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BASIN FOCAL PROJECTS SERIES

Water-use accounts in CPWF basins

Simple water-use accounting of the Yellow River 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 Yellow River basin in China. The Yellow River rises in the Bayan Har Mountains in Qinghai Province in western China, and empties into the Bohai Sea. A unique feature of the river is the large amount of silt it carries.

Net runoff is about 14% of total precipitation. Forest and woodland cover 9% of the basin and use about 15% of the precipitation. Grassland covers much of the upper part of the Basin, consuming about 42% of the precipitation. Irrigated agriculture covers just 6% of the Basin and uses about 11% of the water.

The effect of increased irrigation efficiency shows that local increase of irrigation efficiency does not necessarily translate into changes at the whole basin level. The water transfer to the Yellow River from the Yangtze boost flows to the upper Yellow river and leads to an increase in the flows throughout the river.

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

2. INTRODUCTION

In this note, we describe a simple water account for the Yellow River 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.

These accounts are static, however, providing a snapshot for a single year or for an average year. Furthermore, they do not link water movement to 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 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 Yellow River.

As we shall describe below, the account has been developed using existing data available to the authors, 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

Cai and Rosegrant (2003) describe a hydro-economic model of the Yellow River. Xu et al. (2008) used SWAT (Soil and Water Assessment Tool) model to investigate how streamflow in headwater catchment of the Yellow River Basin is affected by climate change in the future. We understand that the Yellow River Conservancy Commission also has good hydrological models of the river, but we have not surveyed them in detail.

3. BASIC HYDROLOGY AND OUTLINE OF SIMPLE WATER ACCOUNT

3.1. BASIC HYDROLOGY, IRRIGATION AND LAND USE

The Yellow River Basin covers 797,700 km^2 and is drained by the Yellow River and its tributaries (Figure 1 and Table 1). We explain the choice of basin and catchment boundaries in more detail in section 4a below. The Basin consists of 4 distinct landforms, the Qinghai-Tibetan Plateau, the Inner Mongolia Plateau, the Loess Plateau and the North China Plain. The Upper Reaches of the River arise in the Qinghai-Tibetan Plateau of Qinghai province, 3000 to 5000 m above sea level in the northeast. They include the headwater catchments of the Yellow River and its tributaries and the Heihe, and Baihe Rivers. The upper reaches include the Western Highlands, Lanzhou U/S, and Lanzhou catchments. Here runoff is derived predominantly from snowmelt during winter and spring, and from precipitation during summer and autumn. Downstream of Longyangxia, the river flows swiftly through 10 long gorges and 17 wide valleys, with the large storages of the Longyangxia and Liujiaxia hydropower projects influencing downstream flows.

Table 1. Catchments in the Yellow River Basin with their areas.

River	Location	Area, km^2
Huanghe (Yellow)	Western Highlands	49,497
Huanghe	Lanzhou U/S*	88,013
Huanghe	Lanzhou	84,999
Huanghe	Togtoh U/S	121,268
Huanghe	Togtoh	94,447
Huanghe	Longmen	129,195
Jinghe	Zhangjiashan	43,025
Huanghe	Zhangjiashan D/S*	60,841
Huanghe	Sanmenxia U/S	25,698
Huanghe	Sanmenxia	46,802
Yiluo	Heishiguan	18,330
Huanghe	Huayuankou	32,048
Huanghe	Gaocung	3,580
Total		797,743

* U/S = Upstream; D/S = Downstream

The Middle Reaches of the River include Togtoh U/S, Togtoh, Longmen, Sanmenxia U/S, Sanmenxia, Zhiangjiashan, Zhiangjiashan D/S, Huayuankou, and Heishiguan catchments. Here, the river and its tributaries traverse part of the Inner Mongolia Plateau and the Loess Plateau from about 1000 to 2000 m above sea level. Flow from tributaries contributes huge volumes of sediment into the Yellow River, giving the River its name. The River enters a wide alluvial plain downstream of the gorge at Longmen, where two of its major tributaries, the Weihe and Fenhe, converge. The River turns sharply to the east and flows through a series of gorges including the Sanmenxia and Xiaolangdi Gorges before flowing into the Lower Reaches.

The Lower Reaches are comprised of the hilly areas of the Shandong Province and the North China Plain, and include the Gaocung catchment. Deposition and accumulation of sediment are characteristic of the floodplain, where the river is confined by levees to form a "perched river". Gradients are small, and water is not readily discharged, so the region is prone to flooding.

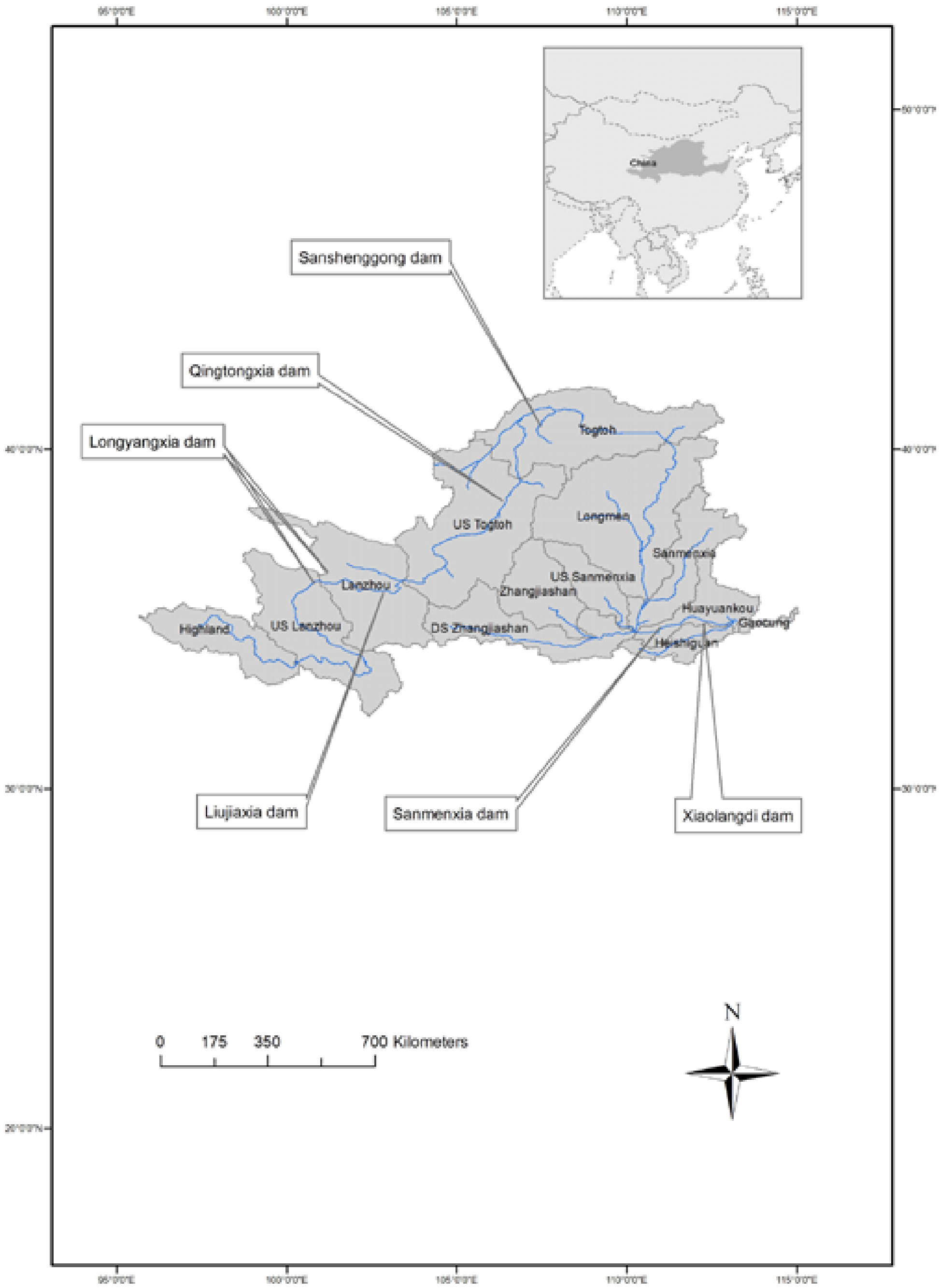

Figure 1. The Yellow River Basin, with the catchments used in the water-use account. The catchment labelled "Highland" is referred to as the Western Highlands throughout this report.

The Yellow River Basin has a continental climate and shows considerable spatial variation as a result of the increasing distance from the sea and change in altitude moving from the coast in the east to its source on the plateau of the Western Highlands in the west. The catchments of the Upper Reach are sub-humid, while those of the Lower Reach are humid. Of the catchments of the Middle Reach, those to the northwest are arid (Togtoh U/S, and Togtoh). From northwest to southeast the climate changes from arid to semi-arid, to sub-humid upstream of the humid Lower Reaches. The temperature declines from the south to the north and from the east to the west of the Basin. As a result, potential evaporation is greatest in the Lower Reach catchments, and Gaocung has the greatest mean annual evaporation of 1180 mm (Table 2). Evaporation is low in the Upper Reach catchments, with the Western Highlands catchment having the lowest annual evaporation of 590 mm. Precipitation is greatest in the south-east of the Basin and declines gradually on moving towards the north-east. The Heishiguan catchment has the greatest annual precipitation (670 mm), and Togtoh the lowest (250 mm). The large spatial variation in climatic conditions across the Basin gives rise to variation in the hydrology of the Yellow River.

Table 2. Mean annual precipitation and potential evaporation for Yellow River Basin catchments.

Catchment	Precipitation (mm)	Evaporation (mm)
Western Highlands	330	590
Lanzhou U/S*	410	770
Lanzhou	370	790
Togtoh U/S	260	1000
Togtoh	250	990
Longmen	410	1030
Zhangjiashan	500	980
Zhangjiashan D/S*	600	950
Sanmenxia U/S	510	1040
Sanmenxia	540	1060
Heishiguan	670	1080
Huayuankou	610	1090
Gaocung	660	1180

* U/S = Upstream; D/S = Downstream

The Basin shows strong seasonal variation in both precipitation and potential evapotranspiration, both peaking in the summer. Rainfall varies from 300 mm in the west to 700 mm near the estuary, and potential evapotranspiration varies from 600 mm to 1200 mm (Figure 2).

As well as the marked seasonal variation in climate, there is some variability in annual precipitation (Figure 3), which causes important variation in annual flows from the Yellow River catchments. Whilst mean annual rainfall in the Basin is 405 mm, rainfall between 1951 and 2000 varied from a minimum of 285 mm in 1965 to a maximum of 575 mm in 1964. Annual potential evaporation is less variable, ranging from a minimum of 890 mm in 1976, to a maximum 990 mm in 1951, with a mean annual value of 940 mm.

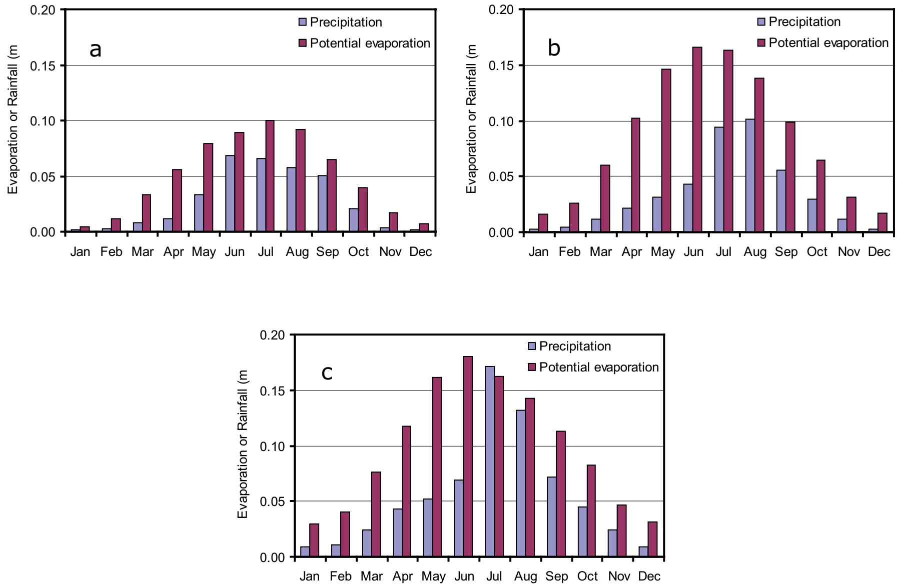

Figure 2. Monthly average precipitation and potential evaporation in the Yellow River Basin. a). Western Highlands; b). Longmen; and c). Gaocung.

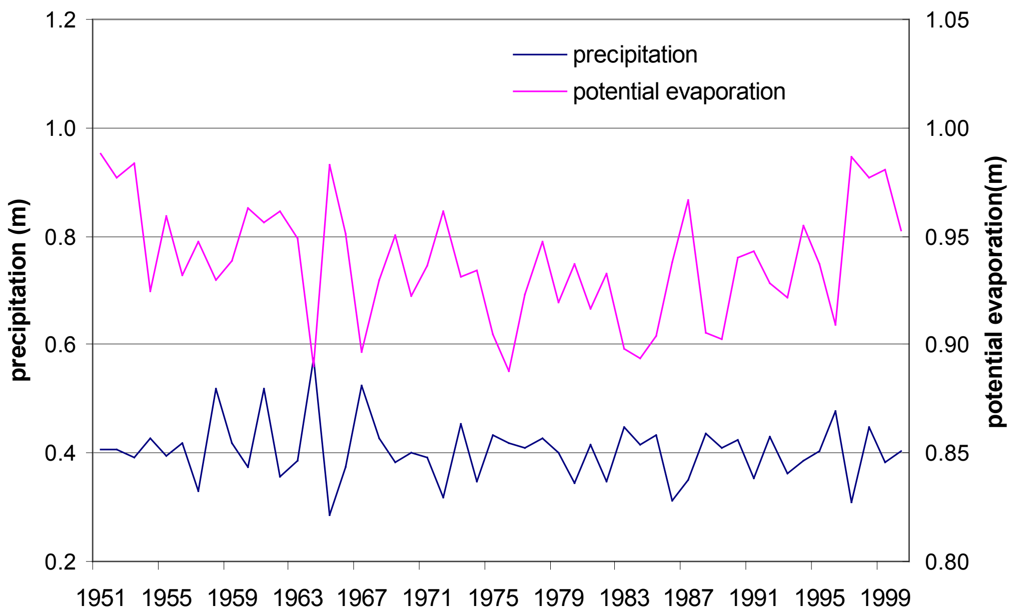

Figure 3. Basin average annual precipitation and potential evaporation from 1951-2000.

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 the 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. Total catchment evapotranspiration is estimated from potential evaporation and water supply from the surface store, and partitioned between rainfed and irrigated land uses based on the ratio of their areas. The rainfed component of evapotranspiration is further partitioned between land uses/vegetation types (agriculture, forest/woodland, grassland, other) based on the ratio of their areas and using crop coefficients to scale their evapotranspiration relative to other land uses.

Runoff flows into the tributaries and thence into the Yellow River, with downstream flow calculated by simple water balance. We assume that the base flow in a catchment comes from a notional groundwater store whose monthly discharge is a fraction of the quantity of water it contains. Deep drainage to the groundwater store is estimated as a proportion of the surface water store. For more details see Kirby et al. (2010). Channel storages and losses from the river are estimated as a function 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.

Crops in each catchment may be irrigated from both surface water and groundwater sources. Extractions from groundwater and surface water diversions for irrigation are based 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 from surface water may be reduced in any year to match supply if the volume stored in the reservoir at the beginning of the cropping season is insufficient to meet crop-water requirements. If reservoir storage becomes insufficient to meet crop demand during the cropping season, irrigation applications are reduced to match supply. Irrigation is assumed to be less efficient, and a proportion of the water applied returns to the groundwater store, and a further amount is lost by 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 m.

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. BASIN AND CATCHMENT BOUNDARIES

We started with the basin and catchment boundaries defined by datasets available from the IWMI website (www.iwmi.org). However, these boundaries differ from those used by the Yellow River Conservancy Commission (Claudia Ringler and YRCC, personal communications, 2008). We have been unable to obtain the YRCC definitions of the boundaries, but have had access to a low resolution image showing them. Rather than attempt to apply a land and catchment classification based on a low resolution image, we excluded catchments from the IWMI basin, such that the reduced basin was approximately the same as the low resolution image to which we had access. We are aware that this is a less than satisfactory procedure. The method and general findings presented here are readily applied to a correctly defined basin, and we expect that the main findings would not change greatly.

4.2. 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).

4.3. FLOWS

Reach flows were taken from a dataset called ds552.1, available on the internet (http://dss.ucar.edu/catalogs/free.html) (Dai and Trenberth 2003). The dataset also gives contributing drainage areas for each flow gauge. Flow records were not available for all the catchments

4.4. 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.

4.5. DATA LIMITATIONS – FLOW DATA

We have been unable to access flow data for 8 of the 16 catchments of the Yellow River Basin, including the Western Highlands, Lanzhou U/S, Northwest Plateau, Togtoh U/S, Sanmenxia U/S, Zhangjiashan D/S, Gaucung D/S, and Estuary catchments. Only limited flow data were available for the Zhangjiashan and Heishiguan catchments. Where data were unavailable, we selected model coefficients that gave parity in calculated and observed flow in downstream catchments, where possible using rainfall-runoff coefficients similar to nearby catchments with similar climatic and physiographic characteristics.

5. COMPONENTS AND RESULTS IN DETAIL

5.1. FLOW

5.1.1. UPPER REACH CATCHMENTS

Flow from the Upper Reach catchments show annual flow peaks in summer months, and minimum flow during winter months (Figures 4 to 6). Flow is continuous throughout the year, and largely reflects the seasonal rainfall distribution (Figure 7). However, discharge from the Lanzhou catchment is influenced by the large storages of the multipurpose Longyangxia and Liujiaxia reservoirs, which provide irrigation, navigation, flood control, hydropower, and aquatic resources.

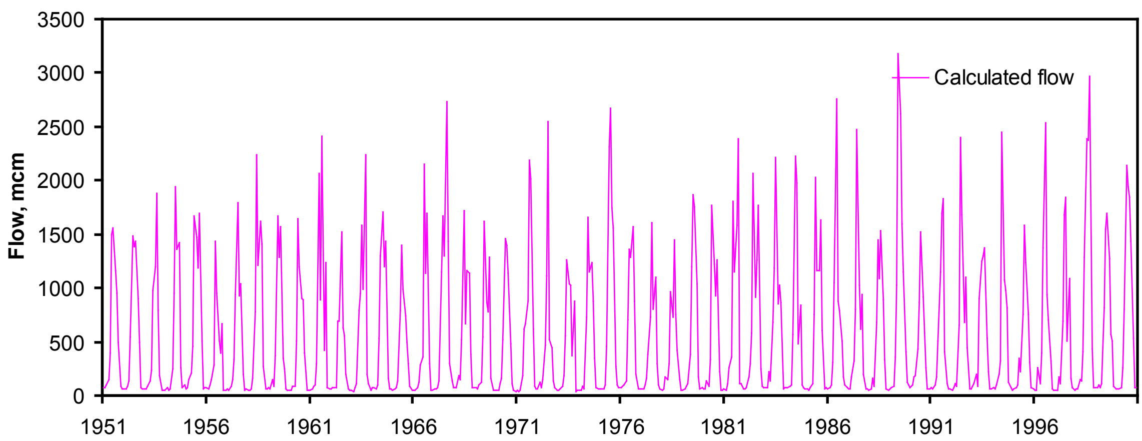

Figure 4. Modelled flow in the Western Highlands catchment.

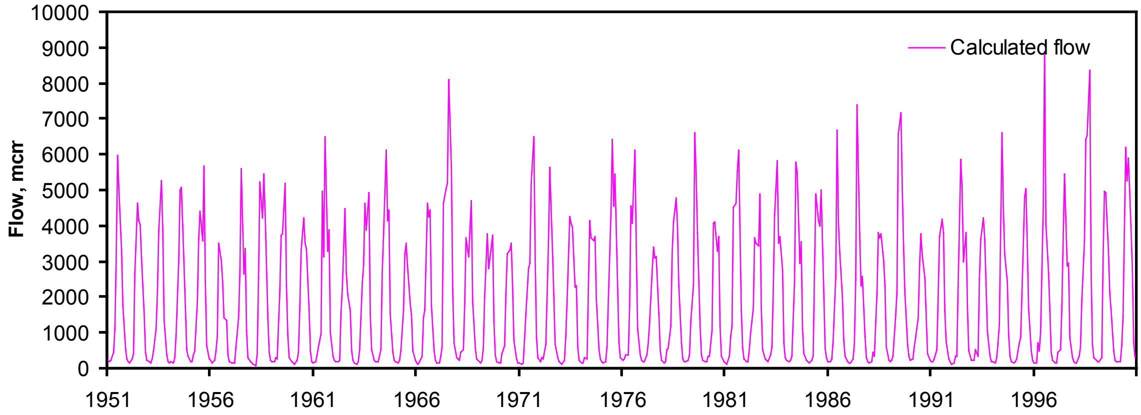

Figure 5. Modelled flow in the Lanzhou U/S catchment.

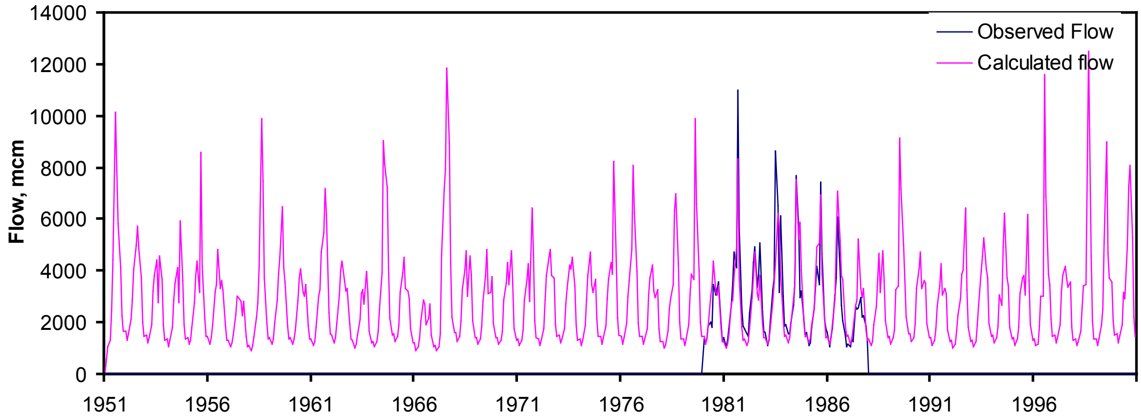

Figure 6. Observed and modelled flow in the Lanzhou catchment.

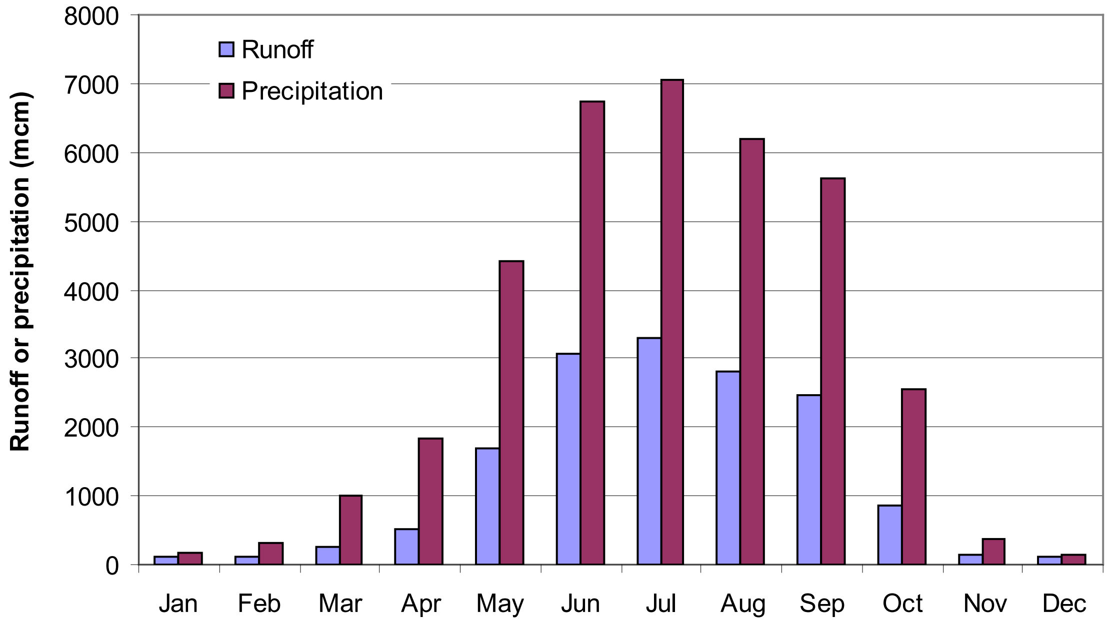

Figure 7. Monthly mean precipitation and locally-generated runoff for the Lanzhou U/S catchment.

The three Upper Reach catchments collectively generate 52% of the total runoff generated in the Basin, although they constitute only 28% of the total area. Although rainfall is relatively low in these three catchments (Table 2), low potential evaporation limits evapotranspiration, so more than 38% of the annual rainfall contributes to runoff. Irrigated agriculture has limited impact on flows from these catchments, since the areas irrigated are less than 2% of the catchment areas. There is no irrigated land in the Western Highlands, while mean annual diversions for irrigation from surface water sources are 6 and 410 mcm/yr in the Lanzhou U/S and Lanzhou catchments, respectively.

5.1.2. THE ARID CATCHMENTS OF THE MIDDLE REACHES

The arid catchments of the Middle Reaches to the northwest of the Basin are characterised by generating very little runoff. Flows from the Togtoh U/S and Togtoh catchments are continuous (Figures 8 and 9), but are dominated by the inflows from the Upper Reach catchments with negligible contribution from local runoff.

Flow in the Yellow River diminishes as it passes through these arid catchments, since losses and diversions for irrigation exceed runoff inputs. Mean (1951-2000) annual flow is reduced by 26%, with 34,210 mcm entering the arid middle reaches at Togtoh U/S and only 25,180 mcm discharging from the Togtoh catchment. Irrigation diversions from surface water sources reduce flows from the Togtoh U/S and Togtoh catchments by an annual average of 1,930 and 6,290 mcm, respectively.

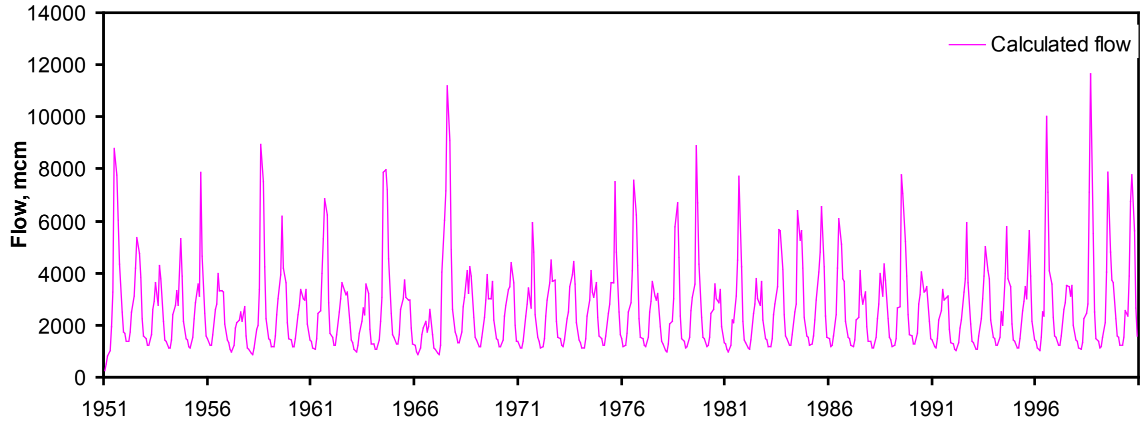

Figure 8. Modelled flow from the Togtoh U/S catchment.

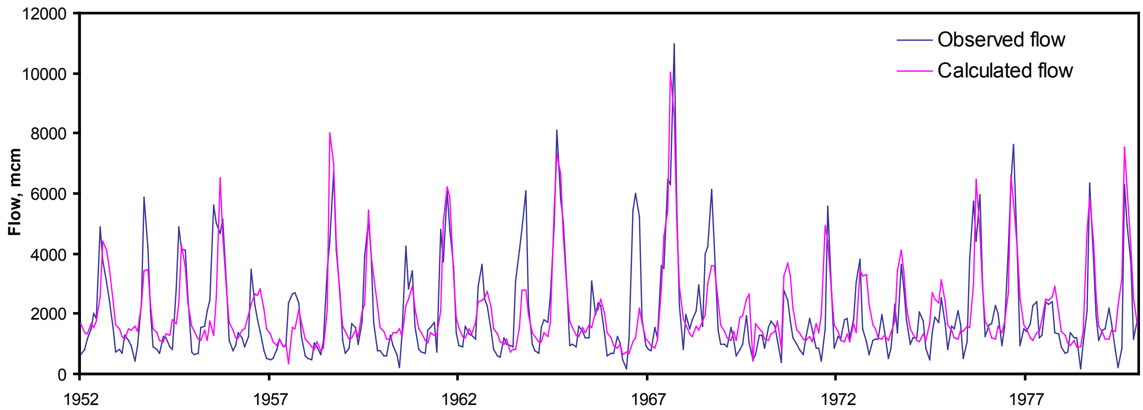

Figure 9. Observed and modelled flow from the Togtoh catchment.

5.1.3. THE SEMI-ARID AND SUB-HUMID CATCHMENTS OF THE MIDDLE REACHES

Flows from semi-arid and sub-humid catchments of the Middle Reaches show seasonal fluctuations, with low flows in December, January, and February and peak flows between July and October (Figures 10 to 16). In the tributary catchments (Zhangjiashang, Zhangjiashang D/S, Sanmenxia U/S, and Heishiguan), flows are periodically reduced to zero by irrigation diversions (Figures 11, 12, 13, and 15). Apart from periods during dam construction, flow is continuous in all catchments on the main River (Longmen, Sanmenxia, and Huayuankou). All catchments are net contributors to flow in the Yellow River, with local runoff contributing 13% or more to their discharge. Runoff from catchments on the main River forms a smaller proportion of catchment discharge on moving downstream. Local runoff from the Longmen catchment contributes 21% to catchment discharge (Figure 17), whilst runoff from the downstream Sanmenxia and Huayuankou catchments contribute 10% and 9% respectively.

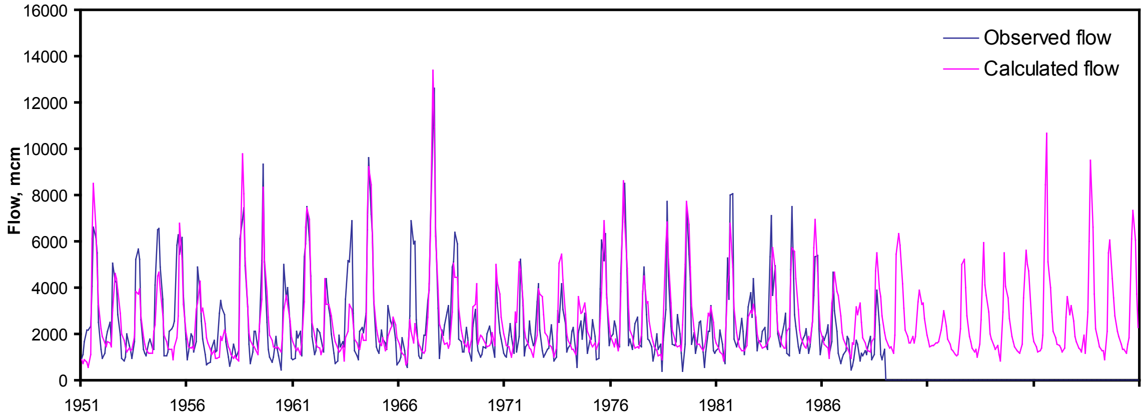

Figure 10. Observed and modelled flow from the Longmen catchment.

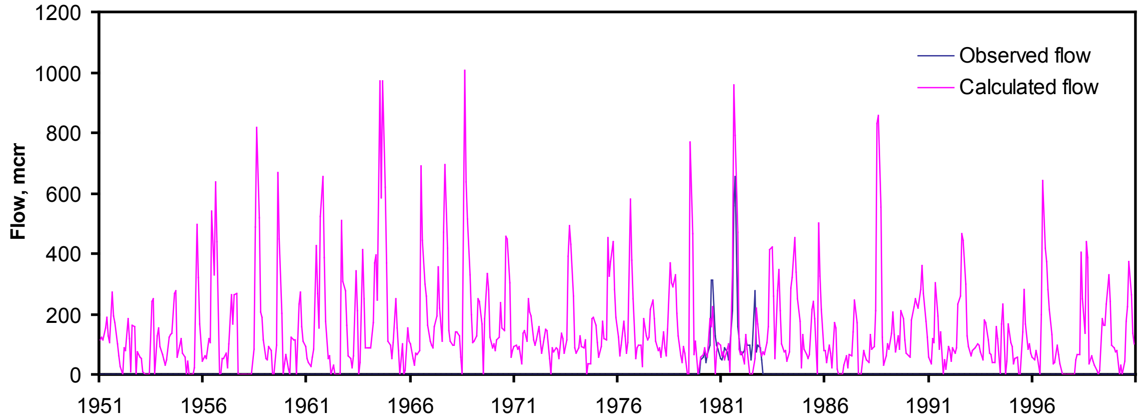

Figure 11. Observed and modelled flow from the Zhangjiashang catchment.

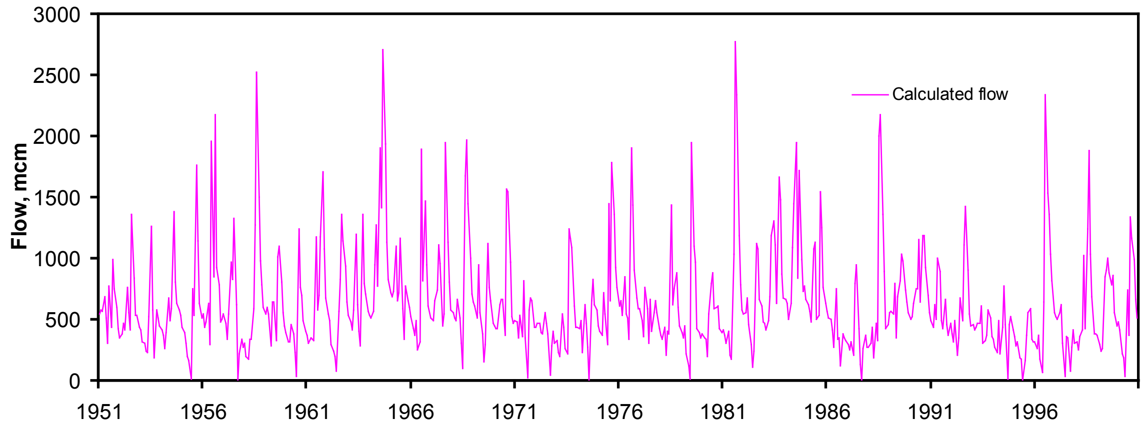

Figure 12. Modelled flow from the Zhangjiashang D/S catchment.

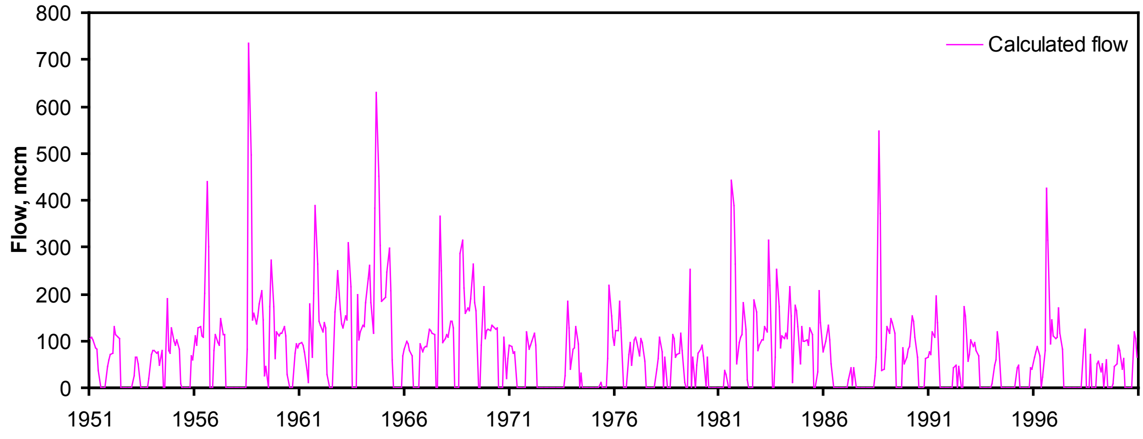

Figure 13. Modelled flow from the Sanmenxia U/S catchment.

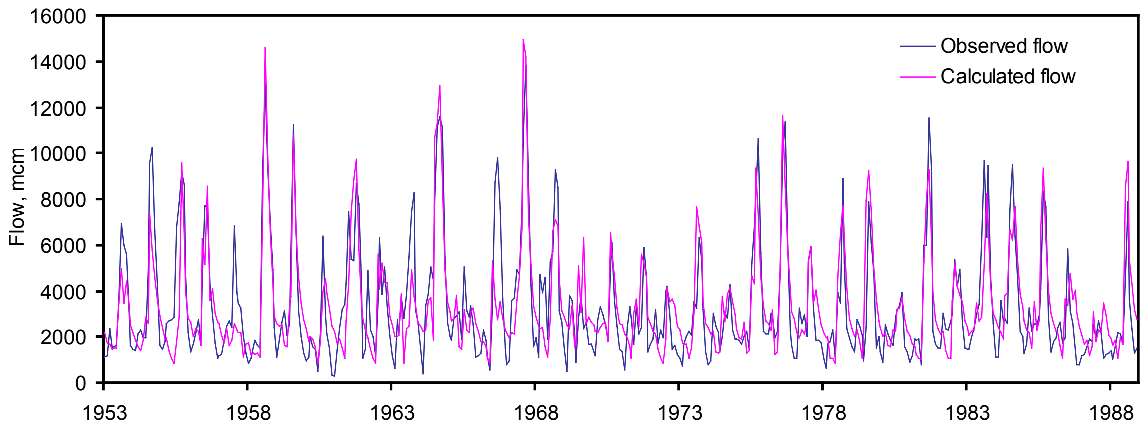

Figure 14. Observed and modelled flow from the Sanmenxia catchment.

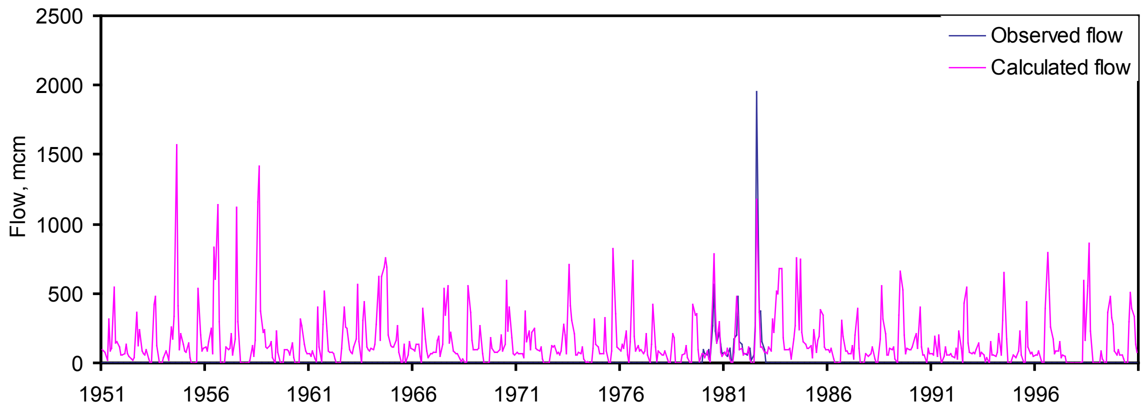

Figure 15. Observed and modelled flow from the Heishiguan catchment.

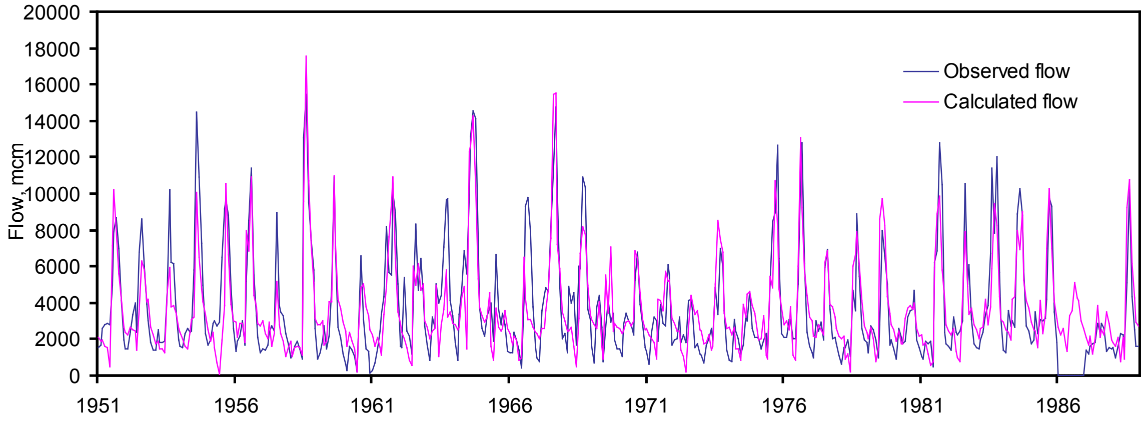

Figure 16. Observed and modelled flow from the Huayuankou catchment

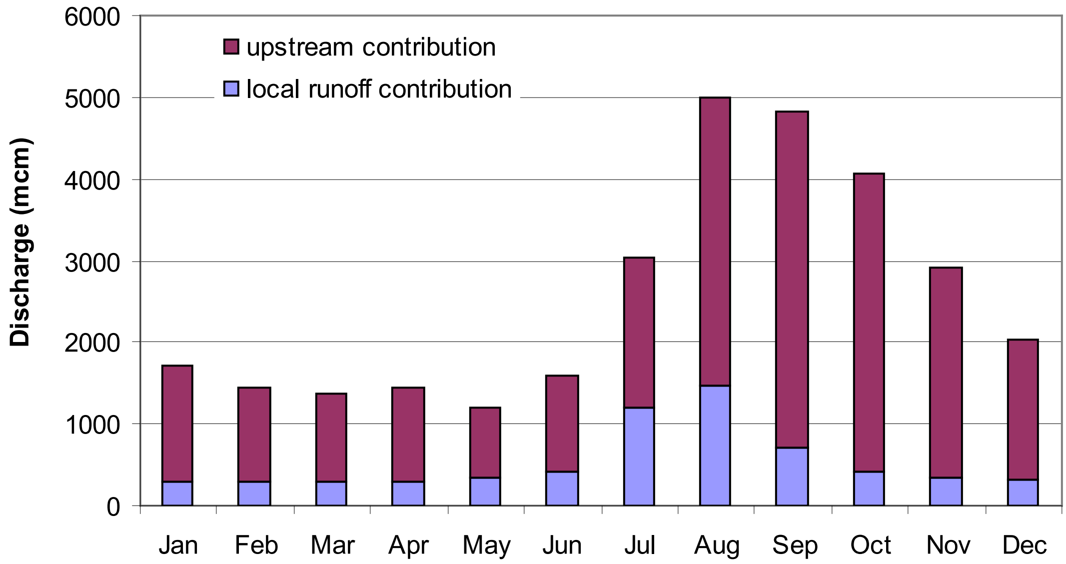

Figure 17. Contribution of upstream inflows and locally-generated runoff to flows from the Longmen catchment.

5.1.4. LOWER REACH OF THE FLOODPLAIN

Figure 18 shows discharge from the Lower Reach where the Yellow River flows on to the floodplain. Flows in this catchment are strongly seasonal with low flows in January and February and peak flows from July to October. This seasonality predominantly reflects the seasonal pattern of inflows from upstream. Flow in the Yellow River diminishes progressively as it passes through these catchments, since losses and diversions for irrigation exceed runoff inputs.

Whole Basin annual runoff and precipitation show similar trends through time from 1951 to 2000 (Figure 19), with peaks in annual rainfall generally resulting in peaks in runoff. Annual average runoff is 67,700 mcm, but shows large temporal variation ranging from 53,100 mcm in 1991 to 93,500 mcm in 1964.

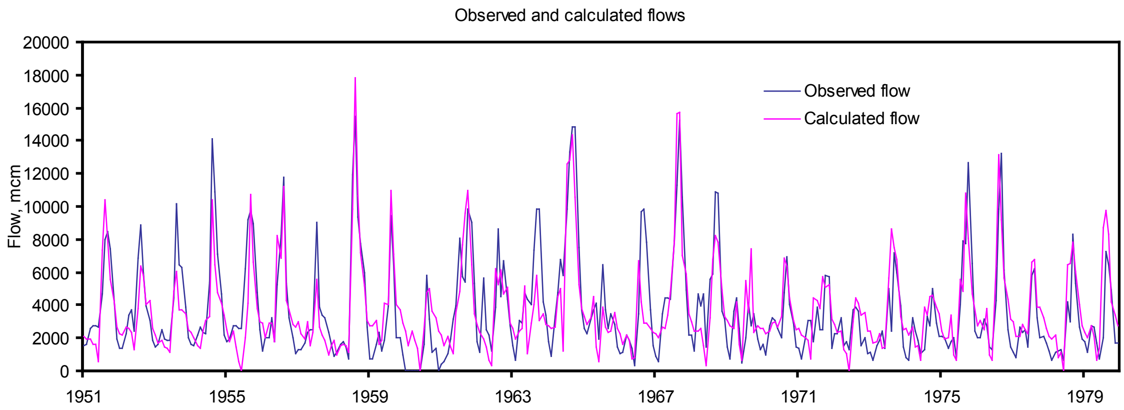

Figure 18. Observed and modelled flow from the Gaucung catchment.

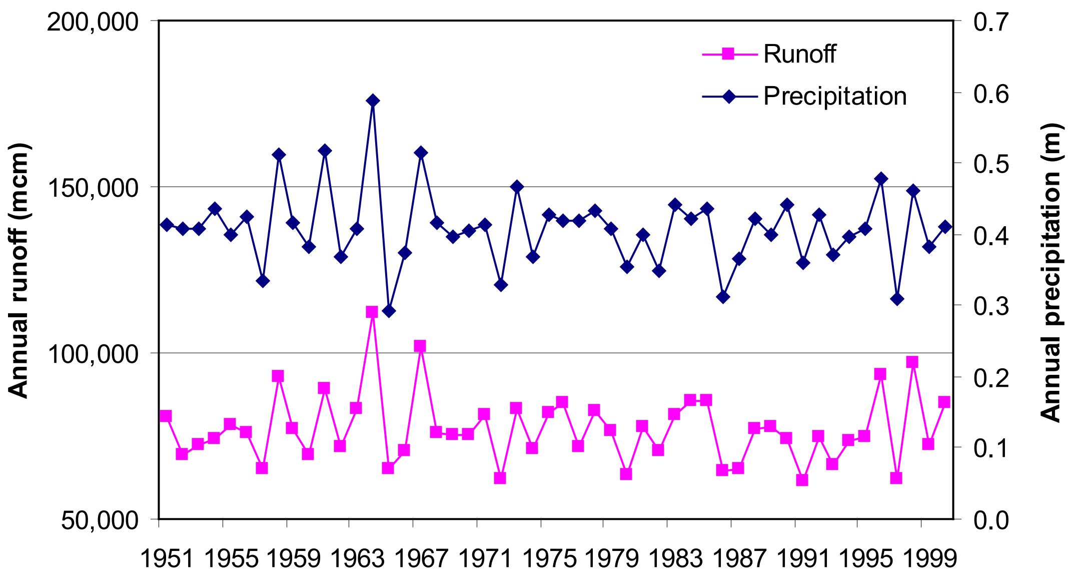

Figure 19. Whole Basin annual precipitation and runoff from 1951 to 2000.

5.2. WATER USE

The mean annual input by precipitation to the Yellow River Basin totals 322,300 mcm. Figure 20 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 just less than 44,000 mcm/yr (annual average, 1951-2000). The aggregated class grassland, which includes shrubland and barren land, is the most extensive land use, covering 71% of the Basin. Its water use is correspondingly high, with a mean annual water use of 140,000 mcm, or 42% of the water used in the Basin (Figure 21).

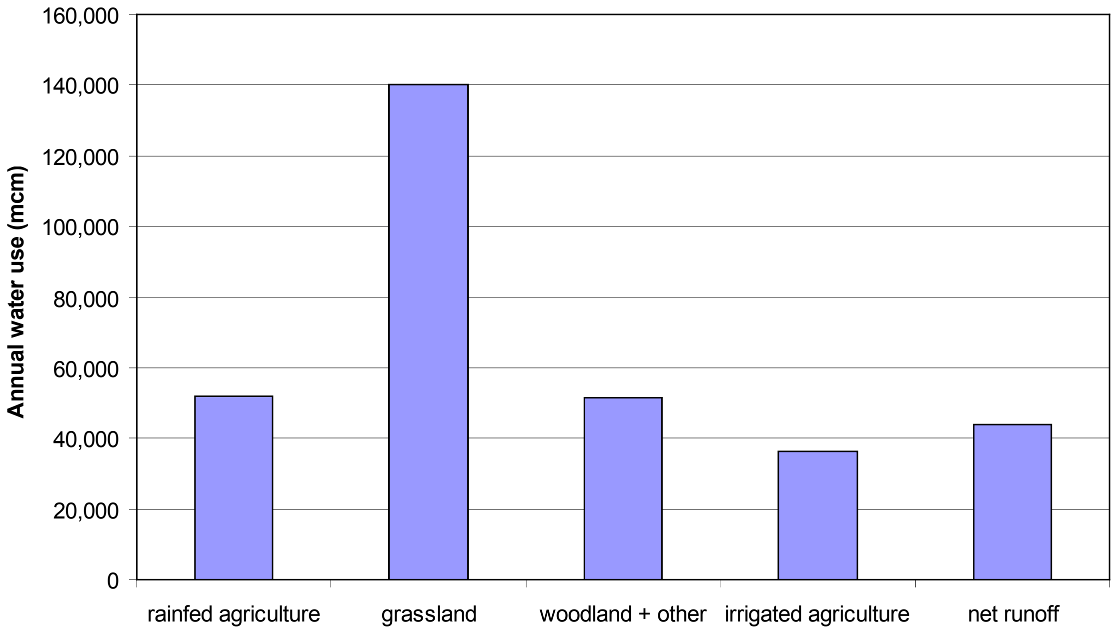

Figure 20. Summary of major water uses in the Yellow River Basin. Grassland includes shrubland and barren land (see Section 4.3).

Rainfed agriculture covers 14% of the Basin and uses 15% of the water in the Basin (51,800 mcm). Land uses included in the 'woodland + other' class are woodlands and forests, wooded tundra, urban land, bare ground, barren land, and sparsely vegetated land. This land-use class covers over 9% of the Basin and uses 51,500 mcm or 15% of the available water. Irrigated agriculture covers only 6% of the Basin, but uses 11% of the total available water (36,100 mcm). The majority of this water (36,100 mcm) is used by crops irrigated from surface water resources, which constitute 96% of the irrigated area of the Basin.

The distribution of the different water uses across the Basin is shown in Figure 21. 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. Irrigation in the lower 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. Net runoff from the whole Basin is shown in Figure 20. Figure 21 shows the different behaviour of the grassland-dominated Upper Basin and the agriculture- and irrigation-dominated Lower Basin. Irrigation is a major water user in lower parts of the Basin.

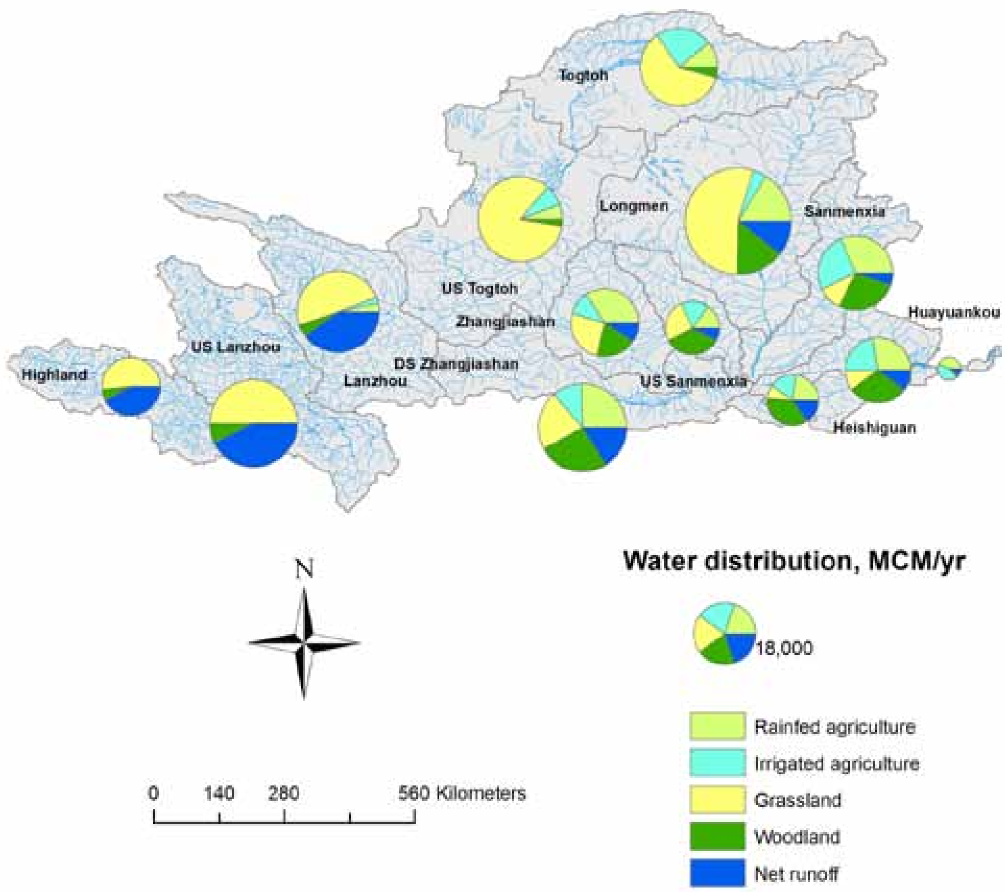

Figure 21. Spatial distribution of major water uses across the catchments of the Yellow River Basin. Grassland includes shrubland and barren land (see Section 4.3).

5.3. CATCHMENT AND BASIN HYDROLOGICAL CHARACTERISTICS

Selected hydrological characteristics will be useful for comparing the hydrological function of the Yellow River Basin 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 Yellow River Basin is 21% (i.e. mean annual runoff is 21% 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).

Catchments in the Upper Reaches of the Basin (Western Highlands, Lanzhou U/S, and Lanzhou) generally show the greatest ratios of runoff to precipitation (39-42%). Runoff ratios are smallest (0.01 to 0.005%) in the arid catchments of the Middle Reaches (Northwest Plateau, Togtoh U/S, and Togtoh). In the remaining Middle Reach catchments the ratio ranges from 13% for the drier Longmen catchment to 23% in the wetter, downstream catchment of Heishiguan. On the humid lower reach of the Floodplain the ratio is 22%.

Table 3. Annual percentage runoff ratios (runoff/precipitation) for catchments in the Yellow River Basin.

Catchment	Runoff ratio (%)
Western Highland	38.8
U/S Lanzhou	42.4
Lanzhou	41.9
U/S Togtoh	0.0
Togtoh	0.0
Longmen	13.2
Zhangjiashan	15.7
D/S Zhangjiashan	20.3
U/S Sanmenxia	18.6
Sanmenxia	19.5
Heishiguan	23.0
Huayuankou	22.4
Gaucung	22.1
Whole basin	21.0

*U/S = Upstream; D/S = Downstream

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 Middle and Lower Reaches of the Basin (Figure 22). As may be expected, runoff/area increases with increasing precipitation. The catchments of the Upper Reaches respond differently to the downstream catchments, producing greater runoff per unit of precipitation than do the downstream catchments.

As shown above (Figure 19) total annual runoff from the Basin reflects the annual variation in rainfall from 1950 to 2000. A single function may be used to quantify the relationship between whole basin annual runoff and precipitation (Figure 23). 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. Xu et al. (2008) suggested an overall decreasing trend in mean annual streamflow in headwater catchment of the Yellow River Basin due to climate change.

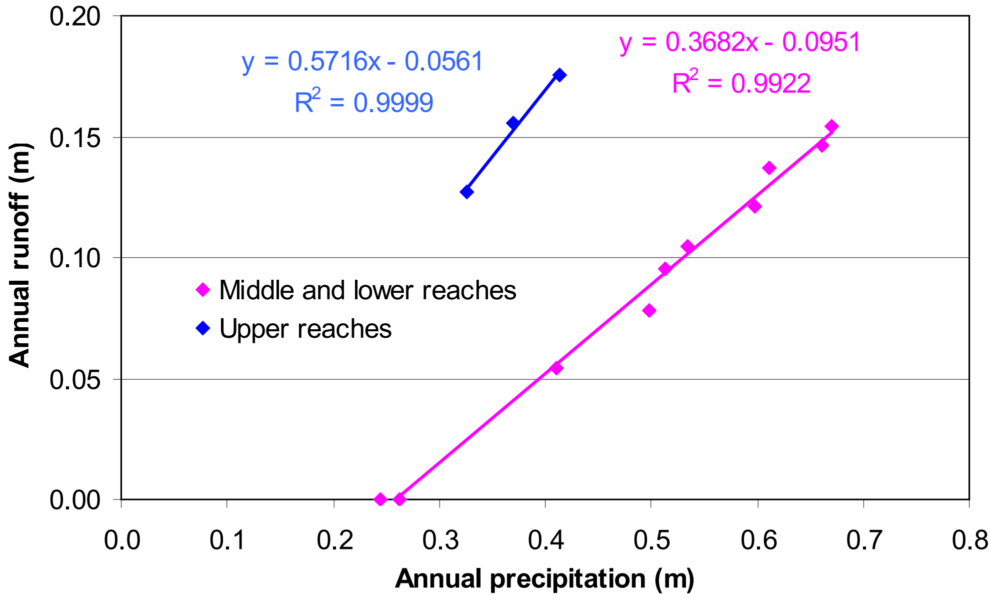

Figure 22. Annual runoff/area as a function of precipitation for catchments of the Yellow River Basin. The catchments of the Upper Reaches (Western Highlands, Lanzhou U/S, and Lanzhou) are shown in blue, and these data were excluded from the linear function fitted by least squares regression for the remaining catchments.

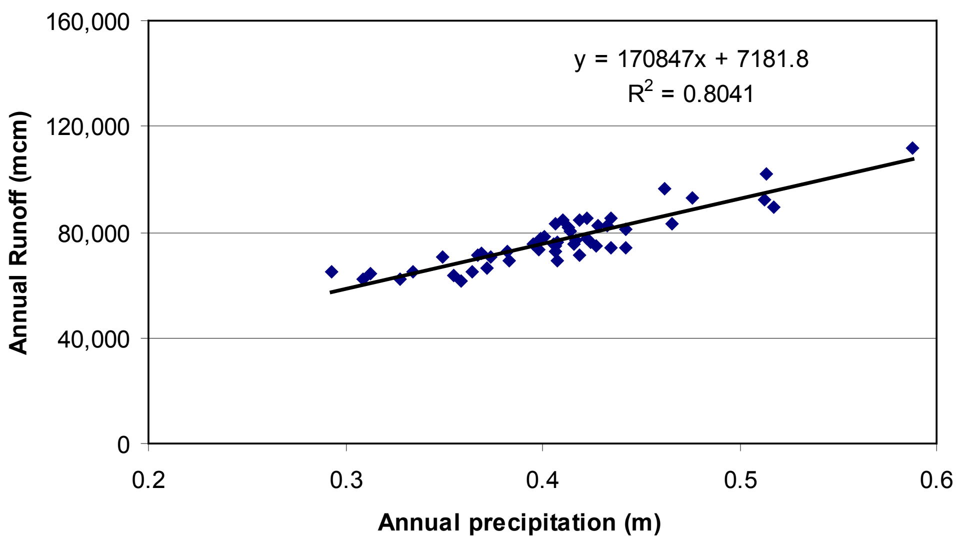

Figure 23. Whole basin annual runoff as a function of annual precipitation.

6. EXAMPLE USE

We give two examples of using the spreadsheet to model two impacts of change, increased irrigation efficiency, and inter-basin water transfers.

Cai and Rosegrant (2003) modelled the increase of water-use efficiency from about 0.5 to 0.7. For the exercise here, we modelled increasing irrigation efficiency from 0.5 to 0.7. Cai and Rosegrant (2003) noted that local increase of irrigation efficiency does not necessarily translate into changes at the whole basin level, because of the potential re-use downstream of saved water. Such effects are built into our water-use account. The impact of the increased irrigation efficiency on flows at Gaucung is shown in Figure 24. The annual average flow at Gaucung is predicted to increase from 43,700 to 47,900 mcm. The annual average water applied as irrigation across the Basin is predicted to decrease from 40,300 to 31,400 mcm.

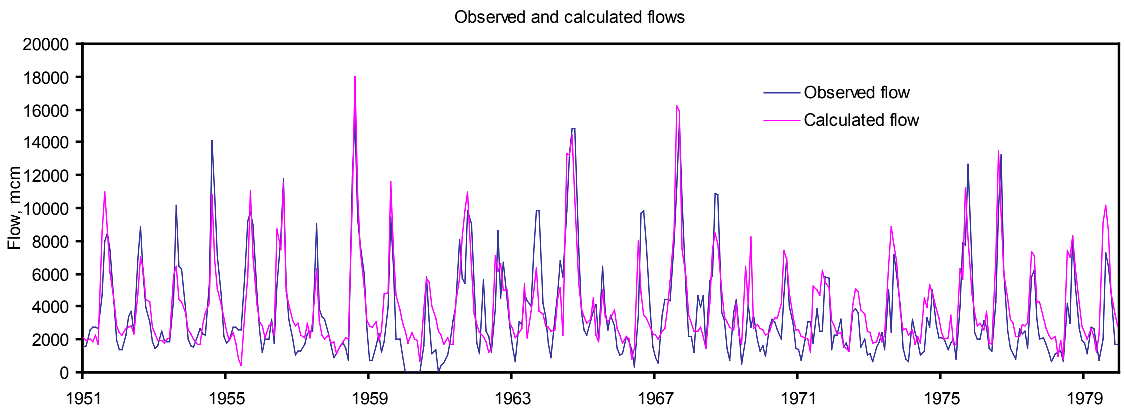

Figure 24. Observed and modelled flow with increased irrigation efficiency from the Gaucung catchment. Compare the calculated flow here with that in Figure 18.

The second example involves the South-North Water Transfer (SNWT), a scheme to take water from the Yangtze River to the North China Plain and Beijing. Cai and Rosegrant (2003) modelled a transfer into the Yellow River for use in irrigation and environmental flows. Three options are being considered in the SNWT, and here we model the option of the western route, in which water from the upper Yangtze will be fed into the upper Yellow River, although some consider this option unlikely to be chosen (US Embassy Beijing 2003). We modelled a transfer into the headwaters of the Yellow River of 9,000 mcm/yr in equal monthly volumes of 750 mcm, and allowed it to flow down the Yellow River as additional environmental flow. The impact on flows at Gaucung is shown in Figure 25. The annual average flow at Gaucung is predicted to increase from 43,700 to 52,500 mcm.

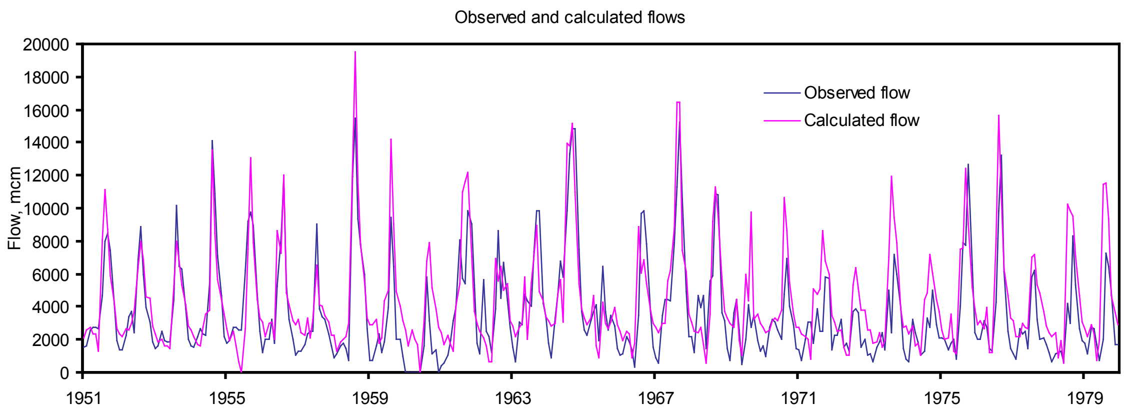

Figure 25. Observed and modelled flow from the Gaucung catchment with increased flow due to transfer of 9000 msm/yr from the Yangtze River to the headwaters of the Yellow River. Compare the calculated flow here with that in Figure 18.

7. CONCLUSIONS

A very simple spreadsheet model with few adjustable parameters has produced plausible runoff and river-flow behaviour in the Yellow River Basin. It must be further developed to give a better representation of water use by different land uses.

The Yellow River Basin has low annual rainfall of about 400 mm, which falls mostly in the summer half of the year, leading to peak river flows usually in the summer. Despite the modest amount of water available, there is considerable irrigation in the lower Basin, and it appears that this relies on groundwater in addition to surface water diversions.

We have used the spreadsheet to develop preliminary scenarios that simulate the impact of increasing irrigation efficiency and inter-basin water transfers. The results suggest that increasing irrigation efficiency, with unused flows returned to the river, would somewhat reduce water use and increase downstream river flows. Water transfer from the upper Yangtze to the upper Yellow River, and used to boost flows in the latter, leads to an increase in the flows throughout the river.

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