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Water-use accounts in CPWF basins

Simple water-use accounting of the São Francisco Basin

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1. ABSTRACT

This paper applies the principles of water-use accounts, developed in the first of the series, to the São Francisco basin in South America. The São Francisco Basin lies wholly within Brazil. There are several major dams and wetlands in the Basin.

Net runoff is about 16% of total precipitation. Grassland is the most extensive land use, covering 59% of the Basin and uses 48% of the water. Rainfed agriculture covers 23% of the basin, but uses 14% of the water in the Basin. Forest and woodland cover 16% of the basin and use about 21% of the precipitation. Grassland covers much of the upper part of the Basin, consuming about 21% of the precipitation. Irrigated agriculture covers just about 2% of the Basin and uses about 2% of the water.

Climate change, using an assumed change in increase in rainfall and evapotranspiration distribution, reduces flow at Juazeiro and storage in the Sobradinho reservoir. The transfer of water from the São Francisco Basin to the northeast of Brazil reduces annual average flow by 6% only. However, the combined impact of the planned diversions and drying due to climate change would be greater again.

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

2. INTRODUCTION

In this note, we describe a simple water-use account for the São Francisco 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, Niger, Nile, São Francisco, and Yellow Rivers, and a collection of small basins in the Andes.

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, these 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 São Francisco Basin.

As we shall describe below, the account has been developed using existing data, 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 know of no other model of the São Francisco Basin.

3. BASIC HYDROLOGY AND OUTLINE OF SIMPLE WATER ACCOUNT

3.1. BASIC HYDROLOGY, IRRIGATION, AND LAND USE

The São Francisco Basin covers 629,885 km^2, and is drained by the São Francisco River and its tributaries (Figure 1 and Table 1). There are several major dams and wetlands in the Basin. The dams have particularly affected the flow regime below Juazeiro, where the Sobradinho reservoir has the largest surface area of any reservoir in Brazil at 4225 km^2, and a capacity of 34,100 mcm.

Table 1. Catchments in the São Francisco Basin with their areas.

Catchment	Area, km^2
Porto da Barra	17,155
Velho da Taipa	8,454
Ponte da Taquara	9,519
Tres Marias	20,598
Montante Barra do Je	40,843
São Romanao (Pcd)	63,463
São Francisco	28,498
Manga	19,169
Boca da Caatinga	29,925
Bom Jesus da Lapa	40,505
Porto Novo	30,359
Morpara	43,401
Boqueirao	67,024
Juazeiro (Pcd)	98,571
Petrolandia	73,089
Traipu	35,339
Estuary	3,975
Total	629,885

The rainfall varies from the wetter south, with annual average rainfall of about 1400 mm, to the drier north, with annual average rainfall of about 600 mm (Figure 2). The rain comes in a distinct wet season, which peaks around December - January each year (Figure 2). The potential evapotranspiration is also greatest in the southern hemisphere summer half of the year. The wet season results in the São Francisco River and its tributaries having a very pronounced seasonal variation in flow, with low flows in the dry season. The rains and the flows vary considerably from year to year (Figure 3).

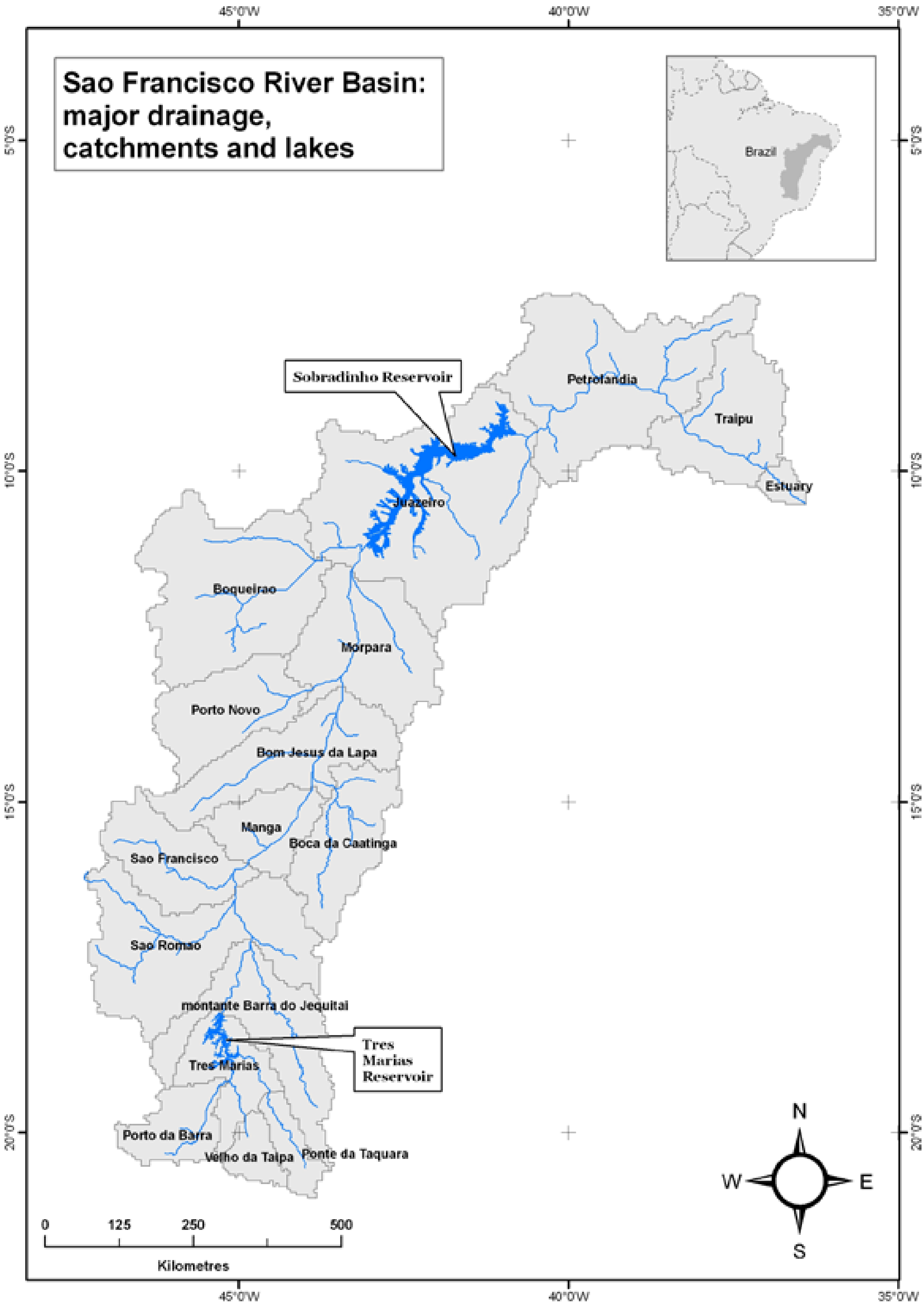

Figure 1. The São Francisco Basin, with the catchments used in the water-use account.

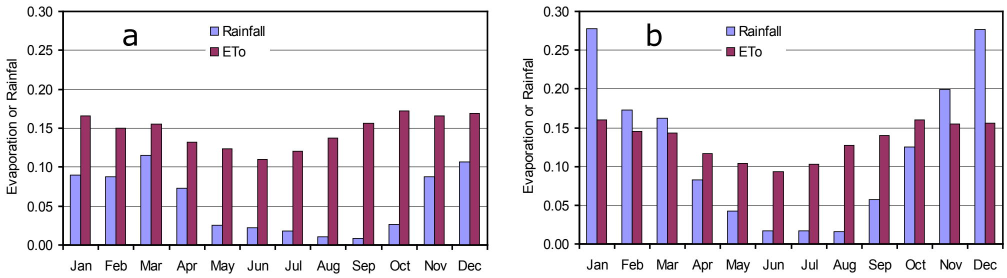

Figure 2. Monthly average rainfall and potential evapotranspiration in the São Francisco Basin. a). In the headwater catchment of Porto da Barra in the southern part of the Basin; and b). In the catchment of Juazeiro in the northern part of the Basin.

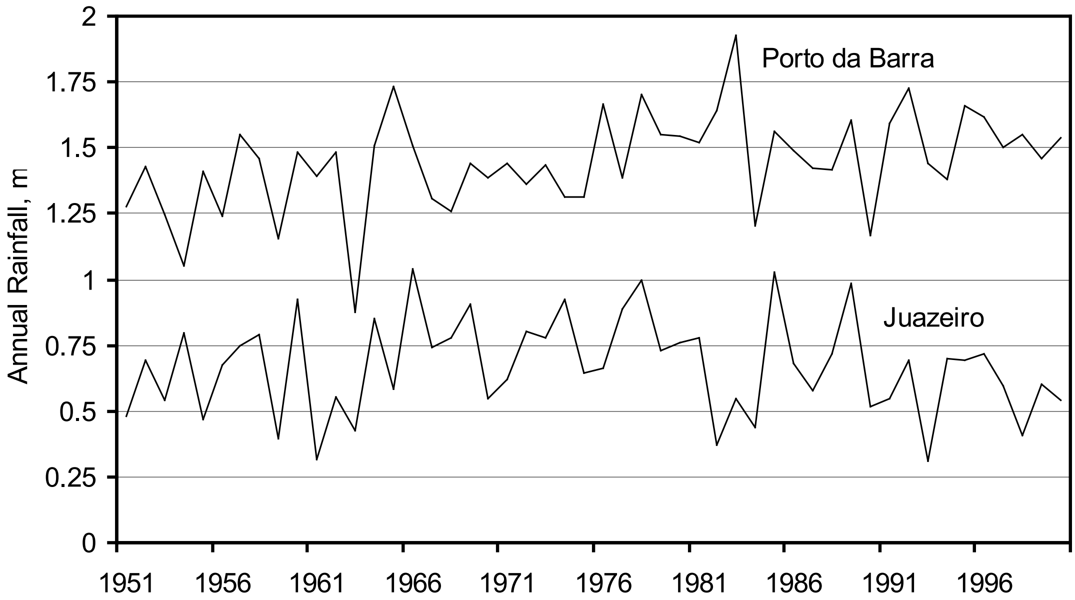

Figure 3. Annual rainfall at Juazeiro and Porto da Barra.

3.2. SIMPLE WATER ACCOUNT

The simple water account has two parts:

- A hydrological account of the water flowing into the basin (primarily rain), 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 runoff and infiltration into a generalised surface store. This is done at the catchment level, with no attempt to model the spatial distribution of hydrological processes and storages within a catchment. We estimate total catchment evapotranspiration from potential evaporation and water supply from the surface store, and partition it between rainfed and irrigated land uses based on the ratio of their areas. We further partitioned the rainfed component of evapotranspiration between land uses/ vegetation types (agriculture, forest/woodland, grassland, other) based on the ratio of their areas and using crop factors to scale their evapotranspiration relative to other land uses.

Runoff flows into the tributaries and into the São Francisco, and we calculated downstream flows by simple water balance. We assumed that the base flow in a catchment came from a notional groundwater store whose discharge was equal to the base flow and was constant throughout the year. We estimated deep drainage to the groundwater store as a proportion of the surface water store. During periods of high flows, some of the flow is stored in the channels, which we estimate, together with losses from the river,as functions of flows. Inflows are stored in reservoirs, and are balanced by evaporation and discharge at the dam. Water is spilled if the capacity of the dam is exceeded.

We based diversions for irrigation on crop water requirements calculated from cropped areas, crop coefficients, potential evaporation and irrigation efficiencies. Maximum irrigated areas are defined based on land-use data, but the area irrigated may be reduced in any one year to match supply if the volume stored in the reservoir at the beginning of the season is insufficient to meet crop water requirements. If reservoir storage becomes insufficient to meet crop demand during the season, irrigation applications are reduced to match the supply.

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. The behaviour of, and equations for, the Sobradinho reservoir are unique to the São Francisco Basin.

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, and calculated 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 dss522.1, available on the internet (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 Tres Marias and Estuary catchments.

4.3. LAND USE

Land use was 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. Irrigation area was taken from the GIAM map and dataset (Thenkabail et al. 2006).

5. COMPONENTS AND RESULTS IN DETAIL

5.1. FLOW

Flows in the São Francisco Basin follow rainfall distribution with an annual flow peak followed by low flow in the dry season (Figure 4, and detail in Figure 5). As shown in Figure 5, there is a small lag between the onset of the rainy season and the onset of flow caused by early rainfall replenishing soil stores and so contributing little to flow. Figures 4 and 5 also show that although there is little rain in the dry season, the river still flows, indicating a base flow, presumably from groundwater. (This is a headwater catchment, so the base flow cannot come from inflow upstream.)

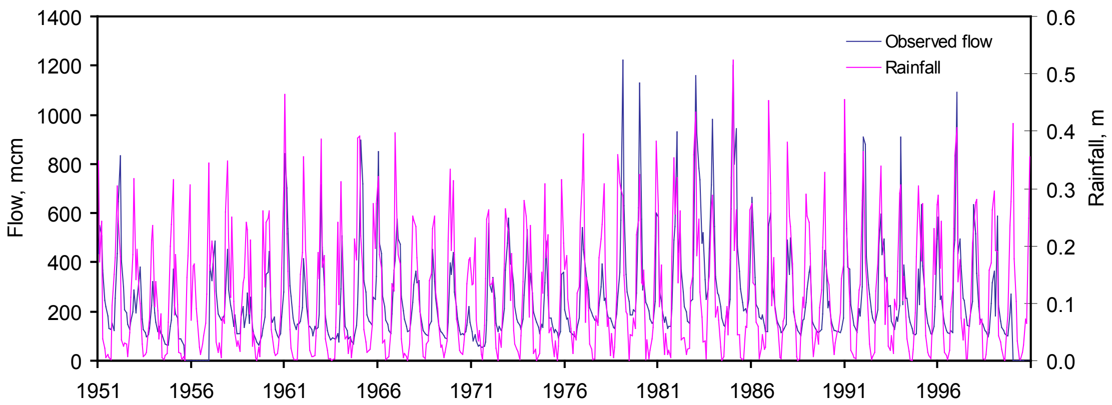

Figure 4. Rainfall and observed flow in the Velho da Taipa catchment.

Figure 5. Rainfall and observed flow in the Velho da Taipa catchment.

5.1.1. THE HEADWATERS AND TRES MARIAS DAM

The flows from the three headwater catchments above the Tres Marias dam are shown in Figures 6 to 9. The catchments all show the annual peak flow with a base flow in the dry season. We have no flow records for the flow from the Tres Marias dam, and the modelled outflow (Figure 9) is based on satisfying the flow at the next downstream gauge (Montante Barra do Jequitai). Tres Marias is a dam for hydropower and flood control, completed in 1961, with a reservoir volume of 21,000 mcm. There is no obvious change in observed flow behaviour after 1961 in the downstream gauges, so the dam may act merely as a run-of-river dam to provide a head for power generation, without greatly affecting flow. Information or data on flow and releases from Tres Marias are required to confirm this observation.

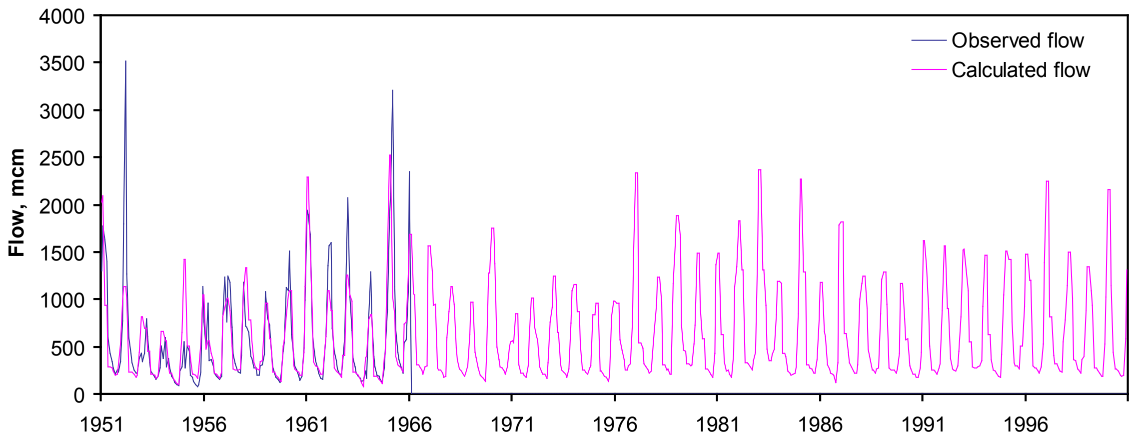

Figure 6. Observed and modelled flow at Porto da Barra.

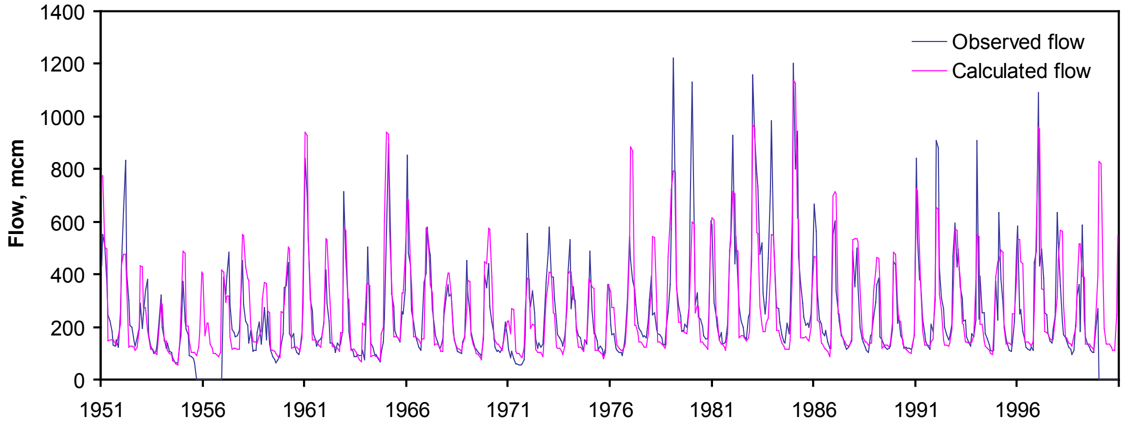

Figure 7. Observed and modelled flow at Velho de Taipa.

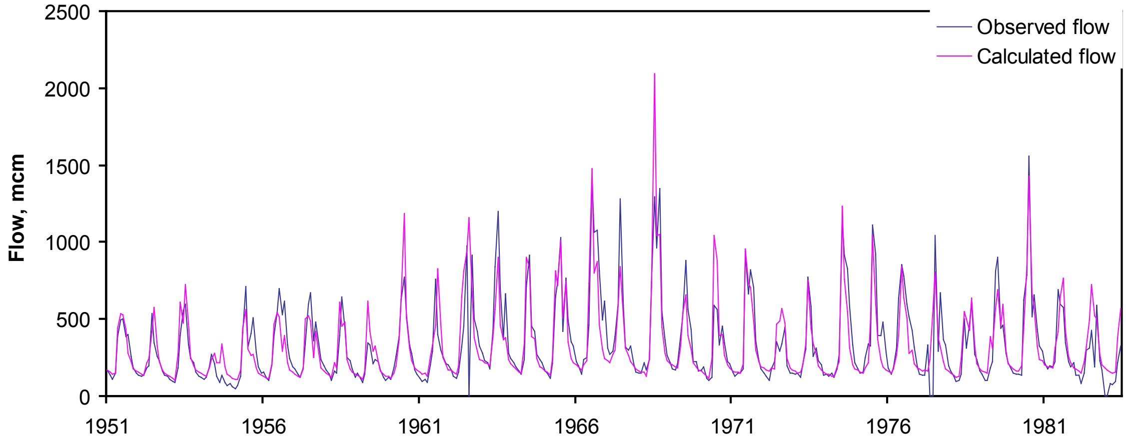

Figure 8. Observed and modelled flow at Ponte da Taquara.

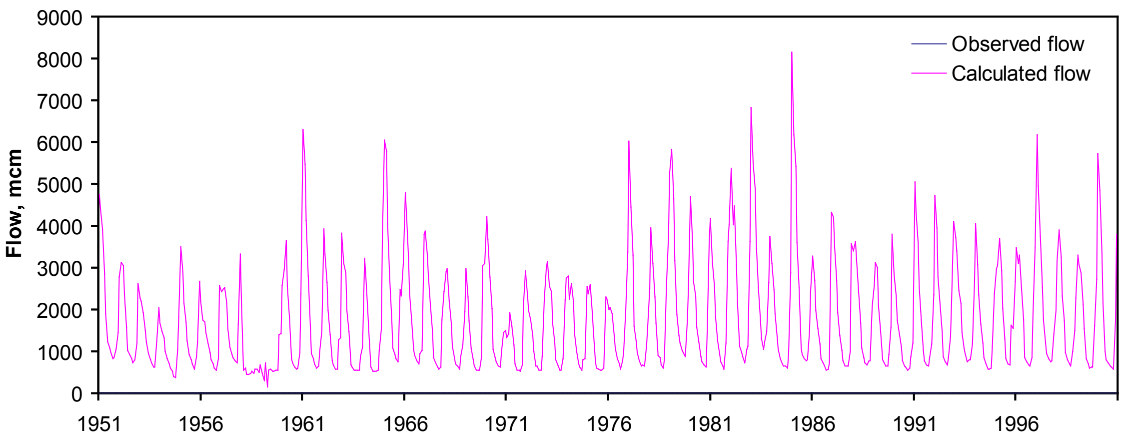

Figure 9. Modelled flow at Tres Marias. We presume that the hiatus in peak flows from 1957 to 1959 is due to the filling of the reservoir.

5.1.2. THE UPPER MIDDLE REACHES: MONTANTE BARRA DO JEQUITAI TO MANGA

Downstream of the Tres Marias dam, the flow pattern remains one of pronounced wet season peaks with a large base flow. The flows in the catchments from Montante Barra do Jequitai to Manga are shown in Figures 10 to 13. The pattern of flow is similar in each case, with the flows increasing downstream.

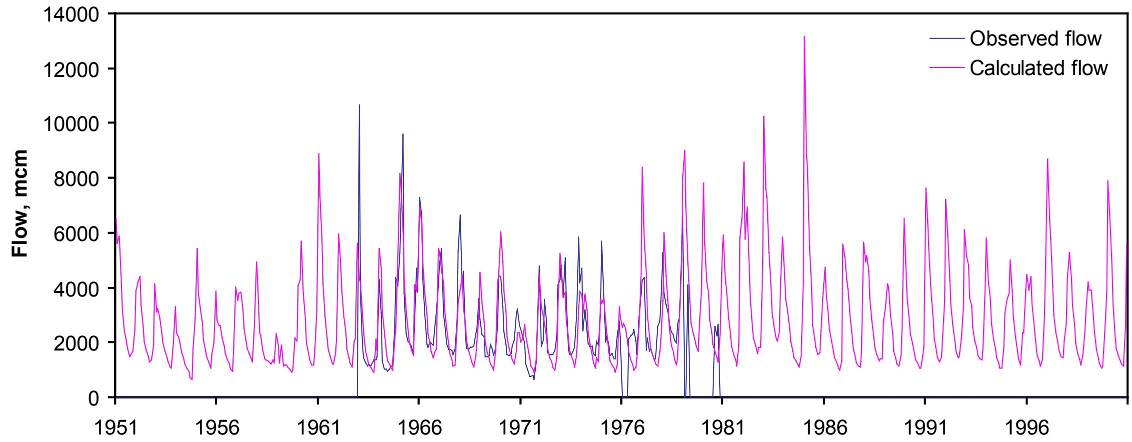

Figure 10. Observed and modelled flow at Montante Barra do Jequitai.

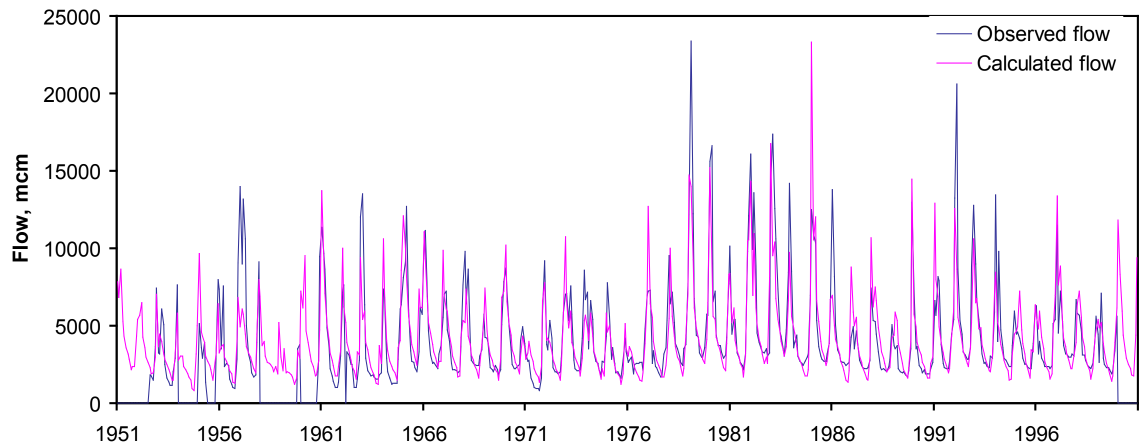

Figure 11. Observed and modelled flow at São Romão.

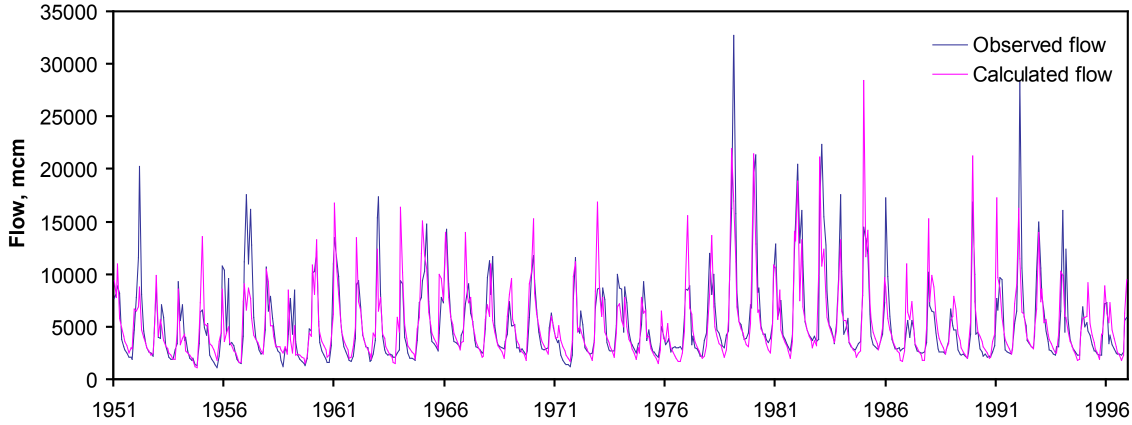

Figure 12. Observed and modelled flow at São Francisco.

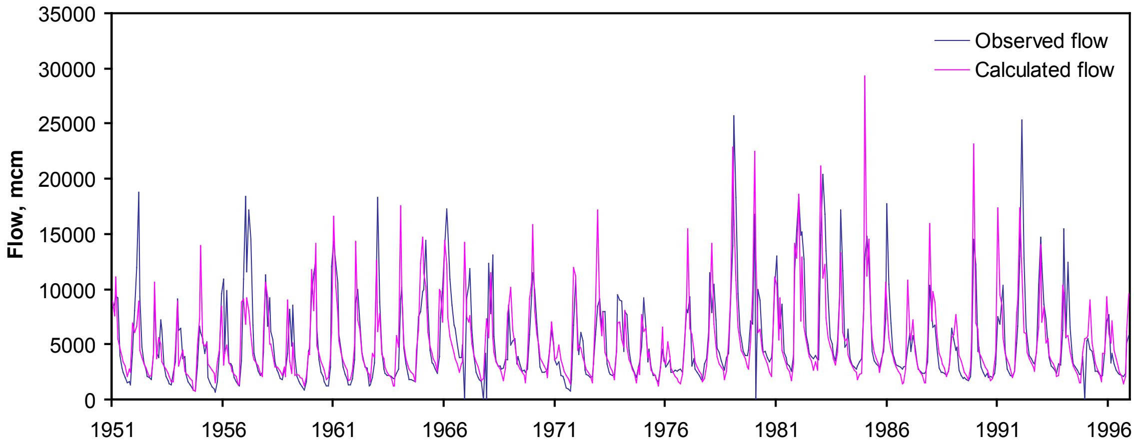

Figure 13. Observed and modelled flow at Manga.

5.1.3. THE LOWER MIDDLE REACHES: BOM JESUS DA LAPA TO BOQUEIRAO

Downstream of Manga, three major tributaries join the São Francisco River. The flow pattern remains generally one of pronounced wet season peaks with a large base flow. The Boca da Caatinga tributary, however, has little base flow (Figure 14). The flows in the catchments from Bom Jesus da Lapa to Boqueirao are shown in Figures 15 to 18. The Porto Novo and Boqueirao tributaries show large base flows with smaller peak flows than elsewhere in the São Francisco Basin (Figures 16 and 18).

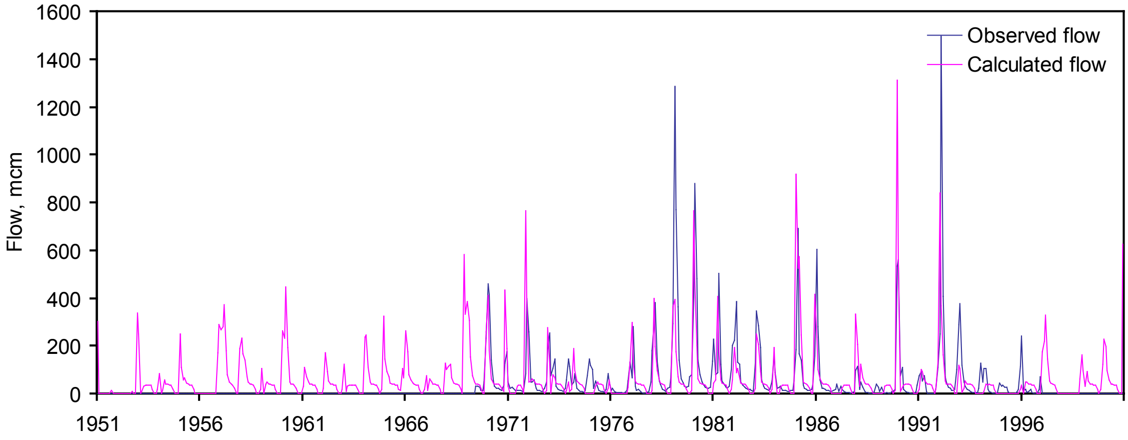

Figure 14. Observed and modelled flow at Boca da Caatinga.

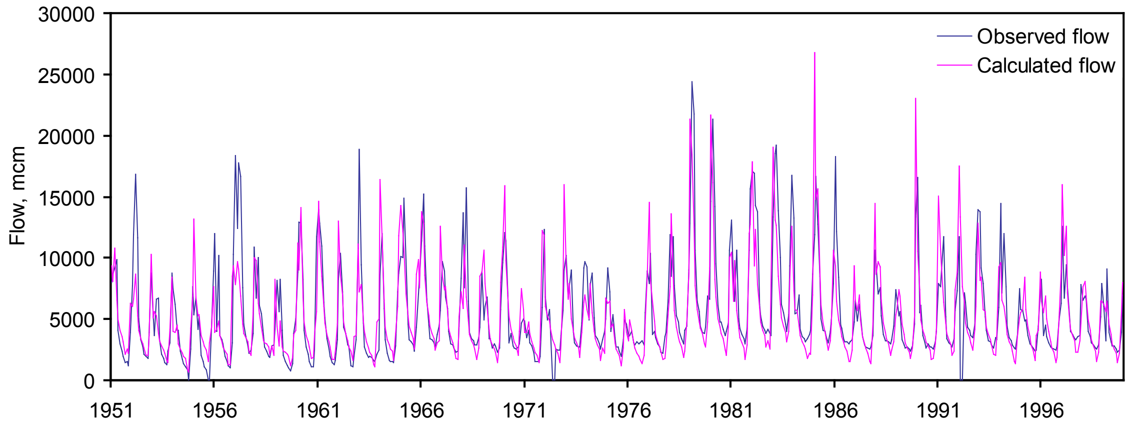

Figure 15. Observed and modelled flow at Bom Jesus da Lapa.

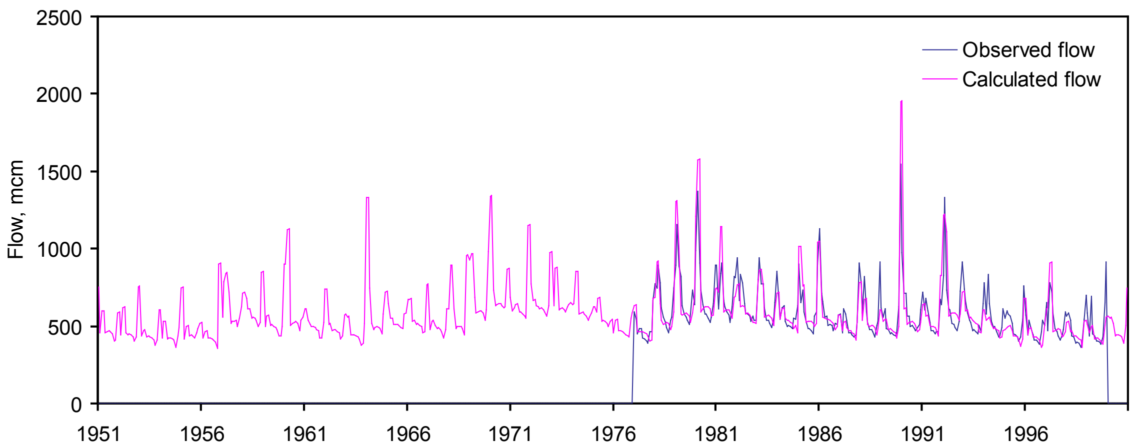

Figure 16. Observed and modelled flow at Porto Novo.

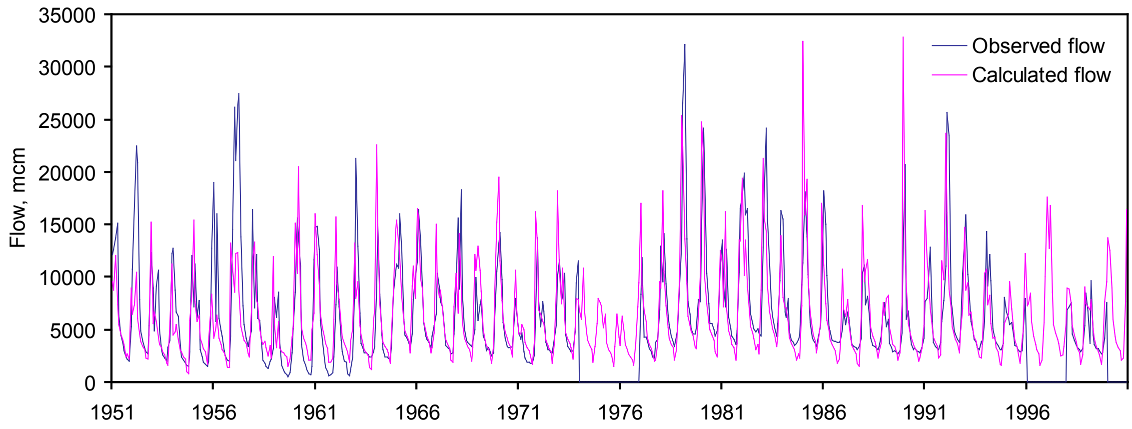

Figure 17. Observed and modelled flow at Morpara.

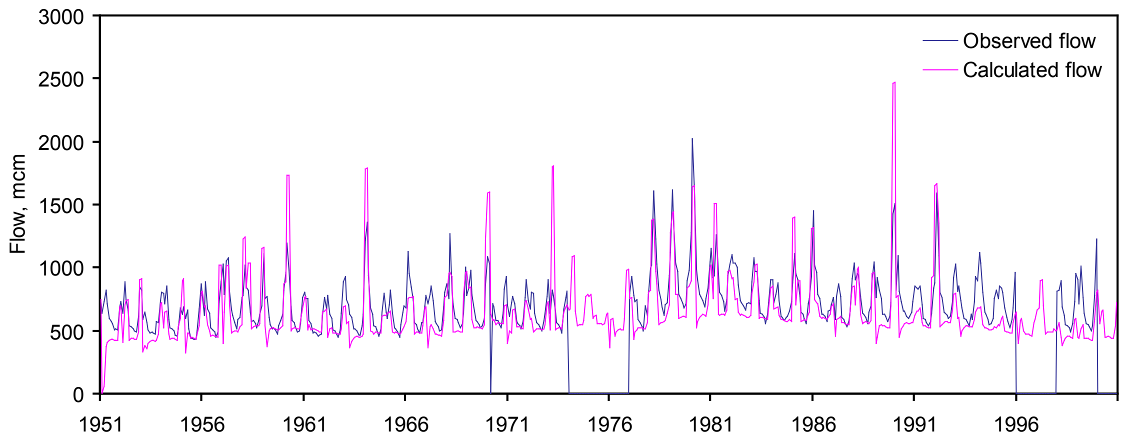

Figure 18. Observed and modelled flow at Boqueirao.

5.1.4. SOBRADINHO, ITAPARICA AND XINGO RESERVOIR

The Sobradinho reservoir in the Juazeiro part of the Basin was filled during the late 1970s, following building of the dam in the mid 1970s. Prior to this, the river flowed naturally. From the late 1970s, the discharge from the reservoir has generally been between about 4,000 and 6,000 mcm. Spills occur in many years when the capacity of the reservoir is exceeded by inflows from upstream. Itaparica and Xingo reservoirs are in the Petrolandia and Traipu Catchment, respectively. The maximum capacity of the Itaparica reservoir is 10,800 mcm and the capacity of the Xingo reservoir is 3,800 mcm.

We modelled the discharge, Q_o, of the reservoir as:

$$Q_o = C_3 \qquad S + Q_i - C_3 \leq S_{\max} \tag{1a}$$

$$Q_o = C_3 + \left(S + Q_i - S_{\max}\right) \qquad S + Q_i - C_3 > S_{\max} \tag{1b}$$

Where Q_i is the sum of the inflows from upstream, S is the storage in the reservoir, S_{max} is the maximum storage, and C_3 is a constant. Equation 1b gives a flood spill when the storage capacity of the reservoir is exceeded.

The change in storage of the lake, S_{LV} in the month is:

$$S_{LV}^{t} \quad = \quad S_{LV}^{t-\Delta t} + Q_i - Q_o - E_{LV} - D \tag{2}$$

where the evaporation, E_{LV}, and irrigation diversion, D, are given by equations in the report *Water-use accounts in CPWF basins: Model concepts and description* (Kirby et al., 2010).

5.1.5. JUAZEIRO CATCHMENT AND SOBRADINHO RESERVOIR

The Sobradinho reservoir in the Juazeiro catchment has the largest surface area of any reservoir in Brazil at 4225 km^2, and a capacity of 34,100 mcm. The dam was built in the mid-1970s and power generation started in 1979. The operation of the dam provides a greater base flow and removes the smaller peaks from the annual flow pattern (Figure 19). The reservoir appears to have filled in the mid 1970s and remained close to full since, with some reduction in storage replenished every wet season (Figure 20).

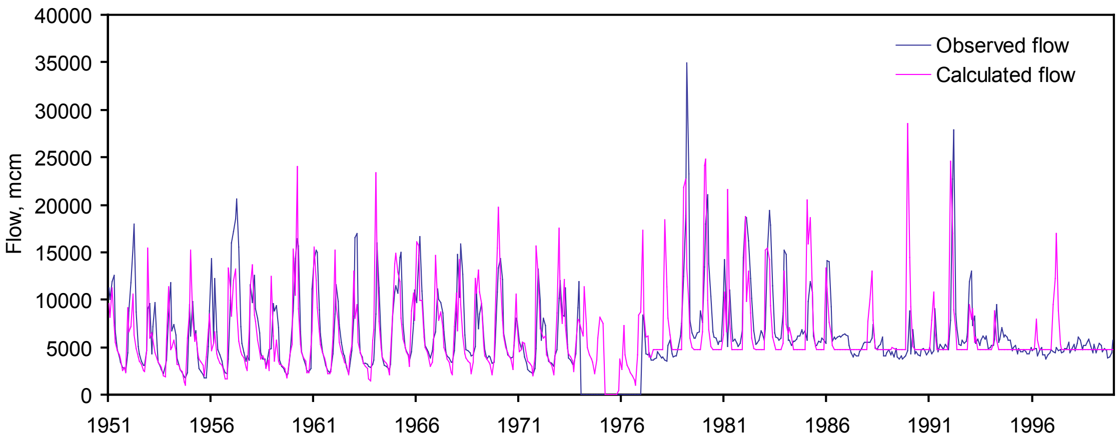

Figure 19. Observed and modelled flow at Juazeiro.

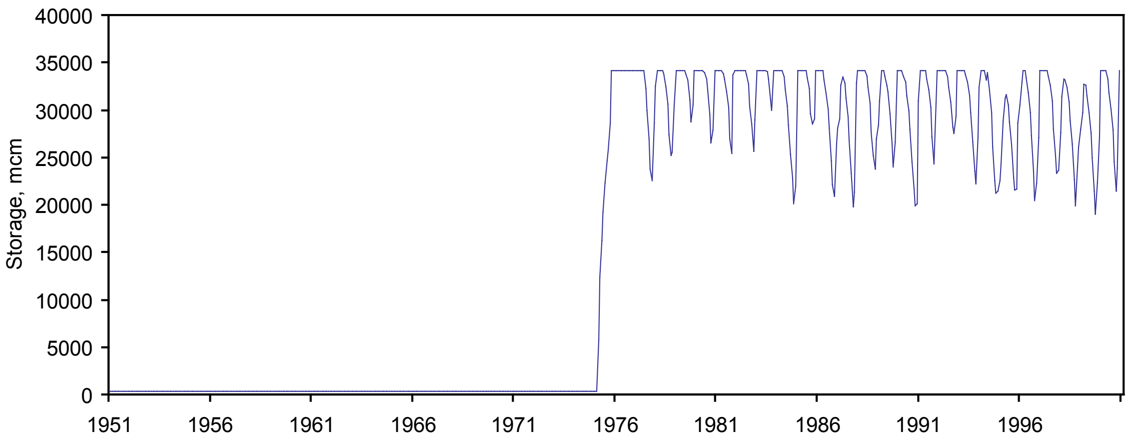

Figure 20. Modelled storage of the Sobradinho reservoir.

5.1.6. THE LOWER REACHES: PETROLANDIA TO THE MOUTH

There are two more reservoirs in the lower reaches downstream of Sobradinho. They are Itaparica reservoir in Petrolandia and Xingo reservoir in Traipu. The capacity of these two reservoirs is 10,800 and 3,800 mcm, respectively. The flow in the lower reaches generally follows that of the discharge from these reservoirs and is influenced by the release from Sobradinho reservoir (or, before the reservoir was completed, of the flow at that point) (Figures 21 to 22). The discharge from the mouth of the São Francisco River is ungauged, although it is unlikely to differ much from the gauge upstream at Traipu (Figure 22). The Sobradinho reservoir in the Juazeiro catchment has the largest surface area of any reservoir in Brazil at 4225 km^2, and a capacity of 34,100 mcm.

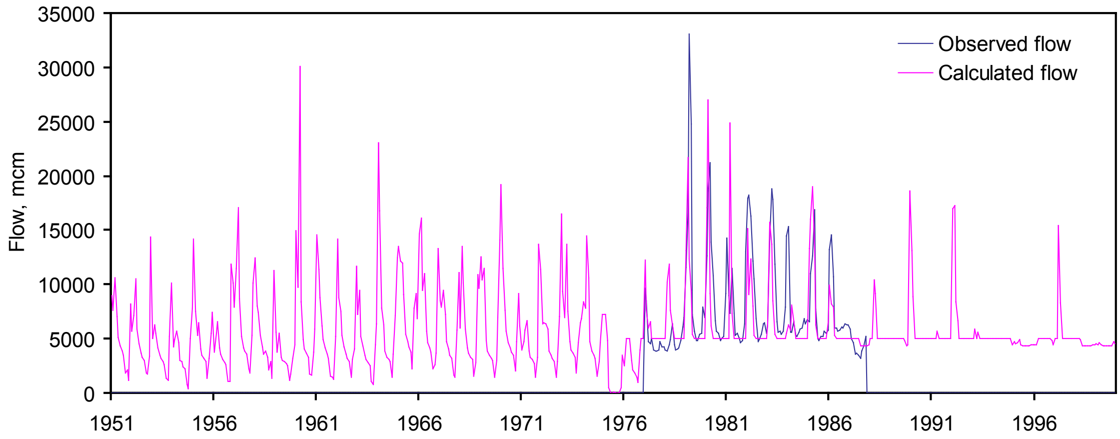

Figure 21. Observed and modelled flow at Petrolandia.

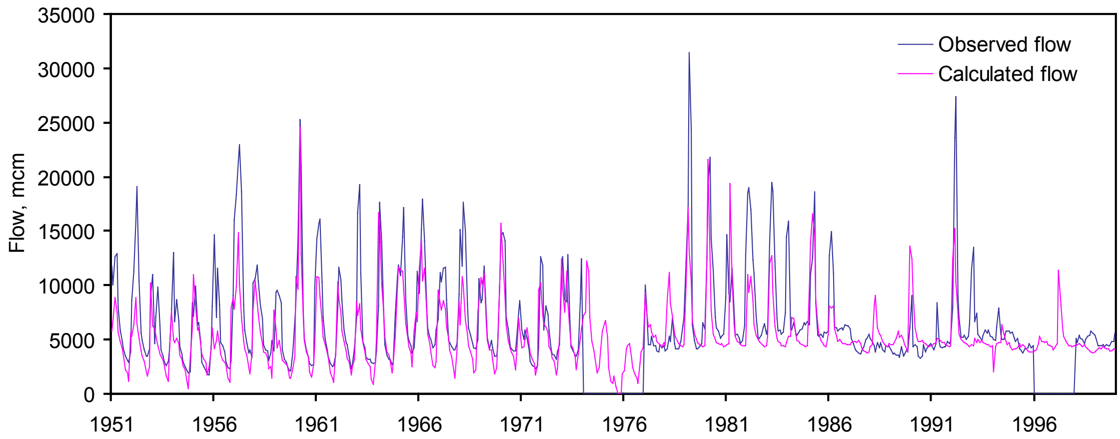

Figure 22. Observed and modelled flow at Traipu.

Annual runoff from the whole Basin and precipitation shows similar trends through time from 1951 to 2000 (Figure 23), with peaks in annual rainfall generally resulting in peaks in runoff. Annual average runoff is 97,000 mcm, but runoff shows large temporal variation ranging from 61,000 mcm in 1954 and 163,000 mcm in 1985.

5.2. WATER USE

The mean annual input by precipitation to the São Francisco Basin totals 623,000 mcm. Figure 24 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 changes in storage and losses. Net runoff from the Basin is 98,000 mcm or 16% of the total input from precipitation. The aggregated class grassland, which includes shrubland and barren land, is the most extensive land use, covering 59% of the Basin. Its water use is correspondingly high, with a mean annual water use of 301,000 mcm, or 48% of the water used in the Basin (Figure 24).

Rainfed agriculture covers 23% of the basin, but uses 14% of the water in the Basin (85,000 mcm). Land uses included in the 'woodland + other' class are woodlands and forests; wooded wetlands; urban; bare ground; barren and sparsely vegetated land. This land-use class covers 16% of the Basin and uses 130,000 mcm or 21% of the available water. Irrigated agriculture covers only 2% of the Basin, and uses about 2% of the total available water (10,000 mcm).

Figure 25 depicts the uses of water in each catchment, and the distribution of water uses across the Basin. Note that the figure does not represent the water balance at a basin level, since water represented as net runoff in the upper basin may be used in downstream catchments. For example, runoff from upper basin catchments may contribute to irrigation in downstream catchments, and thus is double counted at the basin level.

The relative size of each of the major water uses varies for different catchments. Net runoff is most important in the catchments upstream of São Francisco (Porto da Barra, Velo da Taipa, Ponte da Taquara, Tres Marias, Monante Barra do Jequitai, São Romao, and São Francisco). In these catchments, mean annual rainfall is greater than 1300 mm and net runoff ranges from to 21 to 33% of the water available (Figure 24). In the downstream catchments of the São Francisco Basin, mean annual rainfall ranges from 540 mm to 1210 mm, and net runoff ranges from 3 to 20% of the water available.

Grasslands are the most important users of water in all but the Velho da Taipa, Ponte da Taquara, and the Estuary catchments, with grasslands ranging from 45% of the area of the Tres Marias catchment to 81% of the Boqueirao catchment. This result is based on the AVHRR derived land-use classification, which appears to exaggerate grassland areas, perhaps by including some of the shrubby caatinga vegetation (Bassoi, 2008, personal communication). Thus grassland water use is probably also exaggerated. Water use by grassland in these catchments varies between 31% and 63% of the total water used. Grassland water use is also important in the Velho da Taipa, Ponte da Taquara, and Petrolandia catchments, representing 26% or more of the water used.

Rainfed agriculture is the most important water use in the Velho da Taipa, Ponte da Taquara, Juazeiro, Petrolandia, Traipu and Estuary catchments, ranging from 22 to 39% of the total water used. Rainfed agriculture is the dominant land use in the Velho da Taipa and Ponte da Taquara catchments. In the São Francisco, Manga, Boca da Caatinga, Bom Jesus da Lapa, Porto Novo, Morpara, and Boquierao catchments, rainfed agriculture represents a minor water use. Rainfed agriculture comprises 10% or less of the catchment area, and accounts for 8% or less of the total water used in these catchments. In the remaining catchments, water used by rainfed agriculture ranges from 15% to 19% of the total water used in the catchment.

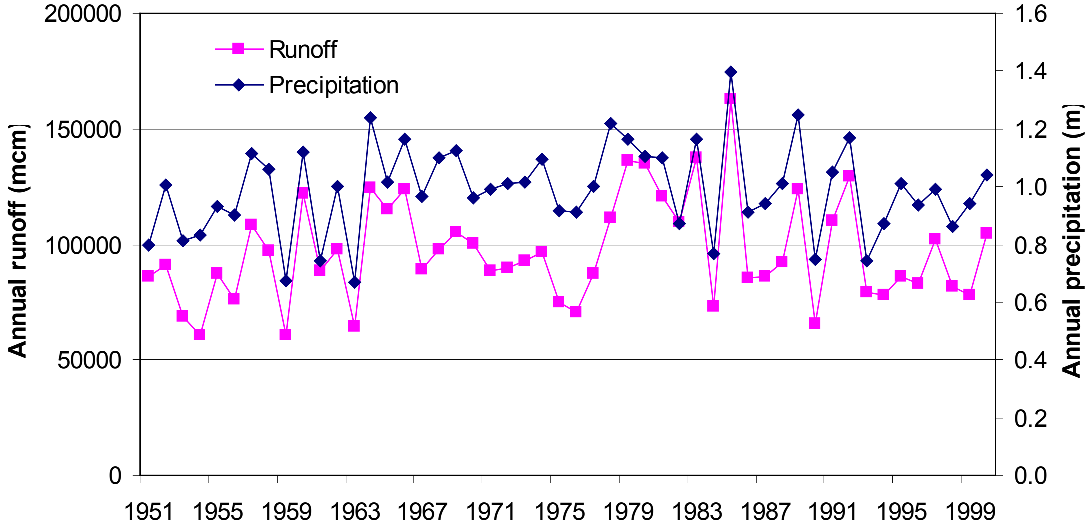

Figure 23. Whole basin annual precipitation and runoff from 1951 to 2000.

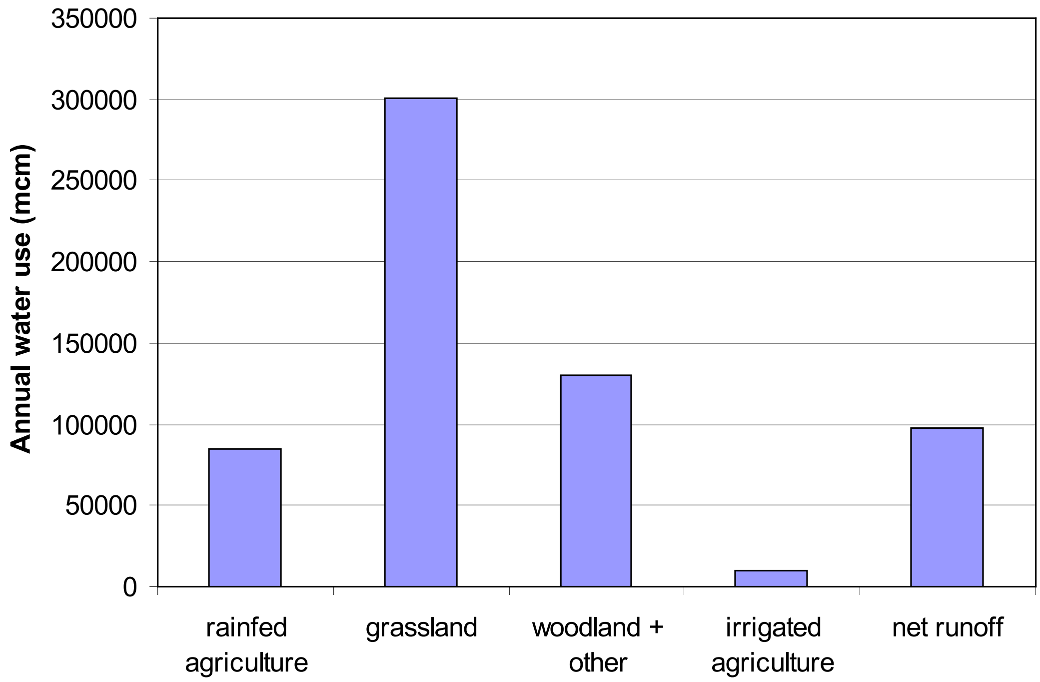

Figure 24. Summary of major water uses in the São Francisco Basin. Grassland includes shrubland and barren land (see Section 4.3).

Water use by the 'woodland + other' land-use class ranges from 8% of the total water used in Tres Marias catchment to 44% in the Estuary catchment. In the Montante Barra do Jequitai, São Romão, São Francisco, Manga, Boca da Caatinga, Bom Jesus da Lapa, Morpara, Boquierao, and the Estuary catchments, water used by this land-use class is important at 20% or more of the water used in the catchment, and the land use covers between 9% and 25% of each catchment. In the remaining catchments, water used by the 'woodland + other' land use is less than 16% of the total water used. Irrigated agriculture is a very minor water use in all catchments, comprising 2% or less of the total water used. This low water use reflects the low incidence of irrigated cropping in the Basin as the proportion of land irrigated is less than 2% in all of its catchments.

5.3. CATCHMENT AND BASIN HYDROLOGICAL CHARACTERISTICS

Selected hydrological characteristics will be useful for comparing the São Francisco 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 São Francisco basin is 15% (i.e. mean annual runoff is 15% of mean annual precipitation). Similarly, comparing annual runoff ratios (Table 2) for the different catchments in the basin shows differences in their runoff characteristics.

The wetter catchments of the Basin upstream of São Francisco show the greatest ratios of runoff to precipitation, ranging from 21% in São Romão to 33% in the São Francisco catchment. The dryer catchments downstream of São Francisco have lower runoff ratios ranging 1% in Juazeiro to 20% in Porto Novo.

When annual runoff from each catchment is expressed on a unit area basis, a single function may be used to describe the relationship between runoff and annual precipitation for catchments of the Basin (Figure 26). As may be expected, runoff/area increases with increasing precipitation.

As shown in Figure 23 above, total annual runoff from the Basin reflects the annual variation in rainfall in the years 1950 to 2000. A single function may be used to quantify the relationship between whole basin annual runoff and precipitation (Figure 27). The relationship may be used as a first estimate of the impact of changing rainfall under climate change scenarios. If potential evaporation were to change significantly under climate change, the rainfall-runoff relationship may also be expected to change.

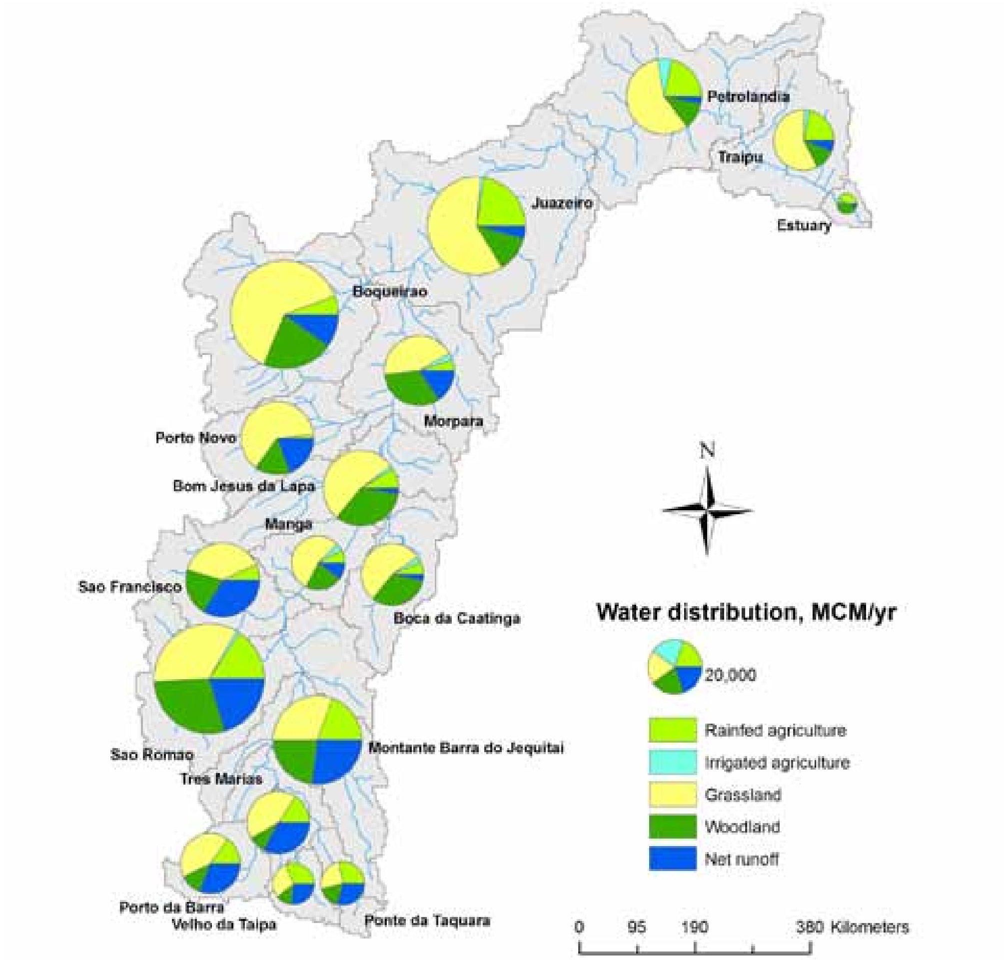

Figure 25. Spatial distribution of major water uses across the catchments of the São Francisco Basin. Grassland includes shrubland and barren land (see Section 4.3).

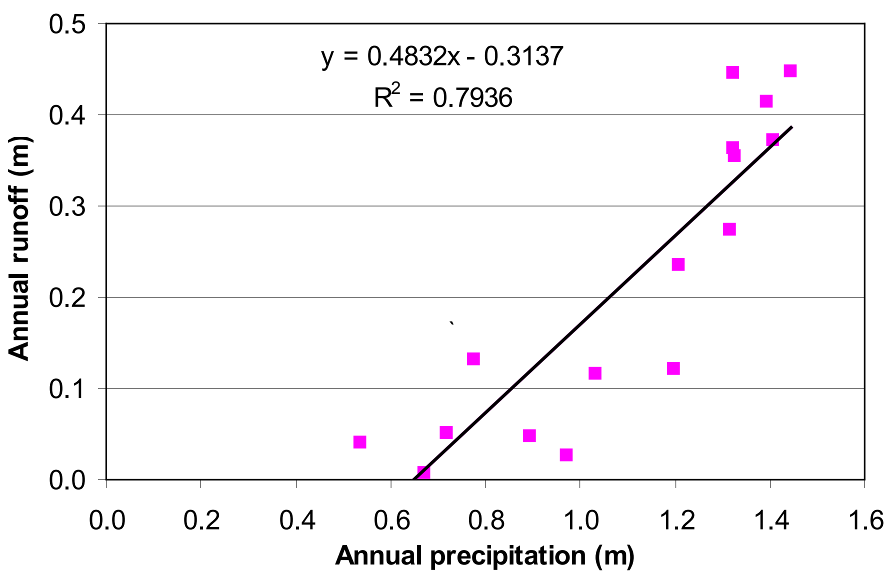

Figure 26. Annual runoff/area as a function of precipitation for catchments of the São Francisco Basin.

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

Catchment	Runoff ratio (%)
Porto da Barra	31
Velho da Taipa	26
Ponte da Taquara	30
Tres Marias	25
Montante Barra do Jequitai	27
São Romão	21
São Francisco	33
Manga	11
Boca da Caatinga	5
Bom Jesus da Lapa	3
Porto Novo	20
Morpara	17
Boqueirao	10
Juazeiro	1
Petrolandia	7
Traipu	7
Estuary	7
Whole Basin	16

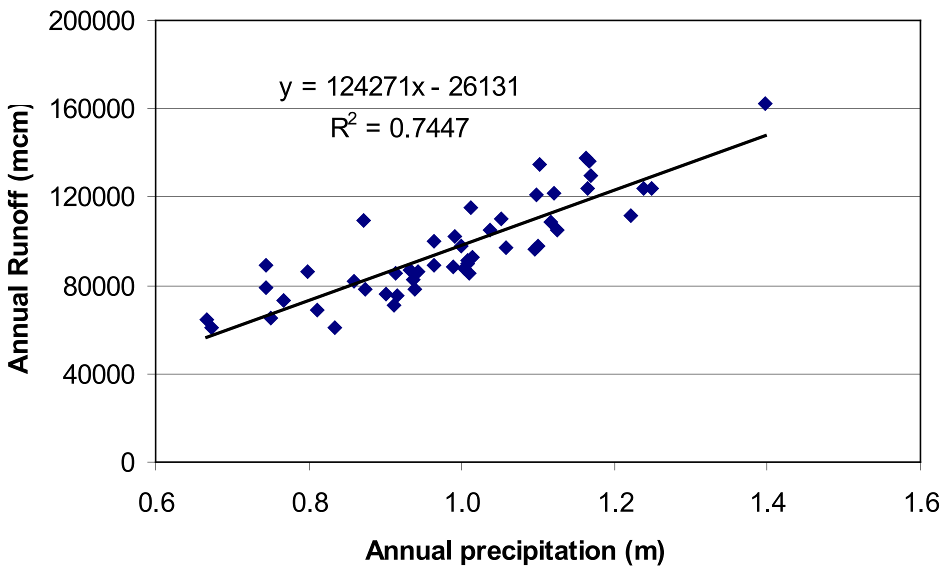

Figure 27. Whole basin annual runoff as a function of annual precipitation.

6. EXAMPLE USE

We give two examples of using the spreadsheet to model the impact of change, firstly of climate change, and secondly of inter-basin water transfers.

Some predictions for climate change in the NE of Brazil show a modest decline in rainfall and an increase in temperatures (Hulme and Sheard 1999). The magnitudes of the predicted changes depend on the climate change scenario, and are also not uniform throughout the year. For demonstration purposes, we use a simple uniform decrease of 5% in rainfall and an increase of 5% in potential evapotranspiration. We emphasise that the scenario is not a prediction; rather it is a demonstration of the use of the model. The (rather obvious) consequence for reduced flow at Juazeiro and storage in the Sobradinho reservoir is shown in Figures 28 and 29.

The second example is the planned transfer of water from the São Francisco Basin to the northeast of Brazil. ICID-CIID (2006) report that the transfer could involve 4000 mcm/yr, about 80% of which would be diverted just below the Sobradinho reservoir and the remainder further downstream. Here we model the consequences by diverting a set fraction of the monthly flow, such that the annual average removed is 3200 mcm at Juazeiro and 800 mcm at Petrolandia. The impact on flows at Traipu is seen by comparing the calculated flows in Figure 30 with those in Figure 22. The impact on flow of this scenario is modest, since the annual average flow in the São Francisco Basin is greater than 70,000 mcm, so the diversion amounts to some 6% of the total. If water were diverted more during the low flows of the dry season and in dry years, the impact on flows would be greater. The combined impact of the planned diversions and drying due to climate change would be greater again. Again, we emphasise that the scenario is not a prediction; rather it is a demonstration of the use of the model.

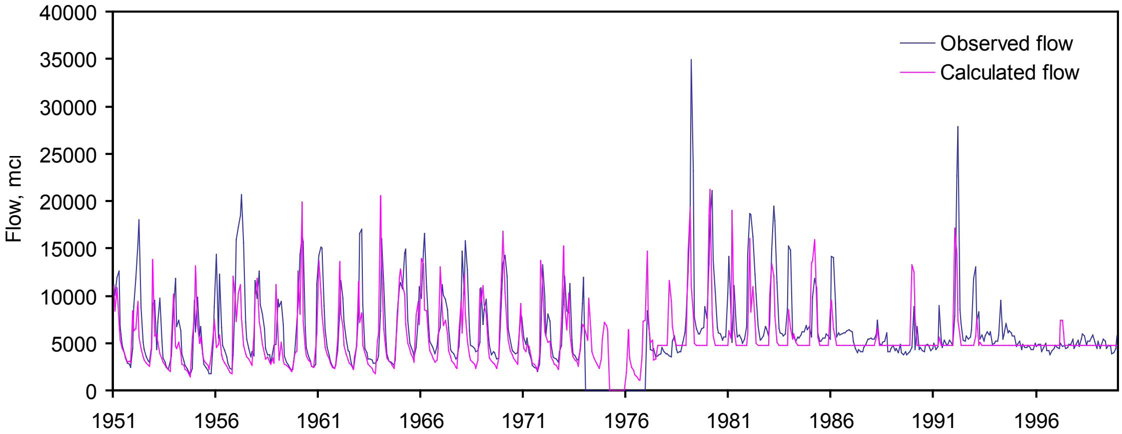

Figure 28. Observed flow and modelled flow at Juazeiro for a 5% increase in both rainfall and evaporation caused by climate change.

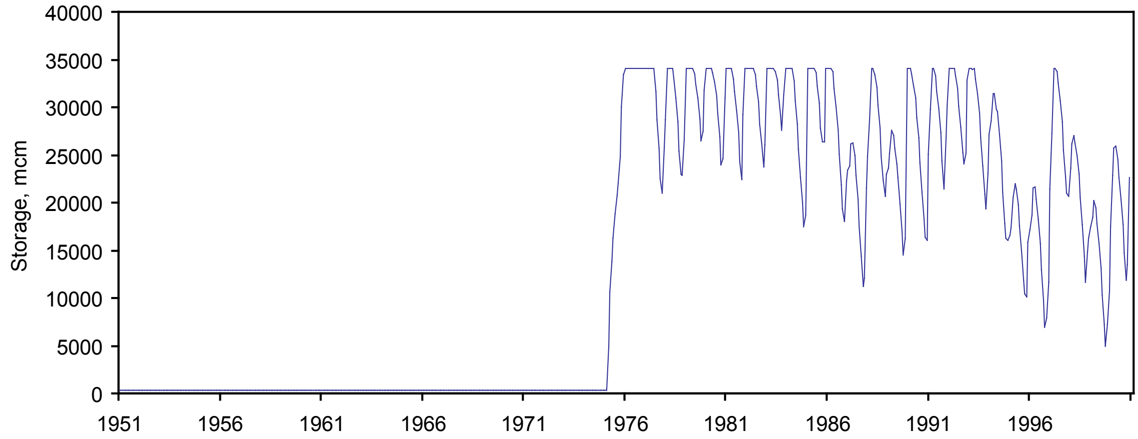

Figure 29. Modelled storage of the Sobradinho reservoir for a 5% increase in both rainfall and evaporation caused by climate change.

7. CONCLUSIONS

A very simple spreadsheet model with few adjustable parameters has produced plausible simulations of runoff and river flow behaviour in the São Francisco Basin. The partitioning of catchment evapotranspiration between various land uses in any catchment relies on the crop coefficients that we have assumed for each land use type. Similarly, the amount of water applied as irrigation in any catchment also depends on the selected crop coefficients. Thus the summary of water uses at both the basin and catchment scale presented in section 4.2 may be further developed to include estimates of crop coefficients derived from local data to give a better representation of water use by different land uses.

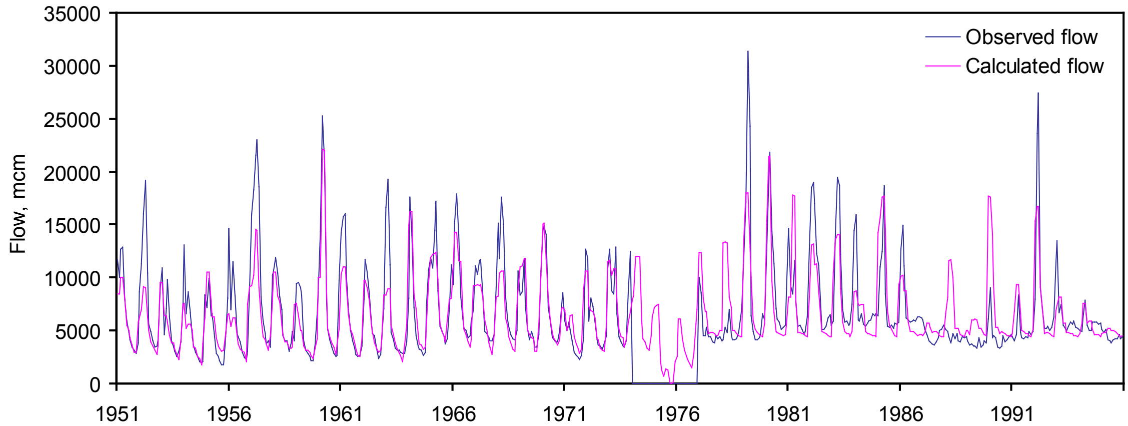

Figure 29. Modelled flow at Traipu under a scenario where 4000 mcm of water is diverted at Juazeiro and Petrolandia for irrigation in the northeast of Brazil.

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