Green and Blue Water Services in Tana River Basin, Kenya

Exploring options using an integrated modeling framework

[D R A F T]

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1 Introduction

Water is a key source for human well being both through direct flows for food production, health maintenance and sanitation, but also through indirect flows to support and maintain societal, economic and ecological systems that daily provide us with goods and services. Despite the fundamental role of freshwater, water resource management and water policy has in the past focused almost exclusively on management of stable runoff water flows in rivers, lakes and groundwater, i.e., the accessible portion of blue water flows. The green water source and flows, i.e. rainfall and evapotranspiration losses, has been ignored to a great extent despite its dominant factor in many people's live.

Studies on the green water flows have initially focused on widening the understanding of water availability and management of water flows in agriculture. The challenge to address malnourishment and food production for a growing population will require rain fed agriculture to continue to produce the bulk of world food. Of the world's 2 billion people in absolute poverty, 70 % live in rural areas largely living on smallholder rain fed farming. Most critical in the green-blue water approach are basins/catchments with hydrological water scarcity due to unfavorable rainfall/evapotarnspiration fractions, combined with large populations in severe poverty. In these hotspots, there are urgent needs for alternative locally adaptive strategies to increase food production and help alleviate poverty whilst maintaining the water resources for other development needs.

Green Water Credits (GWC) is a mechanism for payments to land users in return for specified soil and water management activities that determine the supply of fresh water at source. These activities are presently unrecognized and un-rewarded. Direct payment will enable better management and therefore less damaging runoff, more beneficial infiltration, more groundwater recharge and more stream base flow, particularly in the dry season. At the same time, GWC will provide a reliable, predictable diversification of rural incomes, enabling communities to adapt to economic, social and environmental change through asset-building in the shape of stable soils, more reliable local water supply, improved crops and infrastructure.

Green water is the water held in soil and available to plants. It is the largest fresh water resource but can only be used in situ, by plants. Blue water is groundwater and stream flow that can be tapped for use elsewhere: for domestic and stock water, irrigation, industrial and urban use and that support aquatic ecosystems. Green Water Credits (GWC) is a mechanism for transfer of cash or other benefit to rural people in return for water management activities that determine the supply of green and blue water at source. These activities are presently unrecognized and un-rewarded.

The GWC Proof-of-Concept project is supported by the International Fund for Agricultural Development and the Swiss Agency for Development and Cooperation. It aims to demonstrate the viability and feasibility of the offer–and–demand aspects of the GWC concept as a sustainable environmental service mechanism; improve local resilience to external shocks by asset building (Green water resource, stable soils, shortening the hunger gap, diversified rural incomes); deliver enhanced blue water resources, and to reduce the hazards of floods and landslips downstream (ISRIC, 2005).

Based on a thoroughly analysis of suitable locations to undertake the Proof of Concept phase of GWC, it was decided to focus initially on the Upper and Middle Tana Basin in Kenya (Droogers et al. 2006).

An analysis of the most suitable model to undertake the biophysical analysis to explore GWC options is presented in Appendix XXX. Based on this analysis it is concluded that the SWAT model (Soil and Water Assessment Tool) provides the best opportunities as SWAT is able to evaluate the impact of upstream aspects of crop-land-soil management on downstream users.

This report describes the initial evaluation of GWC options for Tana Basin in Kenya.

2 Tana River Basin

2.1 Overview

Tana river basin is situated in the Eastern part of Kenya (Figure 1). The GWC project will focus on Tana basin upstream Garissa, which is sometimes referred to as Upper and Middle Tana. This part of the basin will be referred to as Tana in this report. Total area of this part of Tana Basin is 3,268,856 ha (32,688 km^2). Geographic corner coordinates of this part of the basins are approximately 36.50 E – 39.75 E; 0.50 N – 1.25 S.

Figure 2 shows a Landsat image of the Tana basin. The Upper Tana River Basin has been substantially altered over the last decades by the construction of five dams (Figure 3); two more are under investigation. Dams have resulted in substantial power generation and reducing downstream floods. Whether this is a positive or a negative impact is arguable. Farmers in downstream areas used to practise flood recession irrigation which is hardly possible anymore. Now flows are more steady and irrigation has expanded.

In terms of potential GWC buyers, four groups may be distinguished: (i) Kenya Electricity Generating Company (KenGen), (ii) Nairobi City Council–Water Supply Department (NCC-WSD), (iii) irrigation section, (iv) Kenya Wildlife Conservation Department. The following issues are relevant to these four potential GWC buyers:

i. Less focused on water but mainly on siltation
ii. Overcome dry spells. Water shortage is expected in 2006 in Masinga
iii. Increase total water availability
iv. Tana River Primate National Reserve (TRPNR). Upper delta, about 75 km from ocean, 169 km^2. Not clear what water resources required.

The potential GWC sellers are mainly the farmers upstream of the reservoirs. Their services can be twofold: (i) measures to minimize runoff and erosion, and (ii) maximize infiltration use of soil water more efficiently and promote extended periods of deep drainage to streamflow.

The Ministries of Agriculture (MoA), and Water & Irrigation through their affiliated institutions are mandated to oversee the effective utilization of available water, both surface and groundwater. The MoA consider GW management as a core concept, which they promote through appropriate soil and water conservation approaches. The necessary legal frameworks exist and most of these activities have been earmarked as approaches that will lead to the attainment of the Millennium Development Goals.

Figure 1. Location of Tana basin in Kenya.

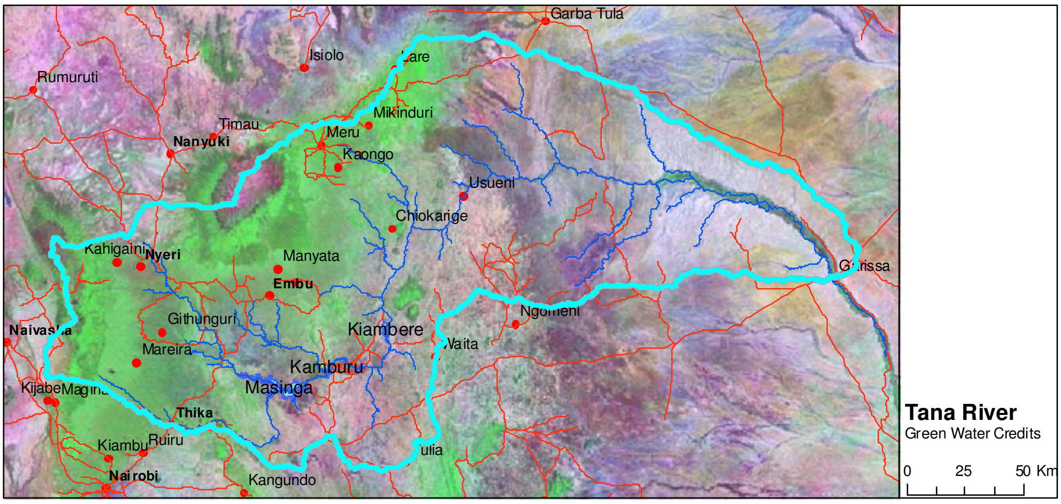

Figure 2. Landsat image of Tana basin.

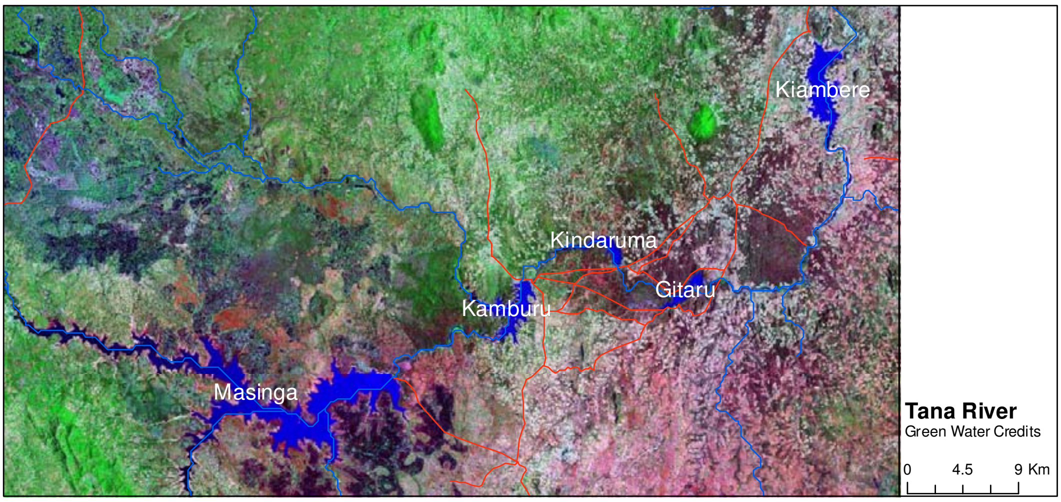

Figure 3. Landsat image of the area around the main reservoirs.

3 Overview Biophysical Modeling Tool

3.1 SWAT

SWAT is the acronym for Soil and Water Assessment Tool, a river basin model developed originally by the USDA Agricultural Research Service (ARS) and Texas A&M University that is currently one of the worlds leading spatially distributed hydrological models.

A distributed rainfall-runoff model – such as SWAT – divides a catchment into smaller discrete calculation units for which the spatial variation of the major physical properties are limited, and hydrological processes can be treated as being homogeneous. The total catchment behavior is a net result of manifold small sub-basins. The soil map and land cover map within sub-basin boundaries are used to generate unique combinations, and each combination will be considered as a homogeneous physical property, i.e. Hydrological Response Unit (HRU). The water balance for HRU's is computed on a daily time step. Hence, SWAT will distribute the Tana into units that have similar characteristics in soil, land cover and that are located in the same sub-basin.

Irrigation in SWAT can be scheduled by the user or automatically determined by the model depending on a set of criteria. In addition to specifying the timing and application amount, the source of irrigation water must be specified, which can be: canal water, reservoir, shallow aquifer, deep aquifer, or a source outside the basin.

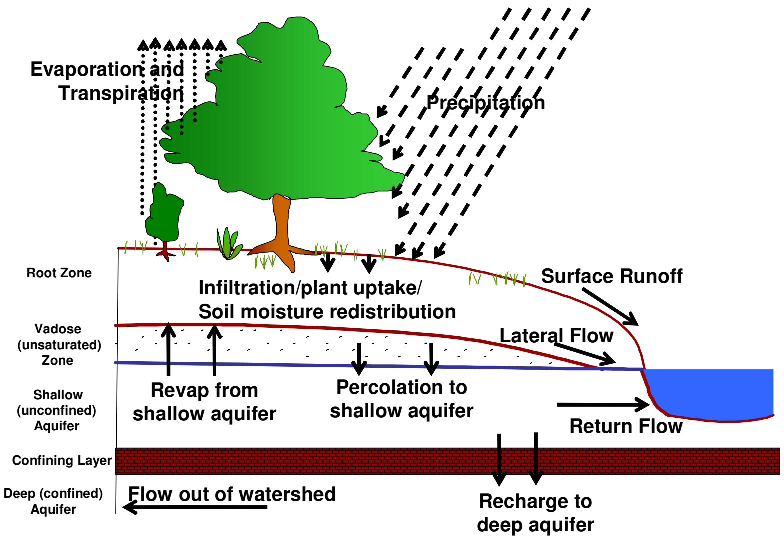

Figure 4. Main land phase processes as implemented within SWAT

SWAT can deal with standard groundwater processes. Water enters groundwater storage primarily by infiltration/percolation, although recharge by seepage from surface water bodies is also included. Water leaves groundwater storage primarily by discharge into rivers or lakes, but it is also possible for water to move upward from the water table into the capillary fringe, i.e. capillary rise. As mentioned before, water can also be extracted by mankind for irrigation purposes. SWAT distinguishes recharge and discharge zones.

Recharge to unconfined aquifers occurs via percolation of excessively wet root zones. Recharge to confined aquifers by percolation from the surface occurs only at the upstream end of the confined aquifer, where the geologic formation containing the aquifer is exposed at the earth's surface, flow is not confined, and a water table is present. Irrigation and Link canals can be connected to the groundwater system; this can be an effluent as well as an influent stream.

After water is infiltrated into the soil, it can basically leave again the ground as lateral flow from the upper soil layer – which mimics a 2D flow domain in the unsaturated zone – or from return flow that leaves the shallow aquifer and drains into a nearby river. The remaining part of the soil moisture can feed into the deep aquifer, from it can be pumped back. The total return flow thus consists of surface runoff, lateral outflow from root zone and aquifer drainage to river.

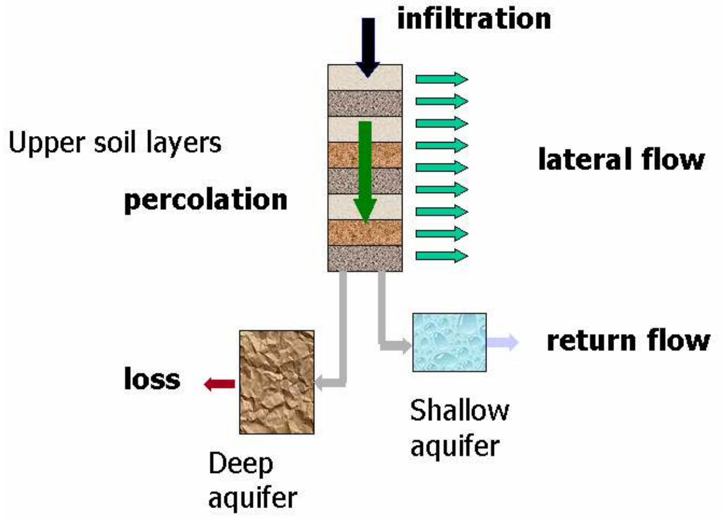

Figure 5. Schematic diagram of the sub-surface water fluxes

For each day of simulation, potential plant growth, i.e. plant growth under ideal growing conditions is calculated. Ideal growing conditions consist of adequate water and nutrient supply and a favorable climate. The biomass production functions are to a large extend similar to SEBAL. First the Absorbed Photosynthetical Radiation (APAR) is computed from intercepted solar radiation, followed by a Light Use Efficiency (LUE) that is in SWAT essentially a function of carbon dioxide concentrations and vapor pressure deficits. The crop yield is computed as the harvestable fraction of the accumulated biomass production across the growing season.

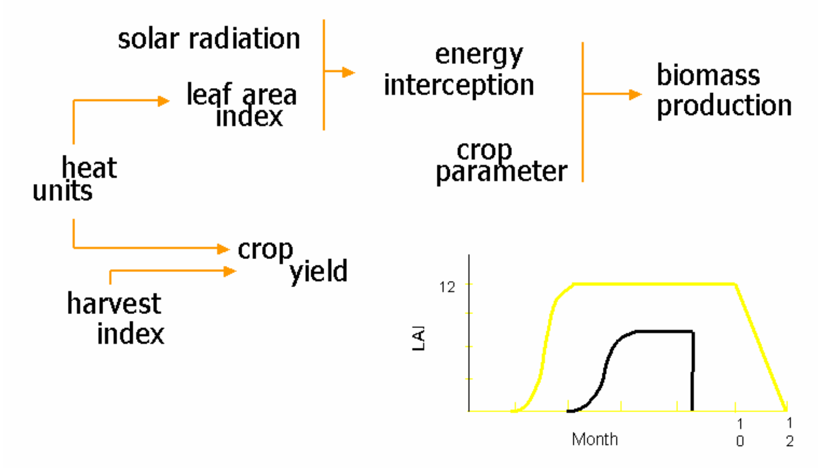

Figure 6. Parameterization of crop production

4 Setting up SWAT Model

4.1 Data

4.1.1 DEM

Digital Elevation data was obtained from the Shuttle Radar Data Topography Mission (SRTM). Data was collected during NASA's Space Shuttle Endeavour flight on 11-22 February 2000, and was collected using a radar device. SRTM data were processed from raw radar echoes into digital elevation models at the Jet Propulsion Laboratory (JPL) in Pasadena, CA. These original data files had samples spaced ("posted") at intervals of 1 arc-second of latitude and longitude (about 30 meters at the equator).

For the United States SRTM data are available at a resolution of 1 arc second (about 30 meter). SRTM data at 3 arc-second (90 meters) is currently available for global coverage between 60 degrees North and 56 degrees South latitude. The product consists of seamless raster data and is available in geographic coordinates (latitude/longitude) and is horizontally and vertically referenced to the EGM96 Geoid.

SRTM-DEM data has been obtained using the USGS Seamless Data Distribution (http://seamless.usgs.gov/). The original data are provided at a resolution of 90 m, but this dataset was too big to handle within SWAT and was therefore resample to a spatial resolution of 250 m.

The DEM forms the base to delineate the catchment boundary, stream network and create sub basins. This is performed by the pre-processing module of the SWAT but requires a so-called minimum catchment area size. For a couple of sizes this has been done and results can be found in Appendix XXX. After some trials a threshold area of 25,000 ha provided a nice balance between sufficient detail and at the same time a number of sub basins that can be handled. As outlet point was Garissa selected. The final Tana basin was having an area of 32,741 km^2 and a total of 82 sub basins was delineated. Note that these 82 units will be divided in smaller units, the Hydrological Response Units (HRU), after overlaying land use and soil maps.

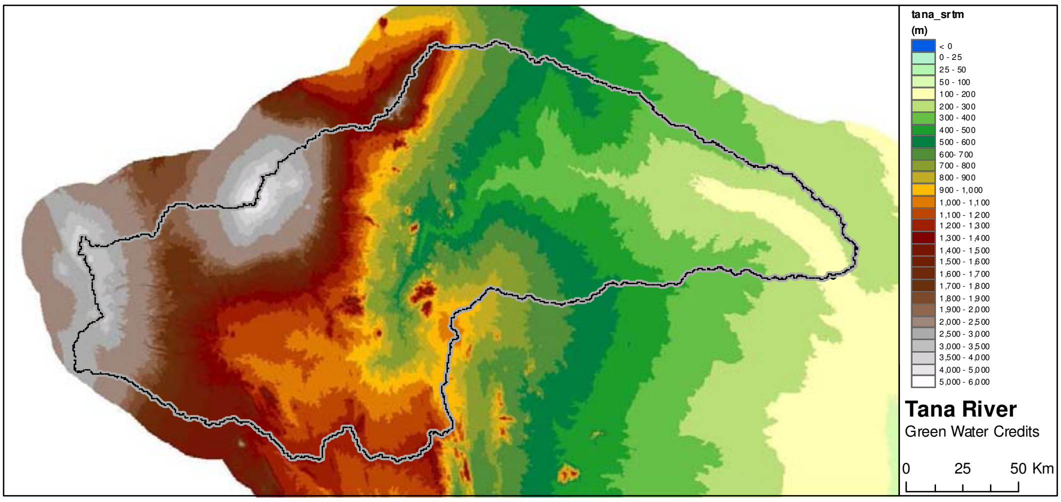

Figure 7. SRTM Digital Elevation Model at 90 m resolution.

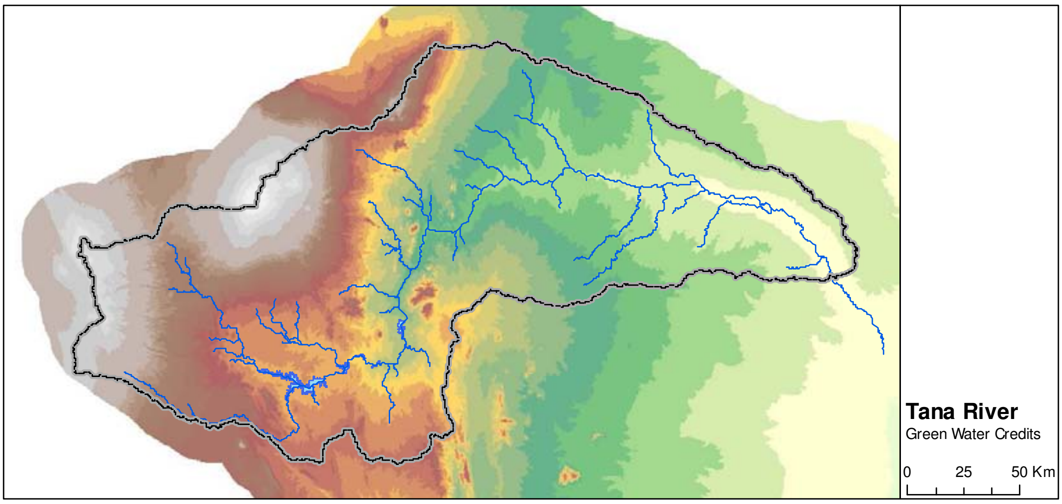

Figure 8. Stream flow network as derived from DEM.

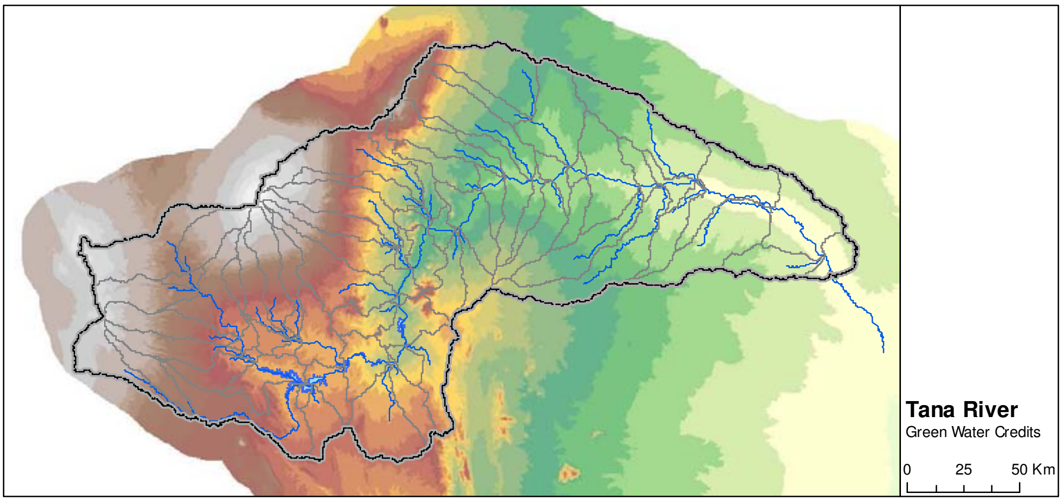

Figure 9. Sub basins as derived from DEM.

4.1.2 Reservoirs

4.1.3 Land use

Land use and land cover is one of the dominant aspects in Green Water Credits assessments. However, it is at the same time one of the most difficult data set to assess and multiple efforts have been undertaken to generate these data. One overview of available datasets is given by the Land Cover Institute (LCI). LCI is established within the United States Geophysical Service (USGS) and has the mission to function as a focal point for coordinating applications and knowledge of land use and land cover information (LCI, 2006).

LCI has identified 19 land cover datasets covering Africa. A major drawback of all these land covers is that they were created for larger scale levels resulting in low spatial detail and non-specific classes. This makes these land cover data sets less suitable for the GWC analysis.

A higher resolution land cover map has been published by the International Livestock Research Institute which is located in Nairobi. This map is derived from a study in 1987 by JICA (Japan International Co-operation Agency), in the context of developing a National Water Master Plan for the country. This map was derived from Landsat 1980 satellite data and has 14 classes: (1)Forest, (2) Woodland, (3) Bush land (dense), (4) Bush land (sparse), (5) Grassland, (6) Barren land (SG), (7) Barren land (R), (8) Swamp, (9) Water body, (10) Water (artificial), (11) Agriculture (dense), (12) Agriculture (sparse), (13) Plantation, and (14) Town. The map clipped to the Upper Tana can be seen in Figure 10 and areas per class in Table 1.

Besides that the map might be somewhat outdated, it is also clear that the resolution of the map is still too course and might not provide sufficient details for GWC analysis.

Table 1. Land use areas as shown in Figure 10.

Land use	Area (km^2)	%
bushland (dense)	9,320	29
agriculture (sparse)	9,221	28
agriculture (dense)	5,473	17
bushland (sparse)	2,883	9
forest	2,500	8
plantation	1,257	4
woodland	723	2
barren land (R)	639	2
grassland	492	2
water (artificial)	146	0
swamp	21	0
town	14	0
Total	32,689	100

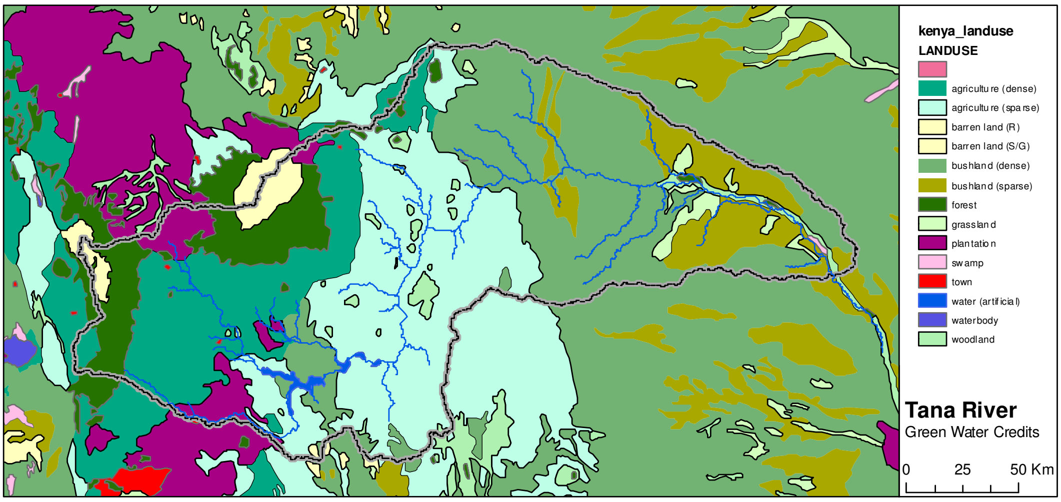

Figure 10. Land use map based on a JICA study (ILRI, 2006).

Another data set is available from the Kenya Department of Resource Surveys and Remote Sensing (DRSRS) survey that was conducted to define land use and land cover for medium and high potential areas (Njuguna 2001). The DRSRS survey resulted in land use/land cover designations for points spaced on an approximate 2400 x 4800 m irregular grid. At each point, the percentage of each land use/land cover was defined. This dataset is known as the AFRICOVER and has a high spatial resolution and an impressive number of 101 land covers are distinguished in Kenya.

In Tana Basin 52 land covers are present and land covers representing over 1% are shown in Table 2. These 52 classes have been converted to SWAT classes resulting in 17 classes (Table 3). The dominant land use class is the Range-Grasses (RNGE), which is a broad group and consists out of the following four classes according to the original AfriCover data set:

- Very open shrubs with closed to open herbaceous and sparse trees (16%)
- Open general woody with herbaceous (10%)
- Open shrubs with closed to open herbaceous and sparse trees (8%)
- Open general shrubs with closed to open herbaceous (2%)

The SWAT class Agricultural Land-Generic (AGRL) covers 26% of the area and is a combination of the following AfriCover original classes:

- Continuos Rainfed Small fields [cereal] (14%)
- Closed to very open herbaceous with sparse shrubs (5%)
- Closed to very open herbaceous (3%)
- Rainfed Herbaceous - Medium Fields (2%)
- Others (2%)

Irrigated areas cover a small portion of the basin (71,000 ha) and are limited to three land covers:

- AGRI: Agriculture general irrigated, 44,575 ha
- RICE: Rice 18,729 ha
- PINE: Pine 7,779 ha

Table 2. Land use areas according to the AFRICOVER land use dataset

Description	**ha**	**%**
Very open shrubs with closed to open herbaceous and sparse trees	518,046	16
Continuos Rainfed Small fields [cereal]	456,134	14
Open general woody with herbaceous	337,205	10
Open shrubs with closed to open herbaceous and sparse trees	248,525	8
Herbaceous - Small Fields - Maize, Rainfed	205,771	6
Closed to very open herbaceous with sparse shrubs	171,651	5
Rainfed Shrub Crop, Small Fields – Coffee	160,609	5
Closed trees with shrubs	148,095	5
Open trees (broadleaved deciduous) with closed to open shrubs	130,738	4
Closed multilayered trees (broadleaved evergreen)	105,906	3
Closed to very open herbaceous	96,641	3
Rainfed Shrub Crop, Small Fields – Tea	82,785	3
Rainfed Herbaceous - Medium Fields	72,122	2
Open general trees with shrubs	65,334	2
Open general shrubs with closed to open herbaceous	63,206	2
Open trees (broadleaved deciduous) with closed to open herbaceous	51,439	2
Others	354,648	11
Total	**3,268,856**	**100**

Table 3. Land use areas according to the AFRICOVER land use dataset converted to SWAT classes.

SWATLCC	**Name**	**ha**	**%**
RNGE	Range-Grasses	1,191,598	36
AGRL	Agricultural Land-Generic	860,793	26
FRST	Forest-Mixed	496,137	15
CORN	Corn	220,270	7
COFF	Coffee	173,943	5
FRSE	Forest-Evergreen	109,042	3
TEA	Tea	83,799	3
AGRI	Agriculture general irrigated	44,575	1
WATR	Water	22,322	1
RICE	Rice	18,729	1
WETL	Wetlands-Mixed	18,531	1
PLAN	Plantation	8,455	0
PINE	Pine	7,779	0
BARE	Bare soils	6,900	0
RNGB	Range-Brush	3,687	0
URML	Residential-Med/Low Density	1,811	0
AGRR	Agricultural Land-Row Crops	484	0
Total		**3,268,856**	**100**

Note: three land covers are under irrigation: AGRI, RICE, PINE

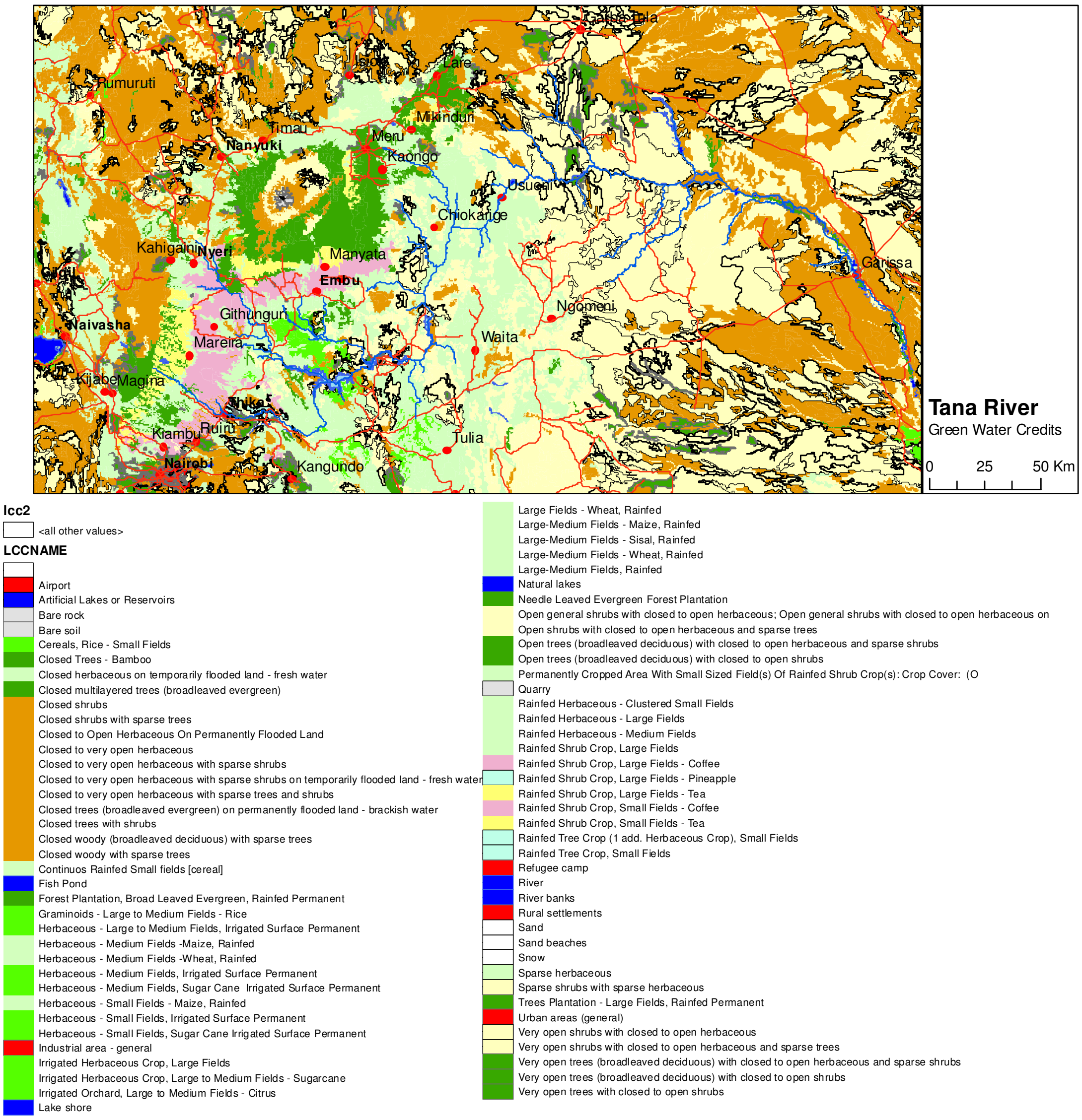

Figure 11. AfriCover land use data set.

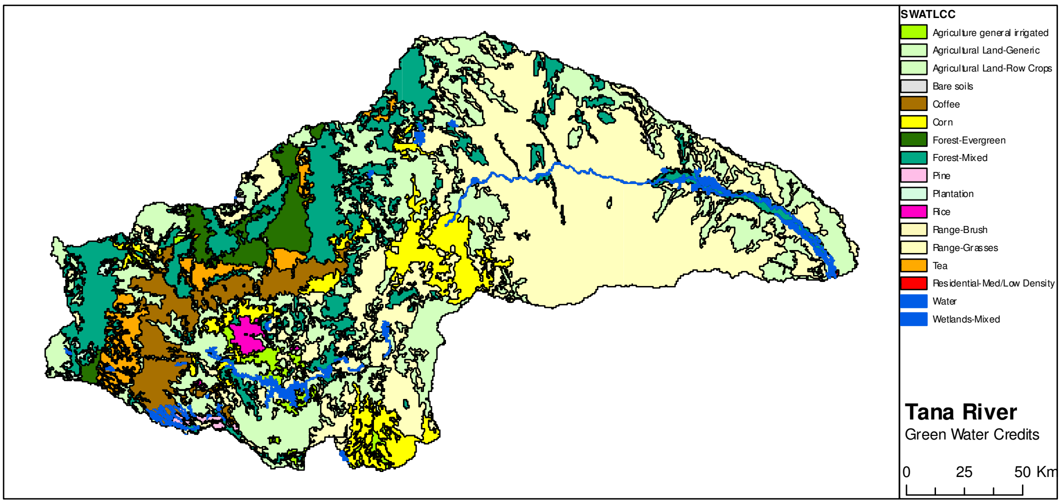

Figure 12. AfriCover land use converted to SWAT units.

4.1.4 Crop Characteristics

In order to simulate crop growth in SWAT crop specific characteristics have to be included in the model. Important is to emphasize that actual crop growth and the actual evapotranspiration is calculated by SWAT. So less optimal growth conditions can occur due to several conditions: water shortage, nutrient deficit, heat stress, less-optimal solar radiation, cold stress.

In Figure 13 an example of Corn is shown required to simulate crop growth. Besides these more or less generic crop characteristics, management information of the crop should be provided. These management data includes planting data, fertilizer application, irrigation if applicable etc.

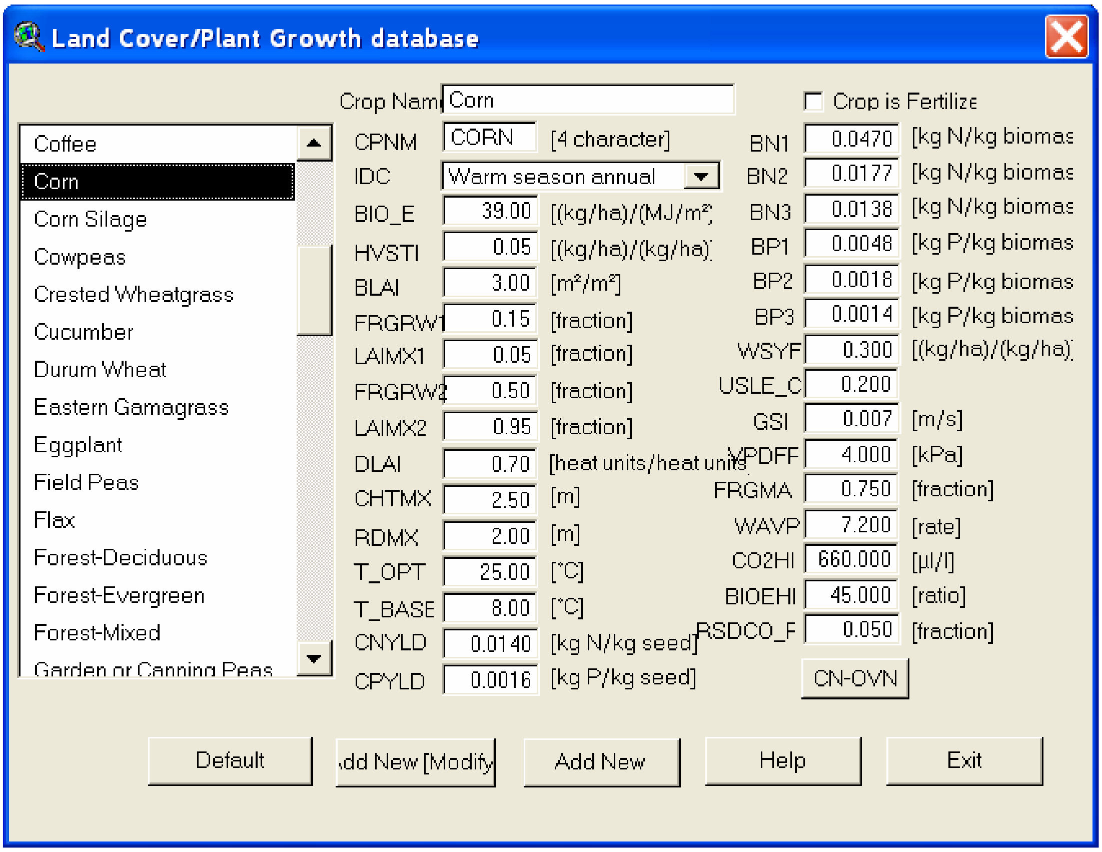

Figure 13. Required crop characteristics for the SWAT analysis. Example of Corn is shown.

4.1.5 Soils information

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An important characteristics not provided in KenSoter is the saturated hydraulic conductivity. A well-developed technique to overcome this problem is to use so-called pedo-transfer functions (PTF). A wide range of pedo-transfer functions have been developed and applied successfully over the last decades over various scales (e.g. field scale in Droogers et al. 2001; basin scale at Droogers and Kite, 2001).

Of the many existing PTF the one based on Campbell is used frequently (Lee, 2005):

$$K_{sat} = 54 \times \exp(-0.07(sa)-0.167(cl))$$

K_{sat} is saturated hydraulic condictivity (mm h^{-1})
sa is sand content (%)
cl is clay content (%)

However, Sobierja et al (2001) concluded from a detailed analysis that most PTFs were not very reliable and the impact on runoff estimates could be considerable. One PTF that generated conductivity values close to measured ones was the Jabro (1992) equation:

$$K_{sat} = \exp(9.56 - 0.81 \log(st) - 1.09 \log(cl) - 4.64\ BD)$$

K_{sat} is saturated hydraulic condictivity (cm h^{-1})
st is silt content (%)
cl is clay content (%)

In SWAT mm h^{-1} is required leading to

$$K_{sat} = \exp(11.86 - 0.81 \log(st) - 1.09 \log(cl) - 4.64\ BD)$$

This one is used to derive K_{sat} values from the KenSoter database.

Table 4. SOTER units covering over 1% of the area.

NEWSUID	Area (km^2)	%
KE181	3,142	9.6
KE218	2,663	8.1
KE162	2,580	7.9
KE242	2,351	7.2
KE92	2,141	6.5
KE235	1,946	6.0
KE191	1,919	5.9
KE234	1,762	5.4
KE113	1,475	4.5
KE156	1,250	3.8
KE176	877	2.7
KE238	864	2.6
KE173	668	2.0
KE94	580	1.8
KE212	519	1.6
KE167	518	1.6
KE233	510	1.6
KE165	490	1.5
KE262	469	1.4
KE239	444	1.4
KE296	433	1.3
KE232	378	1.2
KE216	324	1.0
KE268	318	1.0

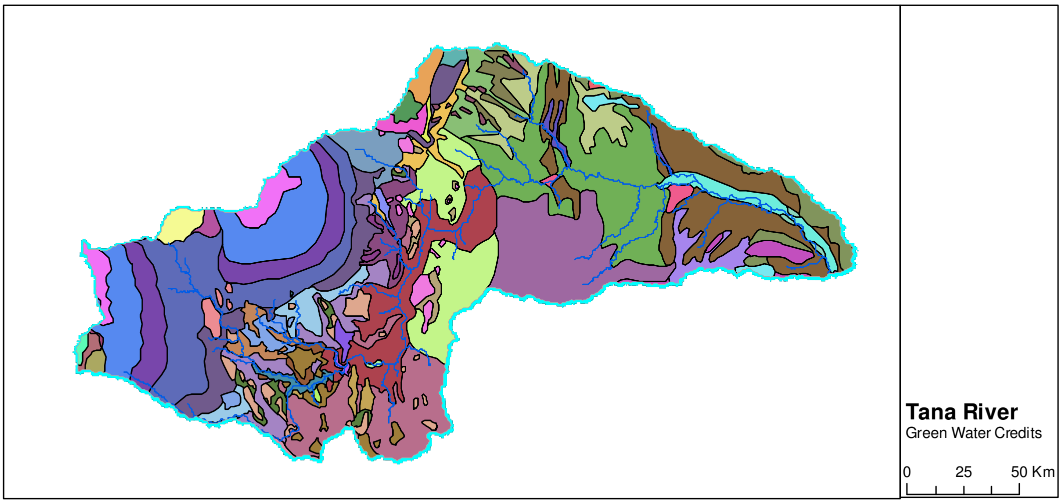


Figure 14. Soil map indicating diffetent soil classes (Batjes and Gicheru, 2004).

The required parameters for the SWAT model are:

Code	Definition	Unit	MIN	MAX
SNAM	Soil name		0.00000	0.00000
HYDGRP	Soil Hydrologic Group		0.00000	0.00000
SOL_ZMX	Maximum rooting depth of soil profile.		0.00000	3500.00000
ANION_EXCL	Fraction of porosity (void space) from which anions are excluded.		0.01000	1.00000
SOL_CRK	[OPTIONAL] Crack volume potential of soil.		0.00000	1.00000
TEXTURE	[OPTIONAL] Texture of soil layer.		0.00000	0.00000
SOL_Z	Depth from soil surface to bottom of layer.		0.00000	3500.00000
SOL_BD	Moist bulk density.		1.10000	2.50000
SOL_AWC	Available water capacity of the soil layer.		0.00000	1.00000
SOL_K	Saturated hydraulic conductivity.		0.00000	2000.00000
SOL_CBN	Organic carbon content .		0.05000	10.00000
CLAY	Clay content.		0.00000	100.00000
SILT	Silt content.		0.00000	100.00000
SAND	Sand content.		0.00000	100.00000
ROCK	Rock fragment content.		0.00000	100.00000
SOL_ALB	Moist soil albedo.		0.00000	0.25000
USLE_K	USLE equation soil erodibility (K) factor.		0.00000	0.65000
NLAYERS	Number of layers in the soil.		1.00000	10.00000
NUMLAYER	The layer being displayed.		1.00000	10.00000

4.1.6 Hydrological Response Units

As introduced before, SWAT uses a concept of Hydrological Response Units (HRU): portions of a subbasin that possess unique landuse/management/soil attributes. An HRU is not synonymous to a field. Rather it is the total area in the subbasin with a particular landuse, management and soil. While individual fields with a specific landuse, management and soil may be scattered throughout a subbasin, these areas are lumped together to form one HRU. HRUs are used in most SWAT runs since they simplify a run by lumping all similar soil and land use areas into a single response unit. It is often not practical to simulate individual fields in cases where the focus lies on entire basins.

Implicit in the concept of the HRU is the assumption that there is no interaction between HRUs in one subbasin. Loadings (runoff with sediment, nutrients, etc. transported by the runoff) from each HRU are calculated separately and then summed together to determine the total loadings from the subbasin. If the interaction of one landuse area with another is important, rather than defining those landuse areas as HRUs they should be defined as subbasins. It is only at the subbasin level that spatial relationships can be specified. The benefit of HRUs is the increase in accuracy it adds to the prediction of loadings from the subbasin. The growth and development of plants can differ greatly among species. When the diversity in plant cover within a subbasin is accounted for, the net amount of runoff entering the main channel from the subbasin will be much more accurate.

In practice the HRUs are defined by overlaying three data layers: (i) subbasins, (ii) land cover, and (iii) soils. A total of 874 HRUs has been used in the analysis (Figure 15)

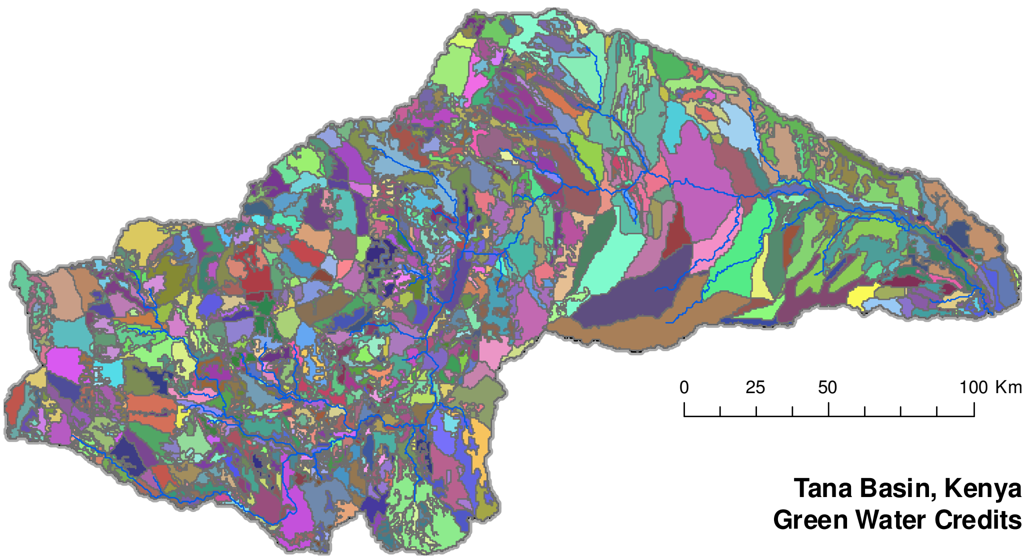


Figure 15. Hydrological response units.

4.1.7 Meteorological data

Accurate meteorological data for this initial analysis was not yet available at a high spatial resolution. Therefore the high-resolution CRU data set was used. The CRU TS 2.0 dataset of the University of East Anglia comprises 1200 monthly grids for the period 1901-2000, and covers the global land surface at 0.5° × 0.5° resolution (Mitchell et al., 2003). The dataset comprises: cloud cover, diurnal temperature range, precipitation, temperature and vapor pressure. The CRU dataset is based on raw station data, which are scarce in some regions and periods. A method called 'relaxation to the climatology' was used to create continuous grids. This implies that, for some areas or regions, data are less accurate. For Tana a total of 28 points were used (Figure 16).

For Masinga Dam annual and monthly average precipitation amounts are plotted in Figure 17 and Figure 18). Precipitation over the last 15 years indicate that mean annual precipitation over this period is 873 mm Table 5. A relative wet year is 1997, and 1996 can be considered as dry.

It was decided to perform the initial analysis on this dry (1996) and wet (1997) year. Since initial conditions of the system are by enlarge unknown, a so-called heating-up year was included. In summary a three years period was simulated, while output of 1996 and 1997 was analyses.

1990	1167
1991	612
1992	785
1993	942
1994	917
1995	984
1996	521
1997	1479
1998	860
1999	670
2000	578
2001	744
2002	1091

Table 5. Annual precipitation for Masinga based on CRU.

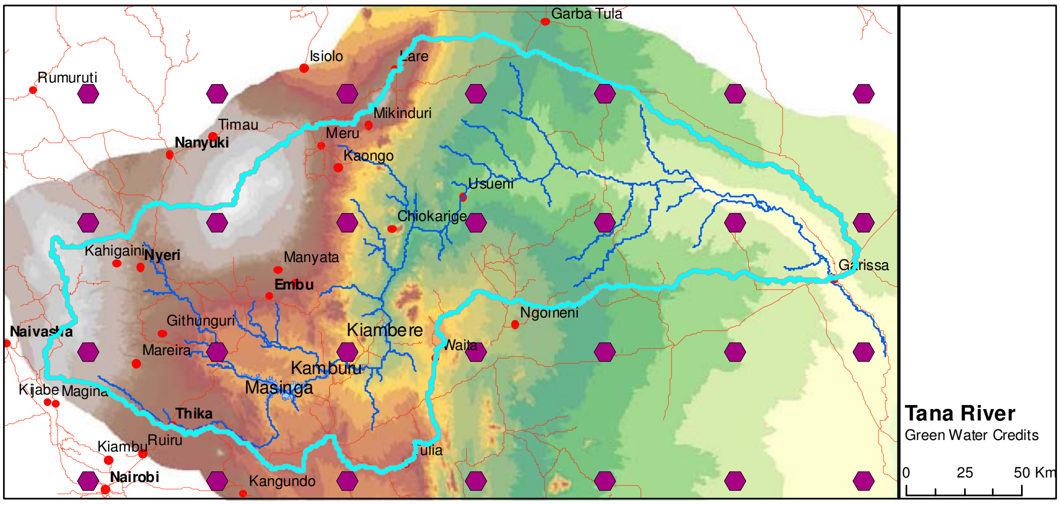


Figure 16. Locations of CRU meteorological data points..

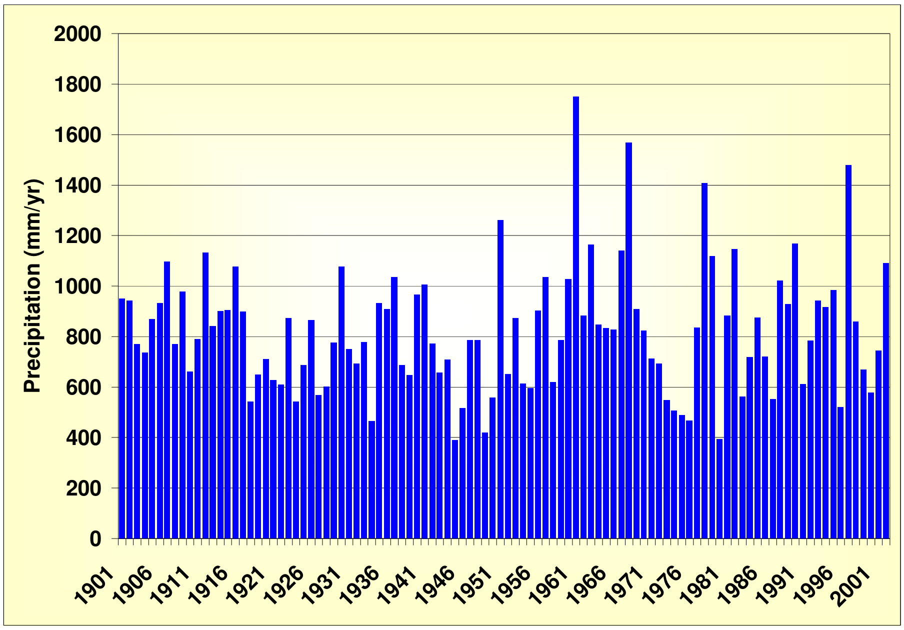


Figure 17. Annual precipitation for the CRU meteorological data point at Masinga.

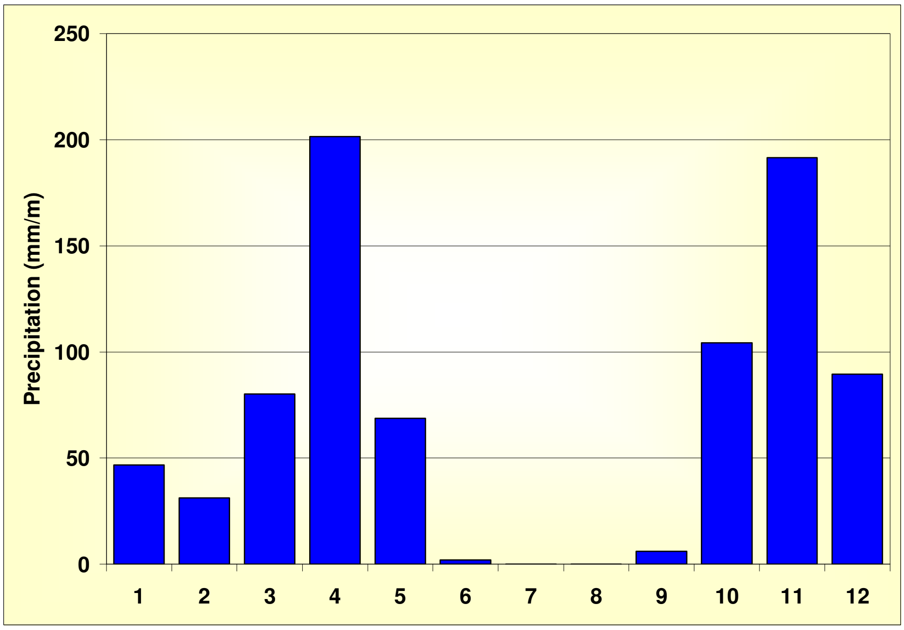


Figure 18. Average monthly precipitation (1901-2002) for the CRU meteorological data point at Masinga.

4.1.8 Erosion

Sediment yield is computed for each sub basin with the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977):

$Y = 11.8 * (V\ q_p)^{0.56} * IC * C * P * LS$

where Y is the sediment yield from the sub basin in ton, V is the surface runoff for the sub basin in m^3, q is the peak flow rate for the sub basin in $m^3 s^{-1}$, K is the soil erodibility factor, C is the crop management factor, P is the erosion control practice factor, and LS is the slope length and steepness factor.

The hydrology model supplies estimates of runoff volume and peak runoff rate. The crop management factor is evaluated as a function of above-ground bio mass, crop residue on the surface, and the minimum C factor for the crop. Other factors of the erosion equation are evaluated as described by Wischmeier and Smith (1978). The three most relevant factors in terme of Green Water Credits scenario's in the MUSLE are the K, P and C factors. All these factors have a range from 0 to 1, where 0 indicates no erosion and 1 indicates a very high change on erosion.

USLE_K is the soil erodibility factor. Some soils erode more easily than others even when all other factors are the same. This difference is termed soil erodibility and is caused by the properties of the soil itself. Wischmeier and Smith (1978) define the soil erodibility factor as the soil loss rate per erosion index unit for a specified soil as measured on a unit plot.. Direct measurement of the erodibility factor is time consuming, costly and not feasible for large scale project. Therefore the USLE_K factor was derived using the transfer functions as derived by Williams (1995). (file: usersoil.dbf)

USLE_P water erosion support practice factor. The support practice factor, USLE_P, is defined as the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down slope culture. Support practices include contour tillage, strip cropping on the contour, and terrace systems. Stabilized waterways for the disposal of excess rainfall are a necessary part of each of these practices. (file: mgt2.dat)

USLE_C water erosion applicable to land cover (file: crop.dat).

It should be emphasized here that SWAT is not using a potential erodibility map as input, but that based on processes the actual soil erosion is calculated.

4.1.9 Reservoir characteristics

In SWAT a reservoir is considered as an impoundment located on the main channel network of a watershed. No distinction is made between naturally-occurring and man-made structures. The features of an impoundment are shown in Figure 19.

SWAT is keeping track of the water balance for a reservoir as follows:

$$V = V_{stored} + V_{flowin} - V_{flowout} + V_{pcp} - V_{evap} - V_{seep}$$

where V is the volume of water in the impoundment at the end of the day (m^3), V_{stored} is the volume of water stored in the water body at the beginning of the day (m^3), V_{flowin} is the volume of water entering the water body during the day (m^3), $V_{flowout}$ is the volume of water flowing out of the water body during the day (m^3), V_{pcp} is the volume of precipitation falling on the water body during the day (m^3), V_{evap} is the volume of water removed from the water body by evaporation during the day (m^3), and V_{seep} is the volume of water lost from the water body by seepage (m^3).

Outflow of the reservoir can be specified by four different operational rules

- measured daily outflow

- measured monthly outflow
- average annual release rate (for uncontrolled reservoir)
- controlled outflow with target release

Last option is used for this study, as this represents the most realistic operational practice for the reservoirs. For this option the following reservoir characteristics and operational rules are required:

- emergency spillway surface area (ha)
- emergency spillway volume (m^3)
- principal spillway surface area (ha)
- principal spillway volume (m^3)

The following initial conditions are required as well

- volume (m^3)
- sediment concentration (mg l^{-1})
- normal sediment concentration (mg l^{-1})

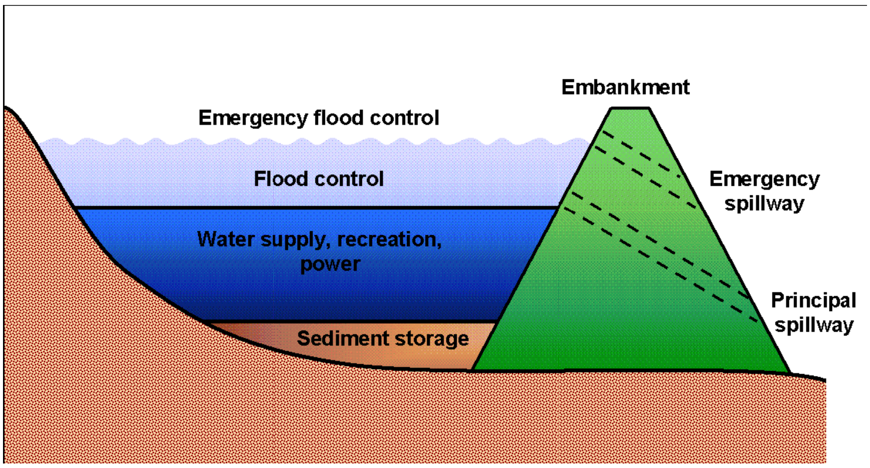


Figure 19. Terminology of reservoirs characteristics in SWAT.

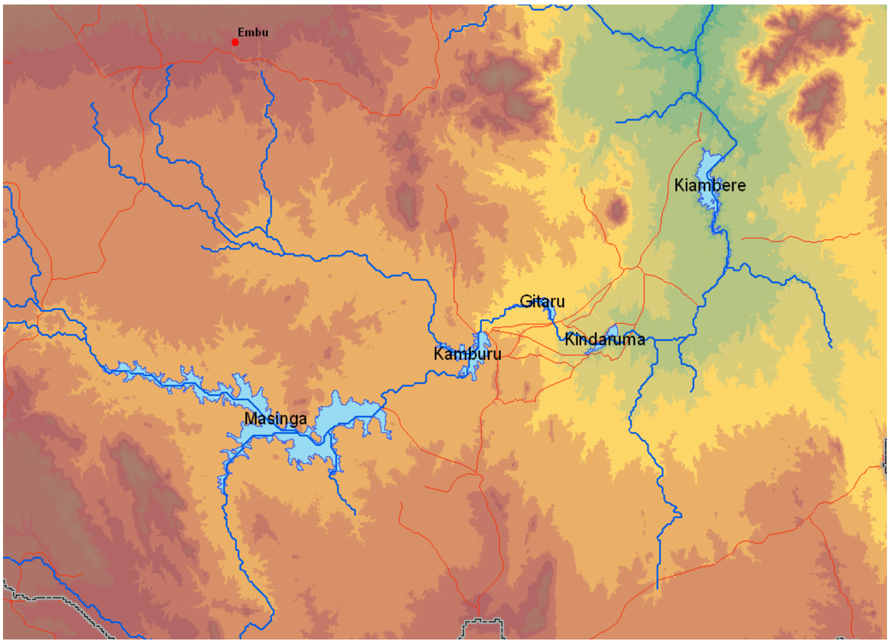


Figure 20. Location of the five reservoirs in Tana.

SWAT allows having only one reservoir per sub basin. For the sub basin delineation as used, three smaller reservoirs fall all in one sub basin and are represented as one bigger reservoir. Therefore, subbasin boundaries have been altered to ensure inidivual reservoirs being included in the model. As indicated in Appendix XXX (GWC Tools Selection) the application of WEAP might be benefical to focus in detail on hydropower benefit/costs.

For this study it was selected to include the following reservoirs into the model:

- Masinga in sub basin 78
- Kamburu in sub basin 79
- Gitaru in sub basin 80
- Kindaruma in sub basin 81
- Kiambere in sub basin 82

Key features of these reservoirs can be seen in Table 6. Annual outflow of the reservoirs is shown in Figure 21. It is clear that outflow from Masinga is somewhat lower than from the other reservoirs indicating that tributaries between Masinga and Kamburu are contributing to flows. Thiba river is the most important one of these.

Figure 22 shows the monthly inflows and outflows of Masinga reservoir. The buffering impact on stream flows of the reservoir is clearly demonstrated where during wet season inflows are higher than outflows and during dry seasons the opposite happens. There are however periods where inflows are too high to have any buffering capacity (1989, 1990, 1998, 2003).

The five reservoirs operate as a cascade and water "lost" over the spillway Masinga can therefore be captured and/or used by the other reservoirs. However, Figure 23 indicates that spills by Masinga are often not captured by one of the other four reservoirs. This clearly leads to the conclusion that there is scope for increasing reservoir storage. Regarding the objectives of the Green Water Credits project would it be very relevant to avoid any additional loss of storage capacity by siltation.

4.1.10 Hydropower

Electricity generation for the five reservoirs is given in Table 7 and Figure 24 shows the power generation of the five reservoirs over the last 15 years. Interesting is that the total power generated is quite stable, except for a short three year period during 2000-2001. In this period rainfall was very low which is reflected as well in the outflow of the reservoirs (Figure 21).

Power generated from hydro sources currently forms about 70% of the total electricity output in Kenya. KenGen's hydropower stations have a total installed capacity of 677.3 MW. The power stations comprise the Seven Forks hydro stations, the Mini hydro stations and Turkwel Power Station.

The Seven Forks hydro stations are situated along the lower part of the Tana River and comprise:

1. Masinga Power Station.
2. Kamburu Power Station.
3. Gitaru Power Station.
4. Kindaruma Power Station.
5. Kiambere Power Station.

These five stations have an installed capacity of 543.2MW. Water has been cascaded from one station to the next, taking advantage of the head created by each dam to produce power. To provide adequate flow during the dry periods, water is stored at Masinga Reservoir and released during the dry season. Two other sites along the river, Mutonga and Grand Falls are yet to be developed.

MASINGA POWER STATION

Installed capacity - 40 MW

Year of commissioning - 1981.

Two vertical Kaplan turbines drive two generators capable of generating 40MW of power. Power generated is transmitted to Kamburu power station for transmission to Nairobi. In addition to the 40MW produced by this station, Masinga serves as a crucial reservoir, which has a capacity of 1.56 billion cubic meters of water. This reservoir is used for water regulation throughout the year. The dam occupies a surface area of 120Km2.

KAMBURU POWER STATION

Installed capacity - 94.2MW

Year of commissioning - 1974.

Kamburu is the first underground power station in the complex. Electric power from Kamburu is conveyed to Nairobi via two 220KV transmission lines from a primary 132KV substation. Water is conveyed to Gitaru Power Station via a 2.9Km tailrace tunnel.

GITARU POWER STATION

Installed capacity - 225 MW

Commissioning date - 1978 (145mw), 1999 (80mw)

Gitaru is the biggest power station in Kenya in terms of installed capacity.

The power produced is transmitted to Kamburu 132KV substation via two 132KV circuits. The discharge from Gitaru Station is conveyed through a 5KM tailrace tunnel which empties into Kindaruma reservoir.

KINDARUMA POWER STATION

Installed capacity - 44MW.

Commissioning date - 1968.

Kindaruma is the first station to be constructed in the Seven Forks Complex.

Despite its age the station is in good condition to prudent maintenance programme. Power from Kindaruma is transmitted directly to Nairobi via a 132KV line or to Kamburu 132KV substation. The water is then passed down to Kiambere - the latest development in the complex.

KIAMBERE POWER STATION

Installed capacity - 144MW.

Year of commissioning - 1988.

Reservoir capacity - 585 Million M3.

As it is currently the last dam on the Tana, the machines run mostly as base load hence the large power output. The underground powerhouse is situated 4Km away from the saddle dam where the intake structure is located. The water conveyance is by a 6m diameter headrace tunnel.

Table 6. Key characteristics of the reservoirs in Tana (kenGen, 2005).

Name		Masinga	Kamburu	Kindaruma	Gitaru	Kiambere
year of completion		1980	1974	1968	1978	1987
height of dam	m	69.5	56.0	24.3	30.0	112.0
capacity	x1000 m^3	1.560E+06	1.500E+05	1.600E+04	2.000E+04	5.850E+05
area	x1000 m^2	120,000	15,000	250	310	25,000
emergency spillway surface area	ha	1.440E+04	1.800E+03	3.000E+01	3.720E+01	3.000E+03
emergency spillway volume	m^3	1.872E+09	1.800E+08	1.920E+07	2.400E+07	7.020E+08
principal spillway surface area	ha	1.200E+04	1.500E+03	2.500E+01	3.100E+01	2.500E+03
principal spillway volume	m^3	1.560E+09	1.500E+08	1.600E+07	2.000E+07	5.850E+08

Table 7. Generated electricity over the last 14 years for the major hydropower plants in GWhr. (kenGen 2005; Oludhe 2003).

	Masinga	Kamburu	Kindaruma	Gitaru	Kiambere
1991/92	185	402	206	811	872
1992/93	177	417	213	844	887
1993/94	180	421	217	856	892
1994/95	200	485	213	704	996
1995/96	225	491	239	701	1031
1996/97	215	446	230	926	1028
1997/98	204	480	198	818	1023
1998/99	223	410	240	789	1037
1999/00	142	247	157	734	813
2000/01	28	181	81	364	293
2001/02	127	330	162	665	703
2002/03	206	470	224	945	999
2003/04	230	470	221	938	1010
2004/05	169	381	170	757	814

Note: Data provided over the financial year ended at June 30th. E.g. 1991/1992 relates to July 1st 1991 to June 30th 1992.

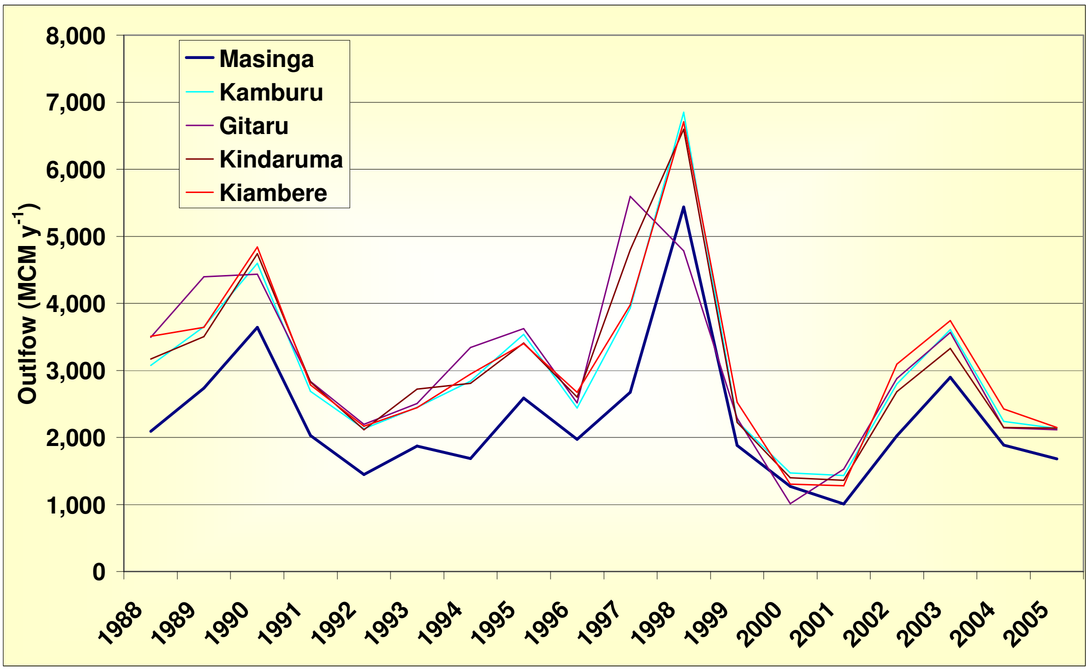


Figure 21. Annual outflow of the five reservoirs along Tana river.

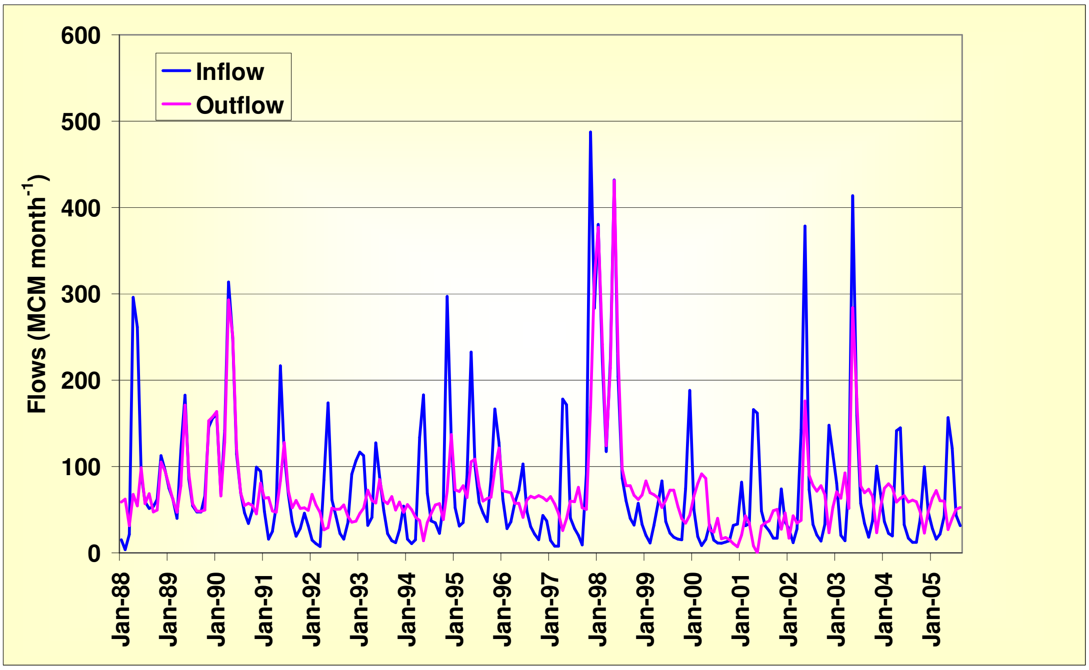


Figure 22. Monthly inflows and outflows of Masinga reservoir.

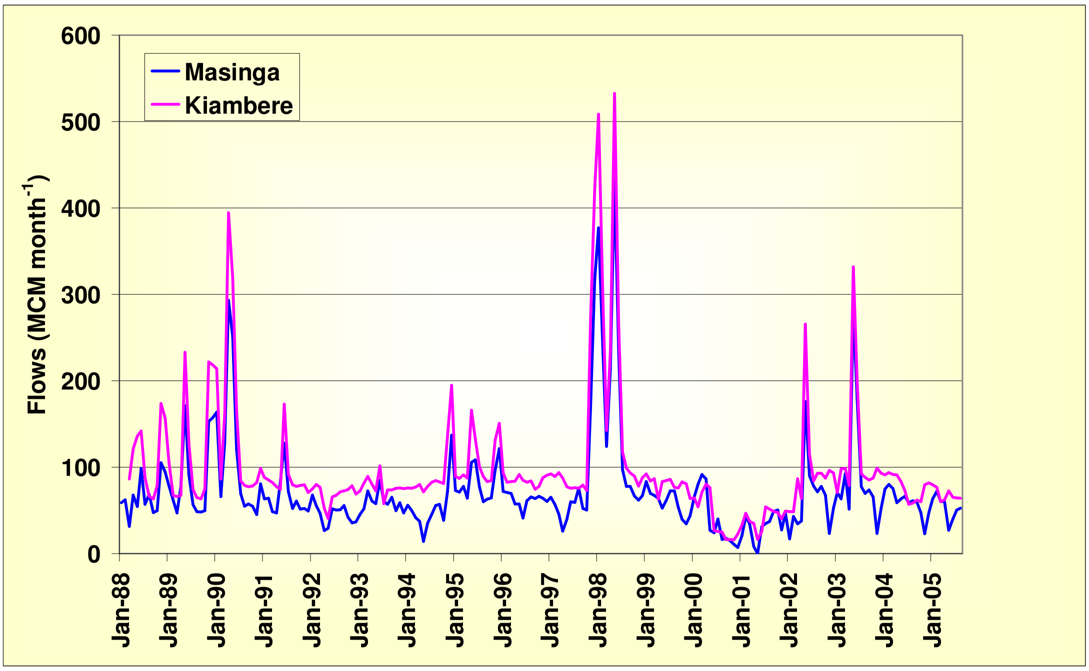


Figure 23. Monthly outflows from Masinga and Kiambere.

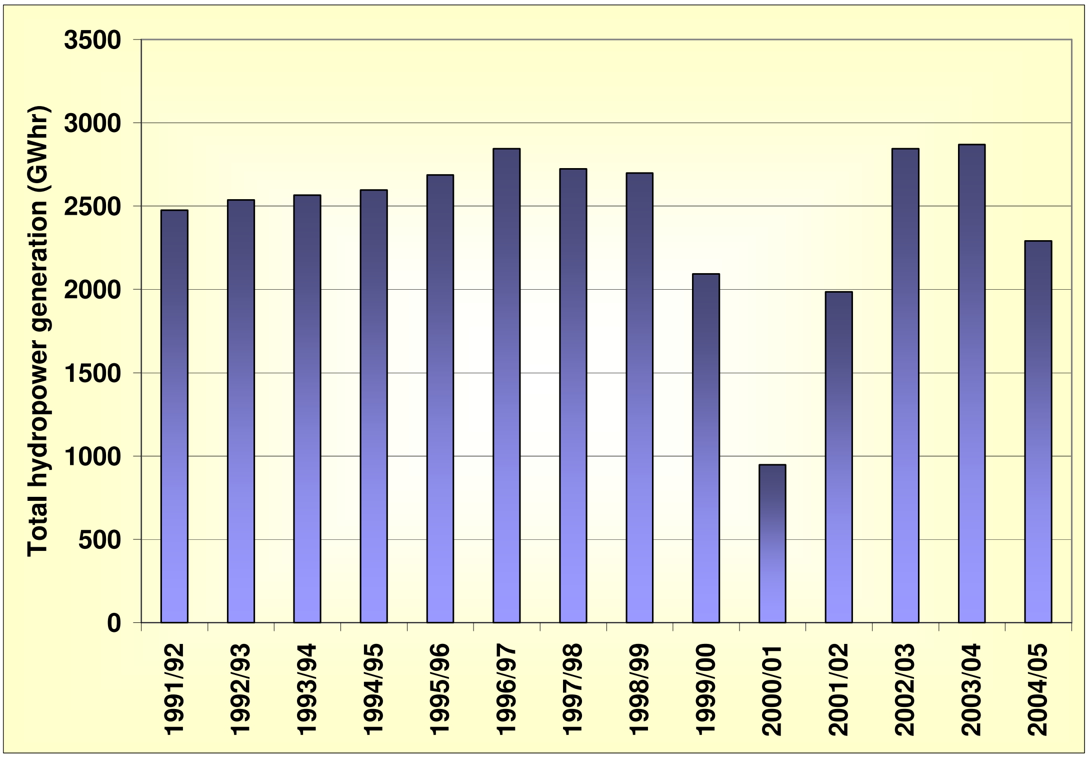


Figure 24. Total hydropower generation in Tana basin.

4.1.11 Discharge observations

Discharge measurements are collected from various sources as no single entity in the country is responsible to observe or collect discharge observations. Also accessible of data have been a major obstacle in the project. The main sources of discharge data obtained during the project were:

- Ministry of Water and Irrigation
- KenGen
- University of Nairobi
- Kenya Soil Survey
- RivDis

Reservoirs inflows and outflows are discussed in the previous paragraph and here only observations in rivers are discussed.

Discharge measurements at Grand Falls, located downstream of Kiambere, show not only a decrease in flow, but especially a lower number of high floods. This decrease in flows is probably due to an increase in development in the upper part of the basin (Figure 25). It should be emphasized that this development is most likely not only extractions from streams and reservoirs but mainly from an increase in groundwater extractions for large commercial farming. This increased groundwater exploration can reduce base flows substantially. Monthly records show a huge decrease in peak flows as a result of the construction of the reservoirs (Figure 26).

For the period 1962 and 1975 flow records of Grand Falls and Garissa were available. A comparison of these two helps to understand the dynamics of Middle Tana. Extreme floods were somewhat reduced in its way from Grand Falls to Garissa probably by flooding. At the same time is during low flow conditions water extracted between Grand Falls and Garissa.

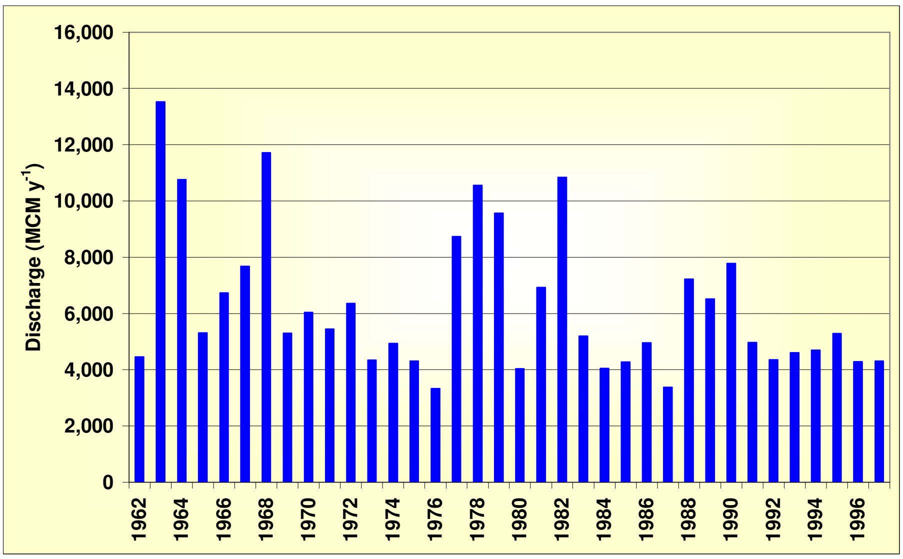


Figure 25. Annual discharge measurements Grand Falls.

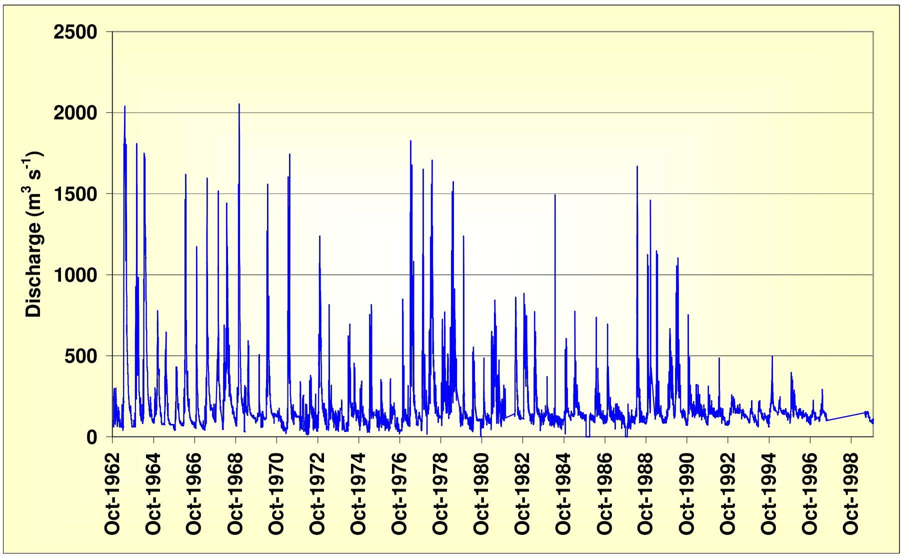


Figure 26. Discharge measurements Grand Falls.

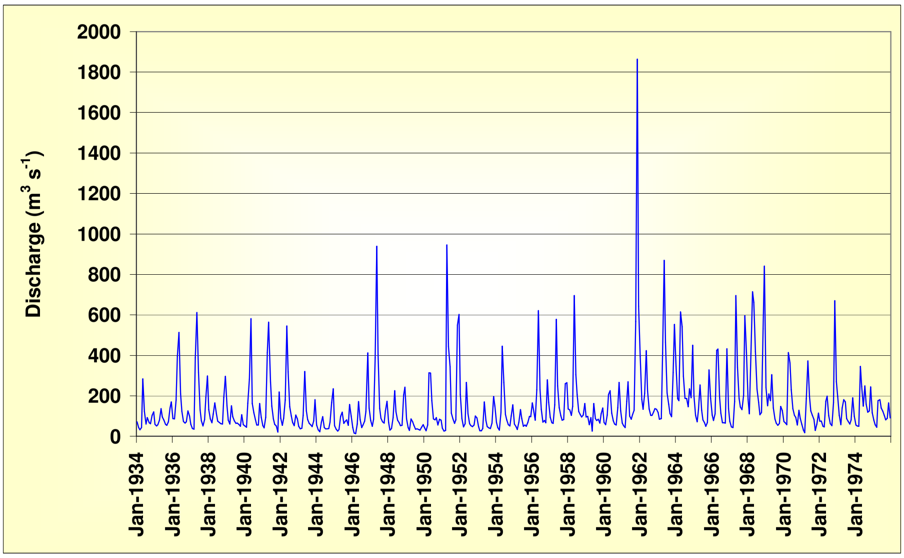


Figure 27. Discharge measurements Garissa.

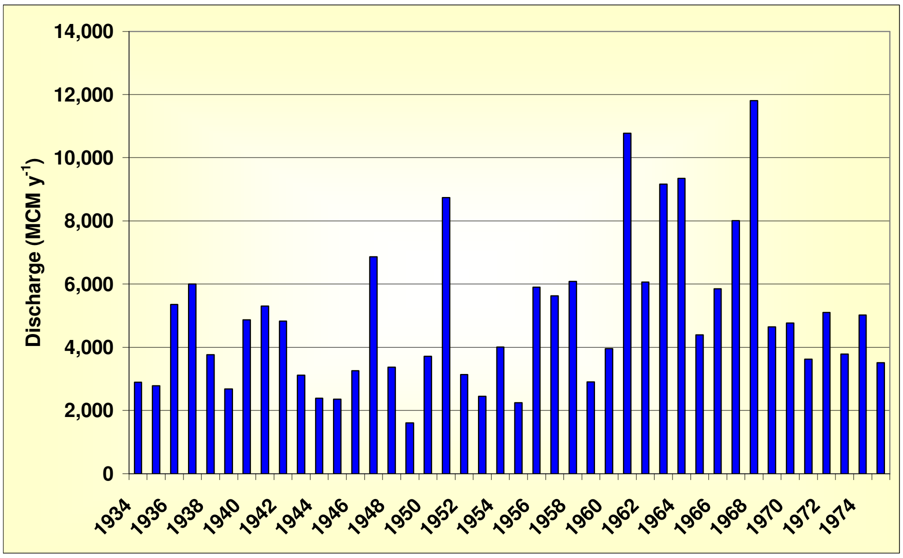


Figure 28. Annual discharge Garissa.

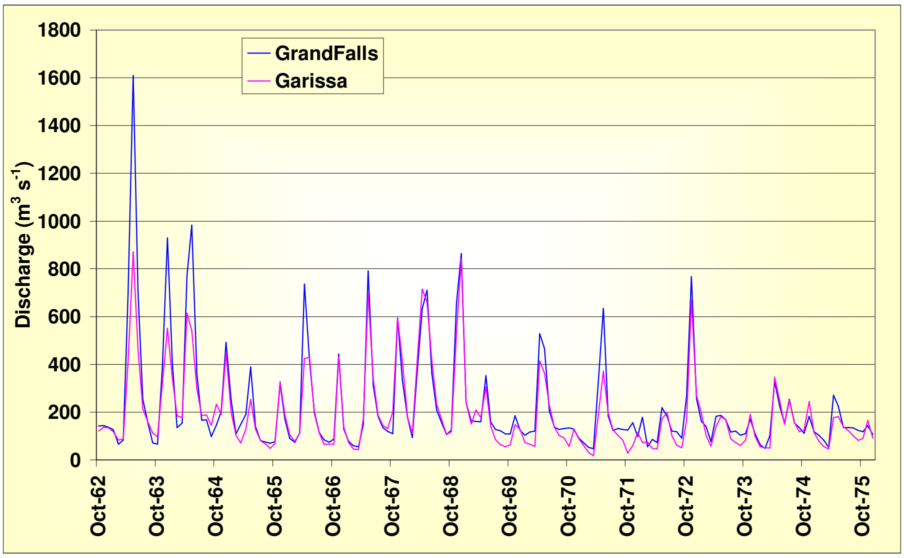


Figure 29. Comparison of monthly flows at Grand Falls and Garissa.

5 Reference situation

A SWAT model for Upper Tana has been built using data and assumptions included as presented in the previous Chapters. It should be emphasized here that a full calibration and verification of the model was not performed as this was not the objective of the Green Water Credits Project. This Proof of Concept phase is looking at the potential of the SWAT model to evaluate measures and scenarios in the context of GWC.

It was decided to run the model for three successive years (1995, 1996, 1997) where 1995 was used to generate appropriate initial conditions for the years 1996 and 1997. These two years were used as they represent a relatively dry (1996) and wet (1997) year. The model can however be run for any other period given that meteorological data are available for that specific period. This can also be future climate conditions generated by climate predictions models (General Circulation Models, GCMs).

This Chapter describes the output as generated by the model to demonstrate capabilities of the model to support Green Water Credit analysis. This will be done for the two years and can be seen as a baseline or reference situation. Next Chapter will show how scenarios of changing management can be explored by the model.

5.1 *Spatial distribution*

One of the key components of this Proof of Concept phase of the Green Water Credits is to explore in which areas opportunities for GWC are. The SWAT model has the unique option to assess Green and Blue water options at a high spatial resolution. Results can be plotted as maps showing this high spatial resolution. Results can also be aggregated at sub basin level or at land cover level showing for which land cover or crop opportunities for GWC exist.

The following maps are plotted here for a relatively dry (1996) and a relatively wet (1997) year:

- Actual evapotranspiration: total amount of water consumed by vegetation (crop transpiration) and water lost by soil evaporation (soil evaporation).
- Actual transpiration: total amount of water that is used by vegetation (agricultural as well as natural vegetation) to produce biomass. This can be considered as Green Water.
- Actual soil evaporation: total amount of water that is lost by soils. This includes bare soils, but also areas partly covered by vegetation. This soil evaporation can be considered as a real loss as it cannot be used anymore in the same area.
- Tfraction: percentage of total evapotranspiration used for crop transpiration (Green Water). This factor indicates the effectiveness of the vegetation to use the Green Water source.
- Blue Water: water entering the streams by surface runoff and drainage that can be used for generating hydropower or being reused by downstream users.
- Groundwater recharge: water that contributes to the groundwater recharge. Only water that enters the deep groundwater is included. Water entering the shallow groundwater which will contribute to drainage is included in the previous item (Blue Water).
- Erosion: total actual sediment loss.

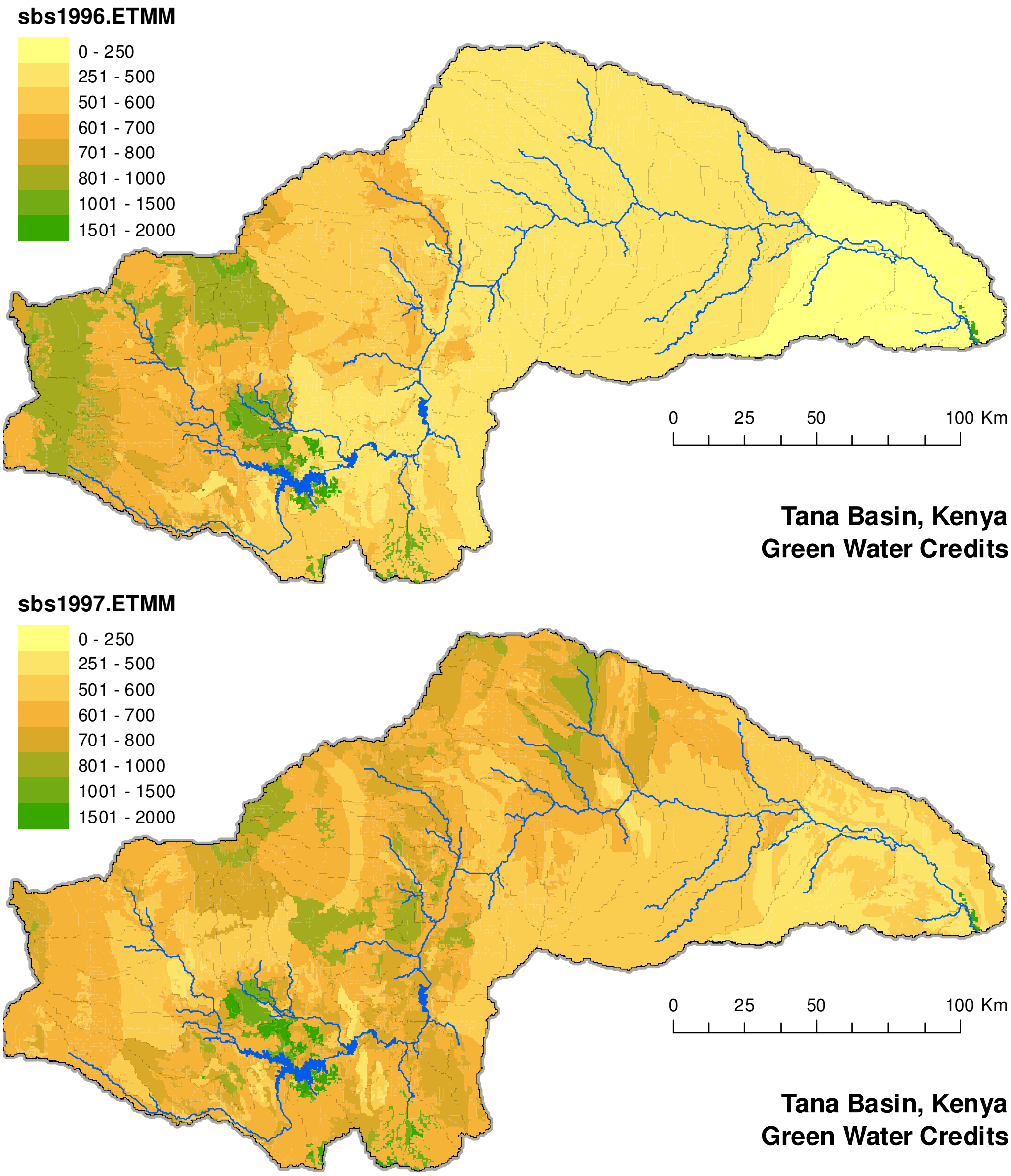


Figure 30. Actual evapotranspiration for a dry year (1996, top) and a wet year (1997, bottom) in mm y^{-1}.

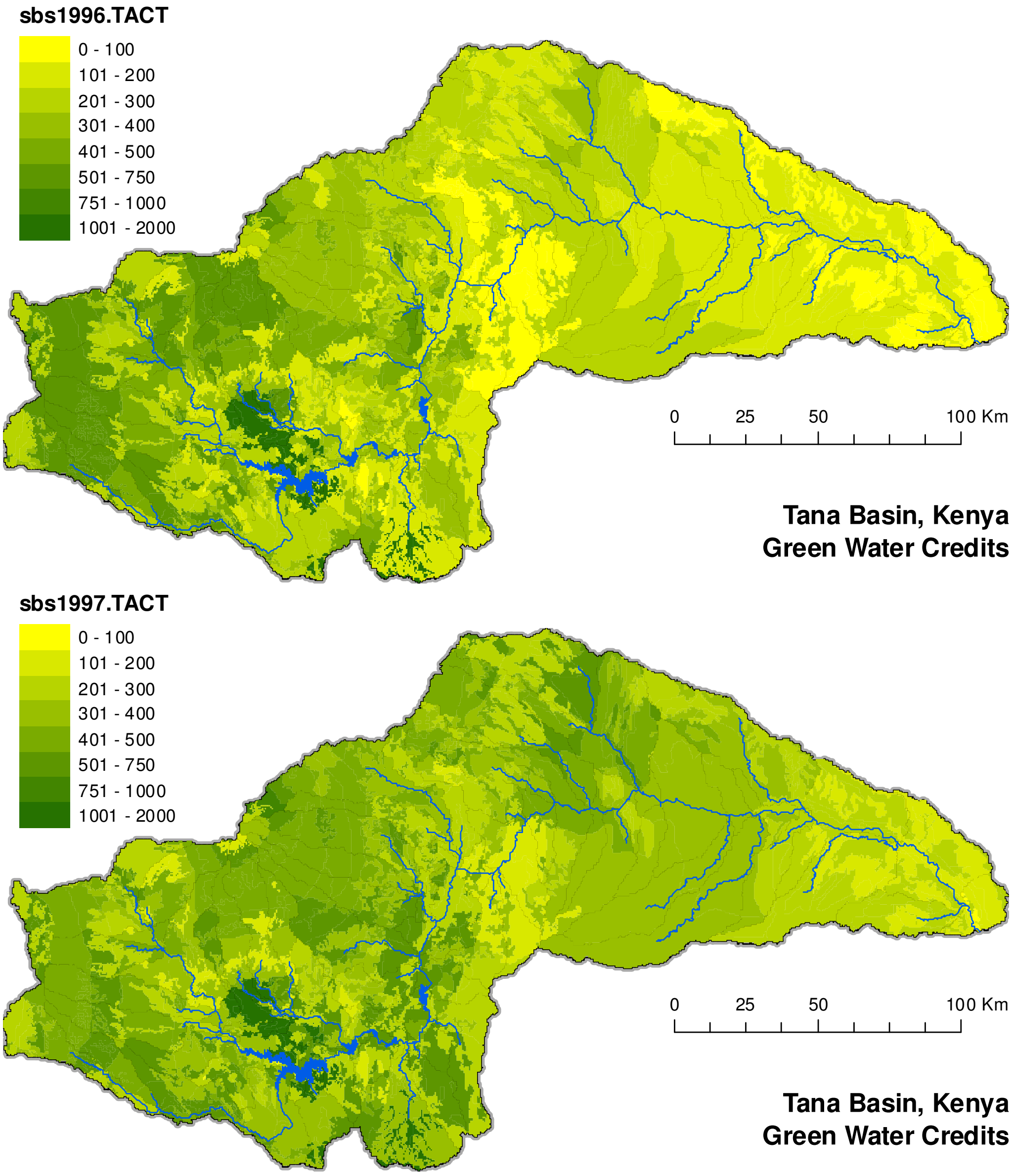
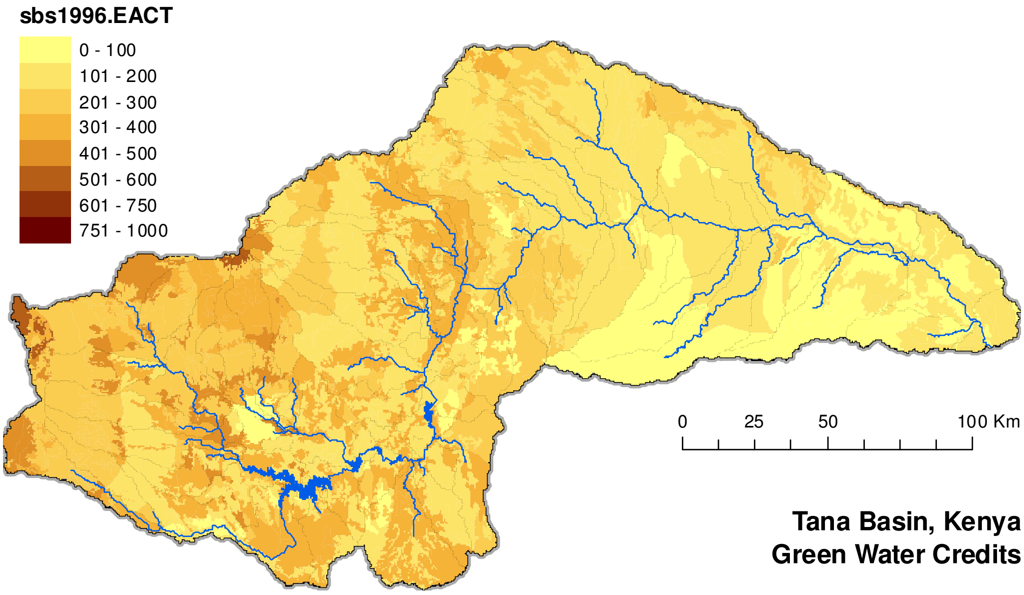


Figure 31. Actual transpiration (Green Water) for a dry year (1996, top) and a wet year (1997, bottom).



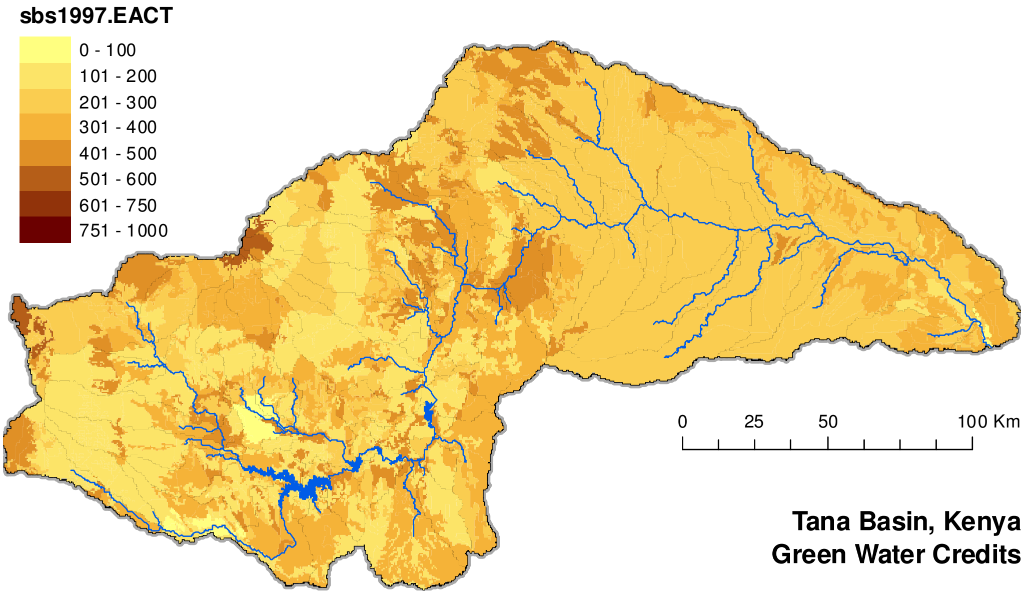


Figure 32. Actual soil evaporation for a dry year (1996, top) and a wet year (1997, bottom) in mm y^{-1}.

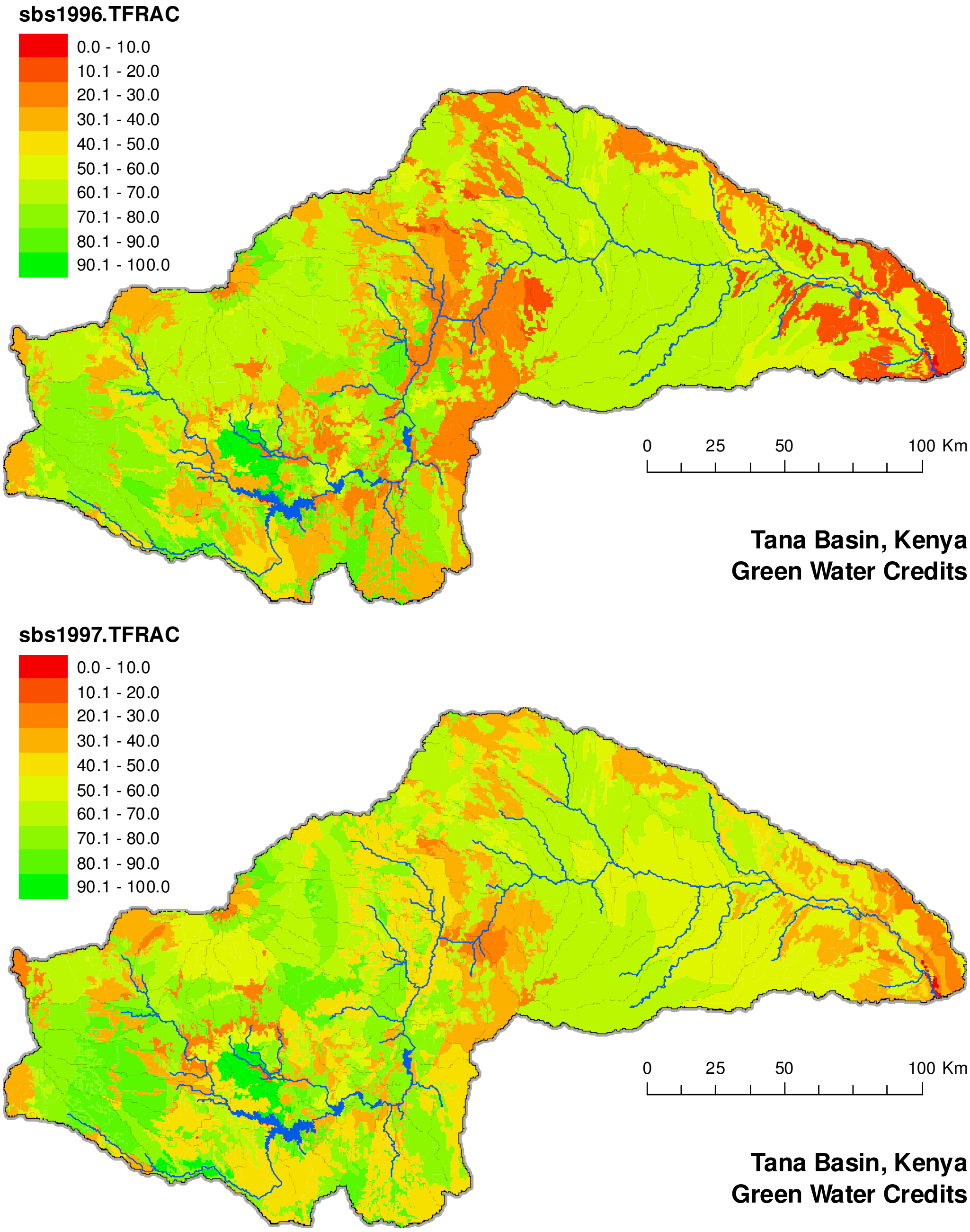
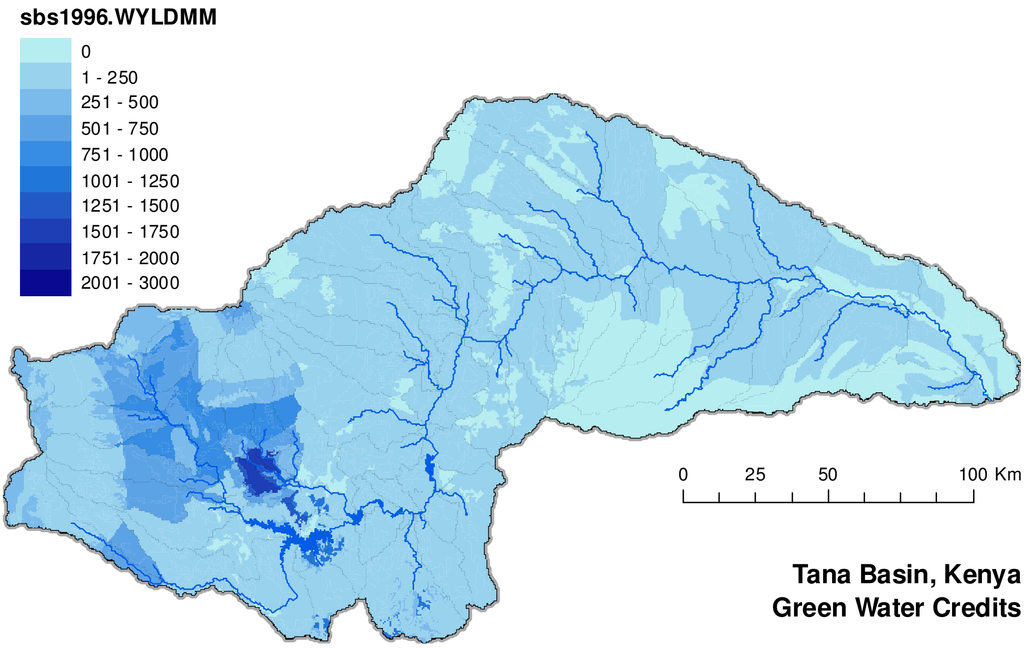


Figure 33. Percentage of total actual evapotranspiration used for Green Water for a dry year (1996, top) and a wet year (1997, bottom).



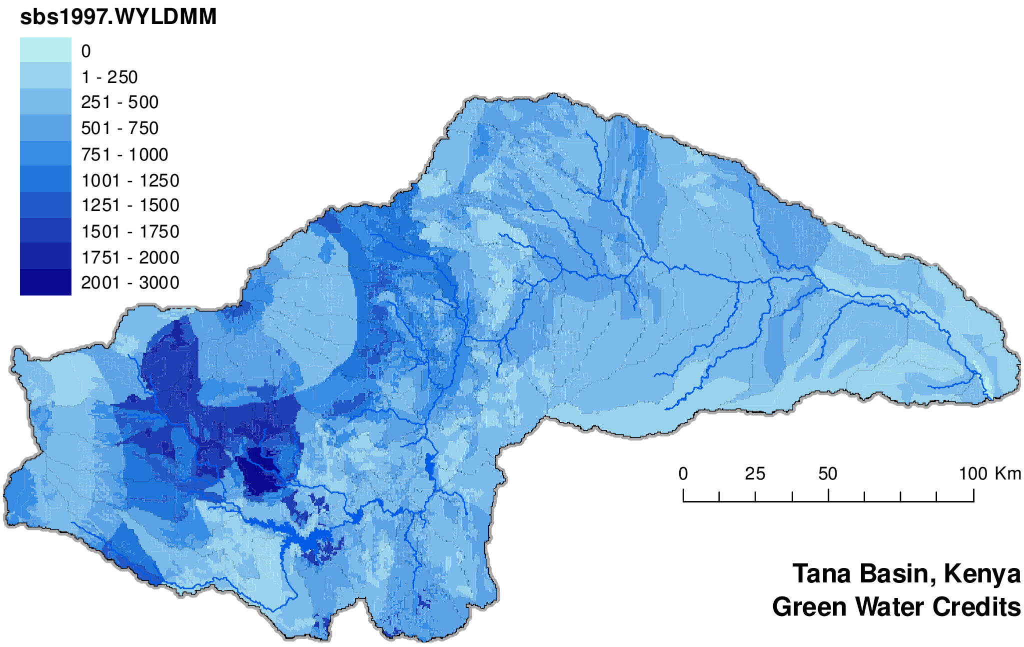


Figure 34. Blue Water (water entering the streams by surface runoff and drainage) for a dry year (1996, top) and a wet year (1997, bottom) in mm y^{-1}.

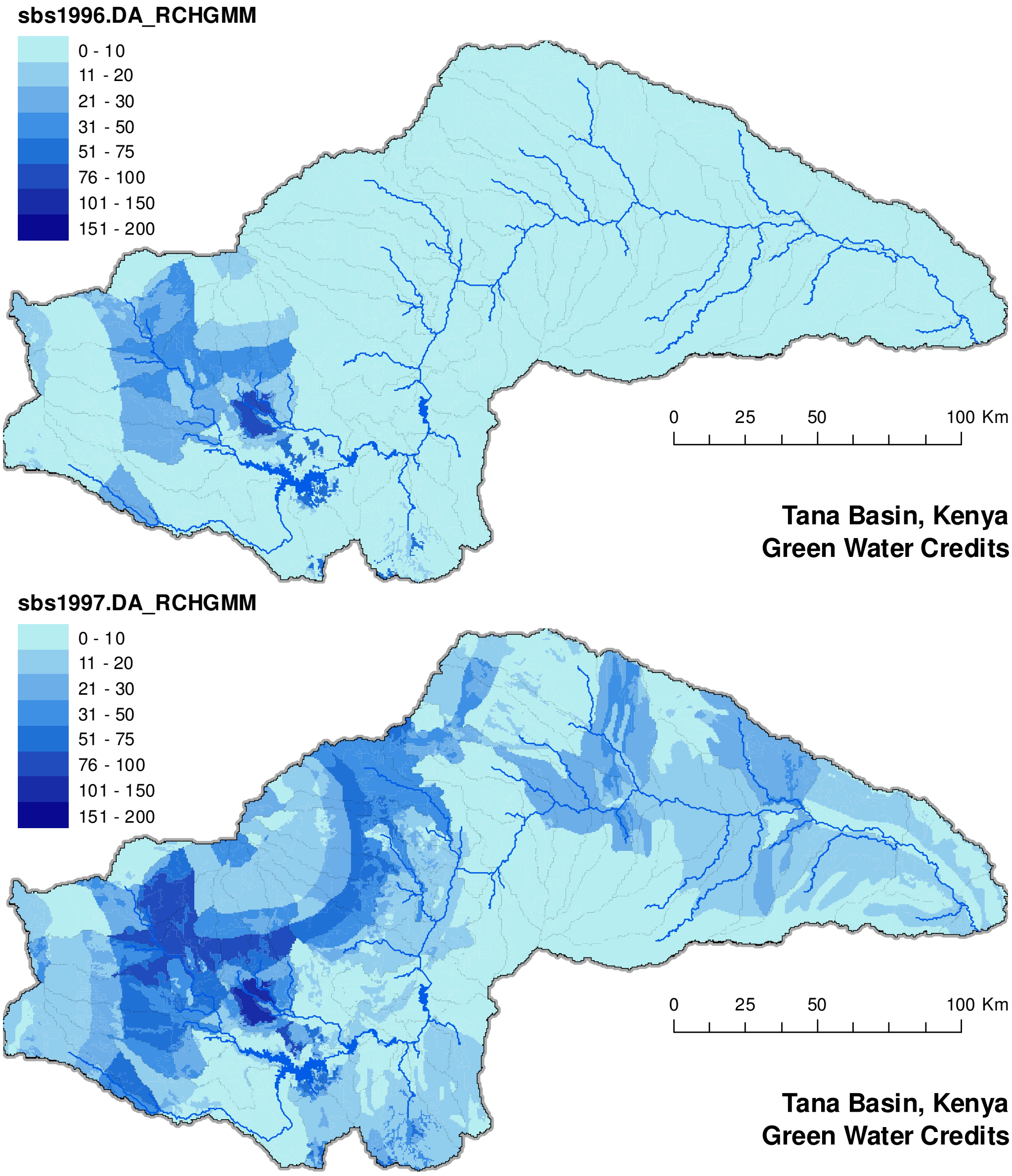


Figure 35. Deep groundwater recharge for a dry year (1996, top) and a wet year (1997, bottom) in mm y^{-1}.

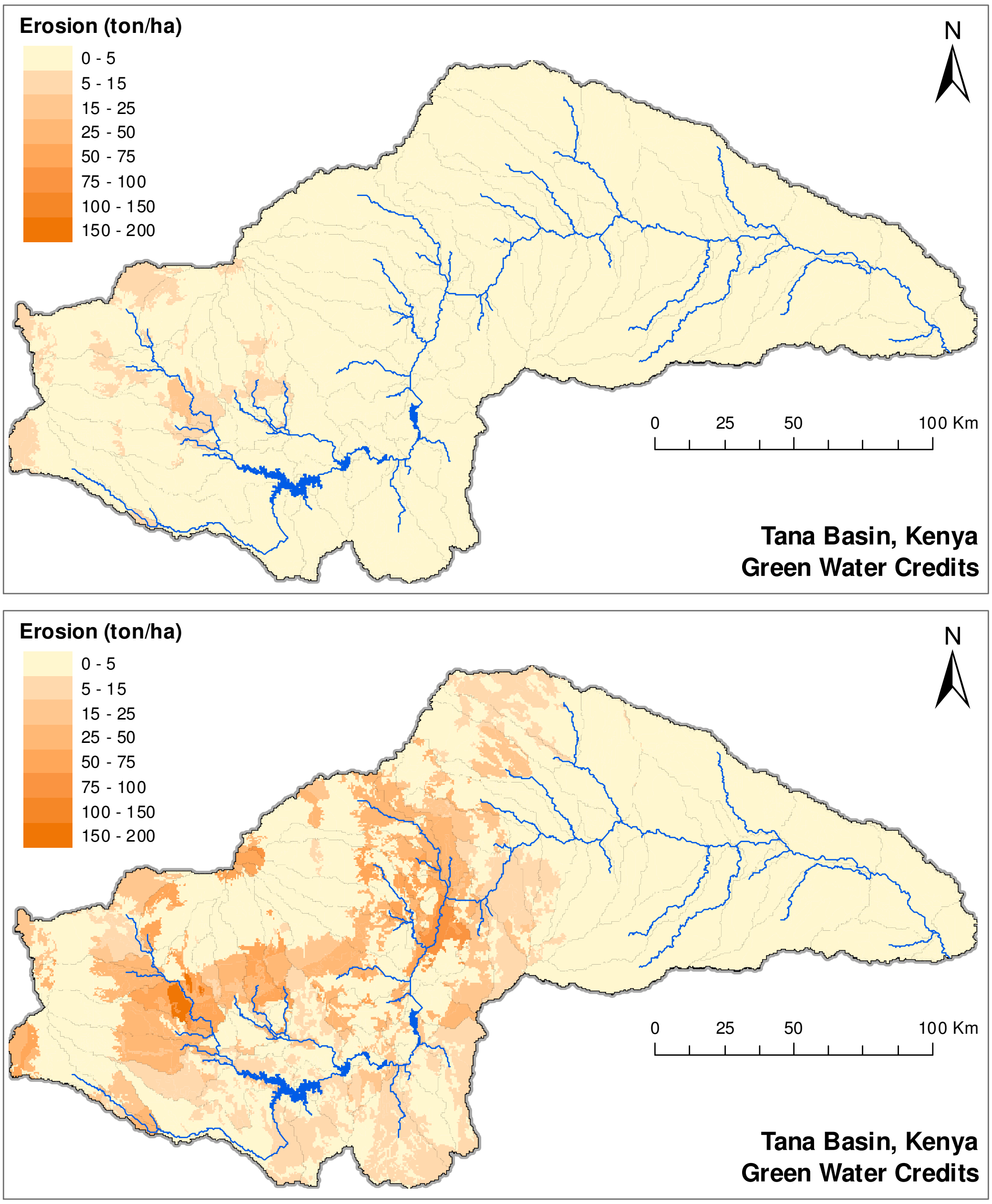


Figure 36. Erosion (ton / ha / yr) for a dry year (1996, top) and a wet year (1997, bottom) .

5.2 *Results aggregated for each land use*

To explore what the most relevant land use classes regarding Green Water Credits are, results were aggregated for each land use class. The most relevant items plotted are:

- Actual evapotranspiration: total amount of water consumed by vegetation (crop transpiration) and water lost by soil evaporation (soil evaporation).
- Tfraction: percentage of total evapotranspiration used for crop transpiration (Green Water). This factor indicates the effectiveness of the vegetation to use the Green Water source.
- Blue Water: water entering the streams by surface runoff and drainage that can be used for generating hydropower or being reused by downstream users.
- Erosion: total actual sediment loss.

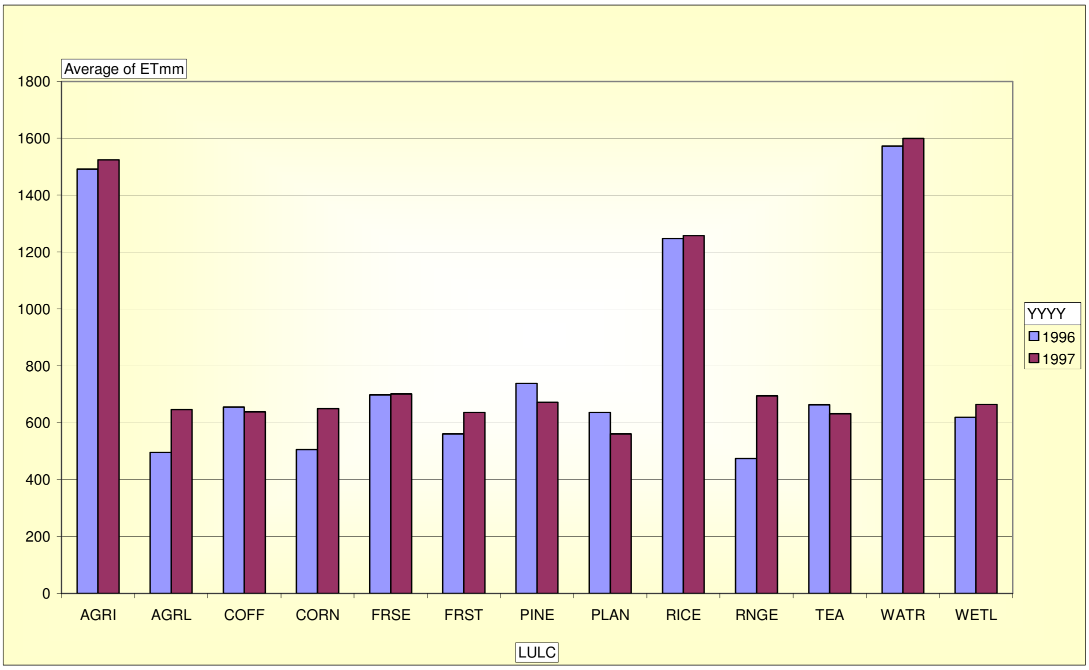


Figure 37. Mean actual evapotranspiration for the land classes defined for a dry year (1996) and a wet year (1997) .

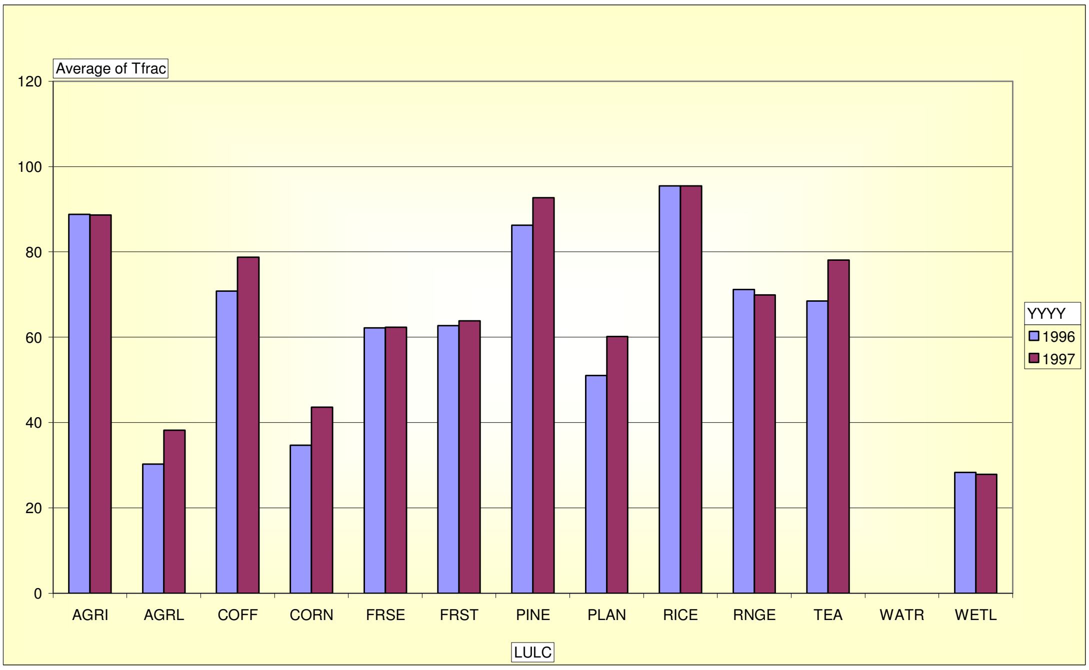


Figure 38. Percentage of total actual evapotranspiration used for Green Water (Green Water) for the land classes defined for a dry year (1996) and a wet year (1997).

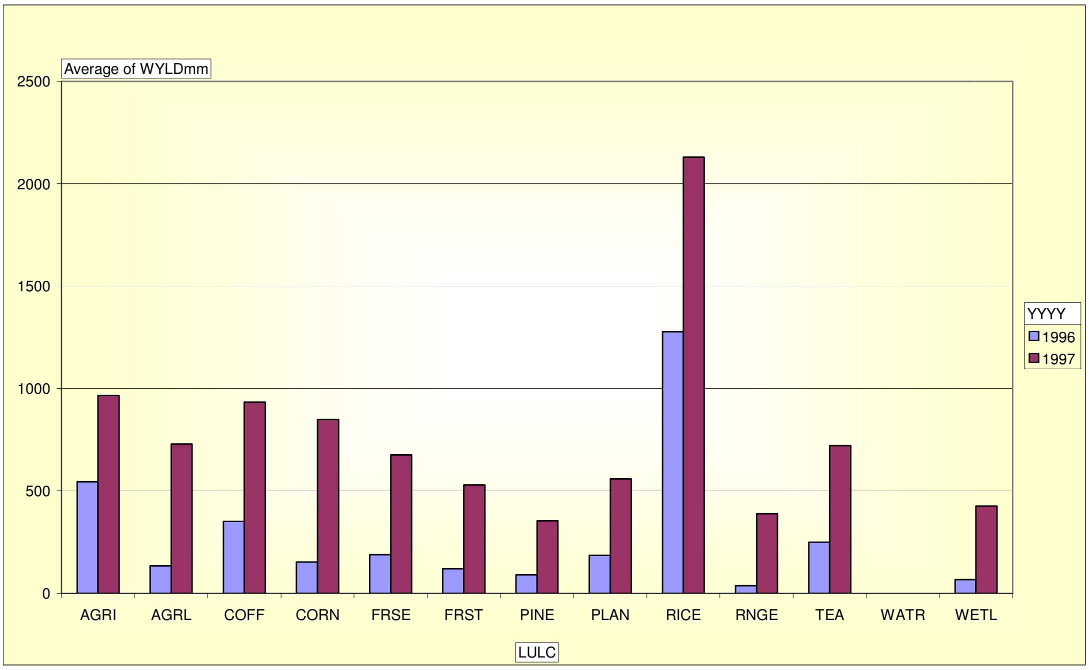


Figure 39. Blue Water (water entering the streams by surface runoff and drainage) for a dry year (1996) and a wet year (1997) in mm y^{-1}.

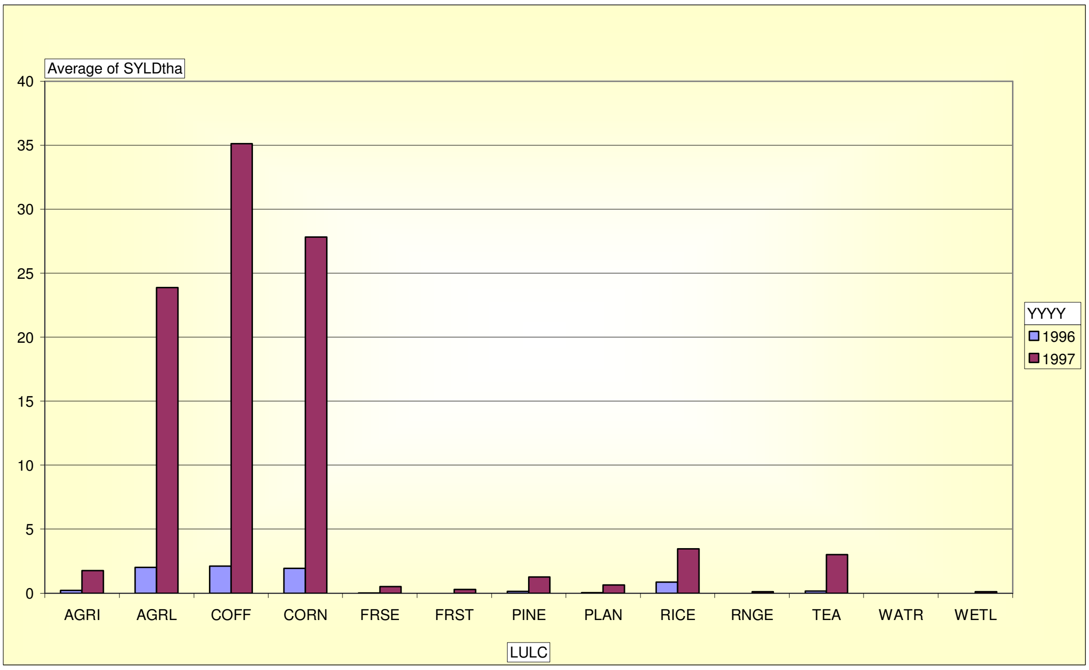


Figure 40. Erosion (ton / ha / yr) for a dry year (1996, top) and a wet year (1997, bottom) .

5.3 Reservoirs and flows

Two of the major issues regarding Green Water Credits in Tana are the conversion from Green water into Blue water and erosion resulting in loss of storage capacity in the reservoirs. The SWAT model is able to simulate at a high level of detail these processes. To demonstrate the capacity of the model and the output that can be generated the following figures are presented:

- Comparison between observed and simulated flows
- Reservoir dynamics
- Sediment transport

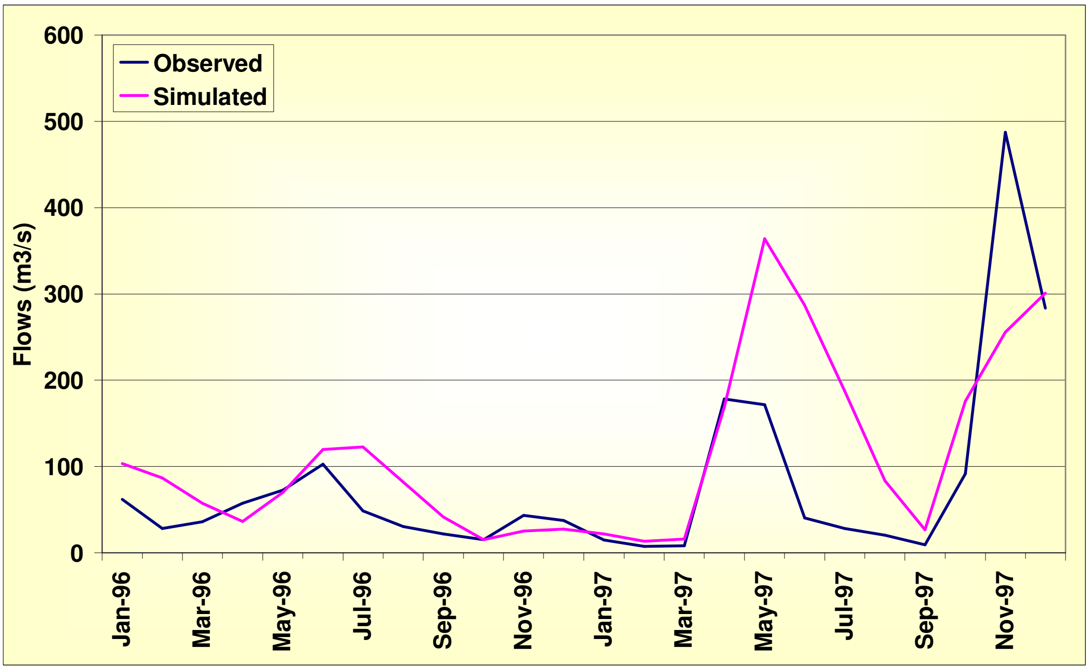


Figure 41. Comparison between observed and simulated inflow in Masinga reservoir.

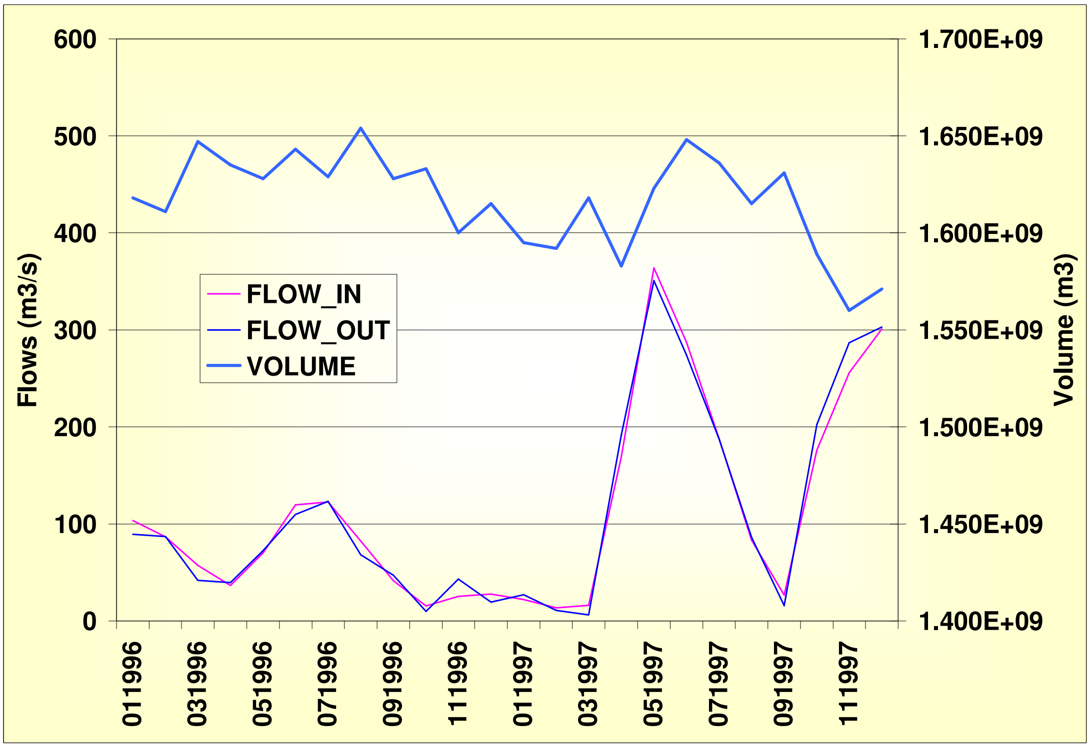


Figure 42. Masinga reservoir volumes, inflows and outflows.

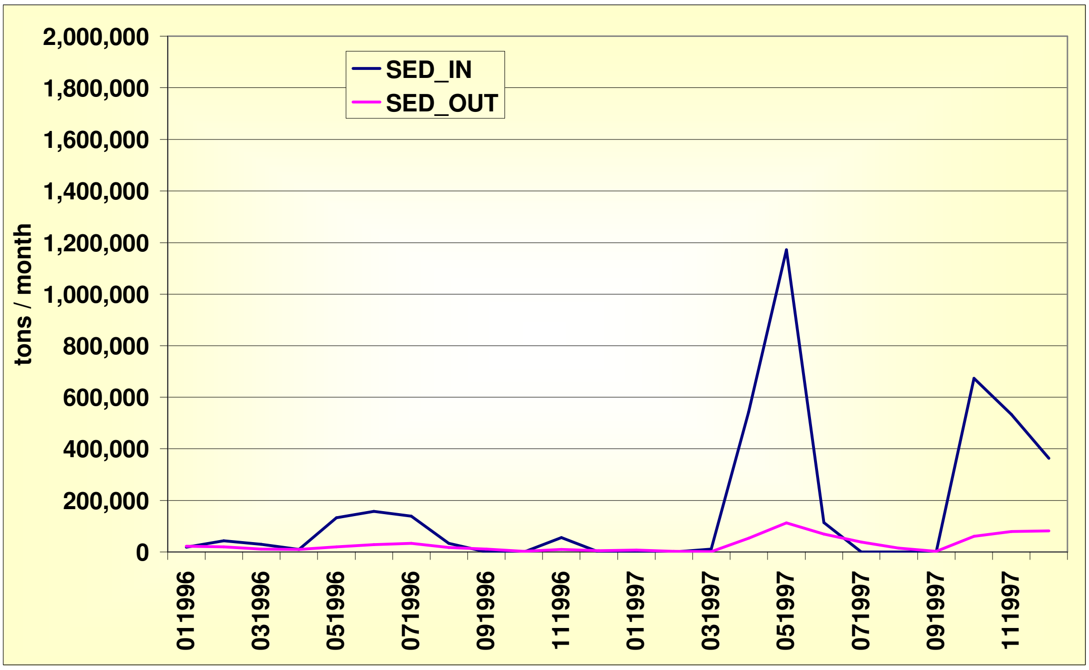


Figure 43. Masinga reservoir sediment inflows and outflows.

5.4 Discussion

The biophysical analysis of Green Water Credits concentrates on two aspects (i) understanding the current situation and (ii) exploring options for GWC. This chapter focuses on the first component by looking at two years, where the focus is on demonstrating what can be achieved by a biophysical analysis. It should be emphasized that for this Proof of Concept phase a rigorous calibration and validation of the model was not undertaken and results should therefore be considered as indicative.

In summary the following conclusions can be drawn from the analysis:

- The analysis as performed with the SWAT model are very supportive to evaluate Green Water Credits in terms of understanding processes related to Green water, Blue water and erosion/sediment. Output of the model is extensive and virtually any process can be evaluated at a very high spatial and temporal resolution. The model can deal with data of different level of detail, where higher accuracy of data will lead to more reliable results.
- The model as it is now was based on quite some data of lower level of detail, but comparison between measured and simulated flow shows already a reasonable agreement.

The following Green Water Credits measures can be determined from the results presented:

- Fraction of rainwater that is not used beneficial (means not used to support crop growth or enhance blue water) various substantially over the basin. Improvement of this might be a very positive GWC measure, as this will not affect total water consumption by evapotranspiration but will only positively affect the ratio crop transpiration over soil evaporation. Measures to achieve this includes: denser cropping, lengthening the growing season, changes in cropping patterns and intercropping. Care should be taken that only the water loss by soil evaporation and weeds will be used to enhance crop transpiration, otherwise the production of Blue water will be negatively affected.
- Increase Water Productivity. The amount of crop or biomass produced per cubic meter of water should be maximized. A change in cropping patterns can change the water productivity positively, where the most obvious one is a change from staple food to marketable crops. Proper marketing mechanisms are required for this. Other options include a shift to high-yielding varieties which is only feasible if other factors are favorable as well (fertilizer, pest control, farmer's skills).
- Reduction in soil erosion is one of the most promising GWC measures for this specific case. Storage capacity of reservoirs is decreasing rapidly and simultaneously is soil productivity declining due to loss of fertile soils.

6 Green Water Credits Options

6.1 *Scenario development*

Based on the analysis for the reference situation as described in the previous chapter and discussions with stakeholders two scenarios for Green Water Credits have been explored: (i) enhance water productivity and (ii) reduce soil erosion.

The measure to enhance water productivity is based on the assumption that by a longer growing season more crop can be produced. Also an increase in crop density will result in higher yields. One of the concerns of this scenario is, although a reduction in soil evaporation will be achieved, crop transpiration might increase even more.

Reduction in soil erosion is a clear win-win situation where less silt will flow into the reservoirs while simultaneous less fertile soil will be lost. A series of measures to achieve this are well-known and described in the WOCAT database.

6.2 *Scenario: enhance water productivity*

The first scenario is implemented in SWAT by increasing the maximum leaf area index of crops and by assuming that planting is done two weeks earlier and harvesting two weeks later. These changes are assumed to be implemented for the land covers AGRL (agriculture generic) and CORN. It was also assumed that these measures were implemented over the entire basin on all fields with these land covers. Obviously, this is somewhat unrealistic, but helps to understand what the impact might be and where the biggest gains are.

In summary the following conclusions can be drawn:

- According to Figure 44 total crop transpiration increases substantially, especially for agriculture generic. At the same time, total water consumption by evapotranspiration increases only slightly. Interesting would be to search for scenarios where only crop transpiration would increase and total evapotranspiration would remain constant.
- Increase in actual crop transpiration under this scenario is not homogenous over the entire basin (Figure 45). Although for all AGRL and CORN the same scenario has been assumed, soil type, slope, and local meteorological conditions result in a spatially distributed pattern. This information is paramount to assess where the most promising areas are to implement Green Water Credits.

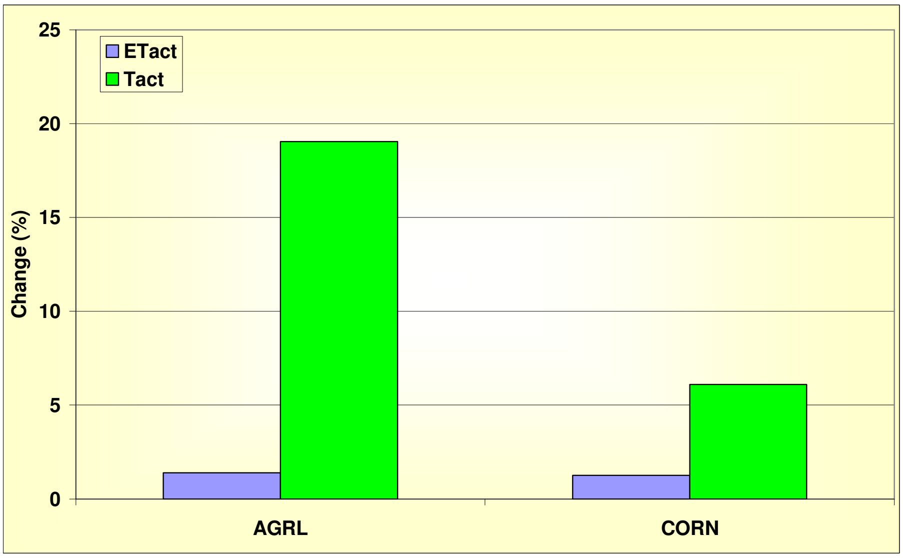


Figure 44. Changes in actual evapotranspiration and actual crop transpiration under the Enhance Water Productivity scenario for 1996. AGRL is generic agriculture.

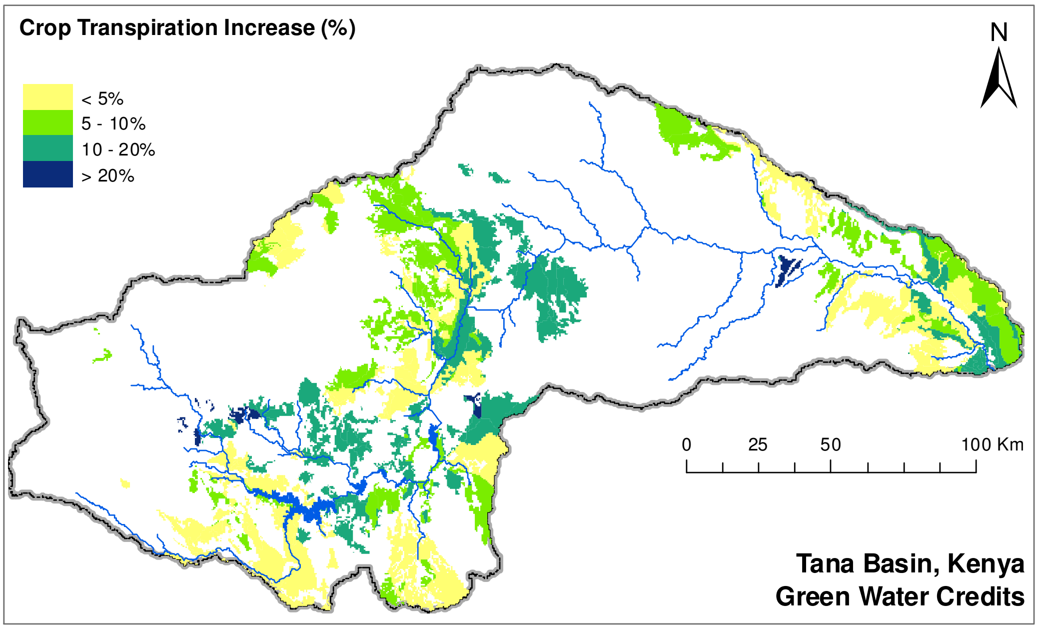


Figure 45. Increase in actual crop transpiration under the Enhance Water Productivity scenario for 1996.

6.3 Scenario: reduce soil erosion

The Reduce Soil Erosion scenario was applied for three land covers: AGRL (agriculture generic), CORN and COFF (coffee). It was assumed that this scenario was applied for the entire basin where these three land cover exists. Main conclusions are:

- A major reduction in soil erosion can be achieved under this scenario (Figure 46), especially for coffee. It should be emphasized here that the scenario was not yet fully defined using existing and proven techniques as described in WOCAT.
- Figure 47 shows that there is a spatial difference of where soil reduction can be actually have a substantial impact. Obviously the coffee zone appears to be the most promising one.

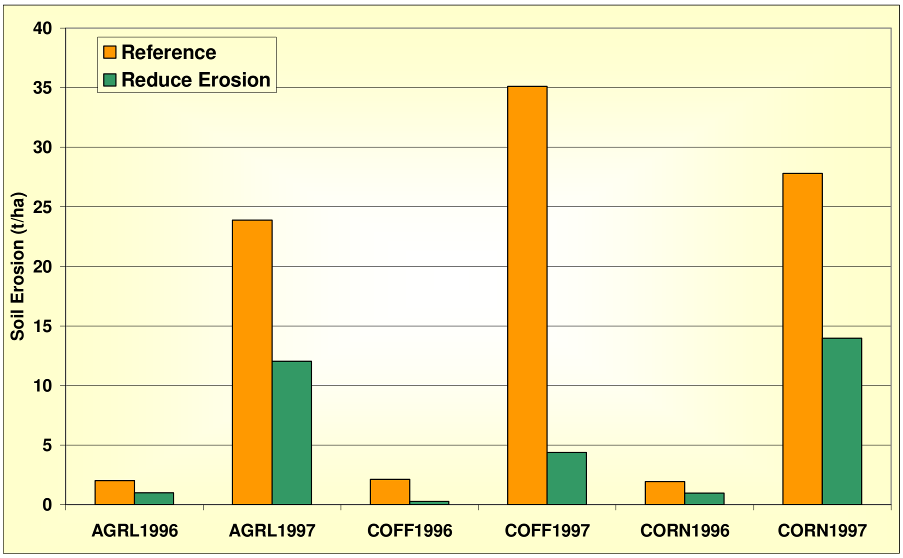


Figure 46. Actual soil erosion under the refenerce situation and the Reduce Soil Erosion scenario for three crops and two years.

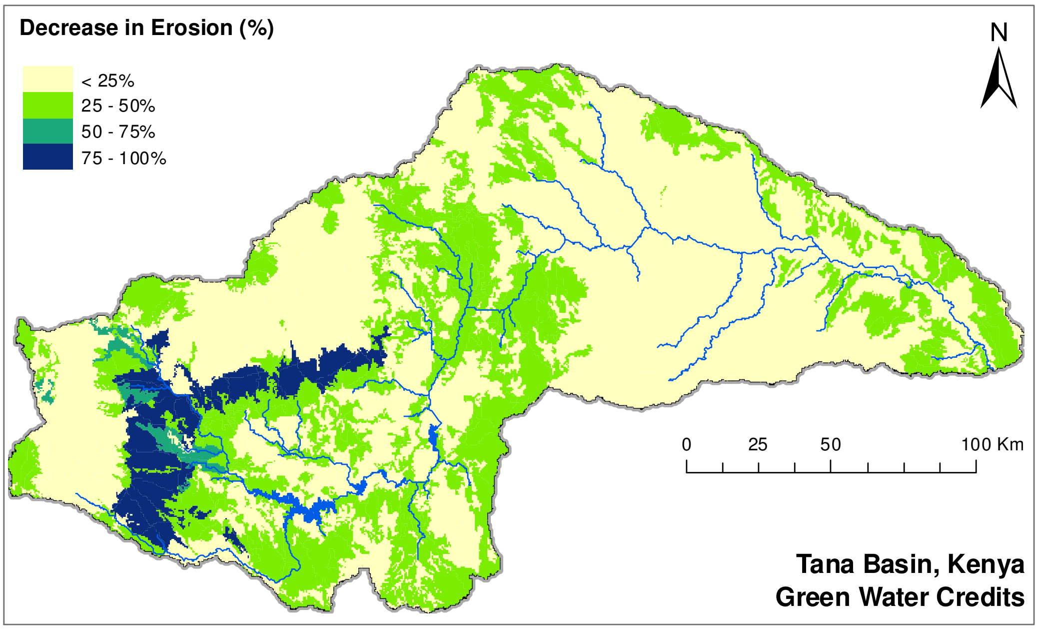


Figure 47. Decrease in soil erosion under the Reduce Soil Erosion scenario for 1997.

7 References

Batjes, N.H. and P. Gicheru. 2004. Soil data derived from SOTER for studies of carbon stocks and change in Kenya. ISRIC World Soil Information Report 2004/01.

Droogers, P., S. Kauffman, K. Dijkshoorn, W. Immerzeel, J. Huting. 2006. Green Water Credits: Basin Identification. Report 1. ISRIC Report 2006/03.

Droogers, P., M. Torabi, M. Akbari, and E. Pazira. 2001. Field scale modeling to explore salinity in irrigated agriculture. Irrigation and Drainage 50: 77-90.

Droogers, P., and G. Kite. 2001. Simulation modeling at different scales to evaluate the productivity of water. Physics and Chemistry of the Earth 26: 877-880.

FAO-Aquastat.

GoK. 2000. Population Census. 1999. Central Bureau of Statistics. Government of Kenya.

LCI. 2006. Land Cover Institute. http://landcover.usgs.gov/

Lee, D. 2005. Comparing the inverse parameter estimation approach with pedo-transfer function method for estimating soil hydraulic conductivity. Geosciences Journal Vol. 9, No. 3, p. 269 – 276.

ILIRI. 2006. International Livestock Research Institute, GIS services. http://www.ilri.cgiar.org/gis/

ISRIC. 2005. Green Water Credits proposal.

KenGen. 2005. Annual Report Kenya Electricity Generating Company. http://www.kengen.co.ke/IPO/

Macharia, P. 2004. Country overview Kenya. FAO and Kenya Soil Survey. http://www.fao.org /ag/agL/swlwpnr/reports/y_sf/z_ke/ke.htm#cover

Oludhe, C. 2003. Capacity Building and the Development of Tools For Enhanced Utilization of Climate Information and Prediction Products for the Planning and Management of Hydropower Resources in Kenya. Report Department of Meteorology,University of Nairobi, Kenya.

Sobieraj, J.A., H. Elsenbeer, R.A. Vertessy. 2001. Pedotransfer functions for estimating saturated hydraulic conductivity: implications for modeling storm flow generation. J. of Hydrology 251: 202-220.

Williams, J.R. 1995. Chapter 25. The EPIC Model. p. 909-1000. In Computer Models of Watershed Hydrology. Water Resources Publications. Highlands Ranch, CO.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall losses: A guide to conservation planning. USDA Agricultural Handbook No. 537. U.S. Gov. Print. Office, Washington, D. C.

Appendix XXX. Modeling tool selection

Appendix 1: DEM delineation

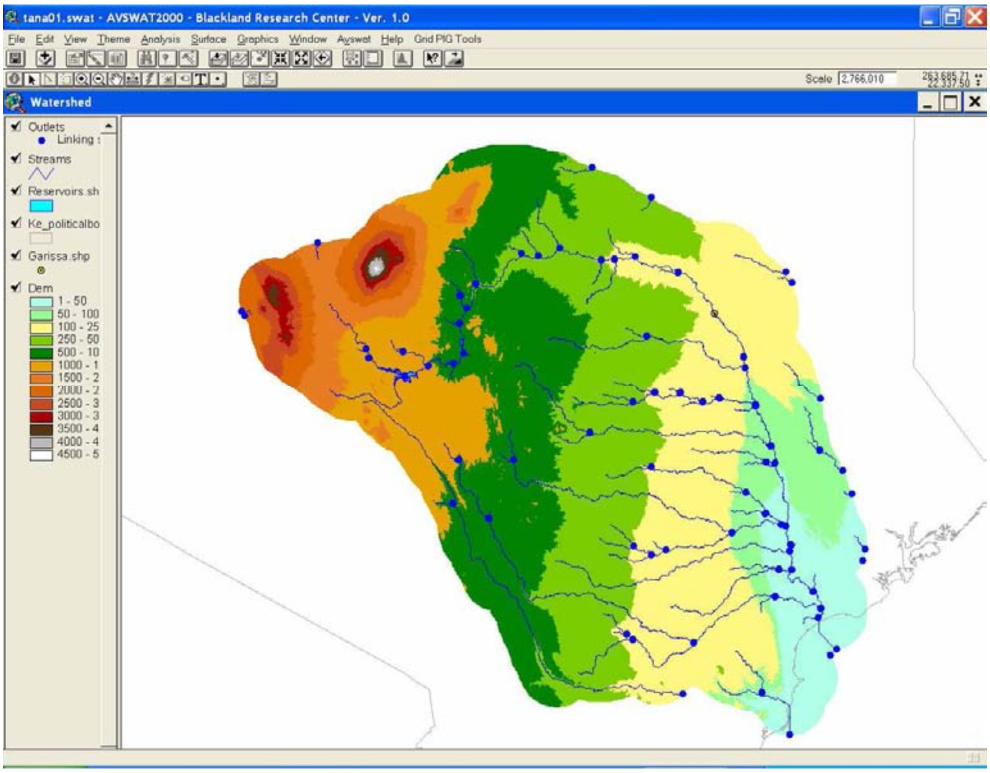


Figure 48. Watershed delineation: DEM 250 m, threshold area 50,000 ha

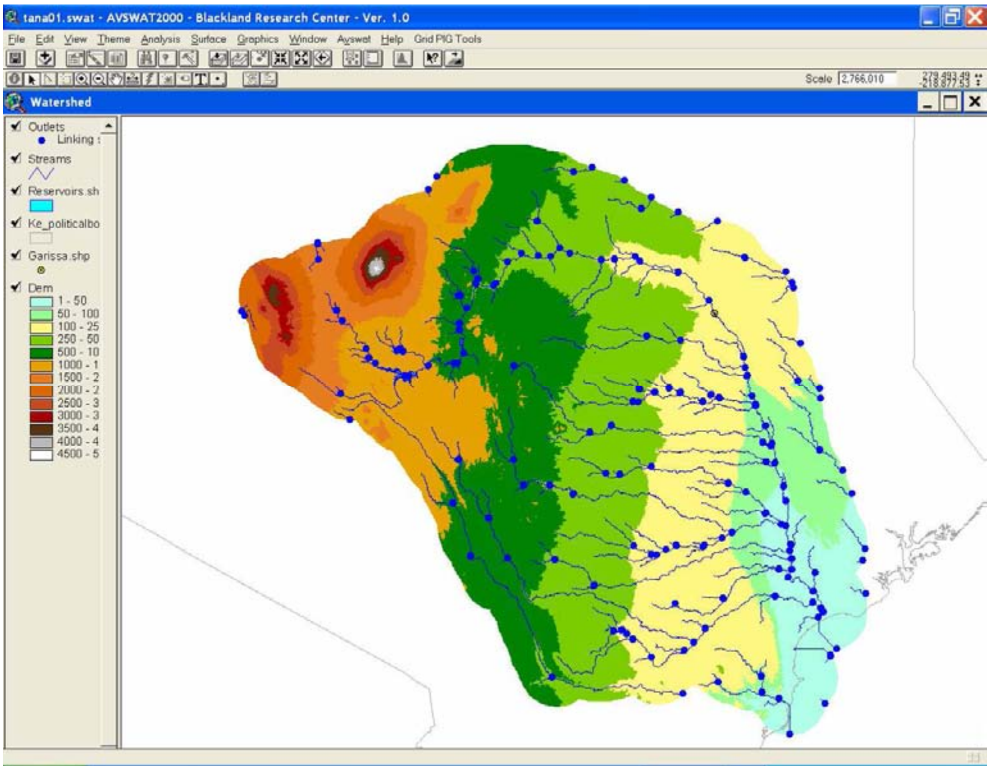


Figure 49. Watershed delineation: DEM 250 m, threshold area 25,000 ha

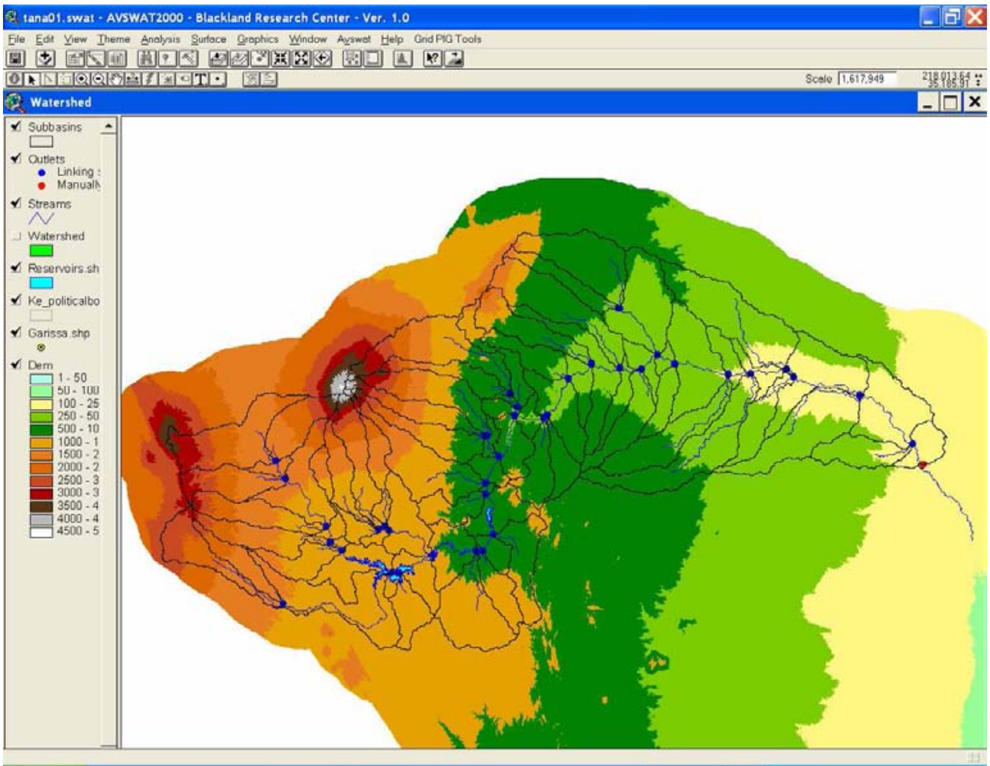


Figure 50. Sub basins based on: DEM 250 m, threshold area 25,000 ha. A total of 82 subbasins is identified.

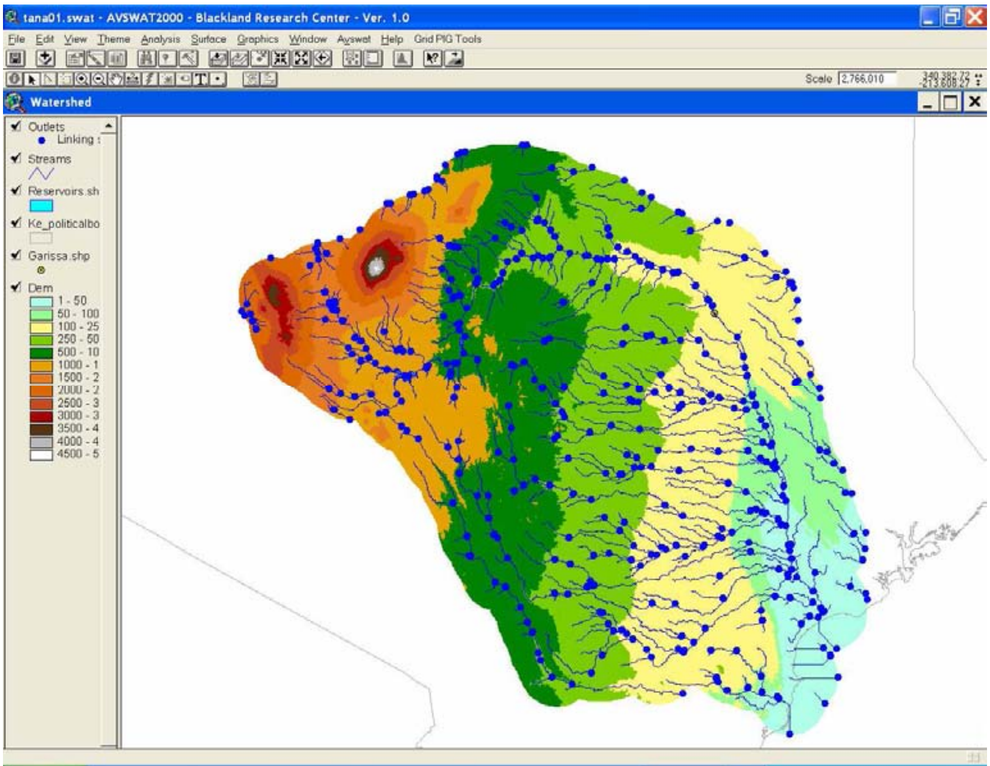


Figure 51. Watershed delineation: DEM 250 m, threshold area 10,000 ha

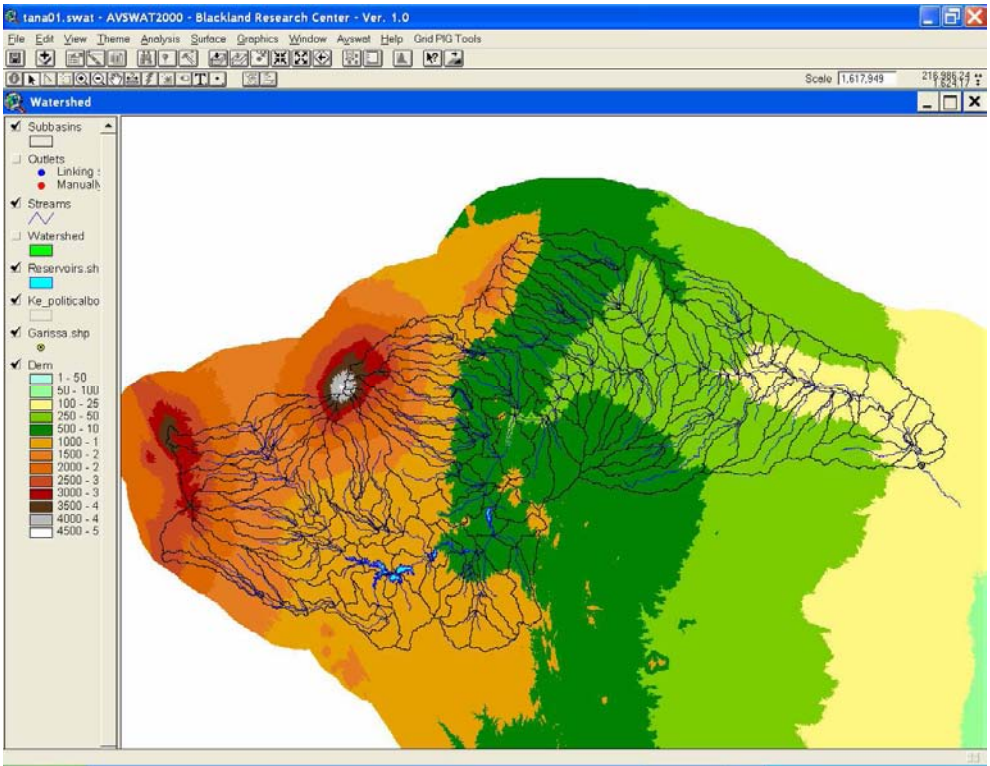


Figure 52. Sub basins based on: DEM 250 m, threshold area 10,000 ha. A total of 251 subbasins is identified.

Appendix 2: Soils data

The following remarks regarding the input file for SWAT.

The Kenya SOTER harmonized. mdb database contains all original and auxiliary files . The file (table) needed for import into SWAT programme is SOTERsummaryFile_ TANA4_SWAT_SELECTIE (2)

It contains all fields as mentioned in the SWAT user manual (and some fields to link to the GIS file). For this purpose SOTER soil unit composition is maintained. All soil components of one SOTER unit are still in database (PROP <100%, but together 100%)

To clarify the fields:

SNAME	PRID_SNAME
HYDGRP	estimated from soil parameters (clay%) , drainage and classification, etc.
Layer	soil layer per 20cm up to actual soil depth (<100 cm) or 100cm. Inserted are the soil depth >100 cm from profile descriptions (layer 6 and 7) Soils can still be deeper, but not described.
Botdep	lower depth from description in cm
SOL-ZMX	max rooting depth from profile description.
ANION_EXCL AND SOL_CRCK AND SOL_K	not done /estimated
SOL_CBN	TOTC in gram/kg soil
SGRADE, SSIZE , STYPE structure description acc. SOTER (see next page).	
CFRAG	Rock fragment/coarse fragments >2 mm
SDTO	Total sand fraction
STPC	silt %
CLPC	CLAY %
PSCL	TEXTURE class USDA
BULK	bulkdensity in gr/cm^3
TAWC	Total avialble water content (between FC = pF2.5 and pF 4.2)
ELCO	electro conductivity dS/m\, when measured.

Table 8. Grade of structure

N	structureless	apedal soil with no observable aggregation or no orderly arrangement of natural planes of weakness (massive or single grain)
W	weak	soil with poorly formed indistinct peds, that are barely observable in place even in dry soil, breaks up into very few intact peds, many broken peds and much apedal material
M	moderate	soil with well-formed distinct peds, durable and evident in disturbed soil, which produces many entire peds, some broken peds and little apedal material
S	strong	soil with durable peds that are clearly evident in undisturbed (dry) soil, which breaks up mainly into entire peds

Table 9. Size classes for structure elements of various types (mm's). (Soil Survey Staff, 1951; FAO, 1990, 2006).

Size classes		Ranges of size of structure elements (mm)				
		platy	prismatic/ columnar	(sub)/ang. blocky	granular	crumb
V	very fine	< 1	< 10	< 5	< 1	<1
F	fine	1- 2	10 - 20	5 - 10	1- 2	1-2
M	medium	2- 5	20 - 50	10 - 20	2- 5	2-5
C	coarse	5-10	50 -100	20 - 50	5-10	-
X	very coarse	>10	100-500	> 50	> 10	-
E	extremely coarse	-	>500	-	-	-

Table 10. Type of structure

P	platy	particles arranged around a generally horizontal plane
R	prismatic	prisms without rounded upper end
C	columnar	prisms with rounded caps
A	angular blocky	bounded by plains intersecting at largely sharp angles
S	subangular blocky	mixed rounded and plane faces with vertices mostly rounded
G	granular	spheroidical or polyhedral, relatively non-porous
B	crumb	spheroidical or polyhedral, porous
M	massive	no structure visible, coherent porous (apedal soil)
N	single grain	no structure, individual grains
W	wedge shaped	structure in horizons with slickensides
K	rock structure	includes fine stratification in unconsolidated materials to unweathered minerals in saprolite

		(consolidated rocks)
	COARSE FRAGMENTS	The presence of any rock and/or mineral fragments (>2 mm) in the horizon is described in nature, abundancy and size classes, items 91 – 93. Mineral nodules are described here in the same way as coarse mineral fragments

Appendix: Conversion Land Cover Classes

The following table is used to convert the AfriCover land cover data set to SWAT classes. Note that four additional groups have been added that were not present in the SWAT standardized data bases:

BARE	Bare soils
COFF	Coffee
TEA	Tea
PLAN	Plantation
AGRI	Agriculture general irrigated

AfriCover	**SWATclass**	**SWATname**	**IRR**
Closed woody (broadleaved deciduous) with sparse trees	FRSD	Forest-Deciduous	
Closed woody with sparse trees	FRST	Forest-Deciduous	
Open general woody with herbaceous	RNGE	Forest-Deciduous	
Open general woody with closed to open herbaceous on temporarily flooded land - fresh water	WETL	Forest-Deciduous	
River	WATR	Forest-Deciduous	
Artificial Lakes or Reservoirs	WATR	Forest-Deciduous	
Natural lakes	WATR	Forest-Deciduous	
Fish Pond	WATR	Forest-Deciduous	
Irrigated Orchard, Large to Medium Fields - Citrus	ORCD	Forest-Deciduous	irrigated
Graminoids - Large to Medium Fields - Rice	RICE	Forest-Deciduous	
Trees Plantation - Large Fields, Rainfed Permanent	PLAN	Forest-Deciduous	
Rainfed Tree Crop (1 add. Herbaceous Crop) - Clustered Medium Fields	AGRR	Forest-Deciduous	
River banks	BARE	Forest-Deciduous	
Lake shore	BARE	Forest-Deciduous	
Cereals, Rice - Small Fields	RICE	Forest-Deciduous	
Rainfed Tree Crop (1 add. Herbaceous Crop), Small Fields	AGRR	Forest-Deciduous	
Rainfed Tree Crop, Small Fields	AGRR	Forest-Deciduous	
Rainfed Tree Crop (1 add. Shrubs Crop), Clustered Small Fields	AGRR	Forest-Deciduous	
Rainfed Tree Crop (1 add. Herbaceous Crop), Clustered Small Fields	AGRR	Forest-Deciduous	
Rainfed Tree Crop, Clustered Small Fields	AGRR	Forest-Deciduous	
Rainfed Tree Crop, Isolated Small Fields	AGRR	Forest-Deciduous	
Sand beaches	BARE	Forest-Deciduous	
Needle Leaved Evergreen Forest Plantation	FRSE	Forest-Deciduous	
Forest Plantation, Broad Leaved Evergreen, Rainfed Permanent	FRSE	Forest-Deciduous	
Closed herbaceous on temporarily flooded land - fresh water	WETL	Forest-Deciduous	
Sparse herbaceous	AGRL	Forest-Deciduous	
Closed to very open herbaceous	AGRL	Forest-Deciduous	

Closed to Open Herbaceous On Permanently Flooded Land	WETL	Forest-Deciduous
Closed to very open herbaceous with sparse trees and shrubs	AGRL	Forest-Deciduous
Closed to very open herbaceous with sparse shrubs	AGRL	Forest-Deciduous
Closed to very open herbaceous with sparse shrubs on temporarily flooded land - fresh water	WETL	Forest-Deciduous
Quarry	BARE	Forest-Deciduous
Snow	WATR	Forest-Deciduous
Rainfed Shrub Crop, Large Fields - Pineapple	PINE	Forest-Deciduous
Rainfed Shrub Crop, Large Fields - Coffee	COFF	Forest-Deciduous
Rainfed Shrub Crop, Large Fields - Tea	TEA	Forest-Deciduous
Rainfed Shrub Crop, Large Fields	AGRL	Forest-Deciduous
Rainfed Shrub Crop, Small Fields - Coffee	COFF	Forest-Deciduous
Rainfed Shrub Crop, Small Fields - Tea	TEA	Forest-Deciduous
Permanently Cropped Area With Small Sized Field(s) Of Rainfed Shrub Crop(s)		
Crop Cover: (Orchard(s))	AGRL	Forest-Deciduous
Rainfed Shrub Crop, Clustered Small Fields - Coffee	COFF	Forest-Deciduous
Rainfed Shrub Crop, Clustured Small Field - Tea	TEA	Forest-Deciduous
Rainfed Shrub Crop, Clustered Small Fields	AGRL	Forest-Deciduous
Rainfed Shrub Crop, Isolated Small Fields - Tea	TEA	Forest-Deciduous
Rainfed Shrub Crop, Isolated Small Fields	AGRL	Forest-Deciduous
Closed multilayered trees (broadleaved evergreen)	FRSE	Forest-Deciduous
Closed trees with shrubs	FRST	Forest-Deciduous
Closed Trees - Bamboo	FRST	Forest-Deciduous
Open trees (broadleaved deciduous) with closed to open herbaceous and sparse shrubs	FRST	Forest-Deciduous
Very open trees (broadleaved deciduous) with closed to open herbaceous and sparse shrubs	FRST	Forest-Deciduous
Open trees (broadleaved deciduous) with closed to open shrubs	FRST	Forest-Deciduous
Very open trees (broadleaved deciduous) with closed to open shrubs	FRST	Forest-Deciduous
Open general trees with shrubs	FRST	Forest-Deciduous
Very open trees with closed to open shrubs	FRST	Forest-Deciduous
Closed trees (broadleaved evergreen) on permanently flooded land - brackish water	FRST	Forest-Deciduous
Open general trees with closed to open herbaceous on temporarily flooded land - fresh water	FRST	Forest-Deciduous
Bare rock	BARE	Forest-Deciduous
Large-Medium Fields, Rainfed	AGRL	Forest-Deciduous
Large Fields - Wheat, Rainfed	SWHT	Forest-Deciduous
Herbaceous - Medium Fields -Maize, Rainfed	CORN	Forest-Deciduous
Herbaceous - Medium Fields -Wheat, Rainfed	SWHT	Forest-Deciduous
Large-Medium Fields - Maize, Rainfed	CORN	Forest-Deciduous
Large-Medium Fields - Sisal, Rainfed	AGRL	Forest-Deciduous

Large-Medium Fields - Wheat, Rainfed	SWHT	Forest-Deciduous	
Herbaceous - Large to Medium Fields, Irrigated Surface Permanent	AGRI	Forest-Deciduous	irrigated
Herbaceous - Medium Fields, Irrigated Surface Permanent	AGRI	Forest-Deciduous	irrigated
Herbaceous - Medium Fields, Sugar Cane Irrigated Surface Permanent	SUGC	Forest-Deciduous	irrigated
Irrigated Herbaceous Crop, Large to Medium Fields - Sugarcane	SUGC	Forest-Deciduous	irrigated
Rainfed Herbaceous - Large Fields	AGRL	Forest-Deciduous	
Rainfed Herbaceous - Medium Fields	AGRL	Forest-Deciduous	
Irrigated Herbaceous Crop, Large Fields	AGRI	Forest-Deciduous	irrigated
Clustered Large-Medium Fields, Rainfed	AGRL	Forest-Deciduous	
Clustered Large Fields, Rainfed	AGRL	Forest-Deciduous	
Rainfed Herbaceous - Clustered Medium Fields, Maize Rainfed	CORN	Forest-Deciduous	
Clustered Large-Medium Fields, Wheat Rainfed	SWHT	Forest-Deciduous	
Rainfed Herbaceous - Clustered Medium Fields	AGRL	Forest-Deciduous	
Rainfed Herbaceous - Isolated Medium Fields, Maize	CORN	Forest-Deciduous	
Rainfed Herbaceous - Isolated Medium Fields	AGRL	Forest-Deciduous	
Herbaceous - Small Fields - Maize, Rainfed	CORN	Forest-Deciduous	
Herbaceous - Small Fields, Sugar Cane Irrigated Surface Permanent	SUGC	Forest-Deciduous	irrigated
Continuos Rainfed Small fields [cereal]	AGRL	Forest-Deciduous	
Herbaceous - Small Fields, Irrigated Surface Permanent	AGRI	Forest-Deciduous	irrigated
Herbaceous - Clustered Small Fields - Maize, Rainfed	CORN	Forest-Deciduous	
Rainfed Herbaceous - Clustered Small Fields	AGRL	Forest-Deciduous	
Herbaceous - Isolated Small Fields - Maize, Rainfed	CORN	Forest-Deciduous	
Rainfed Herbaceous - Isolated Small Fields	AGRL	Forest-Deciduous	
Closed shrubs	RNGB	Forest-Deciduous	
Closed shrubs with sparse trees	RNGB	Forest-Deciduous	
Open general shrubs with closed to open herbaceous	RNGE	Forest-Deciduous	
Very open shrubs with closed to open herbaceous	RNGE	Forest-Deciduous	
Open shrubs with closed to open herbaceous and sparse trees	RNGE	Forest-Deciduous	
Very open shrubs with closed to open herbaceous and sparse trees	RNGE	Forest-Deciduous	
Industrial area - general	UIDU	Forest-Deciduous	
Urban areas (general)	URML	Forest-Deciduous	
Refugee camp	URML	Forest-Deciduous	
Rural settlements	URML	Forest-Deciduous	
Open general shrubs with closed to open herbaceous on temporarily flooded land	WETL	Forest-Deciduous	
Sparse shrubs with sparse herbaceous	RNGE	Forest-Deciduous	
Airport	UTRN	Forest-Deciduous	
Bare soil	BARE	Forest-Deciduous	
Sand	BARE	Forest-Deciduous	