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# Water-use accounts in CPWF basins

## Simple water-use accounting
## of the Niger Basin

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2010

**The CGIAR Challenge Program on Water and Food, Colombo, Sri Lanka.**

This paper is a contribution to the synthesis work of the CGIAR Challenge Program on Water and Food from the CPWF's Basin Focal Projects. The work was funded by the Challenge Program on Water and Food and by CSIRO Water for a Healthy Country.

It should be cited as:

Mainuddin, M., Eastham, J., and Kirby, M. 2010. Water-use accounts in CPWF basins: Simple water-use accounting of the Niger Basin. CPWF Working Paper: Basin Focal Project series, BFP09. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food. 25pp.

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ISSN - 2076-4502

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# CONTENTS

**List of Tables** . . . . 4

**List of Figures** . . . . 4

**1 Abstract** . . . . 6

**2 Introduction** . . . . 6

2.1 Other models . . . . 7

**3 Basic hydrology and outline of simple water account** . . . . 7

3.1 Basic hydrology, irrigation and land use . . . . 7

3.2 Simple water account . . . . 11

3.3 Units . . . . 11

**4 Data sources** . . . . 11

4.1 Rainfall . . . . 11

4.2 Flows . . . . 12

4.3 Land use . . . . 12

4.4 Dam storages . . . . 12

**5 Components and results in detail** . . . . 12

5.1 Flow . . . . 12

5.2 Water use . . . . 18

5.3 Catchment and basin hydrological characteristics . . . . 20

**6 Example use** . . . . 22

**7 Conclusions** . . . . 23

**8 References** . . . . 24

# LIST OF TABLES

Table 1. Catchments in the Niger Basin with their areas. . . . . . . . . . . . .9

Table 2. Annual percentage runoff ratios (runoff/precipitation) for catchments in the Niger Basin. . . . . . . . . . . . . . . . . . . . . 21

# LIST OF FIGURES

Figure 1. The Niger Basin, with the catchments used in the water-use account. 8

Figure 2. Monthly average rain and potential evapotranspiration in the Niger Basin. . . . . . . . . . . . . . . . . . . . . . . . . . . . . 10

Figure 3. Annual rainfall in four locations of the Niger Basin referred to in Figure 2. . . . . . . . . . . . . . . . . . . . . . . . . . . 10

Figure 4. Monthly rainfall and flow in the Kouroussa catchment of the Niger River in the Western Niger Basin. . . . . . . . . . . . . . . . 13

Figure 5. Detailed monthly rainfall and flow for the years 1951-5 in the Kouroussa catchment of the Niger River in the Western Niger Basin. 13

Figure 6. Observed and modelled flow in the Niger River at Kouroussa. . . . . 14

Figure 7. Observed and modelled flow in the Tinkisso River at Ouaran. . . . . 14

Figure 8. Observed and modelled flow in the Niger River at Mopti. . . . . . . 14

Figure 9. Observed and modelled flow in the Niger River at Tossaye. . . . . . 15

Figure 10. Observed and modelled flow in the Gorouol River at Alcongui. . . . 15

Figure 11. Modelled flow of the Dallol Bosso River before its junction with the Niger.. . . . . . . . . . . . . . . . . . . . . . . . . . . 16

Figure 12. Observed and modelled flow of the Niger River at Gaya. . . . . . . 16

Figure 13. Modelled flow of the Kebbi River at Bahindi. . . . . . . . . . . . . 16

Figure 14. Modelled flow of the Niger River at Jebba. . . . . . . . . . . . . . 17

Figure 15. Observed and modelled flow of the Benue River in its headwaters at Garoua, Northern Cameroon.. . . . . . . . . . . . . 18

Figure 16. Modelled flow of the Benue River upstream of its junction with the Niger.. . . . . . . . . . . . . . . . . . . . . . . . . . . . 18

Figure 17. Modelled flow of the Niger River at Onitsha, downstream of its confluence with the Benue River. . . . . . . . . . . . . . . . . . . . 18

Figure 18. Major water uses (annual averages 1951-2000).. . . . . . . . . . . 19

Figure 19. Summary of major water uses in catchments of the Niger Basin. . . 20

Figure 20. Runoff (annual averages 1951-2000) in the catchments in the Niger Basin. . . . . . . . . . . . . . . . . . . . . . . . . . . . 22

Figure 21. Modelled flow of the Niger River at Gaya showing greater flow with 7.5% increase in rainfall in all catchments as a consequence of climate change. . . . . . . . . . . . . . . . . . . . 22

Figure 22. Modelled flow of the Benue River at Garoua in Northern Cameroon showing greater flow with 7.5% increase in rainfall in all catchments as a consequence of climate change. . . . . . . . . . 23

# 1. ABSTRACT

This paper applies the principles of water-use accounts, developed in the first of the series, to the Niger River basin in West Africa. The Niger Basin covers 10 countries, and rises in the highlands of southern Guinea near the border with Sierra Leone just 240 km inland from the Atlantic Ocean, but there are substantial downstream tributaries from Cameroon and Nigeria. A unique feature is the inland delta which forms where its gradient suddenly decreases.

Net runoff is about 12% of total precipitation. Grassland is the most extensive vegetation, covering 50% of the Basin, consuming about 39% of the precipitation. Rainfed agriculture covers 26% of the basin and use about 27% of the precipitation. Irrigated agriculture covers less than 1% of the Basin and uses also less than 1% of the water.

Climate change, using an assumed change in rainfall distribution, shows that climate change may have a large impact on water availability in the lower Basin, and hence on the River's wetlands.

Keywords: Water use accounts, Niger basin, top-down modeling, basin water use.

# 2. INTRODUCTION

In this note, we describe a simple water account for the Niger Basin.

The Challenge Program on Water and Food aims to catalyse increases in agricultural water productivity at local, system, catchment, sub-basin, and basin scales as a means to poverty reduction and improving food security, health, and environmental security. It does this in several priority basins: the Indo-Gangetic Basin, the basins of the Karkheh, Limpopo, Mekong,Nile, São Francisco, Volta, and Yellow Rivers, and a collection of small basins in the Andes. Although the Niger is not one of the CPWF's priority basins, it has a number of unique features that make it relevant.

A useful output for each basin, and a key element of the understanding of basin function, is an overview water-use account. Water-use accounts produced in the same way for each basin would have the further benefit of making easier the development of syntheses of understandings from all the basins.

Water-use accounting is used at national (ABS 2004; Lenzen 2004) and basin (Molden 1997; Molden et al. 2001) scales to:

- Assess the consequences of economic growth;
- Assess the contribution of economic sectors to environmental problems;
- Assess the implications of environmental policy measures (such as regulation, charges, and incentives);

- Identify the status of water resources and the consequences of management actions; and
- Identify the scope for savings and improvements in productivity.

However, those accounts are static, providing a snapshot for a single year or for an average year. Furthermore, they do not link water movement to its use. In contrast to the static national and basin water-use accounts referred to above, our accounts are dynamic, with a monthly time step, and thus account for seasonal and annual variability. They can also examine dynamic effects such as climate change, land-use change, changes to dam operation, etc. The accounts are assembled in Excel spreadsheets, and are quick and easy to develop, modify, and run. We have applied this accounting method to several major river basins including the basins of the Murray-Darling, Mekong, Karkheh, and Limpopo Rivers (Kirby et al. 2006a; Kirby et al. 2006b). Here we describe the application to the Niger Basin.

As we shall describe below, the account has been developed using data readily available on the internet, and gives an overview of water uses within the Basin. The account can be improved with better data and calibration. We recommend that, should it be intended to use the account for any purpose beyond developing an understanding of the broad pattern of water uses in the Basin, that effort be directed to obtaining better data.

### 2.1. OTHER MODELS

We have not researched other models of the Niger Basin.

## 3. BASIC HYDROLOGY AND OUTLINE OF SIMPLE WATER ACCOUNT

### 3.1. BASIC HYDROLOGY, IRRIGATION AND LAND USE

The Niger Basin covers 2,130,000 km$^2$, and is drained by the Niger River and its tributaries (Figure 1 and Table 1). The Niger River is the third-longest river in Africa after the Nile and the Congo Rivers. The Niger rises in the highlands of southern Guinea near the border with Sierra Leone just 240 km inland from the Atlantic Ocean. Joined by a number of other rivers from the Southern Guinean highlands, the Niger flows northeast into Mali. Downstream from Ségou in Mali, the Niger River, joined from the south at Mopti by the Bani River, spreads out over a large inland delta which includes a RAMSAR wetland of 42,000 sq km. A good deal of the flow evaporates, leaving the river flow substantially reduced.

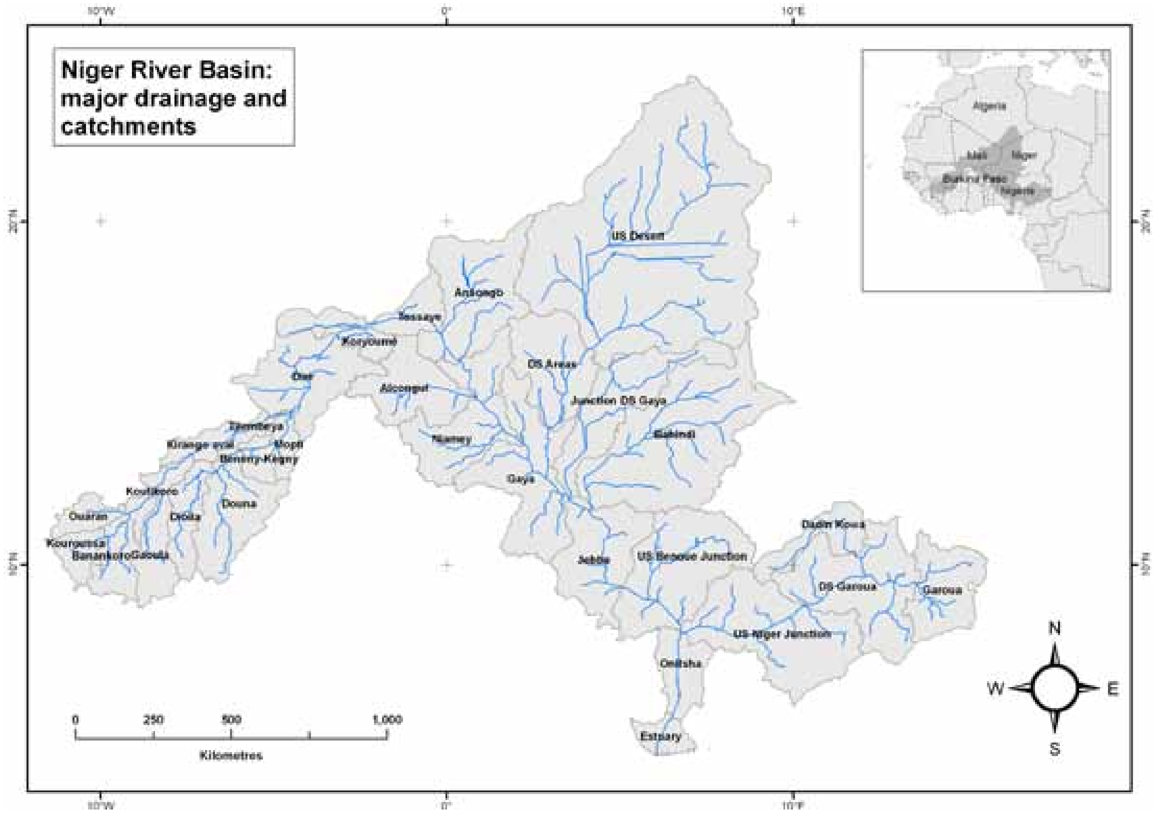

Figure 1. The Niger Basin, with the catchments used in the water-use account. The desert catchments in the north are omitted from some studies of the basin.

After the inland delta, the Niger then flows east between Timbuktu and Bourem and then turns to the southeast through Gao in Mali and Niamey in Niger. The desert catchments in the north are omitted from some studies of the basin: they contribute little flow to the Niger. South of Niamey, before entering Nigeria, the river forms part of the Niger-Benin border. Heavier rainfall, plus inflow from the Mékrou and Sokoto rivers, adds to the Niger's volume in this part of the Middle Reach. In Nigeria, the Kainji Dam forms Kainji Lake, about 135 km long. The Kaduna and Benue Rivers contribute considerable flow in the Lower Reach of the Niger. Before it enters the Gulf of Guinea, the River Niger forms a wide, fan-shaped delta of swamps and low-lying islands with many channels.

Table 1. Catchments in the Niger Basin with their areas.

| Catchment | Location | Area, km$^2$ |
|---|---|---|
| Niger | Kouroussa | 18,900 |
| Tinkisso | Ouaran | 18,195 |
| Niger | Banankoro | 30,536 |
| Sankarani | Gaoula | 33,035 |
| Niger | Koulikoro | 18,766 |
| Niger | Kirango aval | 17,236 |
| Niger | Tilembeya | 7,598 |
| Baoulé | Dioila | 32,563 |
| Bani | Douna | 68,697 |
| Bani | Bénény-Kégny | 14,256 |
| Niger | Mopti | 14,593 |
| Niger | Diré | 79,257 |
| Niger | Koryoumé | 14,569 |
| Niger | Tossaye | 43,239 |
| Niger | Ansongo | 97,651 |
| Gorouol | Alcongui | 60,842 |
| Niger | Niamey | 85,090 |
| Dallol Bosso [1] | Desert Areas U/S | 445,882 |
| Dallol Bosso | Desert Areas D/S | 72,551 |
| Niger | Gaya | 103,836 |
| Niger | Gaya Junction D/S | 79,756 |
| Kebbi | Bahindi | 187,210 |
| Niger | Jebba | 79,745 |
| Niger | Benue Junction U/S | 115,012 |
| Benue | Garoua | 58,693 |
| Gongola | Dadin Kowa | 34,692 |
| Benue | Garoua D/S | 114,546 |
| Benue | Niger Junction U/S | 130,454 |
| Niger | Onitsha | 35,509 |
| Niger | Estuary | 17,270 |
|  | Total | 2,130,179 |

[1] omitted from some studies

Rainfall varies from the wetter, western part of the Basin near the source of the Niger River, with annual average rainfall of about 1700 mm, to the drier northerly central parts of the Basin where rainfall is as low as 200 mm at the River. Rainfall is even lower in the catchments of some of the wadis to the north, which occasionally drain to the Niger River from the desert. In the wetter coastal regions around the Delta, the rainfall rises to as much as 4000 mm. The rain falls in a distinct wet season, which peaks around July to September each year (Figure 2). The annual average potential evapotranspiration is generally around 2000 mm, falling to about 1800 mm in the west and to about 1500 mm at the Delta.

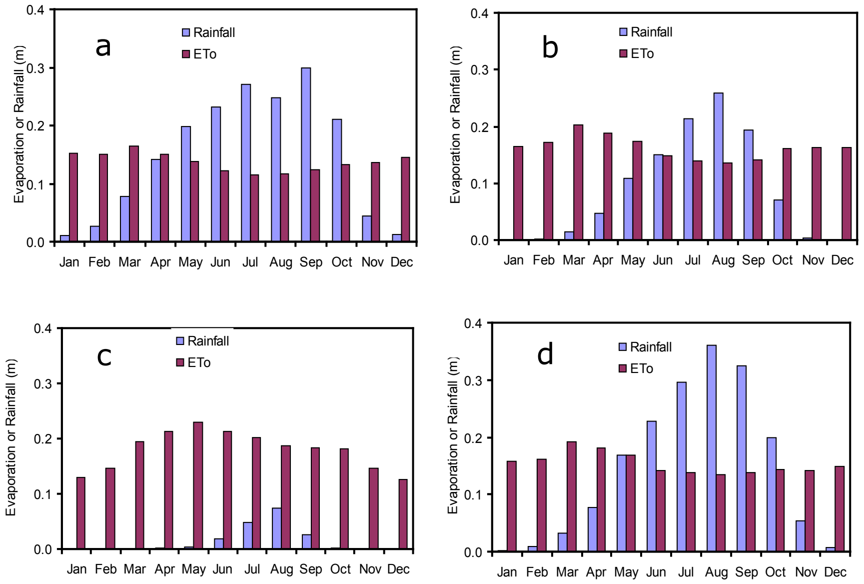

Figure 2. Monthly average rain and potential evapotranspiration in the Niger Basin. a). Kouroussa in the upper Niger of eastern Guinea; b). Tossaye in eastern Mali; c). Garoua in northern Cameroon; and d). The Delta in Nigeria.

Rainfall varies somewhat from year to year. More noticeable than annual variation in some parts of the Basin is a general decline in rainfall since the 1950s (Figure 3). In the western source regions, this is particularly pronounced (as shown by the record for Kouroussa, Figure 3). In other parts of the Basin, the decrease is less pronounced, although the 1970s and particularly the 1980s were drier, with some wetter years in the 1990s.

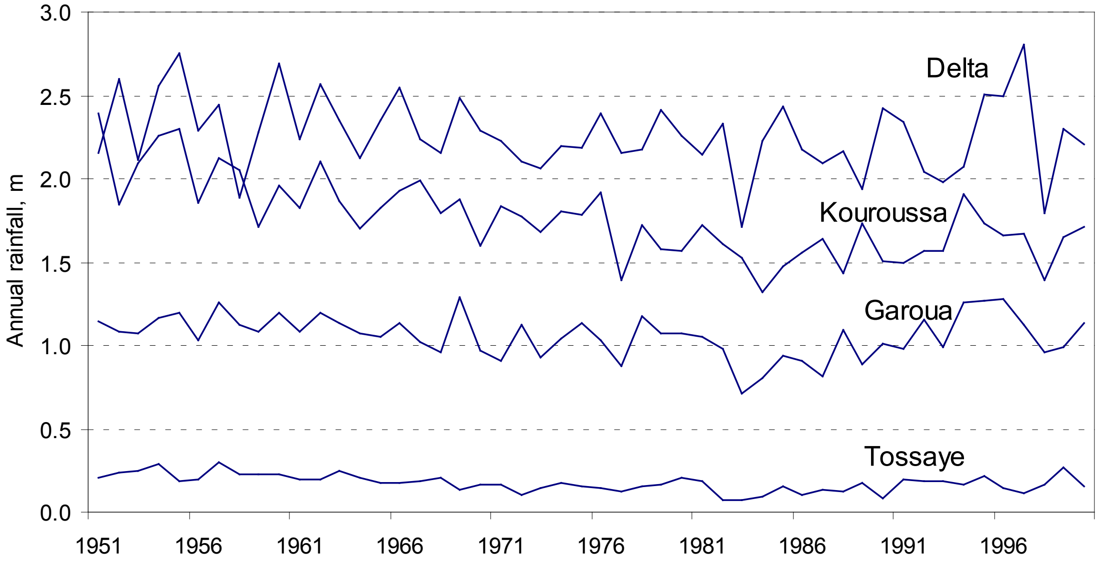

Figure 3. Annual rainfall in four locations of the Niger Basin referred to in Figure 2.

### 3.2. SIMPLE WATER ACCOUNT

The simple water account has two parts:

- A hydrological account of the water flowing into the Basin (primarily rainfall), flows and storages within the Basin, and water flowing out of Basin (primarily as evapotranspiration and discharge to the sea); and
- A further partitioning of the evapotranspiration into the proportion of evapotranspiration accounted for by each vegetation type or land use, including evapotranspiration from wetlands and evaporation from open water.

The simple hydrological account is based on a monthly time step,which we consider adequate for our purpose.

The account is a top-down model (Sivapalan et al. 2003), based on simple lumped partitioning of rainfall into evapotranspiration and runoff. This is done at the catchment level, with no spatial separation into different vegetation types. Runoff flows into the tributaries and thence into the Niger, with downstream flow calculated by simple water balance. During high flows, some of the flow is stored in the channels, and some in lakes and wetlands from which much water is lost to evaporation.

The model is described in detail in a companion report, *Water-use account in CPWF basins: Model concepts and description* (Kirby et al. 2010). Here we describe only that part of the model that differs from the general set of equations.

### 3.3. UNITS

Rain, evapotranspiration and potential evapotranspiration are given in mm.

River flows and storages, and lake storage, are given in mcm (million cubic metres). 1 mcm is equivalent to one metre over one square kilometre. 1000 mcm = 1 bcm (billion cubic metres) = 1000 m over 1 $km^2$ = 1 $km^3$.

## 4. DATA SOURCES

The datasets used in this water-use account were all readily available on the internet.

### 4.1. RAINFALL

The rainfall and other climate data were taken from the Climate Research Unit at the University of East Anglia (specifically, a dataset called CRU_TS_2.10). They cover the globe at 0.5° (about 50 km) resolution, at daily intervals for 1901 to 2002. The dataset was constructed by interpolating from observations. For recent decades, many observations were available and the data show fine structure. For earlier decades, few observations were available and the data were mostly modelled and lack fine structure. We sampled the rainfall and other climate surfaces for each catchment within the Basin, to calculate catchment area-means of rainfall and potential evapotranspiration for each month. The method is described in more detail in Kirby et al. (2010).

### 4.2. FLOWS

Reach flows were taken from a dataset called ds552.1, available on the internet (URL: http://dss.ucar.edu/catalogs/free.html) (Bodo 2001). The dataset also gives contributing drainage areas for each flow gauge. Flow records were not available for all the catchments, and no flow records were available for the Niger below Jebba or for the Benue below Garoua. Thus, we could not calibrate the flow part of the model in the Lower Niger and the Delta region.

### 4.3. LAND USE

Land use data were taken from the 1992-3 AVHRR dataset (IWMI 2006), which has more than 20 land-use classes, many of which have similar patterns of water use. The land-use classes were therefore aggregated into rainfed agriculture, irrigated agriculture, grassland, and woodland and other. The aggregated class of grassland contains important areas of other land uses including shrubland and barren land.

The AVHRR data fail to identify much cropping in most of the basin. Ogilvie and Clanet (personal communication, 2008) suggest that cropping is likely to take perhaps 20 % of the area in much of the basin. Cropping is mostly small scale and may be missed by the 1 km resolution of the AVHRR land use classification. Irrigation area was taken mainly from the GIAM map and dataset (Thenkabail et al. 2006). For Nigeria, GIAM gives the irrigated area as about 1000 km$^2$. However, literature estimates range from “very little” (Uyigue and Ogbeibu 2007) to nearly 10,000 km$^2$ (ICID, 2008, which notes, however, “that the exact amount of land under irrigation is difficult to estimate, because there is no clear commonly agreed definition of irrigation”). The FAO estimate is about 6,700 km$^2$ (FAO, 2008), of which 5,500 km$^2$ is small scale flood recession cultivation. We have adopted this figure, since it reflects cropping based on greater water inputs than rain alone. However, the GIAM dataset gives spatial detail only for the irrigation areas with which actively divert water via canals and other infrastructure. We have assumed that the small scale flood recession cultivation is distributed roughly equally in the four regions of the Niger and the Benue above their junction: this is what the GIAM data show for other irrigation areas.

### 4.4. DAM STORAGES

Dam storage volumes were taken from the FAO AQUASTAT database list of African dams (http://www.fao.org/nr/water/aquastat/damsafrica/index.stm). We considered only dams of greater than 10 mcm capacity.

## 5. COMPONENTS AND RESULTS IN DETAIL

### 5.1. FLOW

The Niger River shows an annual flow peak with low flow in the dry season (Figure 4), following the rainfall distribution (Figure 2), with a decline in flows in the 1970s and 1980s. As shown by the detail in Figure 5, there is a small lag between the onset of the rainy season and the onset of flow. The early rainfall replenishes soil water stores and contributes little to flow. There is no base flow at the gauge shown in Figure 5.

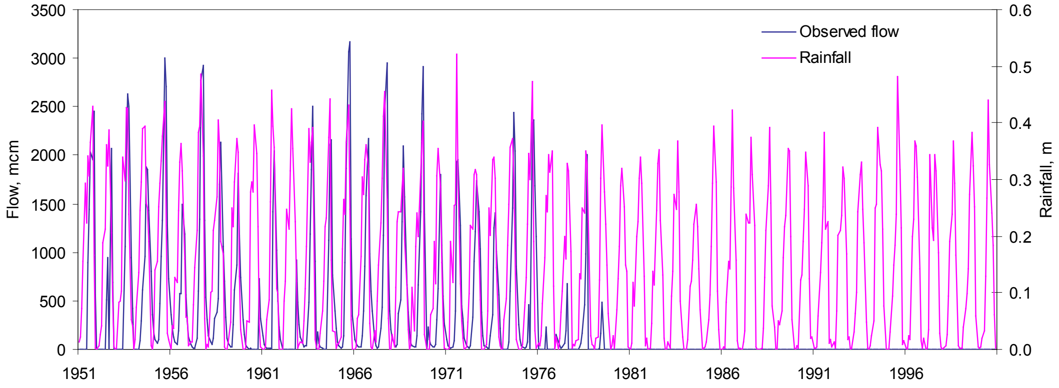

Figure 4. Monthly rainfall and flow in the Kouroussa catchment of the Niger River in the Western Niger Basin.

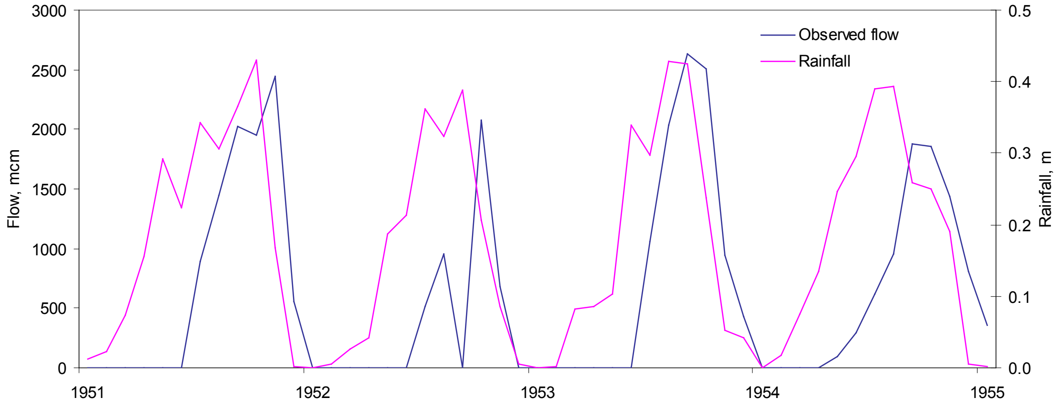

Figure 5. Detailed monthly rainfall and flow for the years 1951-5 in the Kouroussa catchment of the Niger River in the Western Niger Basin.

The flow pattern, with annual peak flow and low flow periods, is similar in most parts of the Basin. We describe the flow in several parts of the Basin, but for brevity we do not show every catchment.

### 5.1.1. THE HEADWATERS AND THE UPPER NIGER

The modest decline in rainfall results in a much greater decline in flows (Figure 4), so that the partitioning rainfall to runoff is non-linear. The headwater catchments of Kouroussa and Ouaran (Figures 6 and 7) and several other tributaries join to form the main Niger River, which then flows through Mali to Mopti (Figure 8), where it has its greatest flow in this section of the Niger before loss by evaporation of considerable volumes of water in the wetlands of central Mali, resulting in lower flow at Tossaye (Figure 9), downstream of the wetlands.

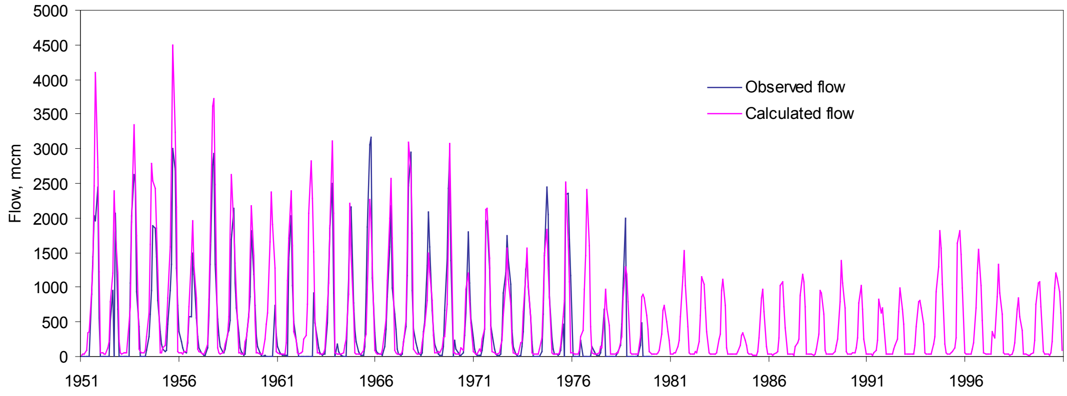

Figure 6. Observed and modelled flow in the Niger River at Kouroussa.

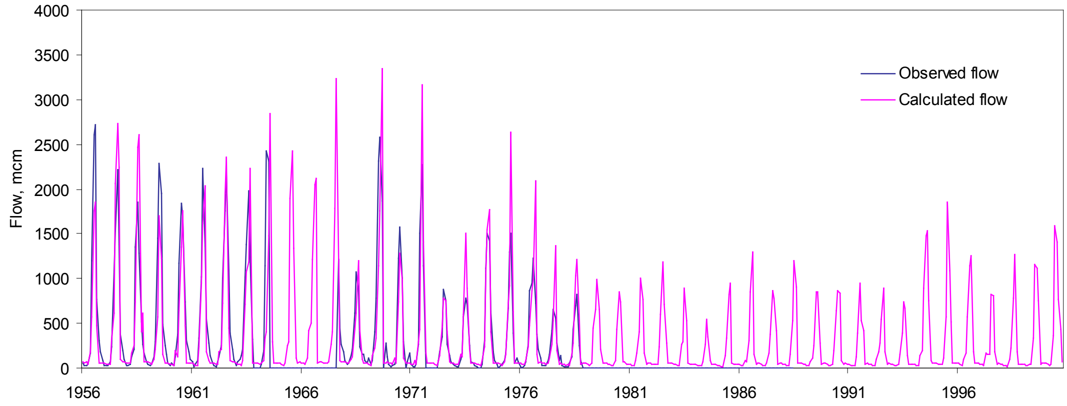

Figure 7. Observed and modelled flow in the Tinkisso River at Ouaran.

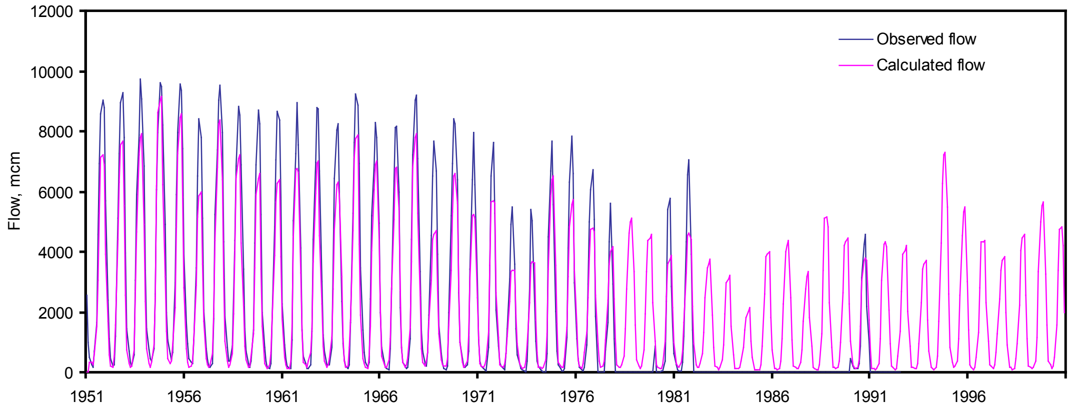

Figure 8. Observed and modelled flow in the Niger River at Mopti.

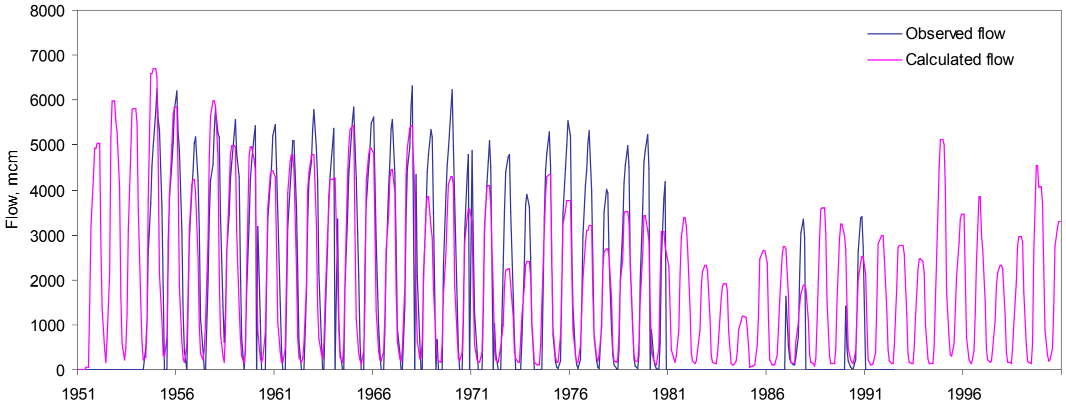

Figure 9. Observed and modelled flow in the Niger River at Tossaye.

### 5.1.2. THE MIDDLE REACHES OF THE NIGER

Downstream of Tossaye, several tributaries join the Niger. The Goroual and the Dallol Bosso Rivers contribute very little flow. Except for the flow at Alcongui (Figure 10), there is little flow information on the internet and the results are therefore speculative. The flow at Alcongui is not well modelled: it has the greatest measured flows in two drier years, and some of the least measured flows in wetter years. This may indicate that land-use changes have changed the rainfall/runoff partitioning characteristics. However, in the absence of information, we have not modelled such a change. The Dallol Bosso drains mostly desert areas, and in most years there is very little flow (Figure 11). We are therefore particularly unsure whether the high flows in a few years are correctly modelled. The gauge on the Niger at Baya (Figure 12) is the furthest downstream flow record on the Niger River available readily on the internet. The Kebbi River at Bahindi (Figure 13) joins the Niger after this gauge, and contributes large peak flows to the Niger (Figure 14).

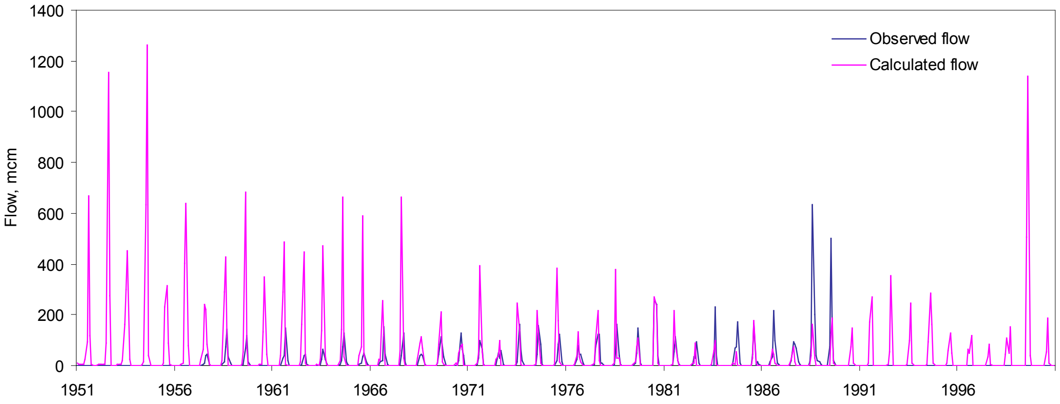

Figure 10. Observed and modelled flow in the Gorouol River at Alcongui.

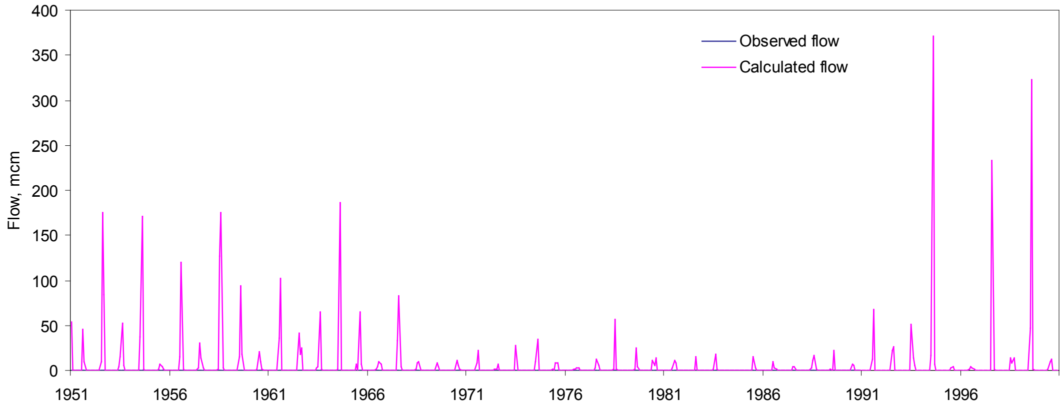

Figure 11. Modelled flow of the Dallol Bosso River before its junction with the Niger.

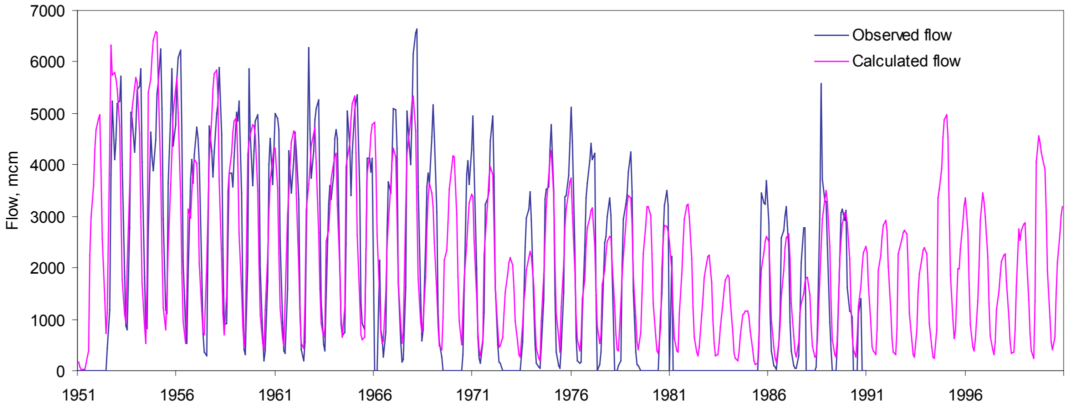

Figure 12. Observed and modelled flow of the Niger River at Gaya.

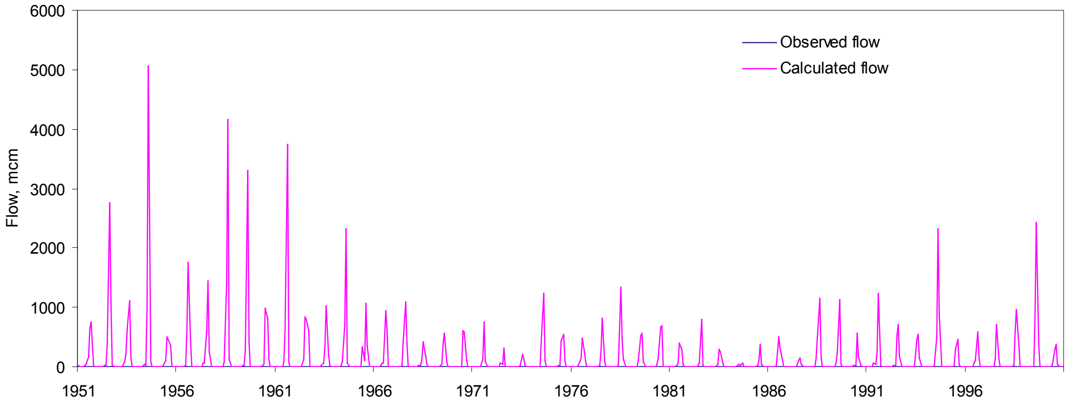

Figure 13. Modelled flow of the Kebbi River at Bahindi.

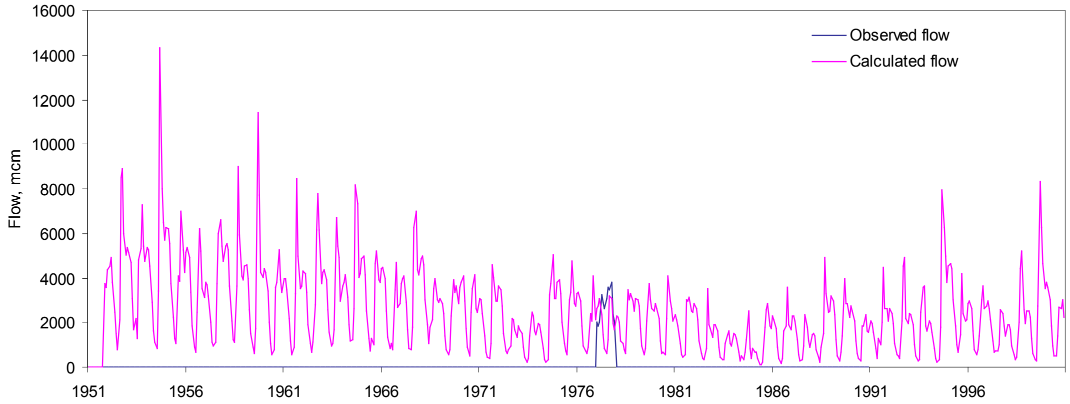

Figure 14. Modelled flow of the Niger River at Jebba.

### 5.1.3. THE BENUE RIVER AND THE LOWER REACHES OF THE NIGER

Downstream of Jebba, the Niger is joined by its largest tributary, the Benue River, which drains much of Eastern Nigeria and part of Northern Cameroon. Flow information is available on the internet at Benue in the headwaters at Garoua in Northern Cameroon (Figure 15), but not downstream, so our prediction of its flow (Figure 16), and that of the Niger below the junction (Figure 17), are speculative.

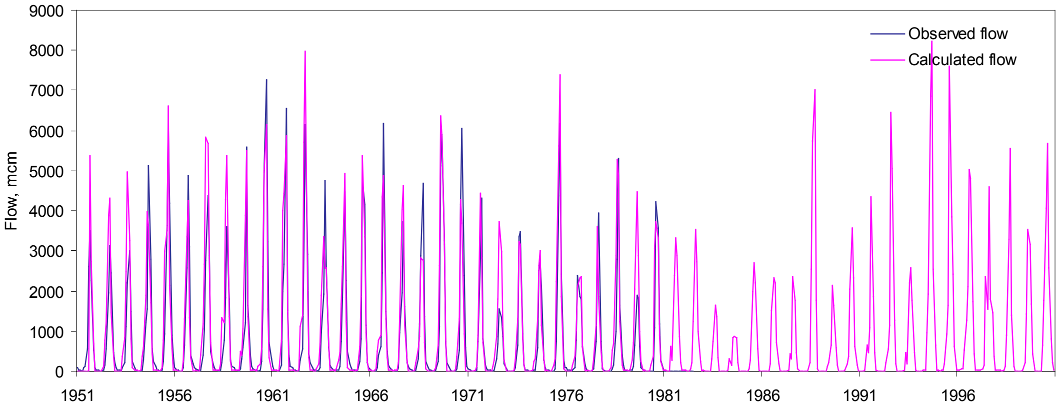

Figure 15. Observed and modelled flow of the Benue River in its headwaters at Garoua, Northern Cameroon.

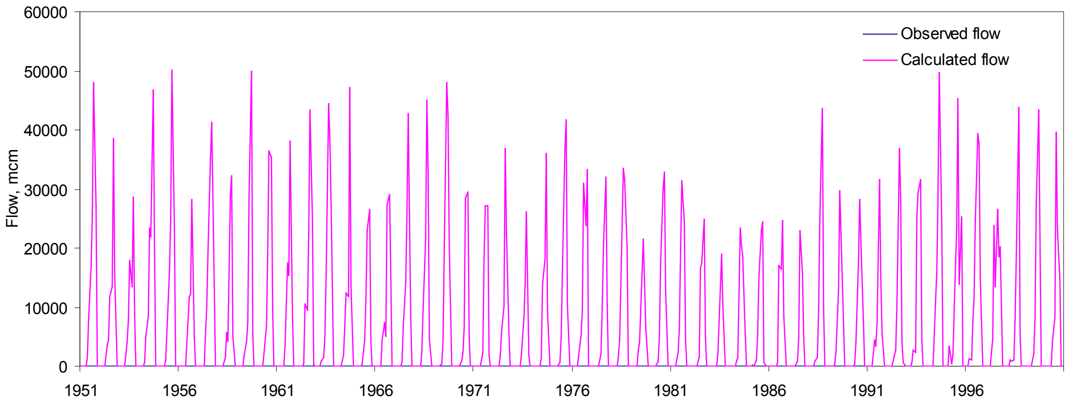

Figure 16. Modelled flow of the Benue River upstream of its junction with the Niger.

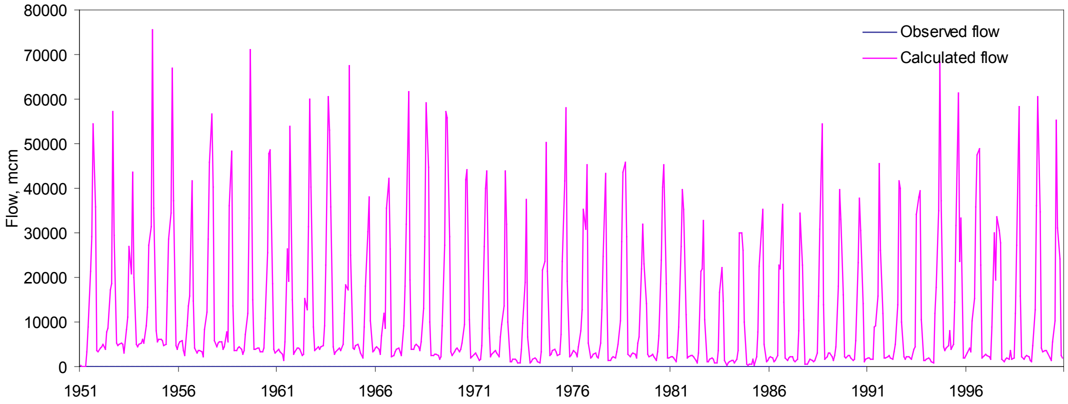

Figure 17. Modelled flow of the Niger River at Onitsha, downstream of its confluence with the Benue River.

## 5.2. WATER USE

The mean annual input by precipitation to the Niger Basin totals nearly 1,500,000 mcm/yr, according to the data supplied. Figure 18 summarizes how this water is partitioned amongst the major water uses in the Basin. Net runoff comprises the runoff remaining after all the water uses in the Basin have been satisfied, and includes all other storage changes and losses. Net runoff from the Basin is about 180,000 mcm/yr or about 12% of the rainfall. The losses primarily indicate water consumed in the wetlands in the Middle Reaches of the Niger in Mali and in Niger. Irrigated and rainfed agriculture are minor water users.

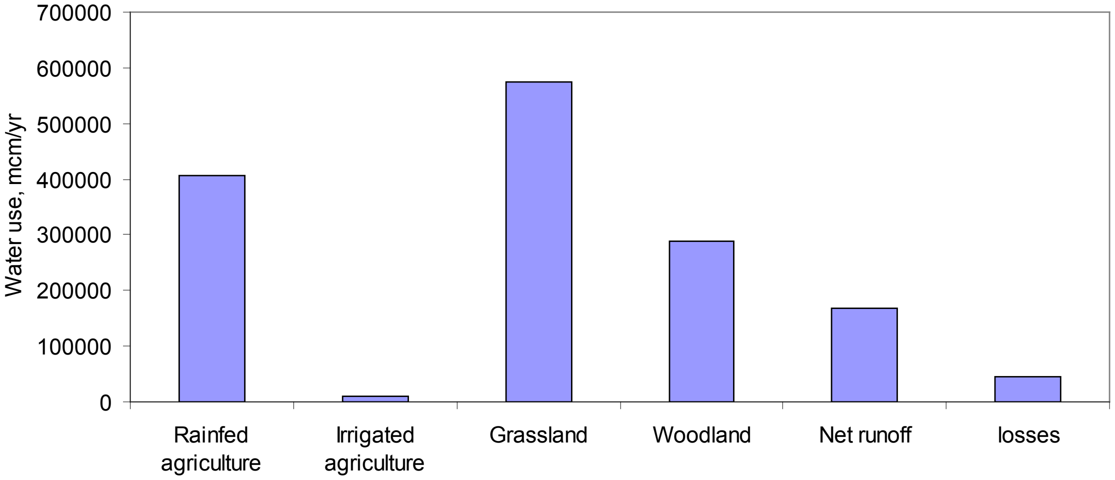

Figure 18. Major water uses (annual averages 1951-2000). Grassland includes shrubland and barren land (see Section 4.3).

The main land uses in the Niger Basin according to the aggregate land-use classification are grassland, which includes shrubland and barren land, and woodland, and these are therefore calculated to be the dominant water uses. However, our experience in the Volta Basin (Kirby et al. 2010) shows that the grassland and woodland land-use classifications include much small-scale cropping and other agriculture. We assume that this is likely to be the case in the Niger, and we assume therefore that agricultural water use is underestimated.

The distribution of the different water uses across the Basin is shown in Figure 19. The figure depicts the water uses in each catchment, and the distribution of water uses across the Basin. It does not, however, represent the water balance at the basin level. Losses in the middle part of the Basin, for example, uses the runoff water from the upper part, and thus this water is double counted at the basin level. The net runoff from the whole Basin is shown in Figure 18. The figure shows the different behaviour of the runoff-generating western and eastern part of Basin and the grassland- and woodland-dominated central parts.

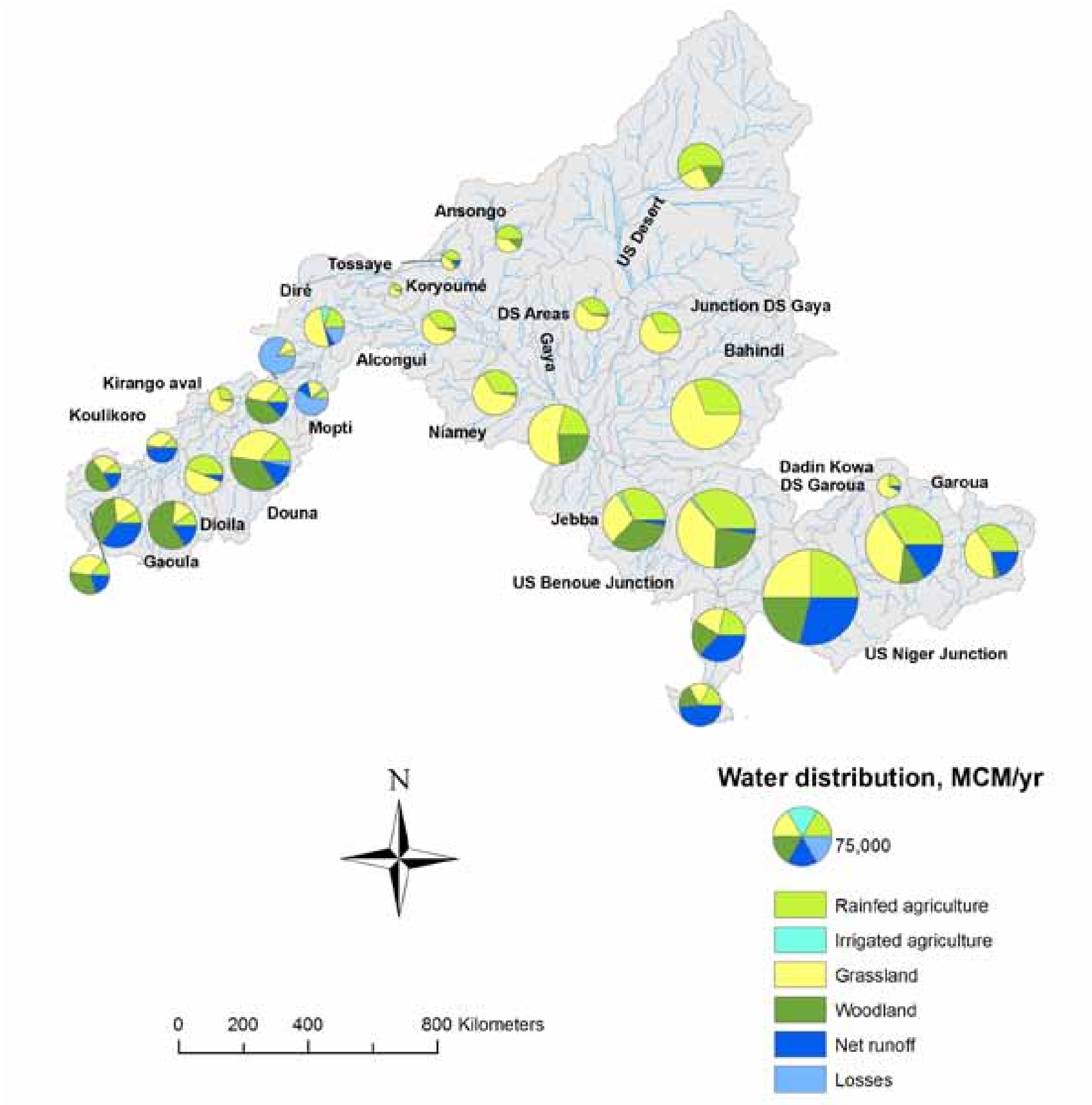

Figure 19. Summary of major water uses in catchments of the Niger Basin. Grassland includes shrubland and barren land (see Section 4.3).

## 5.3. CATCHMENT AND BASIN HYDROLOGICAL CHARACTERISTICS

Selected hydrological characteristics will be useful for comparing the Niger Basin hydrological function and its vulnerability with those of other basins under study in the Challenge Program. Some of these hydrological characteristics are outlined briefly below.

Runoff characteristics for different basins may be compared by comparing their annual percentage runoff ratios (total basin runoff/total basin precipitation). The runoff ratio for the Niger Basin is 11% (i.e. mean annual runoff is 11% of mean annual precipitation). Similarly, differences in runoff characteristics for the different catchments in the Basin can be seen by comparing their annual runoff ratios (Table 3). The runoff ratio is moderate in the east and west of the Basin and very low in the centre.

Table 2. Annual percentage runoff ratios (runoff/precipitation) for catchments in the Niger Basin.

| Catchment | Runoff ratio |
|---|---|
| Kouroussa | 20 |
| Ouaran | 18 |
| Banankoro | 35 |
| Gaoula | 16 |
| Koulikoro | 49 |
| Kirango aval | 3 |
| Tilembeya | 0 |
| Dioila | 13 |
| Douna | 11 |
| Bénény-Kégny | 8 |
| Mopti | 0 |
| Diré | 0 |
| Koryoumé | 7 |
| Tossaye | 12 |
| Ansongo | 1 |
| Alcongui | 2 |
| Niamey | 1 |
| Desert Areas U/S | 0 |
| Desert Areas D/S | 0 |
| Gaya | 2 |
| Gaya Junction D/S | 1 |
| Bahindi | 2 |
| Jebba | 2 |
| Benue Junction U/S | 3 |
| Garoua | 19 |
| Dadin Kowa | 6 |
| Garoua D/S | 17 |
| Niger Junction U/S | 29 |
| Onitsha | 37 |
| Estuary | 49 |
| Total | 11 |

The annual runoff is very low in catchments with less than about 700 mm rainfall, and increases with annual precipitation for values greater than 700 mm (Figure 20).

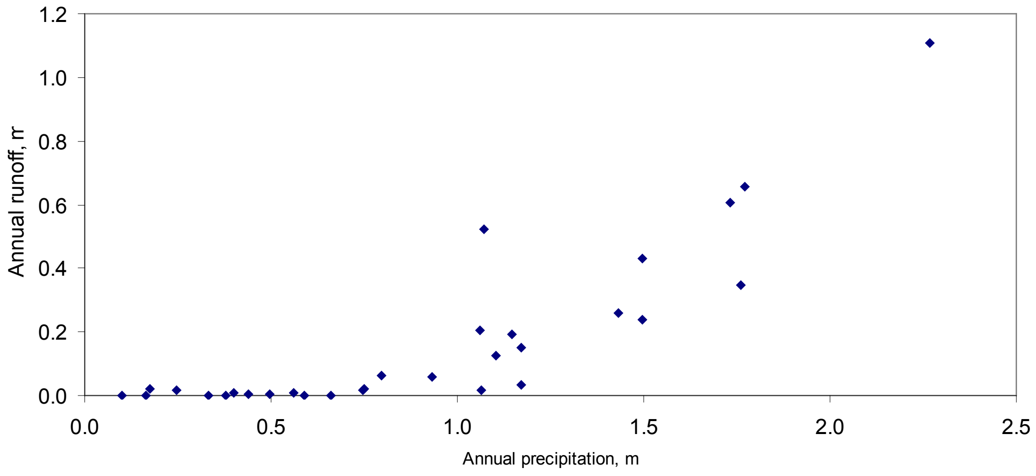

Figure 20. Runoff (annual averages 1951-2000) in the catchments in the Niger Basin.

## 6. EXAMPLE USE

We give here an example of using the spreadsheet to model the impact of climate change. An increase in rainfall of about 7.5% was assumed for one climate change scenario by Andah et al (2003). Here we simply increased rainfall by 7.5% in all catchments. The (rather obvious) consequence for increased flow at Gaya and Garoua is shown in the figures 21 and 22.

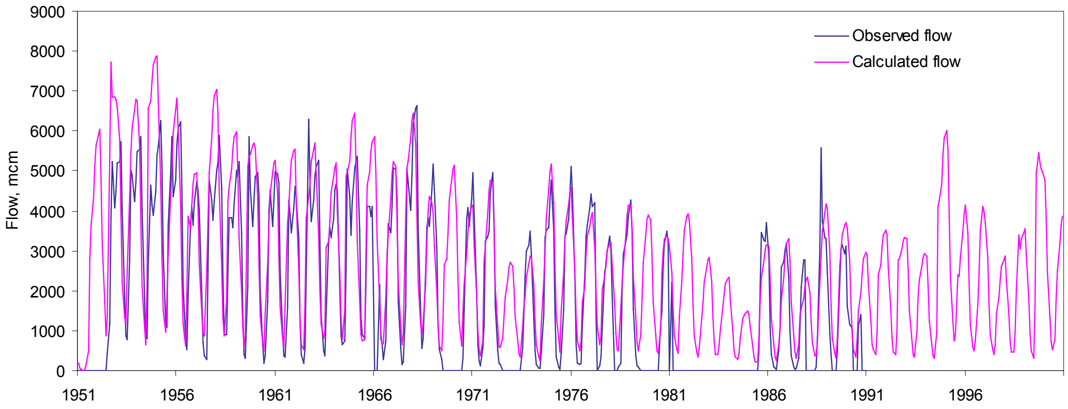

Figure 21. Modelled flow of the Niger River at Gaya showing greater flow with 7.5% increase in rainfall in all catchments as a consequence of climate change. Compare the calculated flow here with the calculated flow in Figure 12. The observed flow is the actual gauged data.

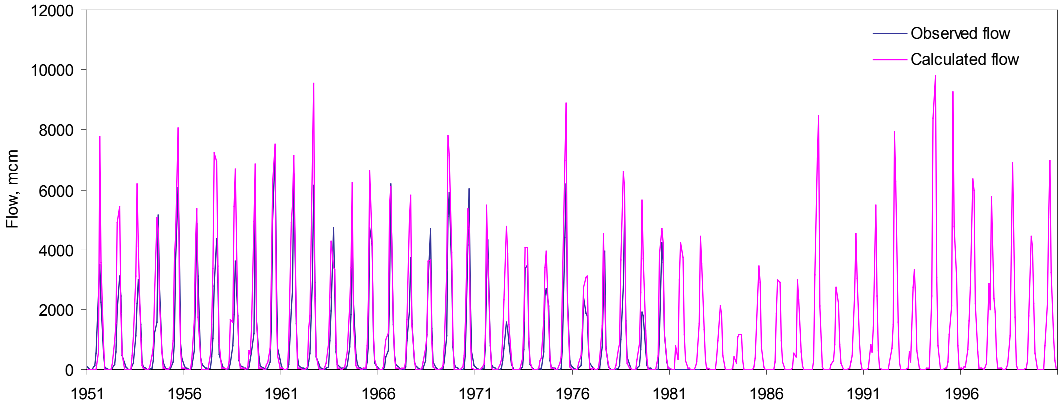

Figure 22. Modelled flow of the Benue River at Garoua in Northern Cameroon showing greater flow with 7.5% increase in rainfall in all catchments as a consequence of climate change. Compare the calculated flow here with the calculated flow in Figure 15. The observed flow is the actual gauged data.

## 7. CONCLUSIONS

A very simple spreadsheet model with a few adjustable parameters has produced plausible runoff and river-flow behaviour in the Niger Basin. If desired it could be further developed. This would entail developing more complete and error-free climate data and obtaining better stream-flow, land-use and crop-coefficient data.

The Niger Basin has modest rainfall, falling mostly from May to October, leading to river flows with large annual peaks and intervening periods of low flow. The main water uses are grassland and woodland, but we assume that agricultural water uses are included in these totals through inadequate land-use classification.

We have developed a preliminary scenario that simulates the impact of a 7.5% increase in rainfall as a consequence of climate change on water availability and flow in the lower part of the Basin. The results suggest that climate change may have a large impact on water availability in the lower Basin, and hence on the River’s wetlands.

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