Feasibility Study for an Integrated Watershed Management Program for the Kagera River Basin

Grant No. TF095177

Annex F: Watershed Assessment Report

10 December 2012

LTS

NOTE: THE COMPLETE HYSIM AND SLEMSA MODELIING TOOL OUTPUTS TOGETHER WITH ALL GIS BASELAYERS AND OVERLAYS WILL BE PRESENTED AT THE FINAL REPORT STAGE ON DVD/CD DUE TO THEIR SIZE.

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Acronyms

CEC	Cation exchange capacity
CITES	Convention on International Trade in Endangered Species
CSIRO	Commonwealth Scientific & Industrial Research Organisation
DOE	Department of Environment
DWD	Directorate of Water Development
EAC	East African Community
ENSAP	Eastern Nile Subsidiary Action Program
FS-IWMP	Feasibility Study-Integrated Watershed Management Project
GHG	Greenhouse Gas
GIS	Geographical Information System
GoB	Government of Burundi
GoR	Government of Rwanda
HYSIM	Hydrological Simulation Model
HYSIM-CC	Hydrological Simulation Model for Climate Change
IPCC	Intergovernmental Panel for Climate Change
IUCN	International Union for the Conservation of Nature
IWRM	Integrated Water Resource Management
KIWMIP	Kagera Integrated Watershed Management Investment Programme
LTS	LTS International Ltd
LVBC	Lake Victoria Basin Commission
LVEMP	Lake Victoria Environmental Management Programme
Masl	Meters above sea level
mm	Millimetre
NBI	Nile Basin Initiative
(A)MSU	(Advanced) Micro Wave Sounding Unit
NELSAP	Nile Equatorial Lakes Subsidiary Action Program
NELTAC	Nile Equatorial Lakes Technical Advisory Committee

NGO	Non-Governmental Organisation
NP	National Park
PET	Potential Evapo-Transpiration
ppm	Parts per million
Ppkm2	Persons per square kilometre
TIWRDP	Kagera River Basin Transboundary Integrated Water Resources Development Project
UKMO	United Kingdom Meteorological Office
UNFCCC	United Nations Framework Convention on Climate Change

1. KAGERA RIVER BASIN CHARACTERISTICS

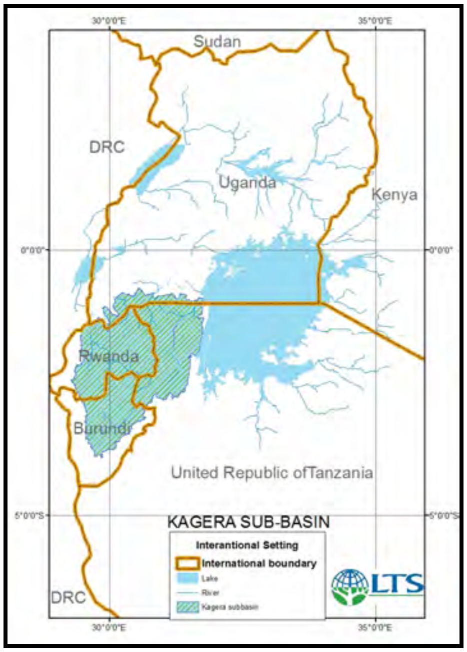
1.1 Basin Setting

Located in the Great Lakes region of Africa and being the southern-most tributary of the White Nile, the Kagera River drains a basin area of 59,800 km$^{2.}$ It is the main river flowing into Lake Victoria providing about 7.42 million m3 (32 per cent of inflow) of the inflow to the Lake (Sutcliffe and Parks, 1999). The other tributaries flowing into the Lake provide some 18.84 million m3 (68 per cent of inflow). However, as noted by Flohn and Burkhardt, (1985) some 85 per cent of the Lake's supply is from rainfall from nocturnal cloud over the Lake.

Its area is distributed among Burundi (22% of the basin area), Rwanda (34%), Tanzania (34%) and Uganda (10%) of the basin area; see DWD/WWAP, 2005).

Map 1. Nile Basin Setting

Map 2. International setting



1.2 Bio-physical Characteristics

1.2.1 Relief and Drainage

1.2.1.1 Relief

Map 3 shows the relief across the Kagera Sub-basin. The western boundary is formed by a narrow ridge rising from 2,000 to 4,400masl. To the east of the ridge is a deeply dissected plateau extending some 100 kms between 1,500 and 2,000masl. Below 1,500masl are undulating plains broken by three series of ridges trending southwest-northeast. The hypsographic curve shows that the greater part of the Sub-basin is altitude between 1250 and 2,000masl.

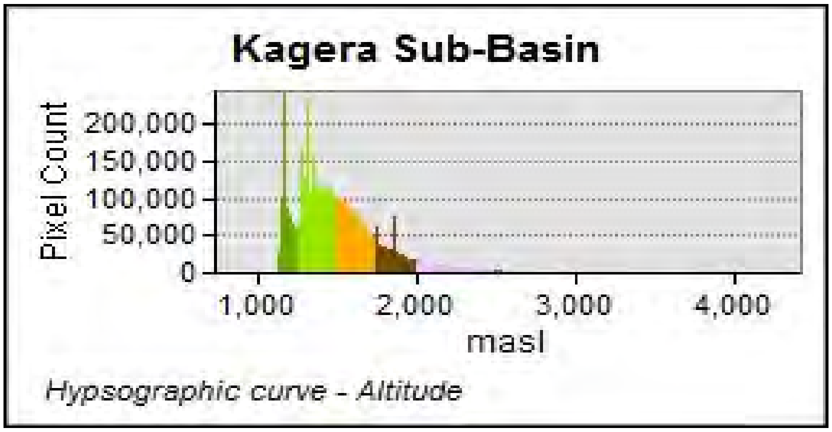
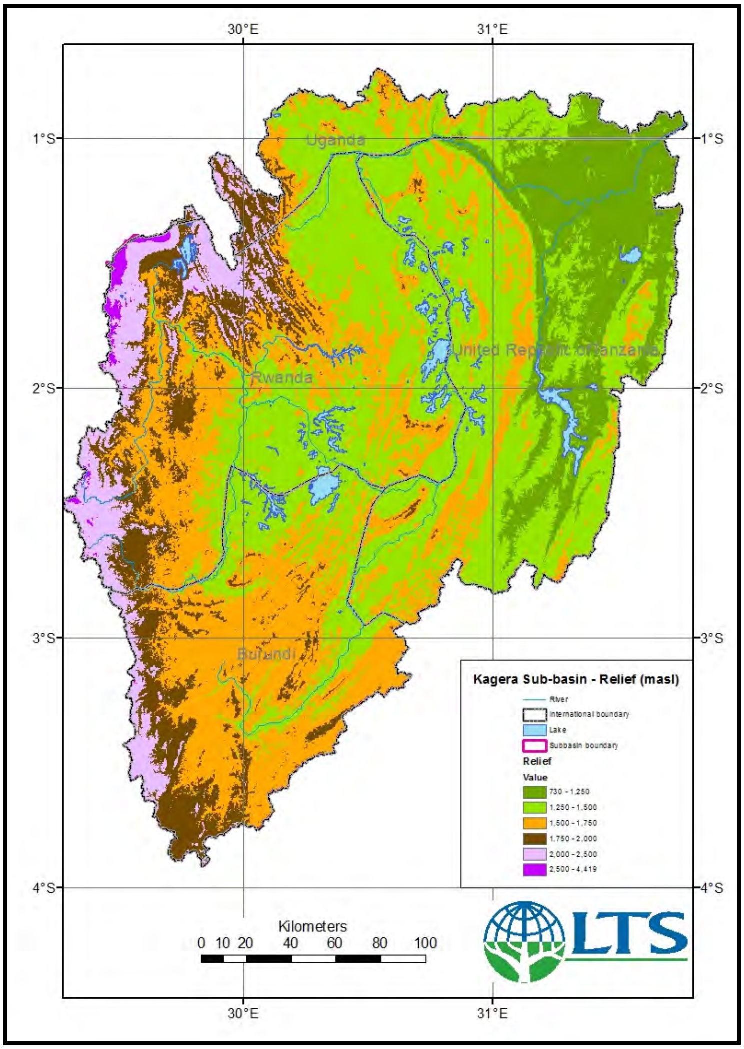


Figure 1.Hypsographic Curve of Altitude (masl)

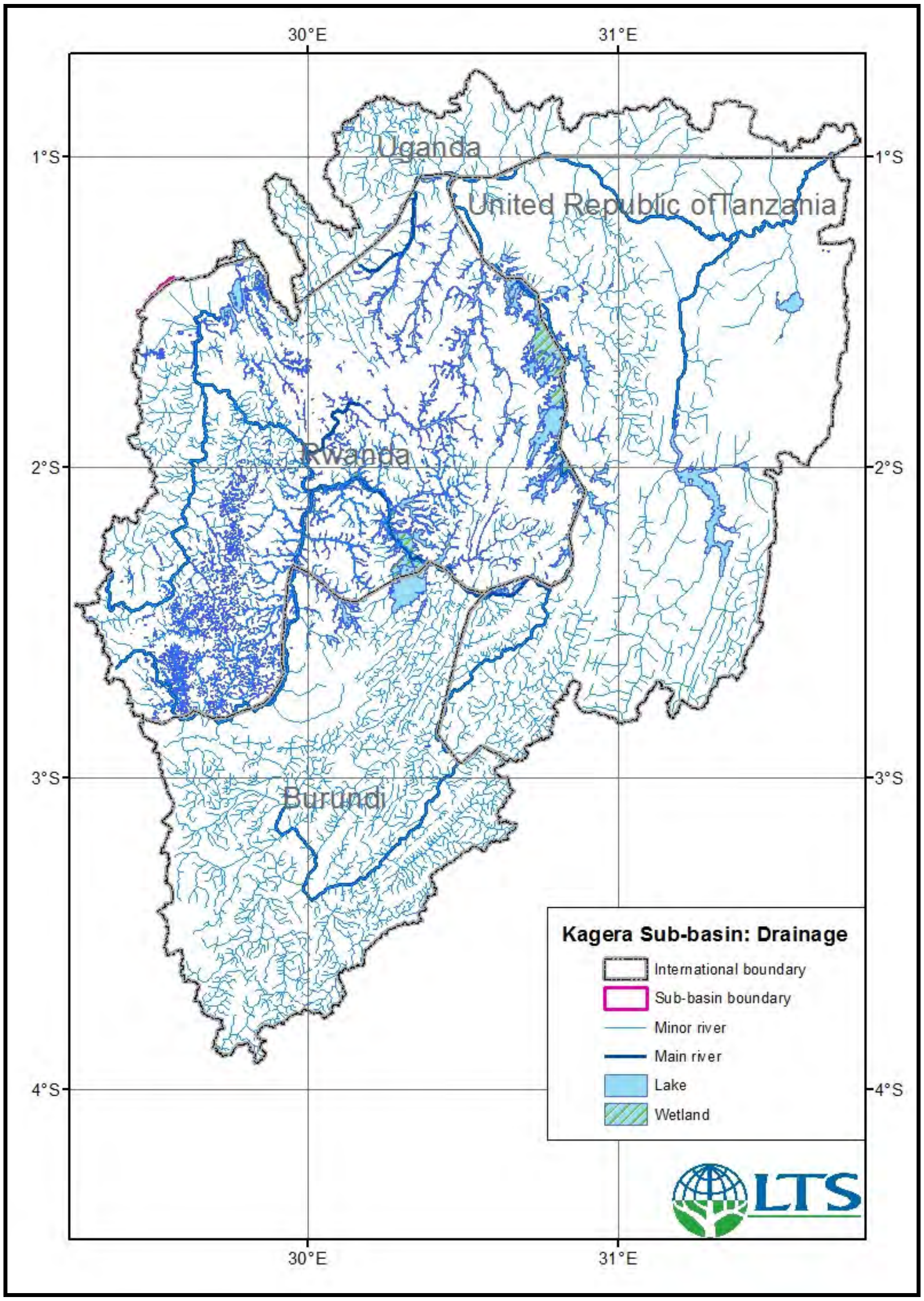
Map 3. Kagera Sub-basin: relief



1.2.1.2 Drainage and Sub-watersheds

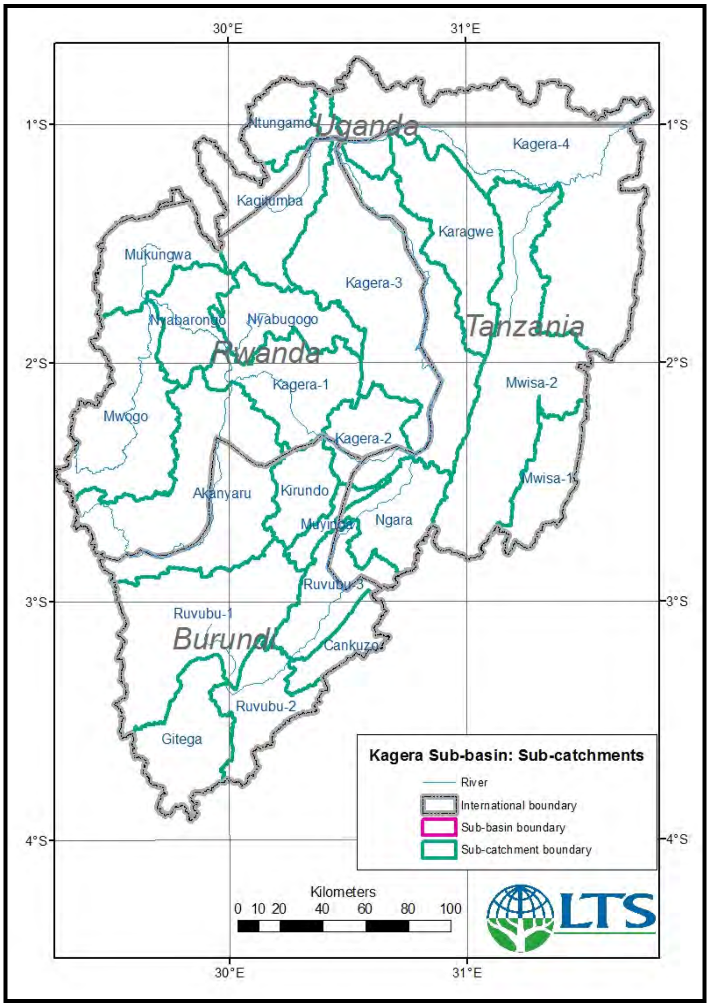
The drain pattern is shown in Map 4. On the montane ridge along the western boundary the drainage is west to east. Below the ridge drainage is orientated southwest-northeast to south-north. The drainage pattern tends to be less dense in the drier eastern and central parts of the Sub-basin.

Map 4.Drainage Pattern



In line with IWRM principles requiring watersheds to be managed as hydrological units, the Kagera Basin was delineated into 22 sub watersheds (Map 5). The criteria used to delineate the sub-basins by the Kagera Monograph were topography derived from the United States Geological Service (USGS) Shuttle Radar Topographic Mission (SRTM) digital terrain model (DTM) with a 90 metres vertical resolution refined by the Consultants using the ASTER DTM with a 30 metres resolution. The criteria to determine the size of the sub-watersheds in the Kagera Monograph was the presence of a Strahler River Order 5 at the outlet[1]. The Sub-watersheds are named after the main river within the Sub-watershed. Only nine of these are trans-boundary in character. The Sub-watersheds are described in detail in part 2 of this Annex.

Map 5. Sub-watersheds



1.2.2 Geology and Soils

1.2.2.1 Geology

The Kagera sub-basin overlies metamorphic rocks of the Precambrian Karagwe-Ankolean series. Geologically recent uplift and tilting have determined the basin's topography which is marked by ridges running in a generally south-west to north-east direction. The lowest point

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[1] The Monograph does not indicate this but a careful examination of the map shows that outlet rivers were all Strahler Class 5 .

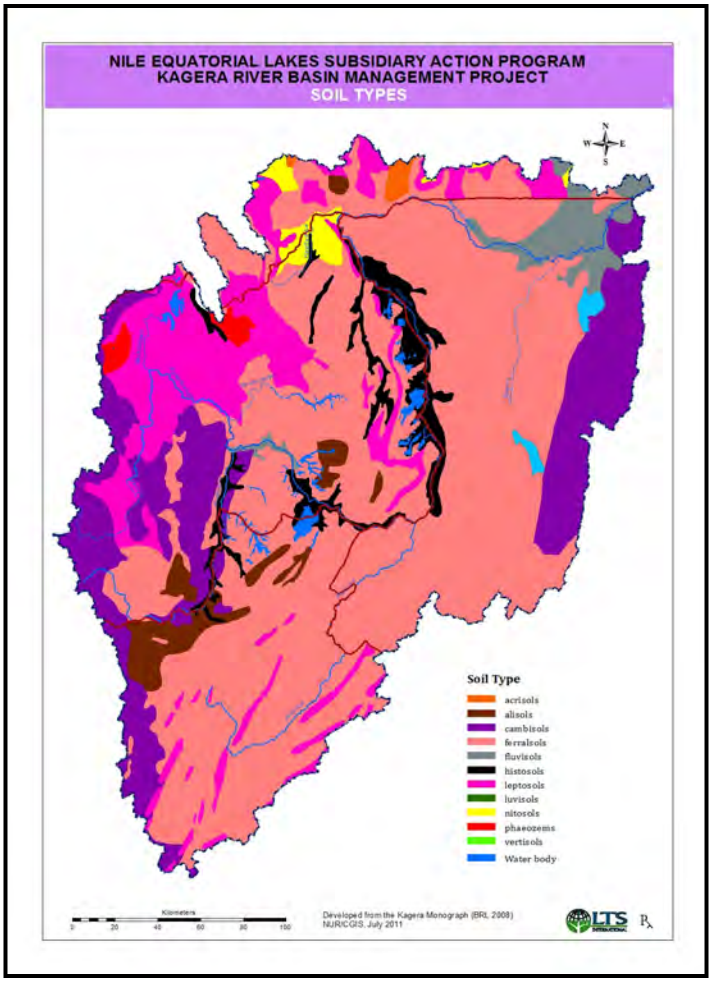
in the sub-basin is the outlet to Lake Victoria (1,133 metres) and the highest is in the west where elevations reach over 4500 metres. Alluvial sediments are found in the valleys. One notable feature of the sub-basin is the number of wetlands that exist.

1.2.2.2 Dominant Soil Types

The most extensive soil types within the located within the central parts of the Sub-basin are Ferralsols (Map 6). These are derived from deeply weathered siliceous rocks and thus are of low fertility, acidic and increasingly with aluminium toxicity. They are generally deep, easy to work and less erodible than other deeply weathered soils. In the northeastern uplands on steep slopes are Leptosols, which are shallow and often stony. Being located on steep slopes they are especially susceptible to erosion and being shallow has low water holding capacity.

Along the eastern and western boundaries of the Sub-basin are Cambisols. They are generally moderately deep, more fertile than Ferralsols having a higher Cation Exchange Capacity (CEC). Associated with and similar to Cambisols are Alisols. These are generally found on steeper slopes, shallower and thus more susceptible to erosion. Along valley bottoms and associated with swamps are Histosols. These soils have a deep organic topsoil. Other minor soils are Nitisols: deep red clay soils of moderate fertility and Fluvisols located on alluvial flats with deep soil profiles, often layered and of moderate to high fertility.

Map 6. Distribution of Soil types (FAO Classification)

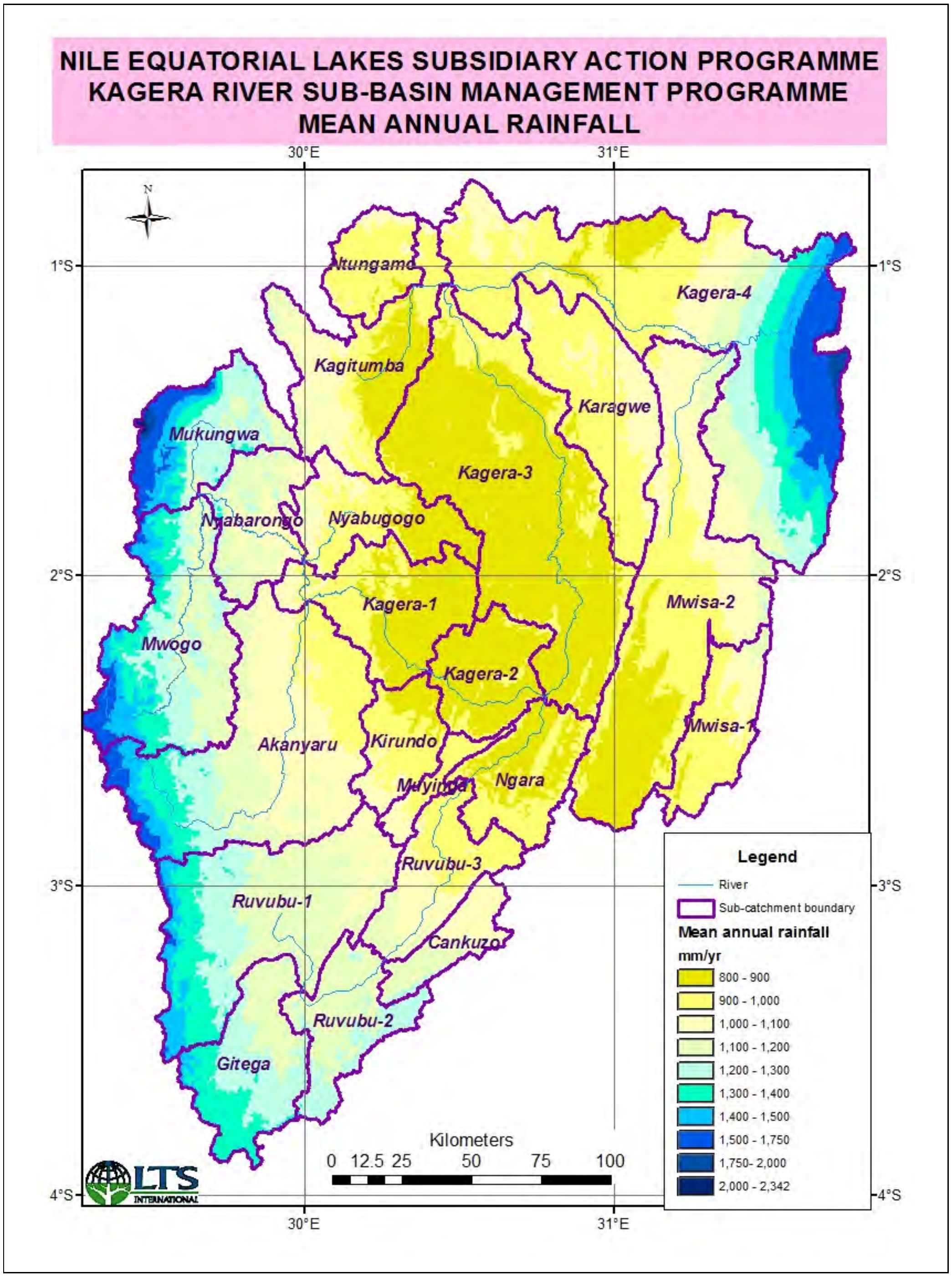


1.2.3 Climate

1.2.3.1 Precipitation

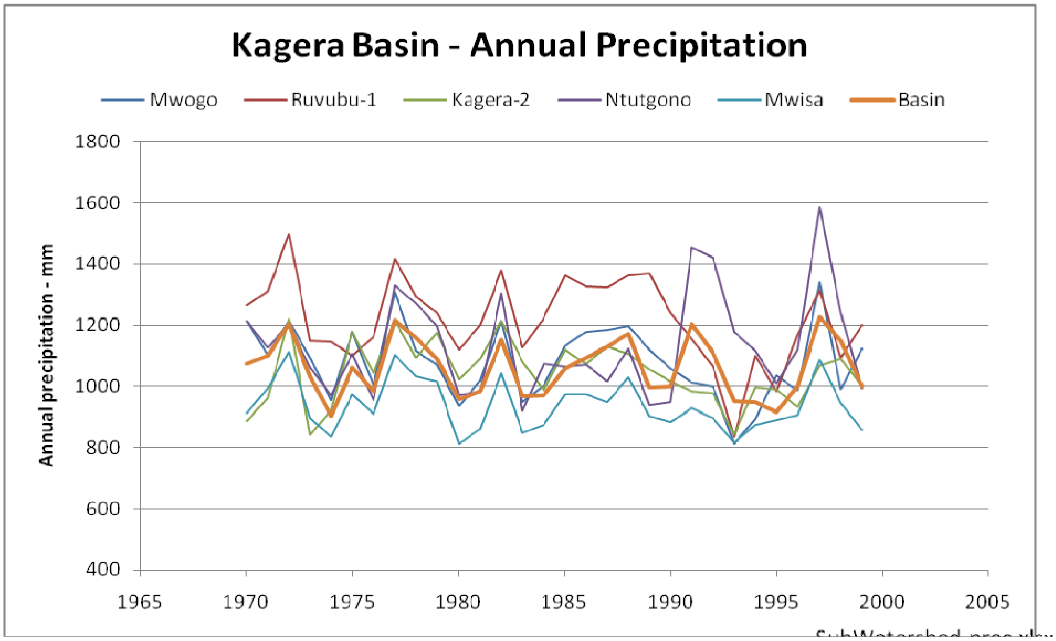
Map 7 shows the mean annual isohyets and the sub-watersheds, with the sub-watersheds ranked from highest to lowest mean annual rainfall. Precipitation exceeds 2000 mm/year in sub-watersheds toward the west, and in the east is over 1800mm/year. The sub-watersheds with the lowest precipitation are in the north and the south-east. The significance in variations in precipitation will become more apparent when we consider evaporation.

Map 7. Average annual precipitation



Annual precipitation for the years 1970-2000 for a selection of sub-watersheds in different parts of the river sub-basin are shown in Figure 2.

Figure 2. Annual precipitation for five sub-watersheds



The five sub-watersheds in Figure 2 were chosen to represent a geographical spread within the Kagera sub-basin:

- Mwogo is to the west of sub-basin, and includes some of the highest rainfall areas.
- Ruvubo-1 is in the headwaters of the Ruvubu River, and also includes high rainfall areas.
- Kagera-2 is the centre of the sub-basin.
- Ntungamo is on the northern edge of the sub-basin.
- Mwisa-1 is to the east of the sub-basin.

Whilst there is a general tendency for similar wet and dry years to occur in different parts of the sub-basin, the relative magnitude of the rises and falls varies from location to location. The average rainfall (based on the average of all sub-watersheds and not just the sub-set shown in Figure 4) has a tendency to reduce by an amount of 0.8 mm per year. This is equivalent to less than 1% per decade, and given the variation in annual rainfall, is not statistically significant.

1.2.3.2 Temperature

Map 8 shows the annual average temperature for the sub-basin. This shows that whilst in general (and as expected) temperatures are lower in the higher fringes of the sub-basin, there is a tendency towards higher temperatures in the valleys of the Ruvubu and Kagera rivers. Indeed, the highest temperatures seem to be in centre of the sub-basin.

Map 8. Annual average temperature - 1970 to 1999

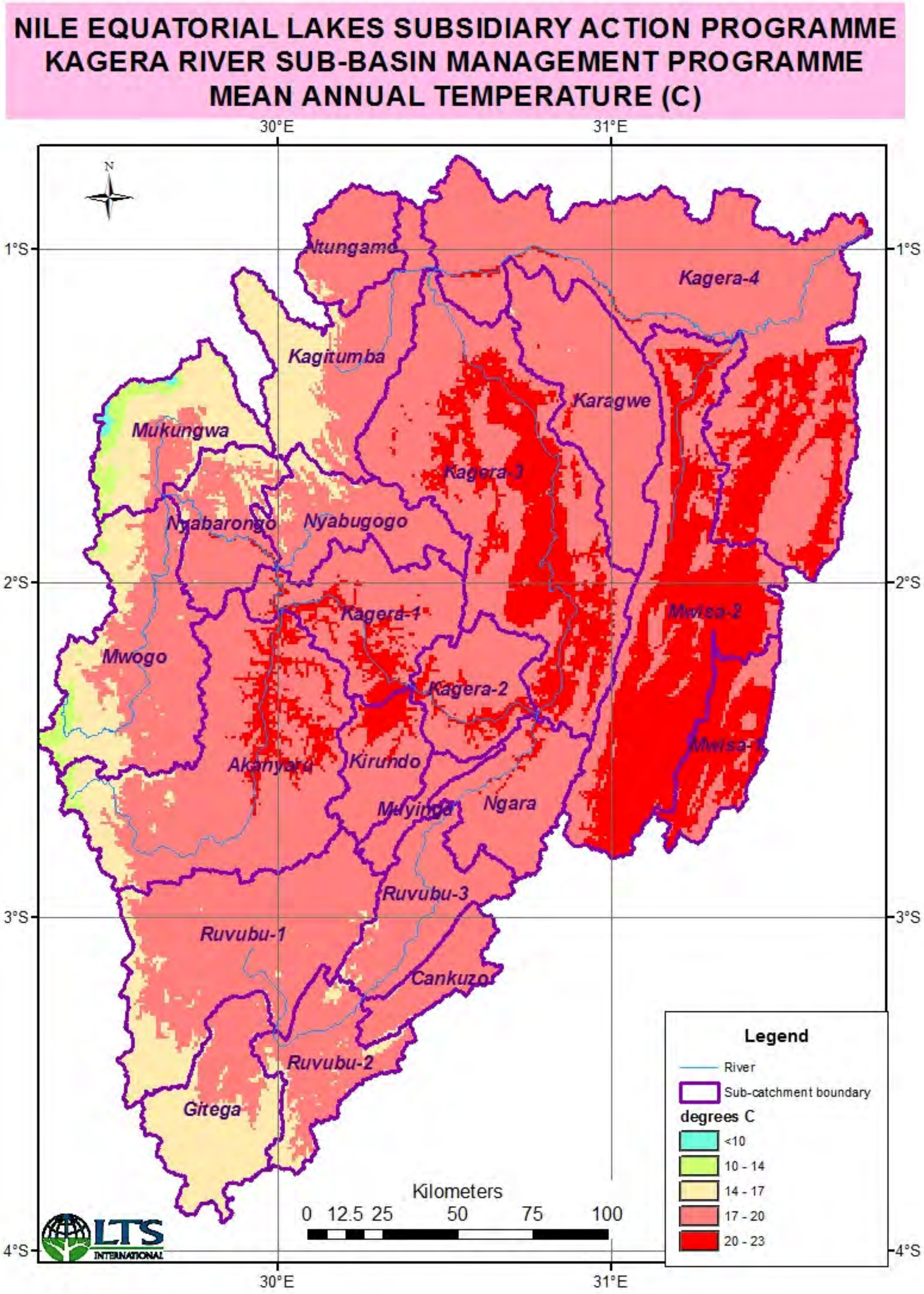
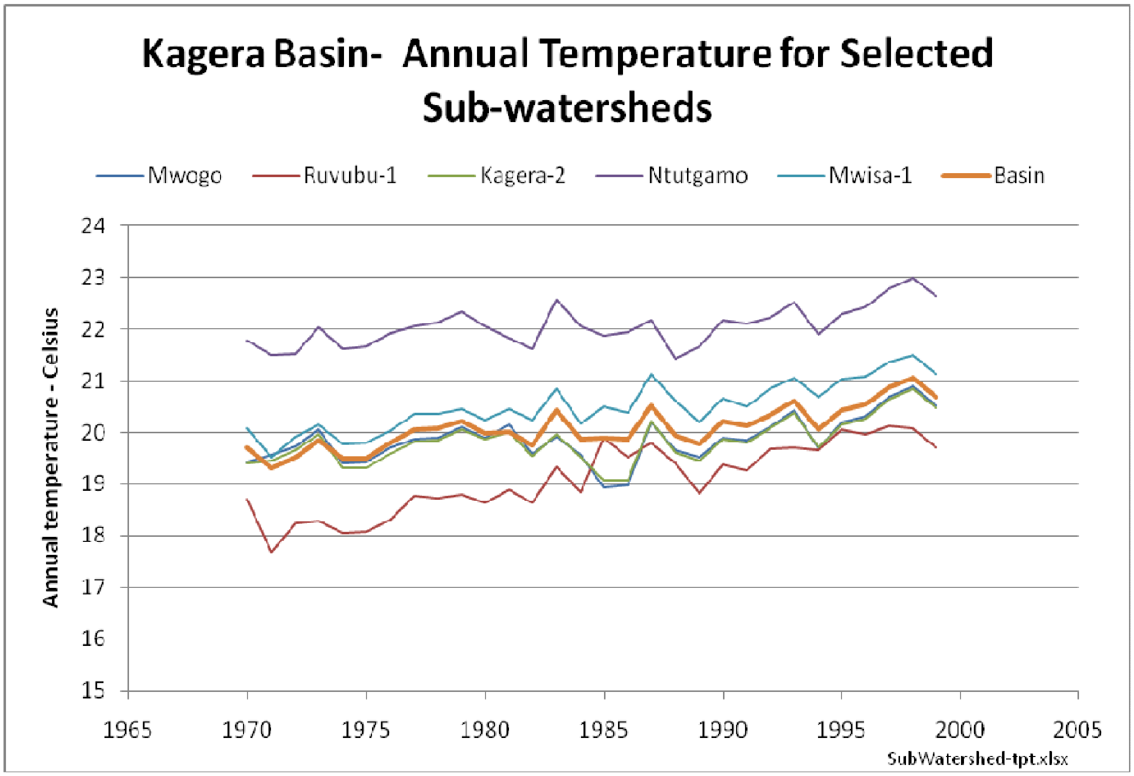


Figure 3 shows the annual temperatures for the same five sub-watersheds used for the previous example.

Figure 3.Annual average temperature at selected sub-watersheds

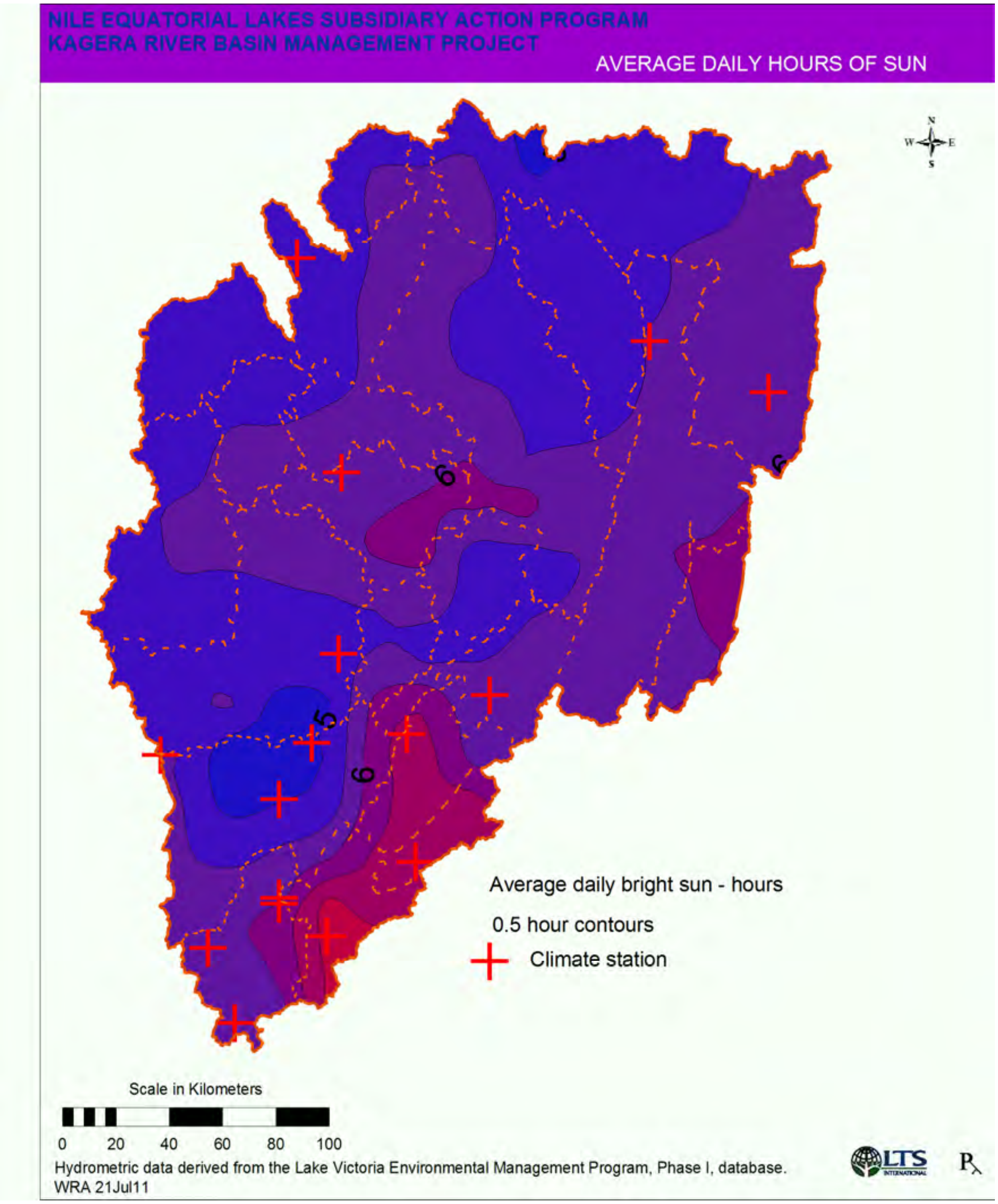


All five selected watersheds show evidence of rising temperature over time; some more strongly than others. For the sub-basin as a whole, the rate of increase is 0.04℃/year, which translates into 4℃ per century. The period from 1970 to 2000 was a period of globally rising temperatures and since then (although temperatures have remained high) there has been no significant increase. The absence of data for the period 2000 to the present provides no evidence one way or another. One possible indicator that it might be following the global trend is the fact that for all sites, the maximum temperature was 1998, the same year as the maximum in the global record and associated with an El Niño event.

1.2.3.3 Hours of Sun

After temperature, radiation is one of the parameters which has most effect on evapotranspiration. Map 9 indicates that hours of sun tend to increase toward the south-east. There is also a tendency for longer sun hours in the valleys than in the higher ground.

Map 9. Hours of sun

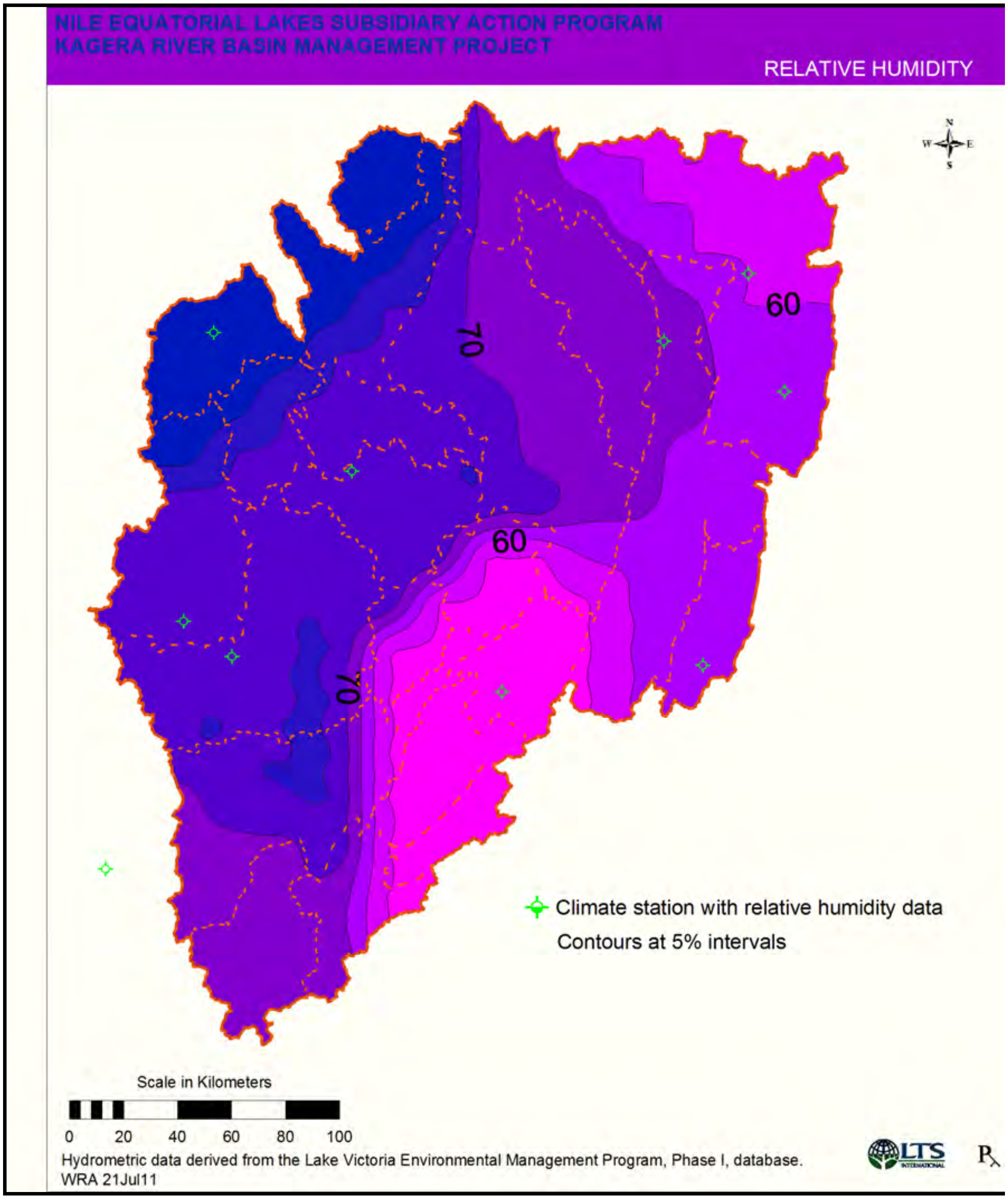


Hydrometric data derived from the Lake Victoria Environmental Management Program, Phase I, database.
WRA 21Jul11

1.2.3.4 Relative Humidity

Relative humidity is a measure of the dryness of the air; 100% represents full saturation, and 0% represents a total absence of moisture. It is also a significant parameter in the calculation of PET. Map 10 of relative humidity shows that the sub-basin tends to be drier toward the south-east, with high humidity toward the mountains in the west.

Map 10: Relative humidity



Hydrometric data derived from the Lake Victoria Environmental Management Program, Phase I, database.
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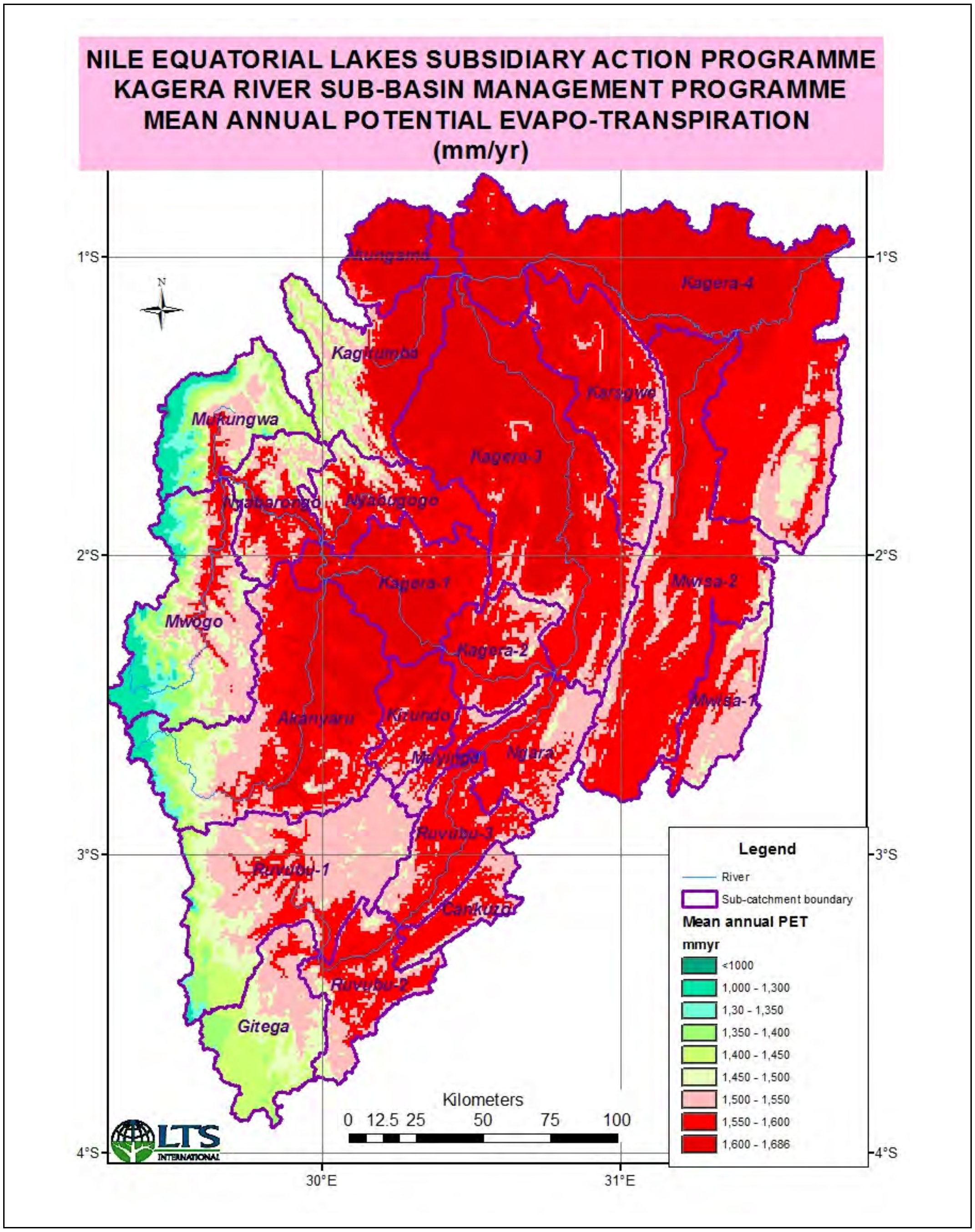
1.2.3.5 Potential Evapotranspiration

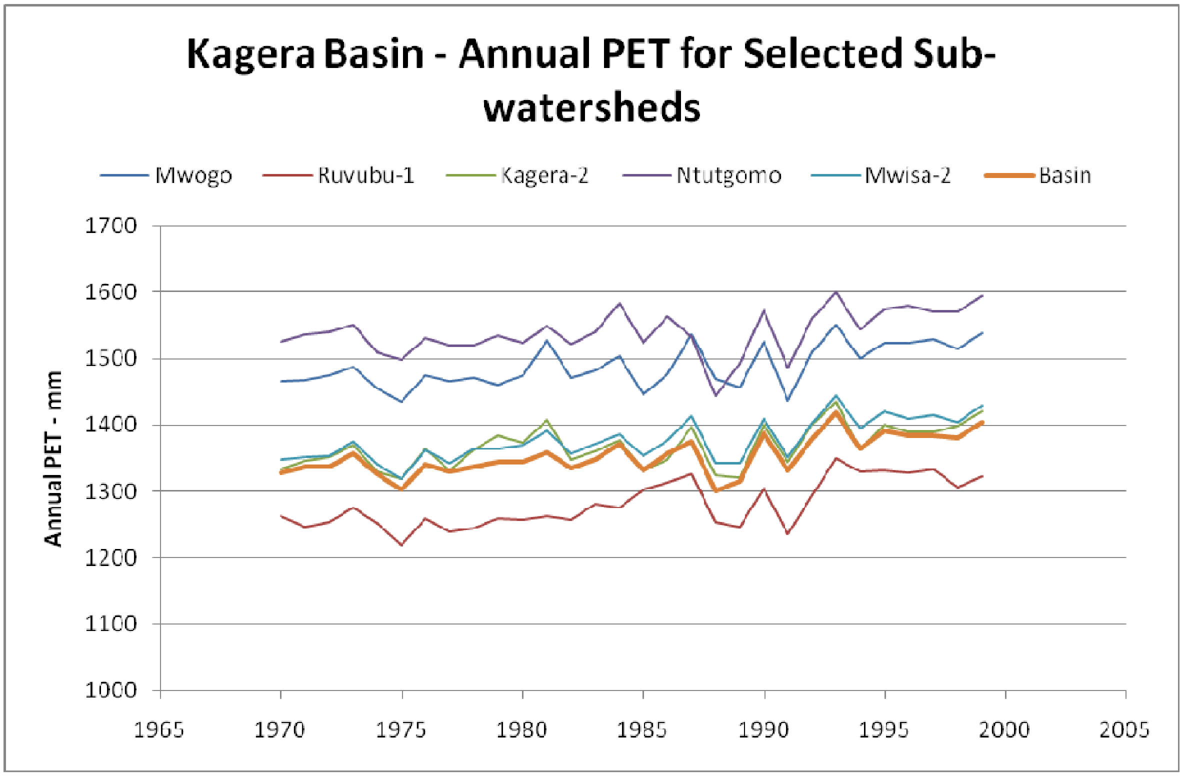
Map 11 shows the average annual evapotranspiration. Values range from around 1000 mm per year in the west of the sub-basin, to 1800 mm per year in the south and east.

Map 11.PET in the Kagera sub-basin



As for other parameters discussed previously, we show the annual evapotranspiration for five representative sub-watersheds, at Figure 4.

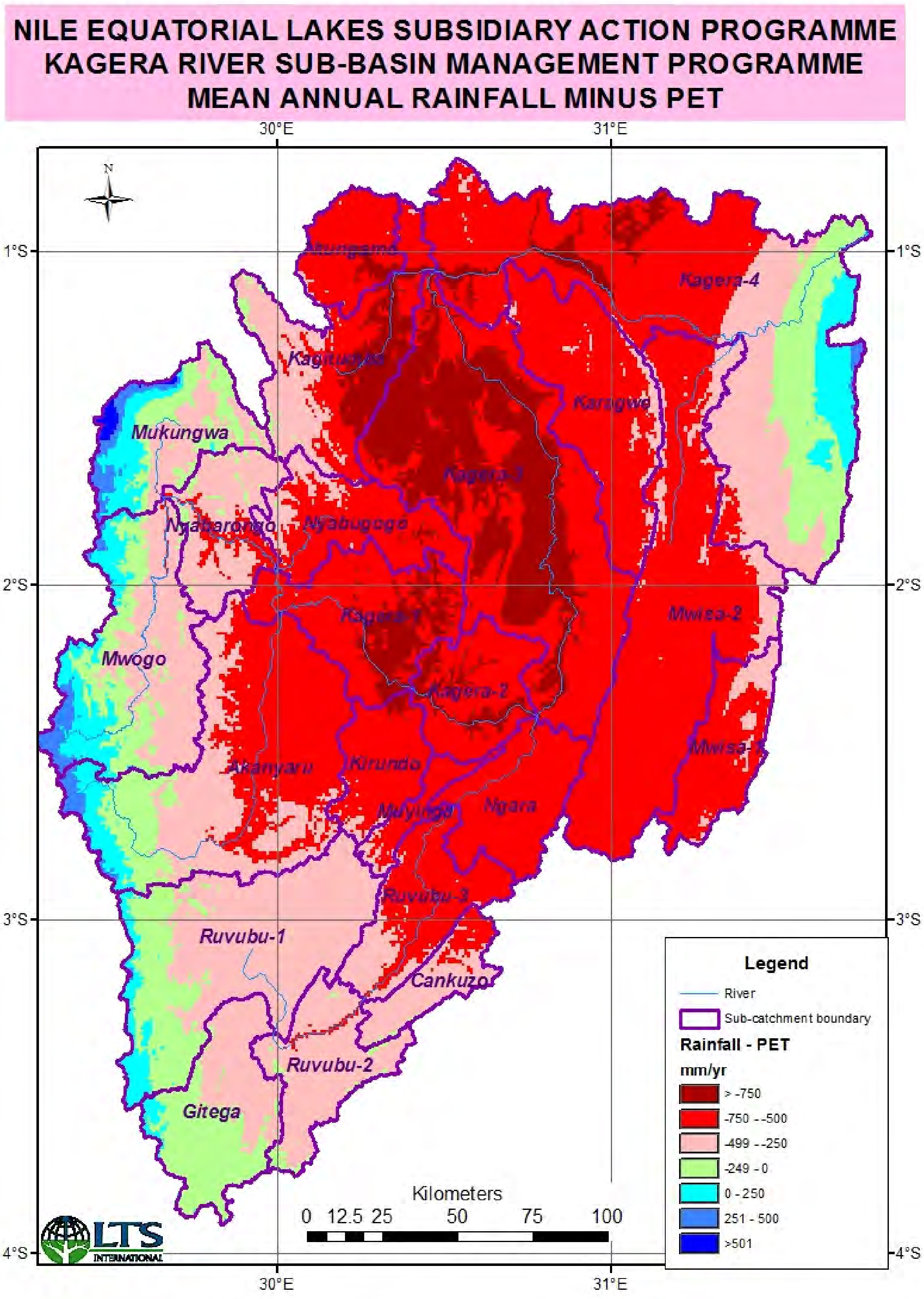
Figure 4. Annual PET for selected sub-watersheds



As with temperature, there is a clear rising trend, in this case 22 mm/decade for the sub-basin as a whole. Whilst temperature is one of the main factors in determining PET, it is not the only one. In this case the maximum PET occurred in 1993 for most sub-watersheds, rather than 1998 as was the case with temperature.

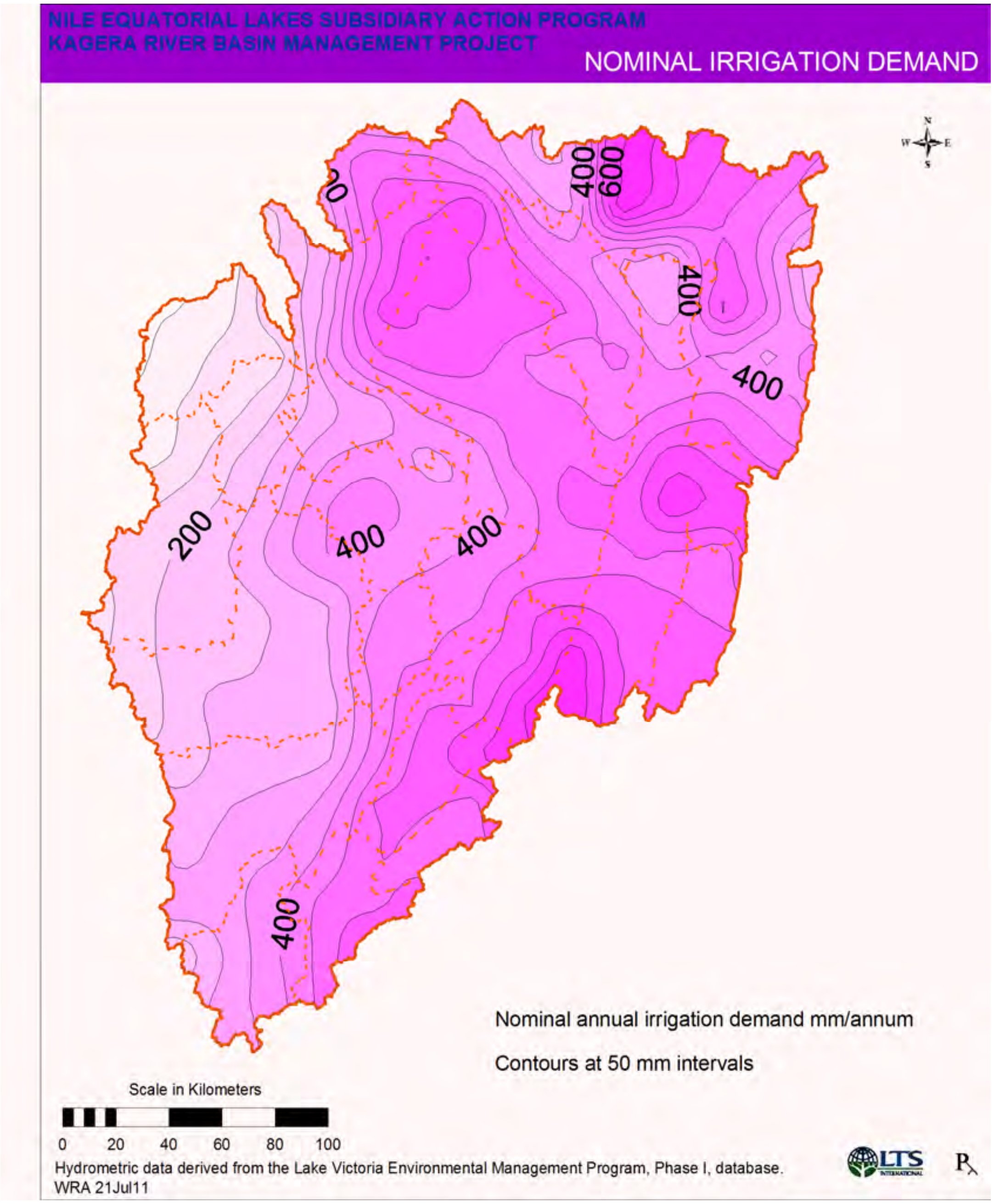
The magnitude of PET need not, of itself, be a problem. What is important is the balance between PET and precipitation. Map 12 shows the importance of this analysis. The highest PET was toward the south-east of the sub-basin, whereas the highest PET deficit is in central strip in the middle of the sub-basin. These data – derived by the present project team – are of great importance in relation to possible interventions in the agricultural sector in the Kagera sub-basin.

Map 12. Precipitation minus PET



Another way of showing the distribution of moisture stress is to consider the nominal amount of irrigation required to prevent such stress. To calculate this, a very simple monthly irrigation model was used: if the soil was saturated, then the excess moisture became runoff; if PET exceeded precipitation, the deficit was allowed to increase to 100 mm; if PET fell below 100 mm the 'irrigation' was applied to return to 100 mm.

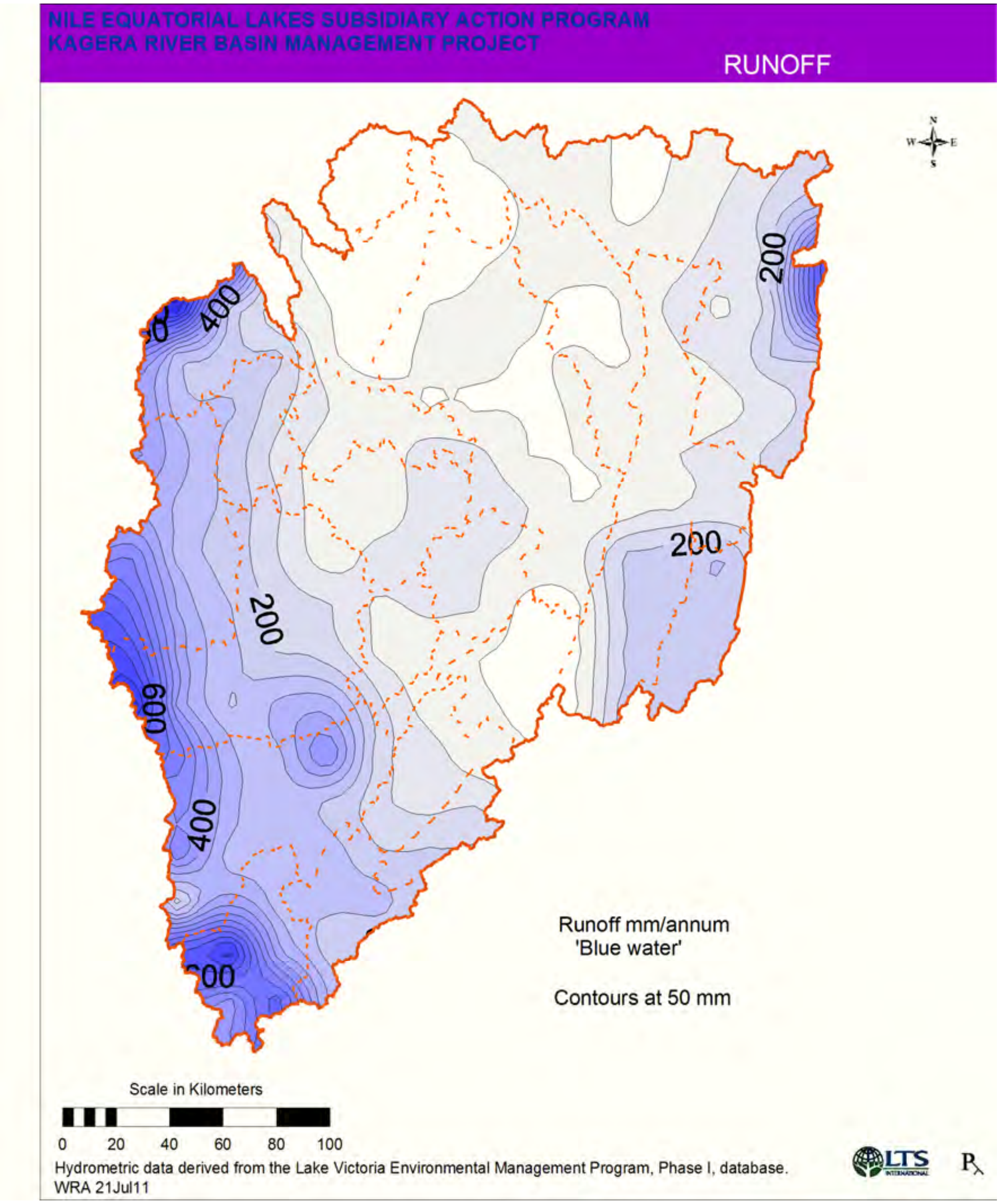
Map 13.Nominal irrigation demand



Hydrometric data derived from the Lake Victoria Environmental Management Program, Phase I, database.
WRA 21Jul11

It is informative to compare the above map (Map 13) with the previous one (Map 12). The earlier map of precipitation minus irrigation shows large parts of the sub-basin where the annual value of precipitation is greater than the value of PET. The later map shows that nearly the entire sub-basin experiences periods of moisture stress. The reason for the apparent anomaly is that even in the wetter parts of the sub-basin, a significant proportion of the precipitation becomes runoff during the wet periods, and therefore cannot balance the PET demand in the drier parts of the year.

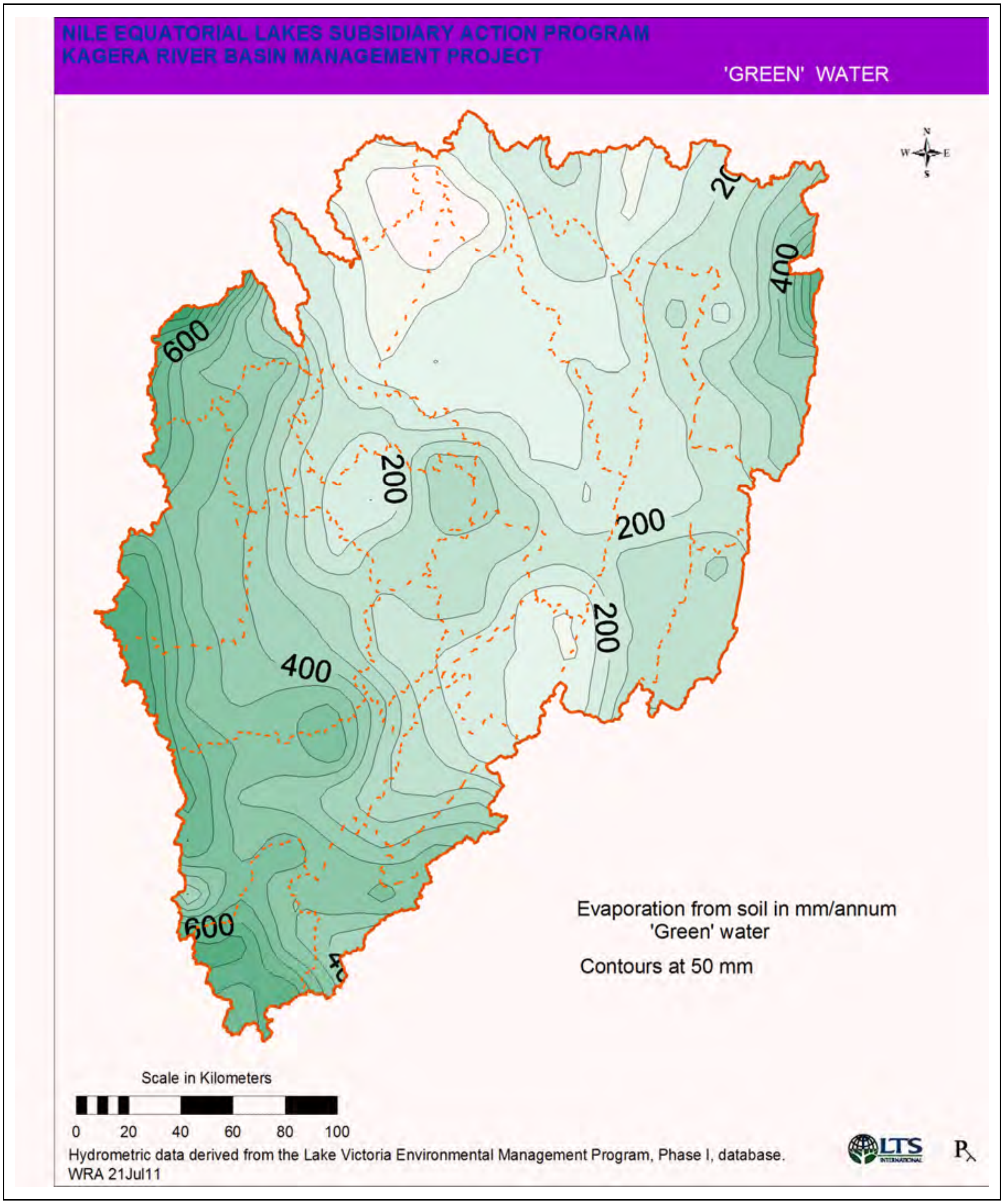
Map 14.Mean annual Runoff (mm/yr)



Map 14 confirms this hypothesis, that in the wet areas of the sub-basin a significant proportion of the precipitation becomes runoff. It should be noted that this map is for illustration only, and is based on the simple soil/irrigation model described above. A more accurate representation of runoff will be provided when the water quantity model is calibrated to observed flows.

Another method of looking at stress in the sub-basin is to consider evapotranspiration from soils, as opposed to potential evapotranspiration. The actual evapotranspiration will never be more than the potential evapotranspiration and will be less than the latter if soils are stressed for part of the year when there is not enough moisture to satisfy the potential demand. Map 15 confirms that soil moisture stress occurs largely in the main river valleys.

Map 15. Actual evapotranspiration



1.2.3.6 Climate change

Temperature since 2000

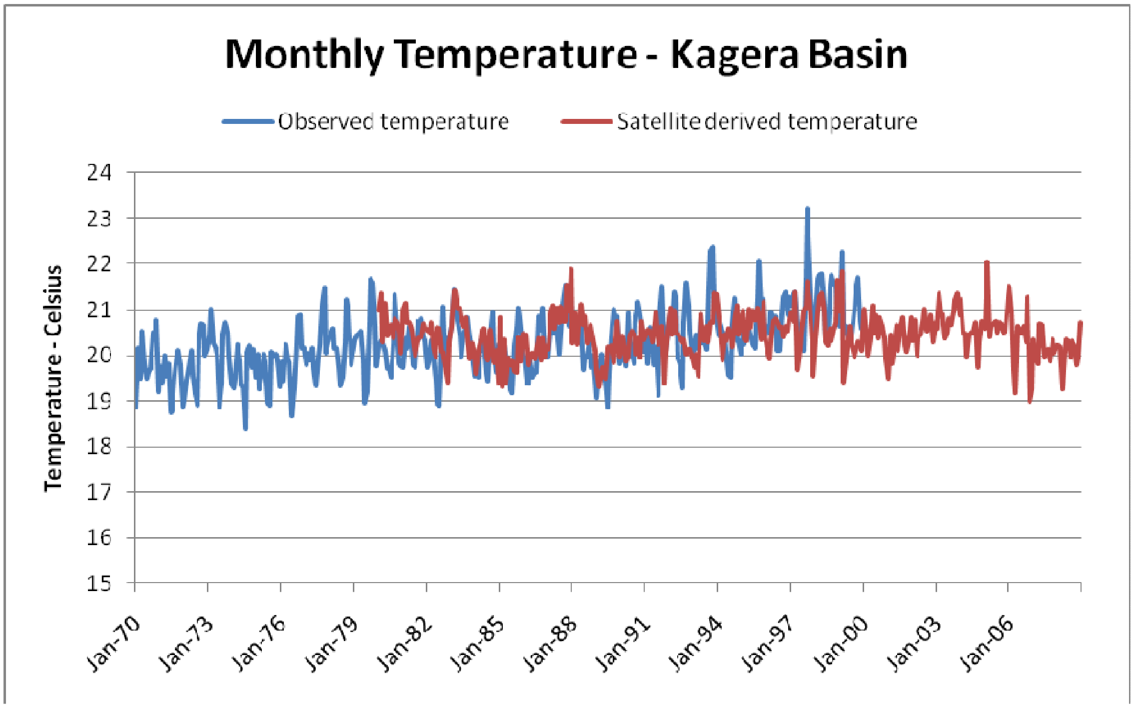
The data collected and analysed to the present indicate that for precipitation, there is no significant trend of increasing or decreasing values. However, for temperature there is a clear increasing trend over time. Since the data only extend to the year 2000 (and not even that for many stations), there is some concern as to whether temperatures have continued to increase or, as has happened at a global scale, tended to level off.

In the absence of measured data we have analysed the satellite-derived temperature series produced by RSS (Remote Sensing Systems). This is one of two 'standard' temperature records based on (Advanced) Microwave Sounding Unit data (AMSU/MSU). The temperature values actually refer to the lower troposphere (TLT). The data are available on a 2.5º grid in a series of annual files from the following link:

(ftp://ftp.ssmi.com/msu/data/uah_compatible_format/)

The data are actually provided as anomalies relative to an average temperature. In this case they were adjusted to average monthly temperature of the sub-basin. Figure 5 shows the sub-basin temperature from 1970 to 1999 based on observed values, and the satellite-derived values from 1980 to 2008.

Figure 5. Monthly temperature, the Kagera sub-basin



It can be seen that the observed and satellite-derived temperature track each other quite closely for most of the period. The satellite-derived data, which cover a larger area than the Kagera sub-basin, show less variation than the observed data. It is therefore reasonable to accept that, at a sub-basin level, the satellite-derived temperature can be considered as a surrogate for the observed data.

The satellite-derived data continue to 2008, and show that for the period since 2000 temperatures have shown no increase, and might even have declined slightly. Given the absence of any temporal trend in precipitation, it is therefore likely that moisture stress in the sub-basin has not increased.

Climate change Models

For a preliminary estimation of the effects of climate change, we analysed 19 simulations from 7 models using the SRESa1b scenario. This scenario has two advantages. Firstly, it includes simulations starting in 1890 (sometimes even earlier), thus allowing an overlap with the period of observed data. Secondly, this scenario is an appropriate one to use, as the A1 family assumes:

- Rapid economic growth.
- A global population that reaches 9 billion in 2050 and then gradually declines.
- The quick spread of new and efficient technologies.
- A convergent world income and a way of life that converges between regions, with extensive social and cultural interactions worldwide.

The A1B scenario has a balanced emphasis on all energy sources.

The choice of models was based on those listed on Table 6 of the IPCC “General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment”, Version 2, June 2007. The models we used and the reason for our choice are given in Table 1. In general, we chose the latest version of a model from the same centre but also took account of the number of scenarios and the length of the simulation period.

Table 1. GCMs listed by the IPCC

Modeling Centre	Country	Model(s) in Table 6 of guidelines	Models used	Notes
Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Australia	CSIRO-Mk2	CSIRO Mk3.0	
Max Planck Institut fur Meteorologie. (MPI)	Germany	ECHAM4/OPYC ECHAM3/LSG	ECHAM5/ MPI-OM	
Hadley Centre for Climate Prediction and Research. (UKMO)	UK	HadCM2 and HadCM3	UKMO HadCM3	In one set of files a missing value was replaced by previous year.
Canadian Centre for Climate Modeling and Analysis (CCCMA)	Canada	CGCM1 And CGCM2	CGCM3.1 (T47)	Has 5 scenarios
Geophysical Fluid Dynamics Laboratory (GFDL)	USA	GFDL-R15 and GFDL-R30	GFDL CM2.1	
National Centre for Atmospheric Research	USA	NCAR DOE-PCM	CCSM3.0	Has more precipitation

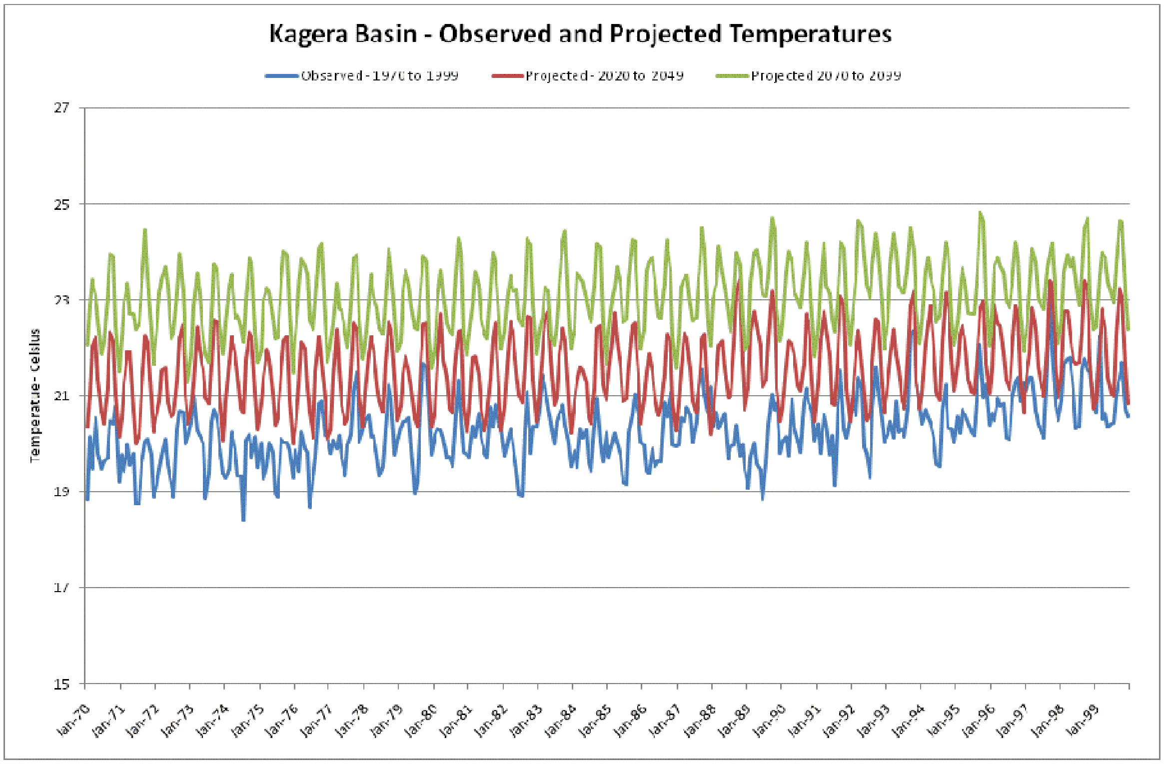
(NCAR)				scenarios.
National Institute for Environmental Studies (MIROC)	Japan	CCSR-NIES	MIROC3.2 (medres)	Covers longer period than ‘hires’ model.

To avoid the results being biased in favour of models with a large number of simulations, the results for each model were first averaged, and then the average of all models was calculated.

Figure 6 shows the observed temperature for the Kagera sub-from 1970 to 1999, and projected temperatures for two periods: 2020 to 2049; and 2070 to 2099. The projections suggest that during the period 2020 to 2049, temperatures will be 1.3℃ higher than the period 1970 to 1999; and during the period 2070 to 2099, the temperatures will be higher than 1970-1999 by 2.7℃.

The potential impact of climate change on river flows is considered in the section on hydrology.

Figure 6. Observed and projected temperatures - Kagera sub-basin



The Kagera sub-basin and climate

Whilst parts of the Kagera sub-basin experience abundant rain and an excess of precipitation over evaporation, this is not generally the case everywhere. Most of the sub-basin exhibits a higher level of potential evapotranspiration demand than of precipitation, with the deficit reaching over 500 mm per year in some sub-watersheds.

The projections of climate change suggest that this situation might become more severe during the present century.

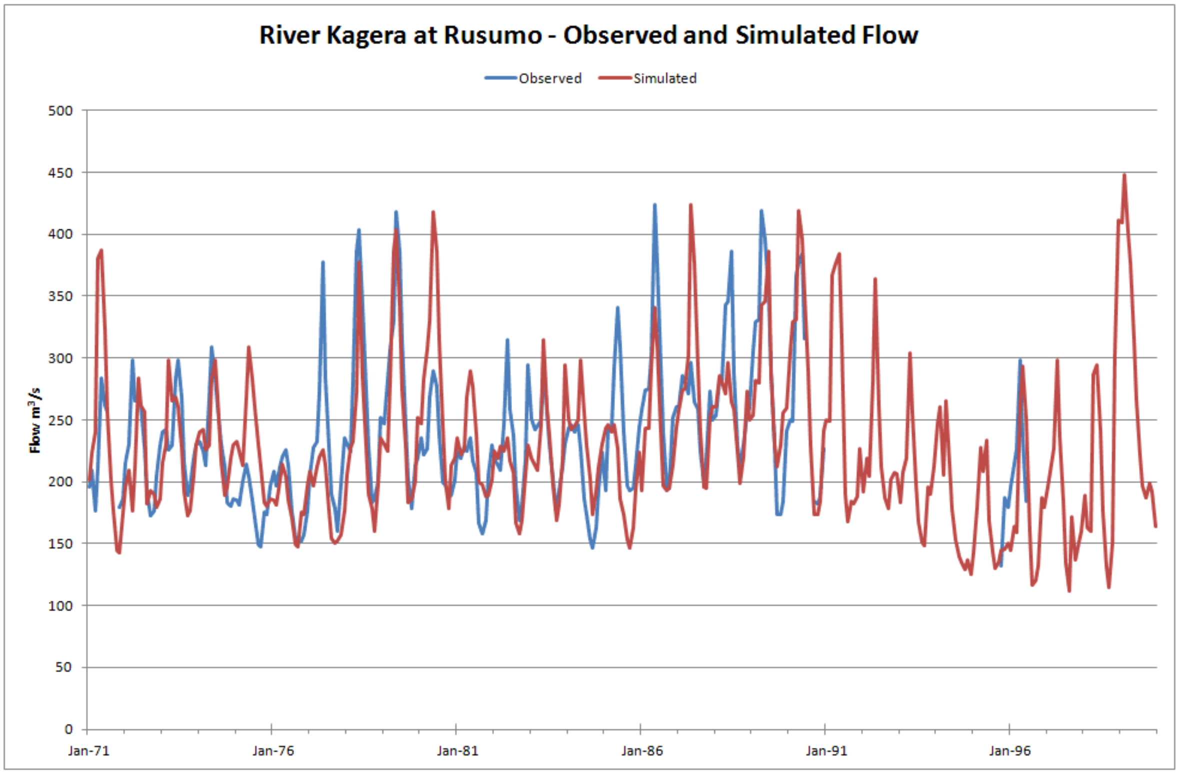
1.2.4 Hydrology

From a development point of view the Kagera basin has two specific positive features; the first is the nature of its perennial flows and the second is its limited vulnerability to long-term climate change. These aspects are considered first in terms of overall basin characteristics and then in more detail at selected sub-watersheds.

1.2.4.1 River Flow: Kagera Basin (at Rusumo)

The following chart shows monthly simulated and observed flows for the Kagera at Rusumo. This site was chosen as a representative site as it covers a large proportion of the basin and for much of the period the flow is observed which provides good comparison with simulated flows from HYSIMCC.

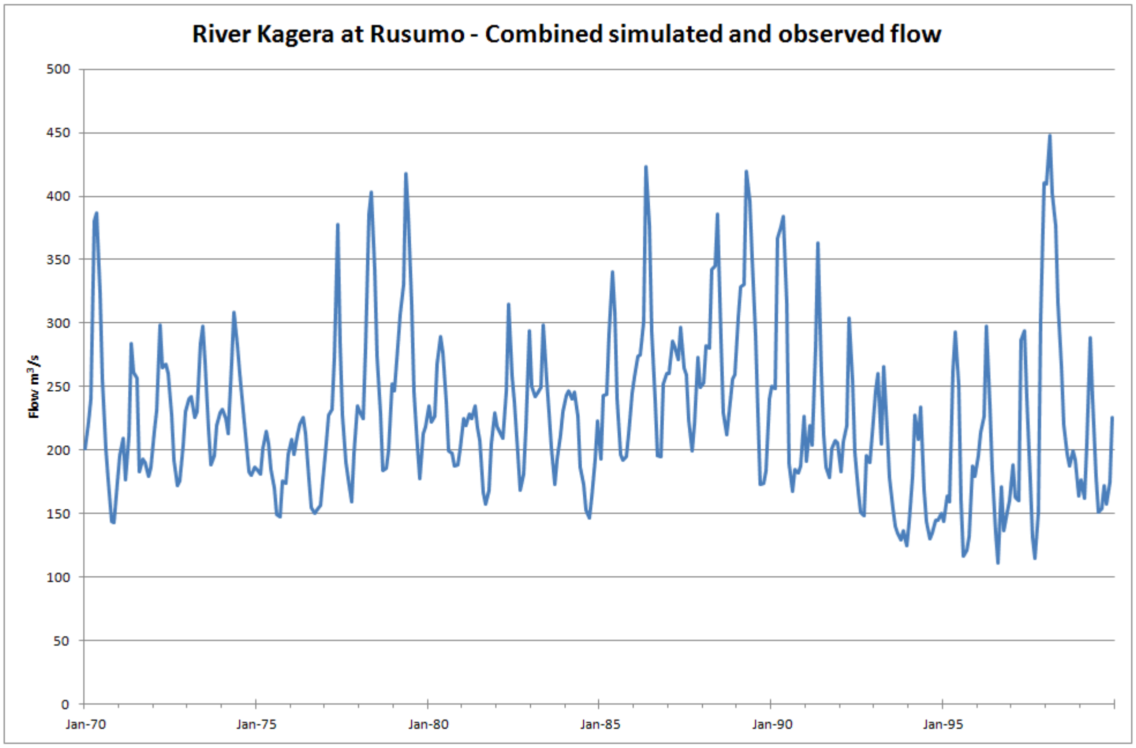
Figure 7. Monthly simulated and observed flows: Kagera River at Rusumo



This graph is presented to demonstrate that the cumulative simulation upstream of Rusumo is reasonably accurate and that therefore conclusions based on modeling will be valid.

The next chart (Figure 8) which combines the observed and simulated flows – is very important for understanding the watershed.

Figure 8. Combined observed and simulated flows: Kagera River at Rusumo



The most important thing to notice with this chart is that the base flow – the flow at the driest time of year – never falls even close to zero. This is borne out by the following statistics:

Parameter	Value
Average flow	235.0 m^3/s
Minimum annual flow	165.2 m^3/s
1-in-20 year annual flow	176.1 m^3/s
Average minimum flow	169.2 m^3/s

The minimum annual flow is 70% of the average long term flow. This is fairly high proportion compared to many of river systems, and shows that the annual flows are resistant to drought. The statistical analysis shows that 1-in-20 year dry annual flow is 75% of the long term average confirming the evidence from specific years of the 30-year record. What these statistics tell is that there is comparatively little variation in annual flow. Look for example at the years from1990 to 1995. This was a very dry period with successively lower flows over this period yet the minimum flow only fell to around 50% of the long term average.

The final statistic is the average minimum flow. This is the average of the minimum monthly flows for each year of the record and is over 70% of the long term flow. This demonstrates that within a year flows are well maintained.

The overall conclusion is that the Kagera basin is very resilient from a hydrological point of view with flows well maintained during and between years.

1.2.4.2 Soil Stress across the Kagera Basin

The duration of soil stress within the Kagera Basin is an important parameter as it indicates for how long within a year soils will be unable to support plant growth. For the purpose of this analysis the number of months where the soil moisture content was less than 20% of field capacity was selected. Field capacity is defined as equal to the soil storage capacity of the HYSIMCC model. For the Kagera to Rusumo the pertinent values are that the average period with moisture stress is 4.1 months with a maximum duration of 6 months (during the 30 years period of simulation). During the 1-in-20 year drought the period is 6.8 months.

This means that in most years cultivation is possible for 8 months of the year without irrigation. This value is rather variable and in occasional years cultivation will only be possible for half the year. This also demonstrates that to get year round cropping would require irrigation.

1.2.4.3 Ground-water Re-charge

The reason that the flows in the basin do not fall close to zero, even during dry parts of a year or during a sequence of dry years, is that some of the rainfall passes through the soils to recharge groundwater. Over the watershed as a whole the precipitation is 1100 mm a year of, which on average, 140 mm becomes recharge for groundwater. Total runoff, including groundwater is 484 mm a year, the balance is evaporation. This recharge figure is fairly constant, the minimum for the 30 year period was 99 mm and the 1-in -20 dry recharge is 110 mm. These figures confirm the importance of groundwater within the watershed.

1.2.4.4 Irrigation across the Kagera basin

As stated above there are periods of the year when soil-moisture stress means that irrigation would be required for year round cropping. On average the amount of irrigation needed is equivalent to 357 mm. This amount does not make any allowance for water used to flush the soils or lost as drainage. However, in most of the Kagera basin there are parts of the years when precipitation exceeds rainfall so there is unlikely to be any major additional demand for soil flushing. During the 30 year period the maximum demand was 447 mm and the 1-in-5 year demand was 400 mm. The reason that the 1-in-5 year demand was used is that irrigation systems are typically reckoned to be viable if the full amount of water is available for 8 years out of ten.

As an approximate guide, if 10% of the 1-in-20 year dry flow of 176 m^3/s was used for irrigation at the rate of 400 mm, it would be possible to irrigate around 11,000 ha of crops to a high degree of reliability with limited negative influence on river flows.

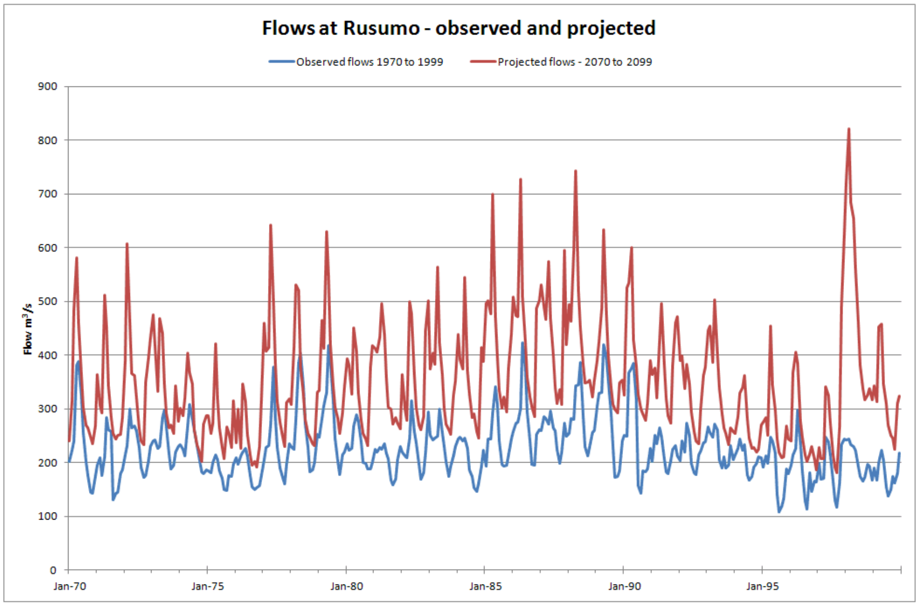
1.2.4.5 Impacts of Climate Change across the Kagera basin

To estimate the effects of climate change the flows for the period 1970 to 1999 were compared with the projected flows for the period 2070 to 2099. The climate scenarios used were the 20c3m scenario for the past century and a1b scenario for the projection. The a1b scenario is generally regarded as the ‘business as usual’ scenario and as no binding successor to the Kyoto agreement has yet been signed this could be considered appropriate. To avoid the results being biased by any particular climate model we used the average of the outputs of 7 models, some of which had more than one simulation for the period we are considering.

For HYSIMCC we also require potential evaporation data but this is not available as a scenario. We therefore used projected temperature with average values of the other three parameters needed for the calculation: relative humidity, wind speed and hours of sun. The first of these is considered not to change in the future; there will be more water vapour in the atmosphere but the temperatures will higher so the relative humidity will remains the same. The other two parameters have a less important effect and as no scenario information is available for them the use of average values is unlikely to bias the conclusions.

The following chart shows observe and simulated flows at Rusumo for the period 1970 to 1999 and project flows for the period 2070 to 2099.

Figure 9. Observed and simulated flows at Rusumo: 1970 – 1999 compared with 2070-2099



This shows that effect of increased precipitation projected for later in this century more than compensates for increased evaporation consequent on increases in temperature. That this is projected to be so gives added confidence in the possibility of investing in water infrastructure without a fear that climate change will negate its benefits.

1.2.4.6 Hydrology of Sub-watersheds: Overview

The following tables present data on the sub-watersheds covering five significant variables: Runoff, groundwater recharge, soil stress, irrigation demand and monthly flow. In each case values are presented for two periods: 1970 to 1999 (the period with sufficient data to run the model) and projected for the period 2070 to 1999. The climate change projections used the a1b scenario. Downscaling was performed by taking the difference between the 20c3m scenario (simulation of 20th century climate) for the period 1970 to 1999 and the projection for 2070 to 2099 and adding that difference to observed values on a sub-watershed level. The projections were for both temperature (used to calculate PET) and precipitation.

In addition to values for individual sub-watersheds aggregated values for larger groupings of sub-watersheds are presented. This was done because values for individual sub-watersheds may not be a precise as those for larger areas (given the lack of flow data for calibration).

1.2.4.7 Sub-Watersheds: Run-off

The sub-watersheds in the group referred to as Ruvubu have a high rate of runoff in the upper sections (> 600 mm/y) and a lower rate in the lower reaches (< 300 mm/year). Sub-watersheds in the Nyabarongo have some of the highest runoff with Mwogo sub-watershed reaching almost 1000 mm/year. For the middle reaches of the Kagera the rate of runoff has further decreased with average of this group being a little over 200 mm/year. For the lower reaches of the Kagera the average is less than 200 mm/year.

The ratio of minimum runoff to average is over 50% for some sub-watersheds, for example Mwogo and for most sub-watersheds is around 30%. These flows represent the contribution of groundwater to runoff. Whilst the ratio of minimum to average runoff declines in the lower part of the basin it is clear that groundwater still makes a substantial contribution to runoff even in those parts of the basin.

In general the impact of long term climate change on runoff is positive for all sub-watersheds.

1.2.4.8 Sub-Watersheds: Ground-water Re-Charge

The pattern of variation in recharge is similar to that for runoff though in dry years the minimum is sometimes only a few percent of the mean or in a few cases is actually zero. The fact that the minimum runoff remains a significant percentage of the long term value but in individual years the groundwater recharge in some sub-watersheds is zero, indicates how important the year-to-year contribution of slow response groundwater is to the basin. As with other variables the impact of climate change is positive.

1.2.4.9 Sub-Watersheds: Soil moisture stress

Soil stress in this table refers to months when for a particular sub-watershed the moisture content at the end of the month is less than 20% of field capacity. It is expressed in calendar months.

The duration of soil stress increases from around 4 months to around 6 months from west to east across the basin. This suggests that for most of the basin it might not be possible to grow perennial crops without irrigation.

1.2.4.10 Sub-Watersheds: River Flows

As with the basin as a whole, most sub-watersheds have minimum flows which are around 30% to 50% of the mean flow. This shows that in most parts of the basin there are strong perennial flows which in turn offers the potential for agricultural development. This aspect is considered in more detail in the following section on irrigation.

1.2.4.11 Sub-Watersheds: Irrigation demand

Irrigation demand refers to total irrigation demand over the course of a calendar year. It assumes a field capacity of 100mm. When moisture levels fall below this the deficit is made up by irrigation.

Compared to other variables the variation in irrigation demand across the watershed is less marked. The implication of this is that for nearly all sub-watersheds crop yields would be enhanced by the use of irrigation.

Whereas for all of the variables above the climate change projections suggest that the sub-watersheds would be under less stress that is not the case for irrigation demand. For the basin as a whole the irrigation demand goes up from an average of 393 mm/year to 629 mm/year (using the 1-in-5 year figures as the designed irrigation demand).

This increase in irrigation demand is a reflection of the projected changes in seasonality of the climate and has important implication for the management of the basin. This indicates that temperatures, and hence potential evapotranspiration, will increase throughout the year.

1.2.4.12 Sub-Watersheds: Impacts of climate change

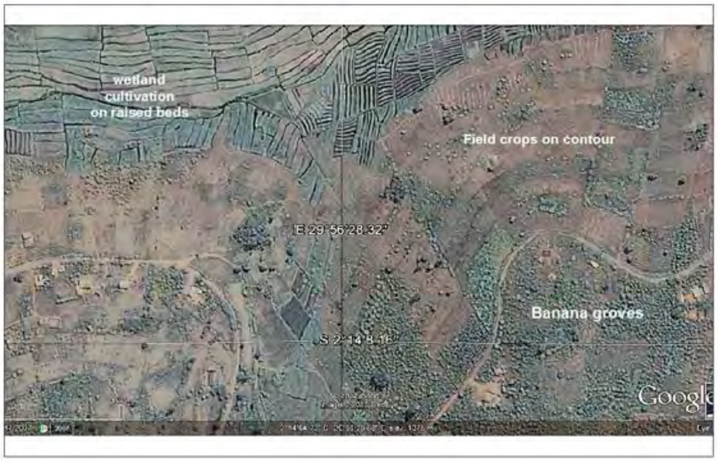
Overall the likelihood is that whilst flows will increase under the impact of climate change more of these flows will be needed to meet irrigation demand. This would either mean more abstraction of flows from the river at a time of low flows, with impacts on the ecology and wet lands in the basin, or the construction of more storage to store the higher wet period flows.

1.2.5 Landcover and Farming Systems

1.2.5.1 Landcover

The spatial distribution of landcover/landuse is shown in Map 16 and the area of dominant landcover types in table 2. It is important to note that the landcover types “Settlement” and “Settlement with gardens” encompass very intensive homestead garden agriculture with large banana groves (Figure 10).

Figure 10. Intensive cultivation: Wetland gardens, banana groves and field crops on contour



Thus very intensive agriculture and settlement with gardens are the most extensive landcover types covering some 52.3 percent of the sub-basin. This is mainly located in the central and western parts of the Sub-basin at higher altitudes and in areas with higher rainfall. Grassland covers some 25.1 percent and is found mainly in the eastern part of the Sub-basin.

Wetland and lakes cover some 7.4 percent of the Sub-basin and are confined to valley bottoms and alluvial and deltaic areas. Although “wetland agriculture” covers a relatively small proportion of the Sub-Basin (0.1percent) it is of considerable economic importance (15).

Figure 11. Cultivated wetland along the Akanyaru River

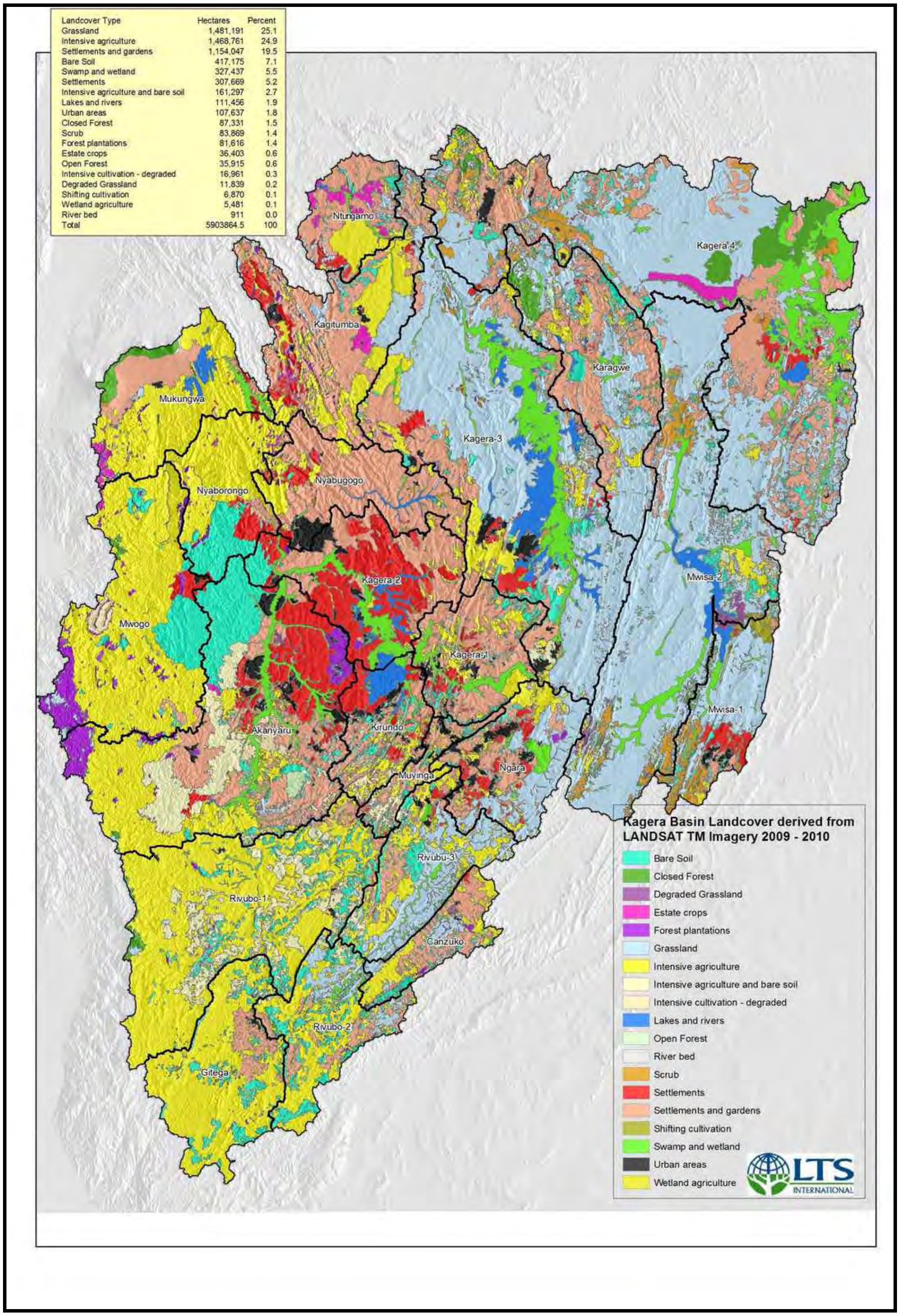
Closed and Open forest are now confined to just 2.1 percent of the area. Forest in the Nyungwe Forest National Park is being encroached by settlement and agriculture (Figure 12).

Figure 12. Agricultural encroachment into the Nyungwe Forest National Park (Rwanda): Radical terraces

Table 2. Landcover/Land use in the Kagera sub-basin (ha and %))

Landcover Type	Hectares	Percent of Total
Grassland	1,481,191	25.1
Intensive agriculture	1,468,761	24.9
Settlements and gardens	1,154,047	19.5
Bare Soil	417,175	7.1
Swamp and wetland	327,437	5.5
Settlements	307,669	5.2
Intensive agriculture and bare soil	161,297	2.7
Lakes and rivers	111,456	1.9
Urban areas	107,637	1.8
Closed Forest	87,331	1.5
Scrub	83,869	1.4
Forest plantations	81,616	1.4
Estate crops	36,403	0.6
Open Forest	35,915	0.6
Intensive cultivation - degraded	16,961	0.3
Degraded Grassland	11,839	0.2
Shifting cultivation	6,870	0.1
Wetland agriculture	5,481	0.1
River bed	911	0.0
Total	**5,903,865**	

Map 16. Land Cover / Use for Kagera sub-basin (Source Kagera Monograph and LANDSAT 2010)



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Wetland agriculture	5,481	0.1
River bed	911	0.0
Total	5903864.5	100

1.2.5.2 Farming Systems

Jones and Egli (1984) have divided the Great lakes region into a number of broad farming systems based partly on altitude. Four of these are applicable to the Kagera Sub-basin (Map 17).

(i) Nile Divide

This is found between 1,800 and 2,800 masl. It is characterized by maize, potatoes, peas, finger millet, wheat and tea. With increasing population pressure cultivation is gradually increasing in altitude.

(ii) High Plateau

This is found between 1,550 and 1,800 masl. Population densities are very high and both upland and wetlands are cultivated. Beans and sorghum are the main field crops with sweet potatoes, cassava and taro the main root crops. Bananas are an important food and beer crop. Coffee (*Coffea robusta*) is the main cash crop.

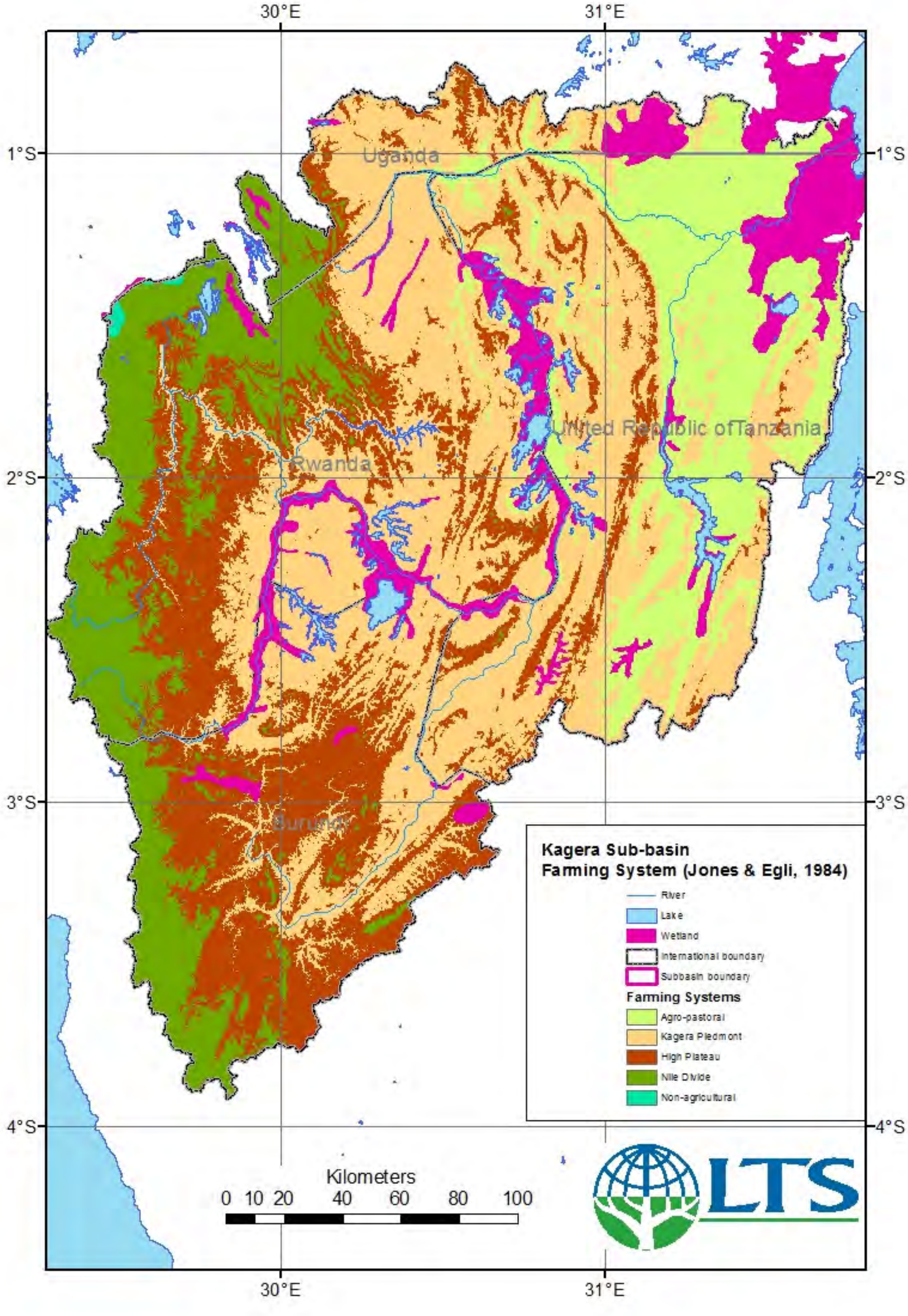
(iii) Kagera Piedmont

Below the High Plateau is the Kagera Piedmont between 1,400 and 1,550 masl. Beans, groundnuts, maize and sorghum are the main field crops with sweet potato and cassava the main root crops. Again, bananas are an important beer and food crop. Coffee is an important cash crop. Increasingly under population pressure and land shortage wetlands are being cultivated.

(iv) Savanna lowlands

These found below 1,400masl eastwards of the Kagera Piedmont. Sorghum starts to replace maize because of rainfall variability and cassava becomes the dominant root crop. Livestock are increasingly important. Robusta replaces Arabica coffee. Cotton and groundnuts

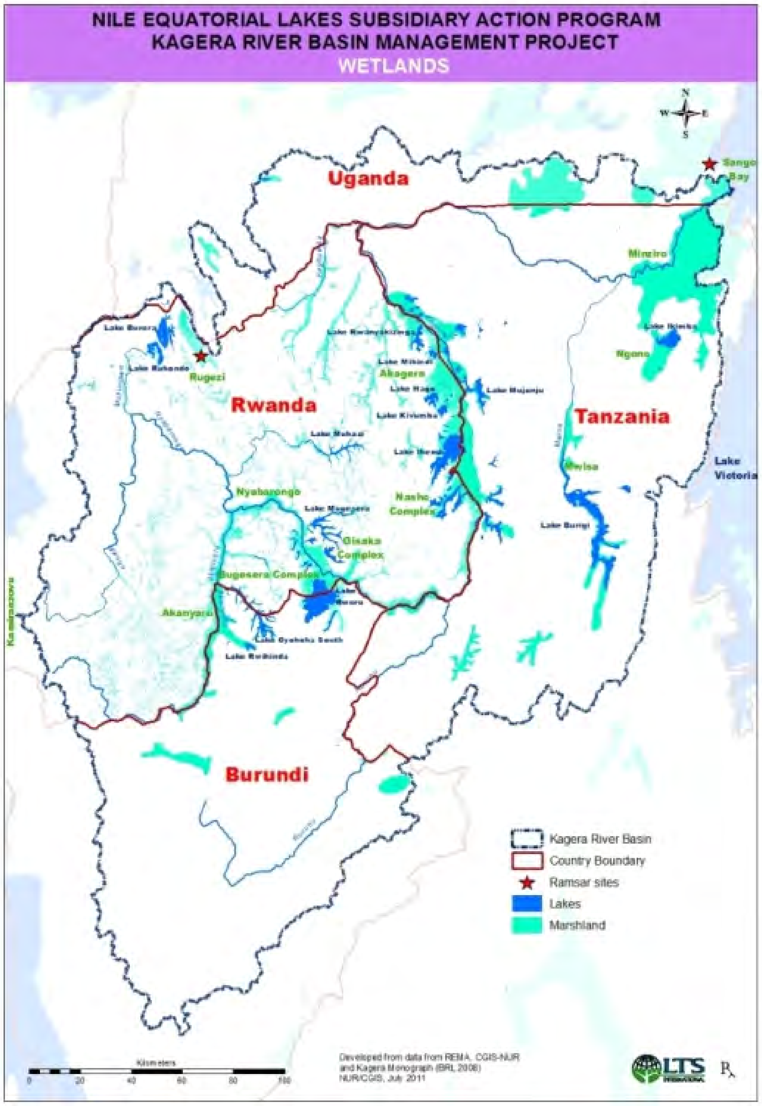
Map 17. Kagera Sub-Basin: Farming Systems (Jones and Egli, 1984)



1.2.6 Wetlands

The Kagera sub-basin includes many lakes and marshlands (Map 18 and Box 1). The lakes and marshlands attenuate river flows, and the Kagera has a high base-flow component resulting from the water storage in these lakes and marshlands (Sutcliffe and Parks, 1999). The marshlands along the river valleys are inundated during floods in the peak rainfall months of April and May, whilst the lowest water levels are in August-October. Marshlands cover 2.9% of the area of the Kagera basin and open water bodies another 1.6%, which does not reflect their significant importance to the sub-basin as a whole.

Map 18.Principal wetlands in Kagera river sub-basin



Box 1: The wetlands and water bodies of the Kagera sub-basin

In this study, the term “wetlands” include marshlands (also referred to in the region as bogs, fens, marshes; *marais* in French), swamps, and open water bodies (i.e. lakes and rivers, according to the wider Ramsar [1971] usage). In this study, wetlands are defined as areas of land permanently or temporarily flooded by surface water or regularly saturated by groundwater and characterised by vegetation adapted to life in saturated soil conditions. The Kagera wetland vegetation is predominantly papyrus grass and floating mats of sedge (BRL, 2008). The wetlands support a rich biological diversity with many endemic species and rare flora and fauna, including 180 species of birds, restricted ranges of species and globally threatened species (FAO, 2000).

The lakes, marshlands and rivers are closely related, as the Kagera basin is comprised of two principal types of marshland ecosystems. The first are lacustrine (associated with lakes), such as those around Lakes Cyohoha, Ihema and Rweru, and at Sango Bay where the Kagera River enters Lake Victoria. The second are riverine (associated with rivers), such as those along the Akagera, Akanyaru, Kagera, Mugesera, Ngono and Nyabarongo Rivers.

1.2.7 Biodiversity and Protected Areas

Critical areas for conservation in the Kagera Sub-basin are shown in Map 19. They include all National Parks, Games Reserves, Forest Reserves, Nature Reserves, Nature Monuments and selected wetlands.

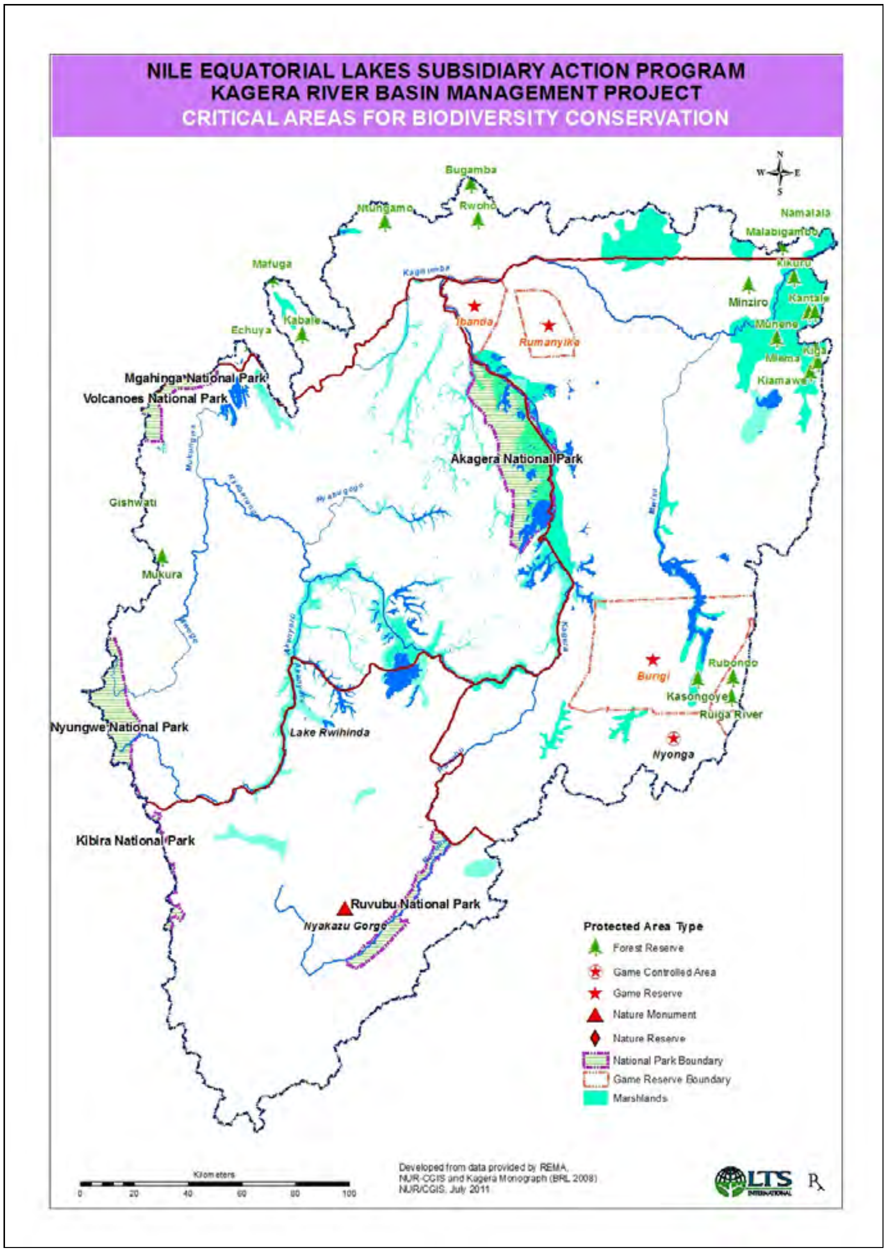
1.2.7.1 Protected Areas

The protected areas in the Kagera River basin include: 4 National Parks, 3 Game Reserves, 1 Game Controlled Area, 3 Nature Reserves and 21 Forest Reserves. Some of the protected areas have been reported to be severely affected by human activities like cultivation, bush fires, settlement creation, poaching / hunting and over-exploitation of timber, fuel wood and charcoal and medicinal plants (NBI, 2001). These include the Akagera NP, Ruvubu NP, Nyungwe NR, Minziro FR, Ibanda GR and Rubondo GR.

Akagera National Park (NP): The Akagera NP (85,000 ha) is located in eastern Rwanda along the Tanzania border. The northern portion of the park shares the border with Ibanda Game Reserve on the Tanzania side. The Park contains Lakes Rwanyikizinga, Mihindi, Hago, Kiyumbo and most parts of Lake Ihema. The Park is also important for supporting unique biodiversity in the area. It has been reduced to one third of its original size due to resettlement of returning refugees into Rwanda in 1996. It constitutes an important reservoir for biological diversity with more than 500 species of birds, 9 amphibians and 23 species of Reptiles. The site contains species of marsh buck or sitatunga (*Tragelaphus spekii),* which are also listed under CITES. Four species of mammals that have been listed under CITES include African elephants *(Loxodonta africana),* buffaloes *(Sincerus caffer),* leopards *(Panthera leo)* and marsh buck *(Tragelaphus oryx).*

Ruvubu National Park: The Ruvubu National Park (50,000 ha) was established in 1982) and contains papyrus wetland with over 400 bird species. It is located in the North-eastern region of Burundi and shares a border with Tanzania. It is comprised of about 98 species of mammals, 20 species of insects, 8 species of bats *(Chiropterus),* 10 primates *(Cercopithecus mitis dogetti)* and 6 species of arthropods[24]. Some of the important mammals in the Park include baboon *(Papio anubis)*, hippopotamus *(Hippopotamus amphibious)*, marshland kob / water buck *(Kobus defassa)* and grey duiker *(Sylvicapra grimmia),* buffaloes (*Syncherus caffer)* and bushbuck *(Tragelaphus scriptus)*. The grey duiker and bush buck are in the 1994 IUCN Red List of Threatened species (IUCN, 2007). The Park is also highly diverse with numerous indigenous tree species of socio-economic importance (e.g. construction, handicrafts, medicinal, fuel wood, charcoal, etc.). The Park has been affected by poaching and there is also a conflict between neighbouring communities with the national park authorities due to destruction of crops by wildlife in adjacent farms.

Map 19. Biodiversity and Conservation of protected Areas



Nyungwe National Park: The Nyungwe NP (90,000 ha) was established as a Nature Reserve in 1999 and as a National Park in 2004. It is located in the south-western region of Rwanda and shares a common border with Kibira National Park in the Burundi side. The reserve has been affected by clearing of land for agriculture, bush fires, over-exploitation of forest resources. Gold washing and saw milling activities have been found (NBI, 2001) leading to serious environmental degradation in the Park.

Rumanyika Game Reserve (80,000 ha) was established in 1970. It is located in the northeast side of the basin. The reserve faced problems of poaching and illegal harvesting of timber and uncontrolled bush fires.

Kibira NP: Kibira National Park, in Burundi, is estimated at 40,000 ha. However, a small part of the Park is situated in the Kagera River Basin (most of the Park is situated at the North East of the Kagera River Basin Burundian part).

Ibanda Game Reserve: The Ibanda Game Reserve (20,000 ha, established in 1974) is located in the extreme north-western region of Tanzania, shares border with Uganda and Rwanda. Another portion of the game reserve is sharing border with northern portion of Rwanda's Akagera National Park. The game reserve is under pressure due to poaching and illegal harvesting of timber and uncontrolled bush fires.

Rubundo Game Reserve: Rubondo GR (45,000 ha, established in 1980) is in the north-eastern region of Tanzania, just south of Lake Victoria near border of Rwanda and Burundi. The game reserve has been affected by wildlife poaching and bushfires.

Mgahinga Gorilla National Park: On the Ugandan side, the important biodiversity hot spot include the **Mgahinga Gorilla National Park.** This Park is important for the endemic species of mountainous gorilla *(Gorilla gorilla berengei)*.

Sango Bay seasonal swamp forest: this ecosystem contains biodiversity of global significance (Davenport & Howard 1996), with endemic species of fish *(Oreochromis esculantus* and *O. variabilis),* dragon flies *(Macromia bispina)* and numerous butterflies *(Tametheria orientalis, Elymnias bammakoo ratrayi* and *Charaxes imperialis ugandacus).* The Reserve also contains some endangered hard wood species *(Podocarpus Sp).* The forest reserve is said to have a high conservation value for butterflies, large moths and birds (Davenport & Howard, 1996).

Minziro Forest Reserve: The Minziro Forest Reserve (25,000 ha) was, established in 1974). It is a wetland area that shares the border with Uganda and is home to rare species, including the *mangabay* monkeys. The forest reserve has been negatively impacted due to cutting trees for building materials, extraction of medicinal plants, fuel wood collection and charcoal making.

1.2.8 Wetlands of Biodiversity Importance

There are a number of wetlands of biodiversity importance that warrant conservation. These include the following:

Lakes Hago and Ruanyakiziga contain large number of wild pigs *Potamochoerus porcus)* and marsh buck *(Tragelaphus spekii)*, which are considered to be important species listed under CITES and IUCN. There are some carnivorous animals such as the spotted genet (*Genetta tigrina)*, which are also listed under IUCN.

Lake Ihema vegetation is dominated by giant marsh grass *(Cyperus papyrus, Potamogeton Sp.*and *Phragmites)*, which constitute an important source of detritus to the Akagera River. It is host to 34 species of Reptiles with 21 Genera and 9 Families. The lake also contain some fish species *(Astatoreochromis alluandi)*, which that are also listed by CITES as protected species. The littoral vegetation is characterized by herbaceous plants *(Aeschynomena elasphroxylon* and giant grass species *(Poaceae* and *Cyperaceae)*, which provide an important habitat and potential source of nutrients to fish. The hippopotamus *(Hippopotamus amphibious)* is the dominant large mammal in the Lake.

Mugesera-Rweru complex, Kagera, Nyabarongo and Akanyaru Wetlands: These have been described as important habitats for a number of globally threatened species and restricted range of species such as water turtles, crocodiles, monitor lizards, snakes, otters. There are also a variety of water birds, including herons, egrets, ducks, warblers and weavers.

The **Rugezi wetland** provides an important habitat for scrub-warbler *(Bradypterus graueri).* As a tourist attraction in the area, it is a socio-economic benefit to the region. It also contains several species listed under CITES, these include marsh grass such as Cyperus *latifolius, Cyperus papyrus* and *Miscanthus violceus*. This wetland is also hosts 19 animal species**,** which are associated with marsh plants like Grauer's scrubwarbler *(Bradypterus graueri)*. About 3000 species of animals in this wetland are considered to be endangered, hence need protection. Rugezi is estimated to have more than 10,000 species of birds and some of the bird species such as *Bostrichia hagedesh, Aonyx capensis* and *Threskion thides aethiopius* are listed by CITES as protected species.

Other important wetland areas include: **Lake Rwihinda (Burundi), Ruvubu Wetlands and Akanyaru Valley on the Burundian side; The Rusumo Swamps (Upstream of Rusumo Falls), Lake Ihema, Lake Cyohoha, Lake Rugweru, Lake Mugesera, Bugesera Wetlands on the Rwanda side; and Minziro-Sango Bay Swamp Forest in Uganda**.

Two wetlands have been declared Ramsar Wetland sites: the Rugezi and the Sango Bay wetlands.

1.2.9 Natural Resource Condition and Trends

As noted in many previous studies the Kagera sub-basin has suffered considerable degradation up to the present time. This is important, and has a significant influence on the specific projects to be selected as preferred interventions for the near future in the sub-basin.

Several distinct forms of degradation exist in the sub-basin, and certain other factors interact with the historical degradation to exacerbate conditions for the basin population. Thus:

- The sub-basin has been heavily deforested already, especially in its upper reaches in much of Burundi and Rwanda. In combination with the introduction of (mainly subsistence) agriculture on land which is often strongly sloped, this has created a range of problems, including soil loss in particular.
- The loss of soils has greatly enhanced the turbidity of the surface water systems, and this in turn has led to negative effects on fisheries and hydropower potential.
- The poor levels of sewage treatment in the sub-basin as a whole have given rise to a concurrent nutrient enrichment of the surface waters, and this has created eutrophic conditions, with the heavy growth of plants such as the water hyacinth.
- Wetlands in the sub-basin have come under significant pressure, and considerable areas of wetland have already been lost or degraded.

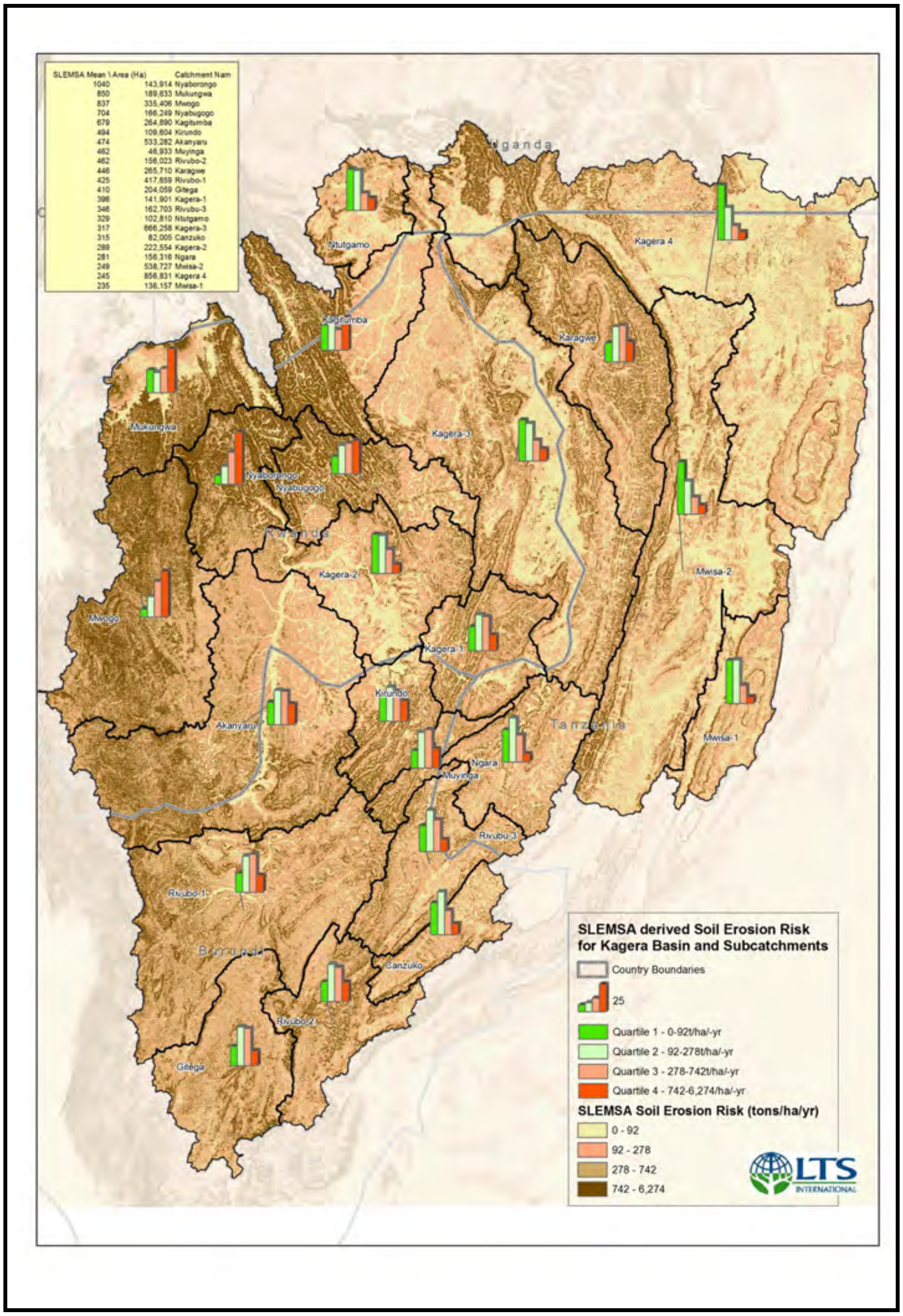
Two key factors have driven much of the degradation observed to the present time in the Kagera sub-basin. These are not directly related to watershed management, but are key development-related factors that will need to be tackled by national authorities to ensure the interventions of NELSAP have any long–term meaningful development and environmental impact. The first of these involves population growth, which remains high for all four of the Basin States and creates continuing and increasing pressure on the fresh water resources.

Map 22 shows the existing population for the sub-basin. This parameter is used as a key threat in prioritising actions for intervention.

The second factor relates to land tenure, which is problematic throughout the sub-basin and leads inevitably over time in many areas to the farming of smaller and smaller plots of degraded land, in a subsistence fashion.

The overall distribution of soil erosion risk across the Sub-basin is shown in Map 20. The highest risk is found on the cultivated areas along the montane ridge and foothills forming the western boundary of the Sub-watershed. The areas of Alisols and Ferralsols are at the highest risk because of their shallowness (Alisols) and low fertility (Ferralsols). Areas of very intensive cultivation based on small hedged homestead fields and extensive banana groves are at less risk, whilst those areas with large open fields with no hedges are at the highest risk.

Map 20. Soil Erosion Risk – basin wide level



SLEMSA Mean	Area (Ha)	Catchment Nam
1040	143,914	Nyaborongo
850	189,833	Mukungwa
837	335,406	Mwogo
704	166,249	Nyabugogo
679	264,890	Kagitumba
494	109,604	Kirundo
474	533,282	Akanyaru
462	46,933	Muyinga
462	156,023	Rivubo-2
446	265,710	Karagwe
425	417,659	Rivubo-1
410	204,059	Gitega
398	141,901	Kagera-1
346	162,703	Rivubu-3
329	102,810	Ntutgamo
317	666,258	Kagera-3
315	82,005	Canzuko
289	222,554	Kagera-2
281	156,316	Ngara
249	538,727	Mwisa-2
245	856,831	Kagera 4
235	136,157	Mwisa-1

Key effects of the high rates of soil erosion and sedimentation include: [a] elevated costs for water treatment to generate potable supplies; [b] negative effects on hydropower production and the siltation of dams; and almost certainly [c] reduced fisheries productivity. The last of these is difficult to quantify in isolation, due to the influence of many other factors on fisheries productivity.

As noted previously, the organic enrichment in the Kagera sub-basin is primarily created by human sewage effluents, coupled to very poor levels of wastewater treatment in most parts of the sub-basin. The resulting eutrophication reaches downstream to Lake Victoria and beyond, into the upper reaches of the White Nile. The main overt result of this is the enhanced primary productivity (as evidenced by the water hyacinth problem, for example), with potential positive effects on fishery production. However, over-enrichment leads to dissolved oxygen sags and to a general decline in secondary production and other problems also exist due to the transfer of pathogens downstream. The latter is of very considerable significance to the human population who rely on surface waters for potable supplies, often without treatment. Bacteria, viruses and parasites are all problematic, and while the population exhibits high levels of immunity to many diseases, intestinal and other infections are present at epidemic proportions and create morbidity and mortality at high levels (with children especially at risk).

In relation to future conditions in the Kagera sub-basin, the following is notable:

- The population growth is a fundamental driver of the pressure on the water resources (and the ecosystem as a whole), and reveals no signs of abating. Current levels of population growth are high throughout the sub-basin, and this continues to generate ever-increasing pressure on potable water resources, and also on food production (which requires the great majority of the available fresh water). Competition between water uses already exists, and will only become more intense over time. In this regard, efforts should be made to increase the available water volume through time, and this can only be achieved if the constraints mentioned previously remain in place by: [a] enhancing the efficiency of water use in specific applications; [b] reusing water as it fluxes through the sub-basin; and/or [c] finding new sources of water, such as groundwater or imported water.
- Only partial recovery is possible for the sub-basin as a whole, over time. The degradation of soil quantity and quality is perhaps the most problematic issue in this regard, especially in the upper watershed area. Much-improved agricultural practices and land husbandry are required.
- The current scenario is not simply a function of the constraints on water resource mobilisation and use, as many other factors are of significance also. As noted previously, the vexed issue of land ownership and tenure is one of these, with farmed plots becoming ever smaller over time, and larger numbers of the population becoming stranded in subsistence agricultural activities, on ever-reducing plot sizes. Specific forms of interventions are required to break this cycle, and the FS-IWMP has recognised these and allocated high priority to them.
- The availability of electrical energy – and indeed other forms of energy – is also linked closely to the overall scenario. While this is improving slowly with the introduction of new hydropower from Rusumo Falls and the eventual inter-connection of the regional grids for electricity, more needs to be done if cross-sectoral allocations of water are to be successful in enhancing rates of economic development.

In certain respects, trans-boundary cooperation will be an important component of future economic growth. The existence of NELSAP is vital in this regard in relation to water resources, but the riparians should move from the planning stage of cooperative efforts, into the implementation of projects which will have material effects in the region. The FS-IWMP has recognised the key importance of trans-boundary projects, and has acknowledged that these include specific projects that do not traverse national borders, but are simply replicated in more than one of the Basin States, providing opportunities for cooperation between the riparians.

1.3 Socio-economic Characteristics

1.3.1 Political and Administrative Structures

The Sub-basin encompasses four countries (Burundi, Rwanda, Tanzania and Uganda) each with its administrative structures (www.statoids.com) (Map 20).

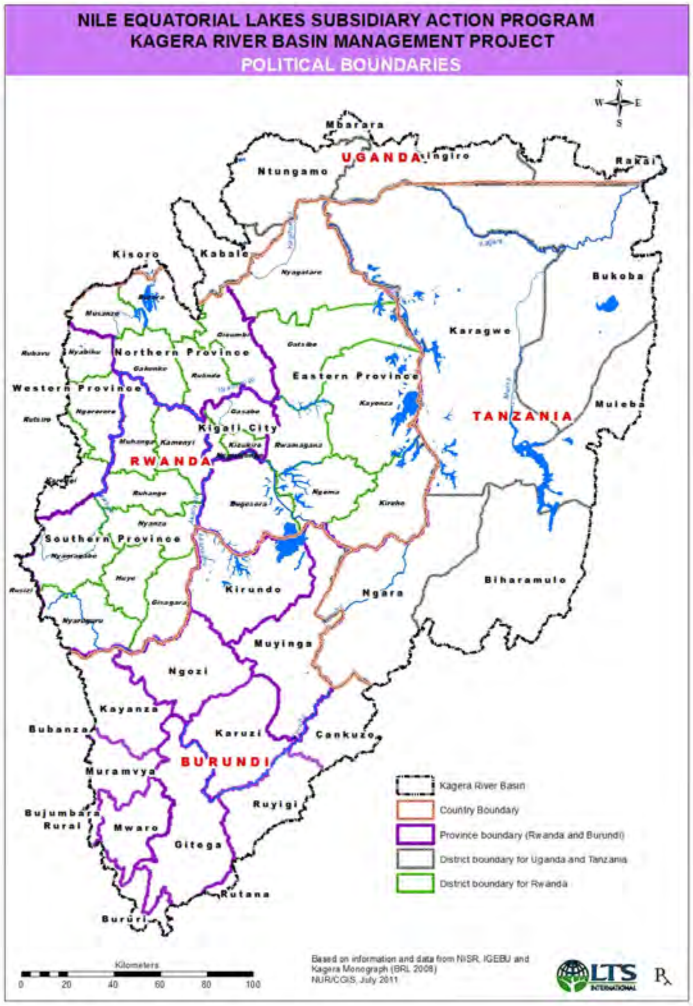
Burundi has as its first layer of administration the Province is the highest. There are 15 to which must be added the urban province of Bujumbura. A governor leads each province. The province is subdivided into communes, each directed by a communal administrator. There are 116 of them. This administrative entity is in turn subdivided into administrative zones, and further into "*collines*" (literally, 'hills').

Rwanda is divided into 5 "*Intara*" (Provinces), 30 "*Uterere*" (Districts), 418 "*Imirenge*" (Administrative sectors) and 9,165 "*Utugari*" (Cells).

Tanzania is divided into 26 "*Mkoa*" (Regions) and 129 "*Wilaya*" (Districts).

Uganda is divided into 80 Districts and 146 Counties.

Map 21.Administrative Structures: 1st Level

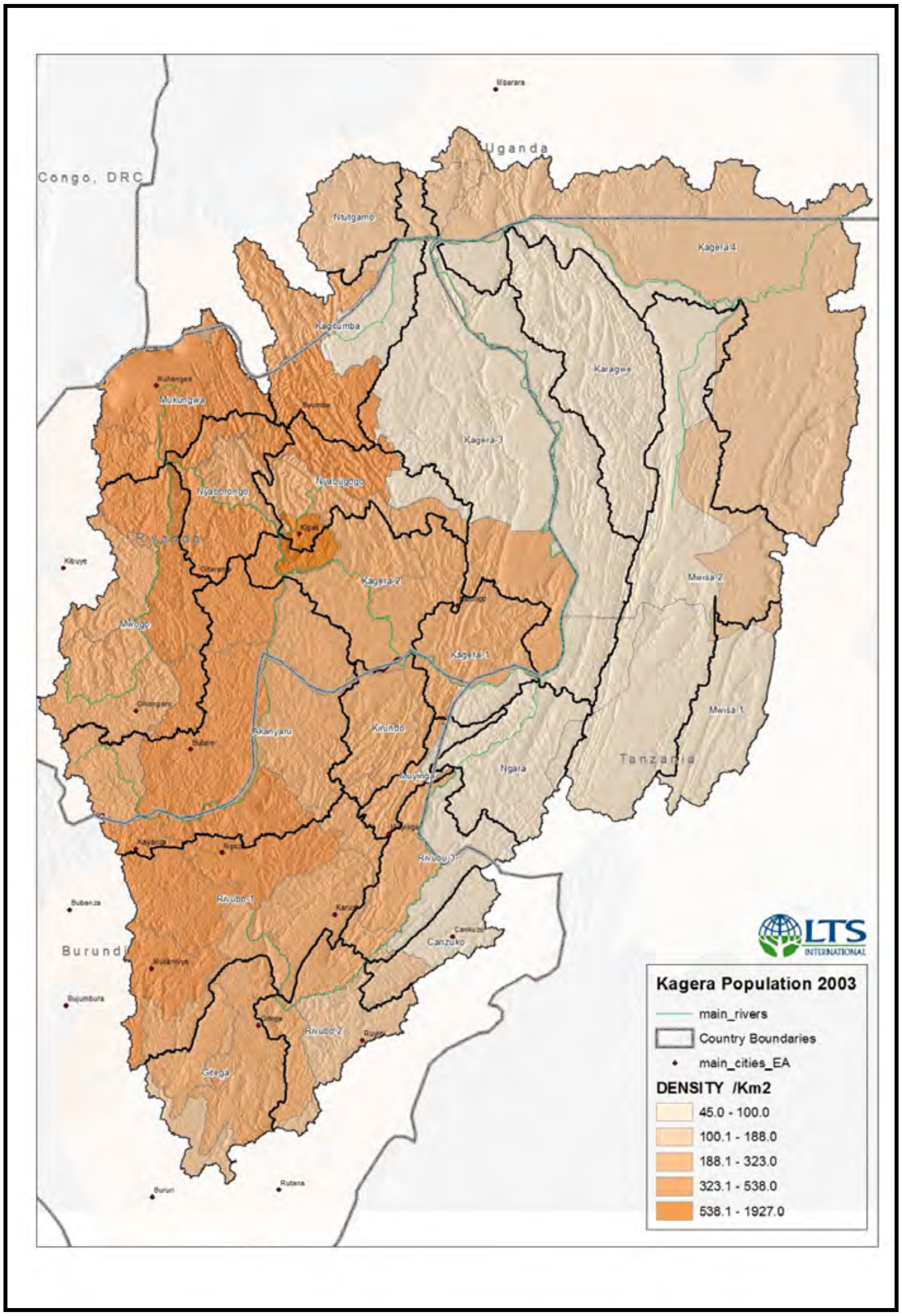


Based on information and data from NISR, IGEBU and Kagera Monograph (BRL 2008)
NUR/CGIS, July 2011

1.3.2 Population Structure and Distribution

The total population of the Sub-basin is some 15 million people (BRL, 2008), almost 40 % of the 35 million within the Lake Victoria basin. The population density within the basin averages 227persons/sq.km and varies between 45 and 1,900persons/km2. The highest densities are found in the eastern half of the sub-basin and the lowest in the central plains (see map 22). The population is growing at 2.2 % per year in Burundi and Rwanda, 3.1 % per year in Tanzania and Uganda.

Map 22.Population density (2003)



1.3.3 Infrastructure

1.3.3.1 Road and Rail

Map 23 shows the surface and air infrastructure in the Sub-basin. Burundi, Rwanda and Uganda presently use both (i) the Northern and (ii) the Central Corridors; with each Corridor offering road and intermodal transport options. Though each individual country's trade has been mostly geared towards imports and exports outside the region, intra-regional trade has been growing significantly, especially between Uganda and Kenya, over the last few years. However, the main trade flows (more than 80%) are still in and out of the region.