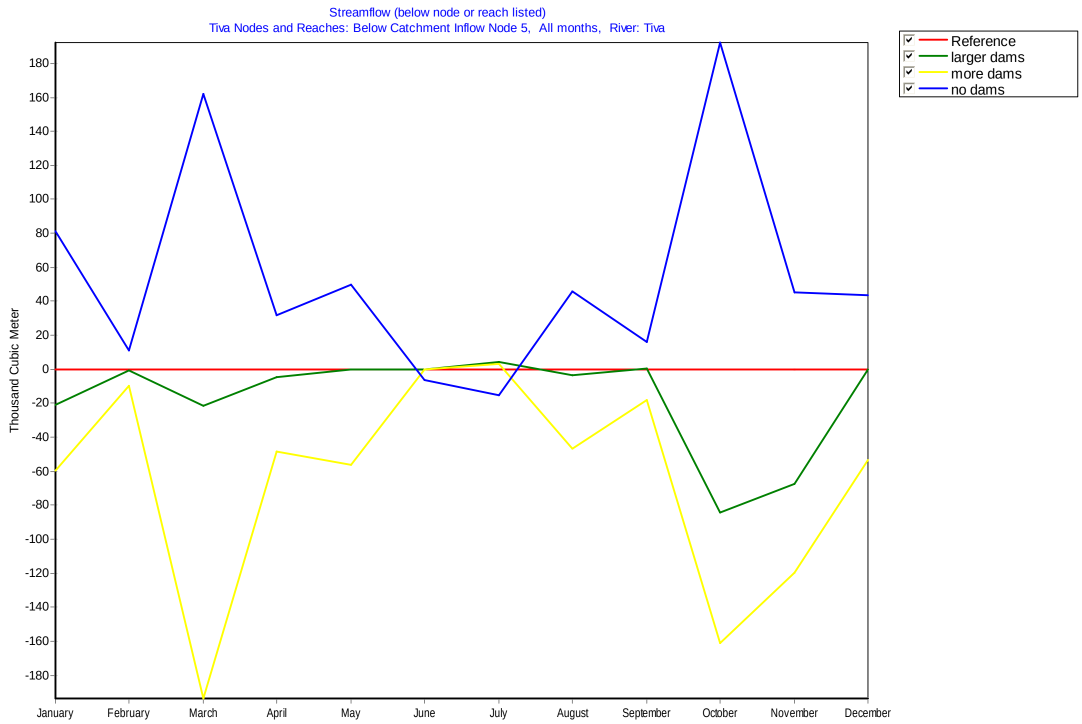

Figure 29. Changes (scenarios minus Reference) in streamflow below the Kitui area in Tiva river. Monthly averages (2000 to 2004) are displayed.

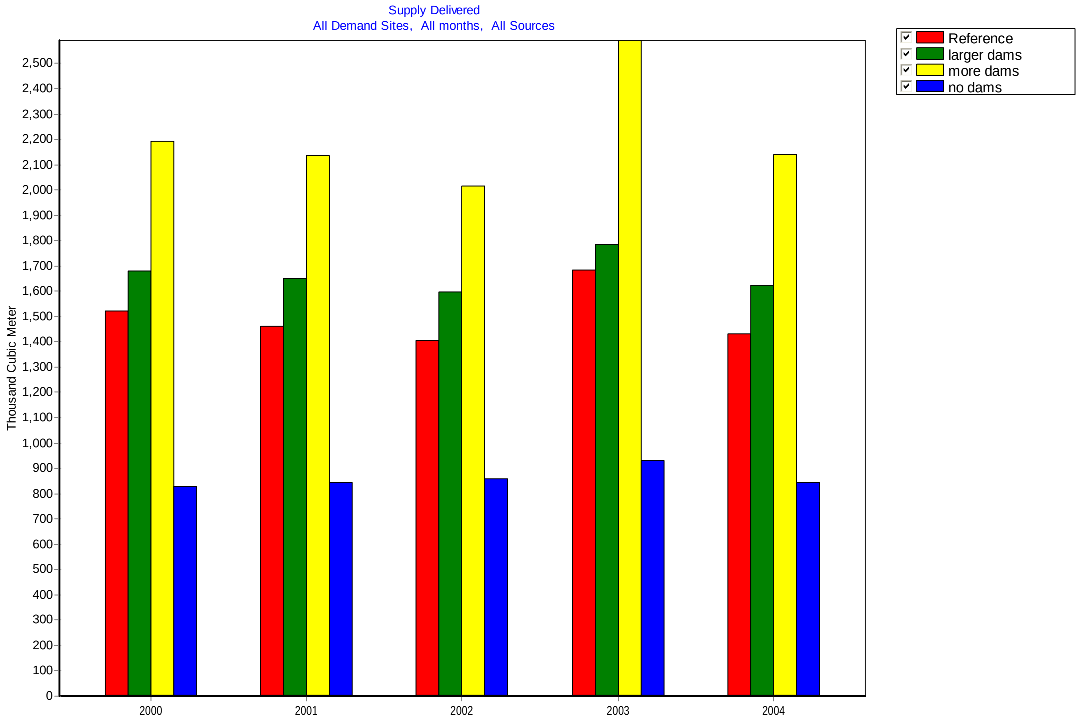

Figure 30. Supply of water delivered under the four scenarios.

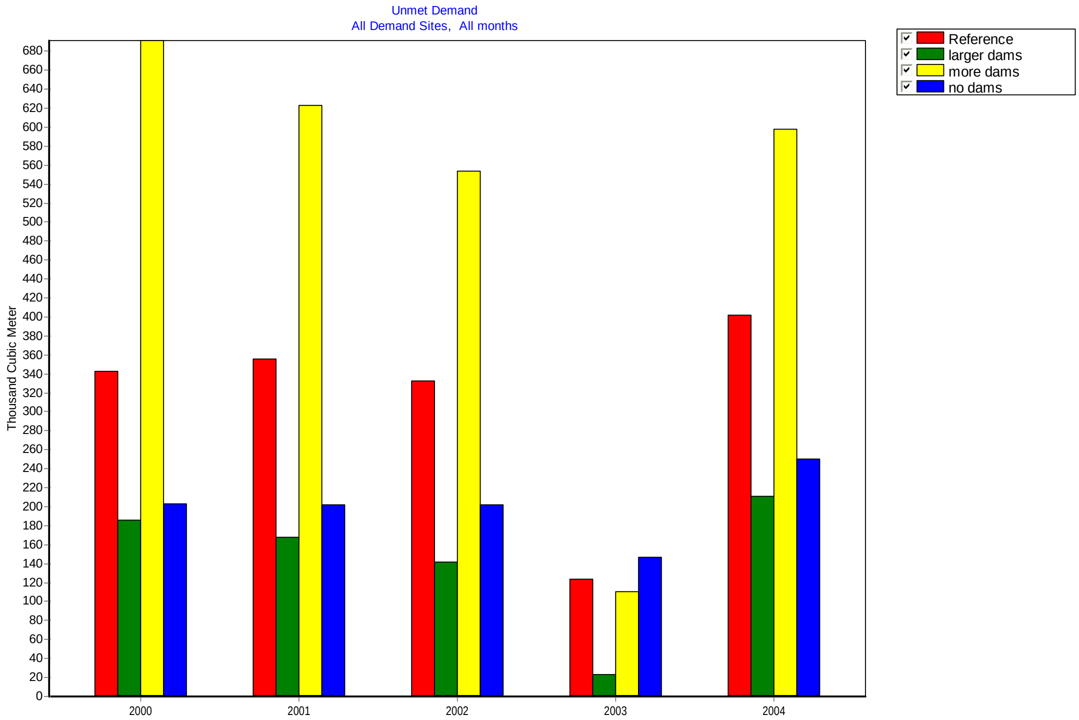

Figure 31. Unmet demand (water shortage) for the four scenarios.

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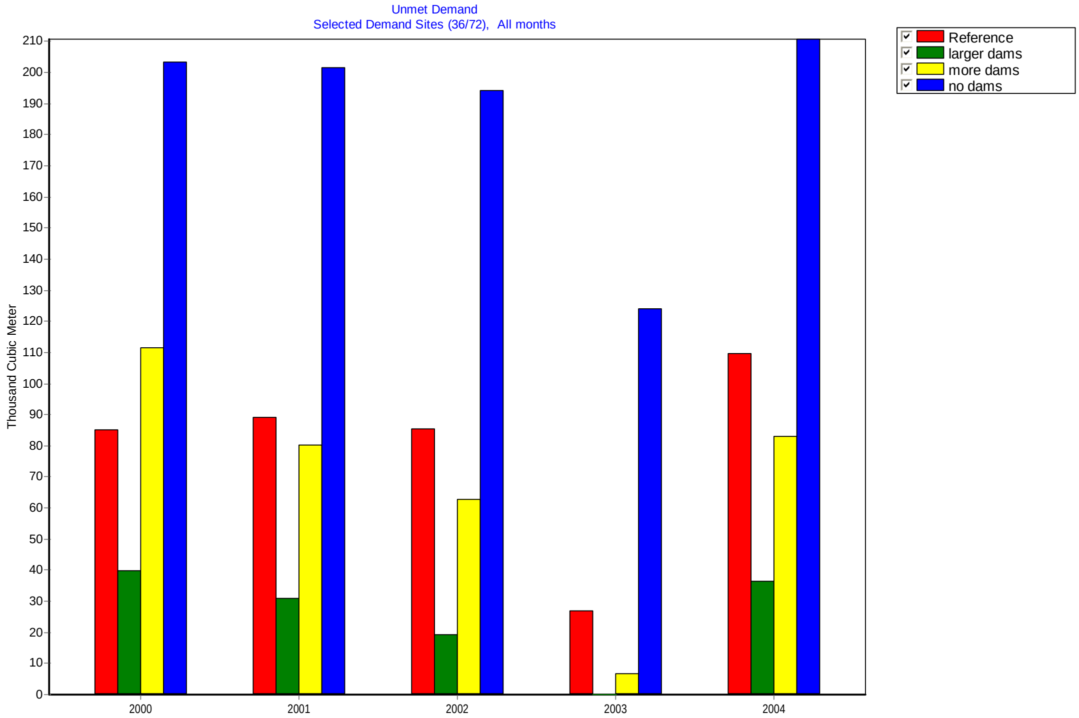

Figure 32. Unmet demand (water shortage) for the four scenarios for only domestic, livestock and other demands.

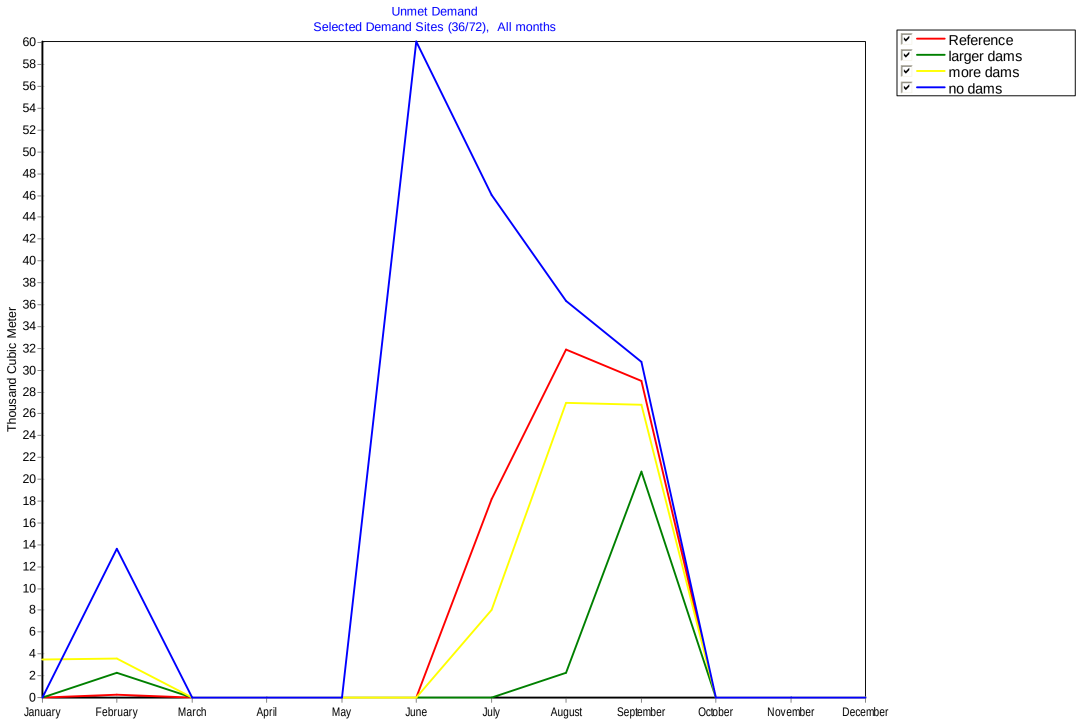

Figure 33. Unmet demand (water shortage) for the four scenarios for only domestic, livestock and other demands. Displayed are monthly averages (2000 to 2004).

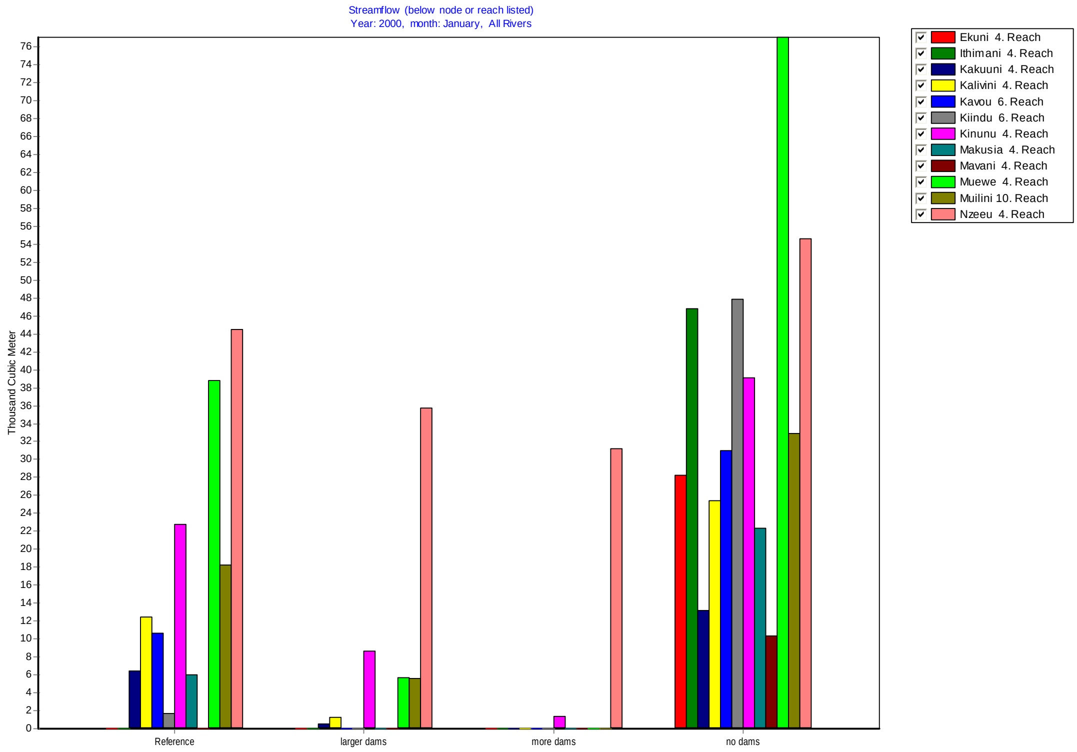

Figure 34. Local impact of sand dams presented for some selected RNNs for January 2000.

5 Conclusion and Recommendations

This study was undertaken to show the strength and weaknesses of WEAP in a setting with relatively low human interaction in the water cycle, a two-season climate with very dry spells and a relatively undeveloped land use. The WEAP model was setup in a relatively short time frame and was mainly based on information in the public domain and reports from earlier studies. WEAP model development is based on a very structured approach, where a consistent use of so-called Key Assumptions (variables) is important. This ensures a fast model development, ease in fine-tuning and most importantly a very flexible scenarios building.

Conclusions regarding this specific case of the Kitui area can be drawn. Regarding the **Reference** scenario the following results and conclusions can be made:

- strong seasonal variation in discharge of Tiva river: 0.0 M m^3 in the dry season to 146.2 M m^3 in the wet season
- the difference between inflow and outflow of RRNs (= consumption) is 0.2%
- the annual total demand is only 0.4% of the annual total discharge
- the coverage for the RRN demand sites ranges from 3% in the dry season to 100% in the wet season, in average the coverage for the RRN demand sites is 76%
- in the dry season even the domestic supply is not met

Overall it can be concluded that the annual demands are negligible in comparison to the annual total discharge, but in the dry season discharge is not sufficient to meet total demand.

Comparing the different scenarios and their impact on **discharge** the following results and conclusions can be extracted from the WEAP analysis:

- in a scenario without dams and irrigated agriculture, the discharge of Tiva river increases with 0.16%
- in a scenario with twice as much dams and irrigated agriculture, the discharge of Tiva river decreases with 0.18%
- in a scenario with a doubled storage capacity and an equal amount of irrigated agriculture, the discharge of Tiva river decreases with 0.05%

In summary it can be concluded that the sand dams do not have influence on the discharge of Tiva river, however in the transition months between the rainy and the dry season the differences in discharge in the rivers directly below the RRNs are large. In the scenario without dams and irrigated agriculture, the discharge of these rivers is 243% of the Reference scenario discharge. And in the scenario with twice as much dams and irrigated agriculture, the discharge of these rivers is 19% of the Reference scenario discharge. Data was obtained from the Ministry of Water in Nairobi, Kenya, for validation of the streamflow results. However, no information was given regarding measuring location, measured parameters, units, etc., so these data were useless. Due to the lack of data, validation of the WEAP model was only done qualitatively though conversations with local staff of SASOL.

WEAP analysis for Kitui regarding **demand and supply** showed:

- in a scenario without dams and irrigated agriculture, the coverage for the sand dam demand sites ranges from 0% in the dry season to 100% in the wet season, in average the coverage for the sand dam demand sites is 70%

- in a scenario with twice as much dams and irrigated agriculture, the coverage for the sand dam demand sites ranges from 6% in the dry season to 100% in the wet season, in average the coverage for the sand dam demand sites is 73%
- in a scenario with a doubled storage capacity and an equal amount of irrigated agriculture, the coverage for the sand dam demand sites ranges from 19% in the dry season to 100% in the wet season, in average the coverage for the sand dam demand sites is 89%

Overall the conclusion can be drawn that the construction of more dams or dams with higher storage capacity does not increase the average coverage significantly, but in the dry season the water shortage is diminished.

The study clearly demonstrated that a framework as WEAP is powerful in evaluating current and future options in water resources. For the Kitui area, additional data would increase the accuracy of the analysis and enable validation of the results. The strong aspect of WEAP is that the framework is already in place so that additional or more accurate data can be included directly and evaluation can be performed in a few minutes. For example, a water quality analysis or an evaluation of the effects of climate change can be done very easily with this WEAP model for Kitui. WEAP can be used in an explorative way to support discussions on data and scenarios. Previous examples of WEAP studies have proven the ability to use WEAP in a workshop, make changes and analyse these changes directly.

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Personal observations (pers.obs. July 2006)

Field visit Kenya July 2006, Anne van Loon and Peter Droogers

A Appendix Data

A.1 Crop coefficient

(From Puttemans et al. 2004)

Mais:

Growing period within the year:

Sowing time: October (short rain season) and March (long rain season)
Harvest time (fresh): January (short rain season) and June (long rain season)
Harvest time (dry): February (short rain season) and July (long rain season)

Crop coefficient and rooting depth per growth stage:

	Initial	*Development*	*Mid*	*Late*	*Total*
Length, fresh (days)	20	35	40	5	100
Length, dry (days)	20	35	40	30	125
K_c-factor (fresh)*	0.30	>>	1.20	0.60	-
K_c-factor (dry)*	0.30	>>	1.20	0.35	-

* Modified values for maize (grain) (FAO irrigation and drainage papers)

Sukuma Wiki:

Growing period within the year:

Sowing time: May-June or January
Harvest time: After 3 months continuously for 1 year

Crop coefficient and rooting depth per growth stage:

	Initial	*Development*	*Mid*	*Late*	*Total*
Length (days)	20	35	25	10-270	90-360
K_c-factor*	0.70	>>	1.05	0.95	-

* Modified values for cabbage, Brassica oleracea var. capitata (FAO irrigation and drainage papers)

A.2 Details input data

In this Appendix the input data for the WEAP model of Kitui are presented.

*Table 5. **Precipitation** in Kitui in mm (Source: IVM, VU Amsterdam).*

	1999	**2000**	**2001**	**2002**	**2003**	**2004**
January	19.1	7.0	244.8	79.5	31.6	48.0
February	2.2	0.0	0.0	7.5	17.2	47.9
March	121.0	52.5	113.0	98.9	115.2	83.1
April	113.8	68.5	88.9	120.4	153.2	121.5
May	9.8	15.6	15.3	126.6	133.8	59.8
June	5.0	6.2	4.3	1.4	0.0	0.7
July	2.4	0.3	4.3	0.0	0.0	0.0
August	4.9	1.8	2.5	0.2	26.3	0.0
September	0.0	2.3	0.0	8.8	21.5	1.0
October	20.6	41.0	7.3	21.2	31.8	47.6
November	257.0	189.8	169.0	144.3	121.1	161.3
December	108.6	98.8	43.6	182.4	24.1	89.5
Total	**661.4**	**483.8**	**693.0**	**791.2**	**675.8**	**660.4**

*Table 6. Area of **catchment sides** in ha (Source: Research Report No.3).*

Catchment side	**Area**
Inflow 1	64,477 ha
Inflow 2	22,047 ha
Inflow 3	10,318 ha
Inflow 4	4,381 ha
Inflow 5	4,460 ha
Inflow 6	2,062 ha
Inflow 7	575 ha
Inflow 8	819 ha
Inflow 9	2,737 ha
Inflow 10	3,024 ha
Inflow 11	1,781 ha
Inflow 12	3,691 ha
Inflow 13	6,599 ha
Inflow 14	1,415 ha
Inflow 15	3,181 ha
Inflow 16	3,642 ha
Inflow 17	7,101 ha
Inflow 18	8,362 ha
Inflow 19	15,309 ha
Inflow 20	8,110 ha

Inflow 21	3,855 ha
Inflow 22	16,748 ha
Total	188,754 ha

*Table 7. Monthly input data on **crop coefficients and climate**.*

month	**Kc-factor maize (-)**	**Kc-factor other vegetation (-)**	**Effective precipitation (%)**	**Potential evapotranspiration (mm)**
January	1.2	1.0	90	140
February	0.35	1.0	99	143
March	0.3	1.0	90	154
April	0.75	1.0	70	123
May	1.2	1.0	85	120
June	1.2	1.0	99	110
July	0.35	1.0	99	106
August	0.1	1.0	99	124
September	0.1	1.0	99	132
October	0.3	1.0	90	152
November	0.75	1.0	70	123
December	1.2	1.0	80	123

*Table 8. Monthly variation of **water loss from evaporation** of the sewage return flows.*

month	**loss from evaporation (%)**
January	40
February	25
March	40
April	60
May	40
June	20
July	20
August	20
September	40
October	50
November	80
December	60

*Table 9. Monthly inflow data for **Masinga reservoir** (m^3/s) (Source: Droogers, 2006).*

	1999	**2000**	**2001**	**2002**	**2003**	**2004**
January	1.36	103.30	21.83	1.36	103.30	21.83
February	10.05	86.71	13.59	10.05	86.71	13.59

March	49.32	57.35	16.08	49.32	57.35	16.08
April	679.00	36.47	169.00	679.00	36.47	169.00
May	289.80	70.27	363.90	289.80	70.27	363.90
June	253.70	119.70	287.00	253.70	119.70	287.00
July	170.80	122.80	187.50	170.80	122.80	187.50
August	99.25	82.22	83.38	99.25	82.22	83.38
September	61.01	41.61	26.59	61.01	41.61	26.59
October	39.06	15.39	175.90	39.06	15.39	175.90
November	26.77	25.24	255.70	26.77	25.24	255.70
December	86.91	27.64	300.90	86.91	27.64	300.90

*Table 10. **Volume elevation curve** of Masinga reservoir.*

volume (Mm^3)	water level (m)
200	5
400	7
800	9
1200	10
1433	10.5

*Table 11. Monthly data on natural recharge of the **Kitui aquifer** in thousand m^3.*

	1999	2000	2001	2002	2003	2004
January	3,220	14,000	489,600	159,000	63,200	96,000
February	440	0	0	15,000	34,400	95,800
March	24,200	105,000	226,000	197,800	230,400	166,200
April	22,760	137,000	177,800	240,800	306,400	243,000
May	1,960	31,200	30,600	253,200	267,600	119,600
June	1,000	12,400	8,600	2,800	0	1,400
July	480	600	8,600	0	0	0
August	980	3,600	5,000	400	52,600	0
September	0	4,600	0	17,600	43,000	2,000
October	4,120	82,000	14,600	42,400	63,600	95,200
November	51,400	379,600	338,000	288,600	242,200	322,600
December	21,720	197,600	87,200	364,800	48,200	179,000

*Table 12. The **RRNs** defined for Kitui and the **storage capacity** for each RRN.*

Name	No of dams	Storage (M^3)	Initial storage (M^3)
Mwiwe	34	18360	3400
Kyuusi	9	4860	900
Kiindu	41	22140	4100
Wii	13	7020	1300
Itoleka	6	3240	600
Mulutu	18	9720	1800

Utooni & Mbusyani	63	34020	6300
Kwa Vonza A	11.5	6210	1150
Kwa Vonza B	11.5	6210	1150
Makusya A	14.5	7830	1450
Makusya B	14.5	7830	1450
Kawongo	37	19980	3700

Table 13. ***Fictive volume elevation curve*** *of an RRN.*

volume (m^3)	water level (m)
5,000	50
10,000	100
15,000	150
20,000	200
25,000	250
30,000	300

Table 14. Monthly data on the ***crop coefficient*** *of Sukuma Wiki (an irrigated crop).*

month	Kc-factor Sukuma Wiki (-)
January	0.70
February	0.88
March	1.05
April	0.95
May	0.95
June	0.95
July	0.95
August	0.95
September	0.95
October	0.95
November	0.95
December	0.95

Table 15. Monthly data of the ***irrigation needed*** *in mm.*

	1999	2000	2001	2002	2003	2004
January	130.9	140	0	67.5	115.4	99
February	186.56	188.76	188.76	181.26	171.56	140.86
March	121.55	190.05	129.55	143.65	127.35	159.45
April	61.48	106.78	86.38	54.88	22.08	53.78
May	161.2	155.4	155.7	44.4	37.2	111.2
June	151.75	150.55	152.45	155.35	156.75	156.05
July	148.65	150.75	146.75	151.05	151.05	151.05
August	171.8	174.9	174.2	176.5	150.4	176.7

September	188.1	185.8	188.1	179.3	166.6	187.1
October	169.0	175.6	209.3	195.4	184.8	169
November	0.0	0.0	6.28	30.98	54.18	13.98
December	66.68	76.48	131.68	0	151.18	85.78
Total	1584.66	1695.06	1569.135	1380.26	1488.54	1503.94

*Table 16. Monthly variation in **agricultural water use** (%).*

	1999	**2000**	**2001**	**2002**	**2003**	**2004**
January	8.26	8.26	0.00	4.89	7.75	6.58
February	11.77	11.14	12.03	13.13	11.53	9.37
March	7.67	11.21	8.26	10.41	8.56	10.60
April	3.88	6.30	5.50	3.98	1.48	3.58
May	10.17	9.17	9.92	3.22	2.50	7.39
June	9.58	8.88	9.72	11.26	10.53	10.38
July	9.38	8.89	9.35	10.94	10.15	10.04
August	10.84	10.32	11.10	12.79	10.10	11.75
September	11.87	10.96	11.99	12.99	11.19	12.44
October	12.37	10.36	13.34	14.16	12.41	11.24
November	0.00	0.00	0.40	2.24	3.64	0.93
December	4.21	4.51	8.39	0.00	10.16	5.70

*Table 17. Monthly variation in **other water use**.*

month	**other uses (m^3)**	**other uses (%)**
January	10.56	43
February	0.88	3.5
March	0	0
April	0	0
May	0	0
June	10.56	43
July	0.88	3.5
August	0.88	3.5
September	0.88	3.5
October	0	0
November	0	0
December	0	0

A.3 Details WEAP analysis

This Appendix presents the results of the WEAP model of Kitui. The Results are structured into the Sections Current Accounts, Reference scenario, NoDams, MoreDams and LargerDams scenario. Per scenario the results are compared with those of the Reference scenario.

Current accounts year 1999

Table 18. The water balance in the headflow catchments in 1999.

month	precipitation (M m^3)	potential evapotranspiration (M m^3)	actual evapotranspiration (M m^3)	runoff from catchments (M m^3)
January	36.7	285.1	33.0	3.7
February	4.2	220.3	4.2	0.0
March	232.3	232.7	172.5	59.9
April	218.5	218.2	152.9	65.5
May	18.8	244.4	16.0	2.8
June	9.6	224.0	9.5	0.1
July	4.6	163.3	4.6	0.0
August	9.4	172.9	9.3	0.1
September	0.0	184.0	0.0	0.0
October	39.6	229.7	35.6	4.0
November	493.4	218.2	218.2	275.2
December	208.5	250.5	166.8	41.7
Total	**1275.6**	**2643.4**	**822.6**	**453.1**

Table 19. Inflow from catchment sides into river system and outflow at the outlet of Tiva river for the year 1999.

month	inflow from catchments (M m^3)	inflow from Kitui and Matinyani (M m^3)	streamflow outlet Tiva (M m^3)
January	3.7	0.0078	3.5
February	0.0	0.0071	0.1
March	59.9	0.0078	59.6
April	65.5	0.0076	65.5
May	2.8	0.0078	2.7
June	0.1	0.0076	0.1
July	0.0	0.0078	0.1
August	0.1	0.0078	0.1
September	0.0	0.0076	0.0
October	4.0	0.0078	3.7

November	275.2	0.0076	275.1
December	41.7	0.0078	41.6
Total	**453.1**	**0.0922**	**452.2**

Table 20. Inflow into river tributaries downstream from RRNs.

month	**inflow from catchments into upstream river reach (M m^3)**	**inflow from RRNs into downstream river reach (M m^3)**	**storage volume RRNs (M m^3)**
January	3.2	3.1	0.248
February	0.0	0.0	0.119
March	9.4	9.2	0.265
April	14.5	14.4	0.265
May	7.6	7.5	0.263
June	0.0	0.0	0.119
July	0.0	0.0	0.078
August	0.0	0.0	0.072
September	0.0	0.0	0.068
October	0.8	0.6	0.199
November	18.4	18.3	0.265
December	20.8	20.7	0.265
Total	**74.9**	**73.9**	**2.2**

Table 21. Demand, supply and coverage of the demand sides Kitui and Matinyani.

month	**demand (M m^3)**	**supply (M m^3)**	**losses (M m^3)**	**unmet demand (M m^3)**	**coverage (%)**
January	0.028	0.031	0.003	0.00	100
February	0.025	0.028	0.003	0.00	100
March	0.028	0.031	0.003	0.00	100
April	0.027	0.030	0.003	0.00	100
May	0.028	0.031	0.003	0.00	100
June	0.027	0.030	0.003	0.00	100
July	0.028	0.031	0.003	0.00	100
August	0.028	0.031	0.003	0.00	100
September	0.027	0.030	0.003	0.00	100
October	0.028	0.031	0.003	0.00	100
November	0.027	0.030	0.003	0.00	100
December	0.028	0.031	0.003	0.00	100

Total	0.329	0.365	0.036	0.00	100

Table 22. Demand, supply and coverage of the other demand sides (at RRNs).

month	demand (M m^3)	supply (M m^3)	unmet demand (M m^3)	coverage (%)
January	0.154	0.154	0.00	100
February	0.137	0.137	0.00	100
March	0.106	0.106	0.00	100
April	0.075	0.075	0.00	100
May	0.126	0.126	0.00	100
June	0.163	0.163	0.00	100
July	0.123	0.050	0.073	40
August	0.134	0.026	0.108	19
September	0.141	0.004	0.137	3
October	0.143	0.143	0.00	100
November	0.045	0.045	0.00	100
December	0.079	0.079	0.00	100
Total	**1.428**	**1.109**	**0.318**	**78**

Reference scenario

Table 23. Yearly inflow from catchment sides into river system and outflow at the outlet of Tiva river (Refrence scenario).

year	inflow catchments (M m^3)	inflow from Kitui and Matinyani (M m^3)	streamflow outlet Tiva (M m^3)
1999	453.1	0.092	452.2
2000	248.2	0.096	247.4
2001	425.5	0.099	424.7
2002	358.4	0.101	357.7
2003	296.3	0.101	295.4
2004	278.5	0.101	277.8
Total	**2060.0**	**0.591**	**2055.1**

Table 24. Inflow from catchment sides into river system and outflow at the outlet of Tiva river for the year 2000.

month	inflow from catchments (M m^3)	streamflow outlet Tiva (M m^3)
January	1.3	1.3

February	0.0	0.0
March	10.7	10.4
April	39.5	39.4
May	4.5	4.4
June	0.1	0.1
July	0.0	0.0
August	0.0	0.1
September	0.0	0.1
October	7.9	7.6
November	146.2	146.2
December	37.9	37.9

Table 25. Inflow from catchment sides into river system and outflow at the outlet of Tiva river for the year 2002.

month	**inflow from catchments ($M\ m^3$)**	**streamflow outlet Tiva ($M\ m^3$)**
January	15.3	15.2
February	0.1	0.1
March	44.0	43.8
April	69.3	69.3
May	36.5	36.4
June	0.0	0.1
July	0.0	0.0
August	0.0	0.0
September	0.2	0.2
October	4.1	3.8
November	88.2	88.1
December	100.7	100.6

Table 26. Storage volume of RRNs for the years 1999, 2000 & 2002 (Reference scenario).

month	**storage volume RRNs 1999 ($M\ m^3$)**	**storage volume RRNs 2000 ($M\ m^3$)**	**storage volume RRNs 2002 ($M\ m^3$)**
January	0.248	0.225	0.265
February	0.119	0.106	0.160
March	0.265	0.265	0.265
April	0.265	0.265	0.265
May	0.263	0.265	0.265
June	0.119	0.127	0.106
July	0.078	0.078	0.077
August	0.072	0.071	0.071
September	0.068	0.068	0.070

October	0.199	0.262	0.201
November	0.265	0.265	0.265
December	0.265	0.265	0.265

Table 27. Yearly demand of the demand sides Kitui-town and Matinyani.

year	**demand Kitui-town and Matinyani ($M\ m^3$)**
1999	0.37
2000	0.38
2001	0.40
2002	0.41
2003	0.43
2004	0.45
Total	**2.43**

Table 28. Demand of the RRN demand sides for the year 2000.

month	**demand ($M\ m^3$)**	**supply ($M\ m^3$)**	**unmet demand ($M\ m^3$)**	**coverage (%)**
January	0.159	0.159	0.00	100
February	0.138	0.119	0.020	86
March	0.140	0.140	0.00	100
April	0.098	0.098	0.00	100
May	0.123	0.123	0.00	100
June	0.162	0.162	0.00	100
July	0.124	0.051	0.073	41
August	0.136	0.014	0.122	10
September	0.140	0.012	0.128	9
October	0.133	0.133	0.00	100
November	0.045	0.045	0.00	100
December	0.084	0.084	0.00	100
Total	**1.482**	**1.140**	**0.343**	**77**

Table 29. Demand of the RRN demand sides for the year 2002.

month	**demand ($M\ m^3$)**	**supply ($M\ m^3$)**	**unmet demand ($M\ m^3$)**	**coverage (%)**
January	0.123	0.123	0.00	100
February	0.135	0.135	0.00	100
March	0.117	0.117	0.00	100
April	0.072	0.072	0.00	100

May	0.068	0.068	0.00	100
June	0.165	0.165	0.00	100
July	0.124	0.029	0.095	23
August	0.137	0.007	0.130	5
September	0.137	0.036	0.100	26
October	0.143	0.143	0.00	100
November	0.060	0.060	0.00	100
December	0.047	0.047	0.00	100
Total	**1.327**	**1.002**	**0.325**	**76**

NoDams-scenario

Table 30. Yearly inflow from catchment sides into river system and outflow at the outlet of Tiva river (NoDams-scenario).

year	streamflow outlet Tiva Reference scenario (M m^3)	streamflow outlet Tiva NoDams-scenario (M m^3)
1999	452.2	452.2
2000	247.4	248.3
2001	424.7	424.7
2002	357.7	358.2
2003	295.4	296.1
2004	277.8	278.3
Total	**2055.1**	**2058.4**

Table 31. Storage volume of RRNs in the years 1999, 2000 & 2002 (NoDams-scenario).

month	storage volume RRNs 1999 (M m^3)	storage volume RRNs 2000 (M m^3)	storage volume RRNs 2002 (M m^3)
January	0.248	0.027	0.027
February	0.119	0.008	0.014
March	0.265	0.027	0.027
April	0.265	0.027	0.027
May	0.263	0.027	0.027
June	0.119	0.008	0.008
July	0.078	0.007	0.007
August	0.072	0.007	0.007
September	0.068	0.007	0.011
October	0.199	0.027	0.027
November	0.265	0.027	0.027

December	0.265	0.027	0.027

Table 32. Demand of the RRN demand sides for the year 2000 (NoDams scenario).

month	**demand (M m^3)**	**supply (M m^3)**	**unmet demand (M m^3)**	**coverage (%)**
January	0.090	0.090	0.00	100
February	0.046	0.019	0.027	41
March	0.047	0.047	0.00	100
April	0.045	0.045	0.00	100
May	0.047	0.047	0.00	100
June	0.088	0.042	0.047	48
July	0.050	0.002	0.048	4
August	0.050	0.007	0.043	14
September	0.049	0.009	0.039	18
October	0.047	0.047	0.00	100
November	0.045	0.045	0.00	100
December	0.047	0.047	0.00	100
Total	**0.651**	**0.447**	**0.204**	**69**

Table 33. Demand of the RRN demand sides for the year 2002 (NoDams-scenario).

month	**demand (M m^3)**	**supply (M m^3)**	**unmet demand (M m^3)**	**coverage (%)**
January	0.090	0.090	0.00	100
February	0.046	0.036	0.010	78
March	0.047	0.047	0.00	100
April	0.045	0.045	0.00	100
May	0.047	0.047	0.00	100
June	0.088	0.024	0.064	27
July	0.050	0.000	0.050	0
August	0.050	0.001	0.049	2
September	0.049	0.027	0.022	55
October	0.047	0.047	0.00	100
November	0.045	0.045	0.00	100
December	0.047	0.047	0.00	100
Total	**0.651**	**0.456**	**0.195**	**70**

MoreDams-scenario

Table 34. Yearly inflow from catchment sides into river system and outflow at the outlet of Tiva river (MoreDams-scenario).

month	streamflow outlet Tiva Reference scenario (M m^3)	streamflow outlet Tiva MoreDams scenario (M m^3)
1999	452.2	452.2
2000	247.4	246.4
2001	424.7	424.1
2002	357.7	357.1
2003	295.4	294.5
2004	277.8	277.1
Total	**2055.1**	**2051.3**

Table 35. Storage volume of RRNs for the years 1999, 2000 & 2002 (MoreDams-scenario).

month	storage volume RRNs 1999 (M m^3)	storage volume RRNs 2000 (M m^3)	storage volume RRNs 2002 (M m^3)
January	0.248	0.294	0.544
February	0.119	0.186	0.330
March	0.265	0.495	0.544
April	0.265	0.544	0.544
May	0.263	0.534	0.544
June	0.119	0.305	0.291
July	0.078	0.159	0.157
August	0.072	0.145	0.145
September	0.068	0.139	0.139
October	0.199	0.443	0.369
November	0.265	0.544	0.544
December	0.265	0.544	0.544

Table 36. Demand of the RRN demand sides for the year 2000 (MoreDams-scenario).

month	demand (M m^3)	supply (M m^3)	unmet demand (M m^3)	coverage (%)
January	0.243	0.219	0.024	90
February	0.252	0.107	0.144	42
March	0.254	0.254	0.00	100
April	0.162	0.162	0.00	100

May	0.216	0.216	0.00	100
June	0.253	0.253	0.00	100
July	0.215	0.148	0.067	69
August	0.241	0.021	0.220	9
September	0.251	0.015	0.236	6
October	0.238	0.238	0.00	100
November	0.045	0.045	0.00	100
December	0.130	0.130	0.00	100
Total	**2.5**	**1.808**	**0.691**	**72**

Table 37. Demand of the RRN demand sides for the year 2002 (MoreDams-scenario).

month	demand (M m^3)	supply (M m^3)	unmet demand (M m^3)	coverage (%)
January	0.164	0.164	0.00	100
February	0.244	0.244	0.00	100
March	0.203	0.203	0.00	100
April	0.105	0.105	0.00	100
May	0.095	0.095	0.00	100
June	0.258	0.258	0.00	100
July	0.215	0.134	0.081	62
August	0.243	0.013	0.230	5
September	0.244	0.041	0.203	17
October	0.260	0.228	0.032	88
November	0.079	0.079	0.00	100
December	0.047	0.047	0.00	100
Total	**2.155**	**1.611**	**0.546**	**75**

LargerDams-scenario

Table 38. Yearly inflow from catchment sides into river system and outflow at the outlet of Tiva river (LargerDams-scenario).

month	streamflow outlet Tiva Reference scenario (M m^3)	streamflow outlet Tiva (M m^3)
1999	452.2	452.2
2000	247.4	247.0
2001	424.7	424.6
2002	357.7	357.5
2003	295.4	295.3

2004	277.8	277.6
Total	**2055.1**	**2054.1**

Table 39. Storage volume of RRNs for the years 1999, 2000 & 2002 (LargerDams-scenario).

month	Storage volume RRNs 1999 (M m^3)	storage volume RRNs 2000 (M m^3)	storage volume RRNs 2002 (M m^3)
January	0.248	0.329	0.531
February	0.119	0.241	0.425
March	0.265	0.509	0.531
April	0.265	0.531	0.531
May	0.263	0.531	0.531
June	0.119	0.393	0.372
July	0.078	0.270	0.247
August	0.072	0.162	0.153
September	0.068	0.145	0.144
October	0.199	0.460	0.385
November	0.265	0.531	0.531
December	0.265	0.531	0.531

Table 40. Demand of RRN demand sides for the year 2000 (LargerDams-scenario).

month	demand (M m^3)	supply (M m^3)	unmet demand (M m^3)	coverage (%)
January	0.159	0.159	0.00	100
February	0.138	0.088	0.051	64
March	0.140	0.140	0.00	100
April	0.098	0.098	0.00	100
May	0.123	0.123	0.00	100
June	0.162	0.162	0.00	100
July	0.124	0.124	0.00	100
August	0.136	0.116	0.021	85
September	0.140	0.026	0.114	19
October	0.133	0.133	0.00	100
November	0.045	0.045	0.00	100
December	0.084	0.084	0.00	100
Total	**1.482**	**1.298**	**0.186**	**88**

Table 41. Demand of RRN demand sides for the year 2002 (LargerDams-scenario).

month	demand (M m^3)	supply (M m^3)	unmet demand (M m^3)	coverage (%)

January	0.123	0.123	0.00	100
February	0.135	0.135	0.00	100
March	0.117	0.117	0.00	100
April	0.072	0.072	0.00	100
May	0.068	0.068	0.00	100
June	0.165	0.165	0.00	100
July	0.124	0.124	0.00	100
August	0.137	0.095	0.042	69
September	0.137	0.045	0.092	33
October	0.143	0.143	0.00	100
November	0.060	0.060	0.00	100
December	0.047	0.047	0.00	100
Total	**1.328**	**1.194**	**0.134**	**90**

All scenarios

Table 42. Discharge in the tributaries downstream of RNNs in the month January 2000.

RNN	**discharge Reference scenario (x1000 m^3)**	**discharge NoDams-scenario (x1000 m^3)**	**discharge MoreDams-scenario (x1000 m^3)**	**discharge LargerDams-scenario (x1000 m^3)**
Mwiwe	38.8	77.1		5.7
Kyuusi	44.5	54.6	31.2	35.7
Kiindu	1.6	47.8		
Wii	18.3	32.9		5.6
Itoleka	6.4	13.2		0.6
Mulutu	10.7	31.0		
Utooni & Mbusyani		46.8		
Kwa Vonza A	12.5	25.4		1.3
Kwa Vonza B	10.3			
Makusya A	22.8	39.1	1.4	8.7
Makusya B	6.0	22.3		
Kawongo		28.3		
Total	**171.9**	**418.5**	**32.6**	**57.6**
Percentage of Reference scenario	**100**	**243**	**19**	**34**