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BASIN FOCAL PROJECTS SERIES

Water-use accounts in CPWF basins

Simple water-use accounting of the Karkheh 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 Karkheh River basin in Iran. The Karkheh Basin lies primarily in Iran with its extreme downstream discharge into the Hawr Al Azim marshes on the border with Iraq. The northern part of the Basin where the Karkheh and its tributaries rise is mountainous, cooler, and wetter. The River spills out on to the hotter, lower semi-arid plains at its southern end. Near the downstream end of the Karkheh River is a major dam, built recently to supply water for irrigation. Precipitation, mainly in winter, varies from 400-500 mm in the upper part of the Basin falling to about 230 mm in the lower reaches. Rainfall exceeds evaporation only for a few winter months, and only in the upper catchment. Preciptiation varies considerably from year to year.

Net runoff from the basin is less than 2% of total precipitation. Total water use exceeds rainfall by about 14%, the difference is assumed to be largely pumped groundwater in the upper and middle parts of the basin. Grassland is the most extensive land use and uses about 50% of the total available water. Irrigation, although occupying a smaller area, consumes about 28% of the available water followed by rainfed agriculture, which consumes about 20%.

Plausible figures for the effect of the Karkheh Dam suggest that it will reduce flows downstream of the Dam and the inflow into the Hawr Al Azim marshes.

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

2. INTRODUCTION

In this note, we describe a simple water-use account for the Karkheh Basin of Iran.

The Basin Focal Project of the Challenge Program on Water and Food (CPWF) aims to explore threats, opportunities, and trade-offs in water access and impact on agricultural productivity and hence poverty, livelihoods, and environment. It does this in several priority basins: the Indo-Gangetic Basin, the basins of the Karkheh, Limpopo, Mekong, Niger, Nile, São Francisco, and Yellow River, and a collection of small basins in the Andes.

To address the aims, the CPWF wants a model that integrates hydrology with social uses and benefits of water. It must be quick and easy to develop, modify, and run, and must run using the limited data available in the Karkheh Basin. It must be capable of looking at the trade-offs amongst uses, opportunities such as increased irrigation, and threats to the water resource such as land use change and climate change.

Here, we describe a demonstration-level water account part of an overall model. It is based on a similar water account of the Mekong River basin, developed in a companion Basin Focal Project. The Karkheh demonstration water account is an Excel spreadsheet.

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, and Limpopo Rivers (Kirby et al. 2006a; Kirby et al. 2006b). Here we describe the application to the Karkheh Basin.

As we shall describe below, the account has been developed using existing data, and gives an overview of water uses within the Basin. There are some problems with the data, which we shall describe, and 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.

3. BASIC HYDROLOGY AND OUTLINE OF SIMPLE WATER ACCOUNT

3.1. BASIC HYDROLOGY, IRRIGATION, AND LAND USE

The Karkheh Basin covers about 60,000 km^2, and is drained by the Karkheh River and its tributaries (Table 1 and Figure 1). The Basin is mountainous, cooler, and wetter in the north, where the Karkheh River and its tributaries rise. The River spills out on to the hotter, lower semi-arid plains at its southern end. Near the downstream end of the Karkheh River is a major dam, built recently for the supply of irrigation water. Downstream of the dam, the river discharges into the Hawr Al Azim marshes, where most of the remaining water is lost as evapotranspiration. Presumably, there is discharge from the marshes into the Tigris-Euphrates system during extreme floods.

The precipitation varies around 400 to 500 mm per year in much of the upper part of the Basin, falling to about 230 mm per year in the lower part (Figure 2). The precipitation falls mainly in the winter (November to March), with almost no rain in the summer, and often falls as snow in the upper catchment. Potential evapotranspiration is low in the winter, but peaks in the summer (June to August). Rainfall exceeds potential evapotranspiration only for a few months in the winter, and only in the upper catchment. In addition to the spatial variability of precipitation, there is considerable year-to-year variability (Figure 3).

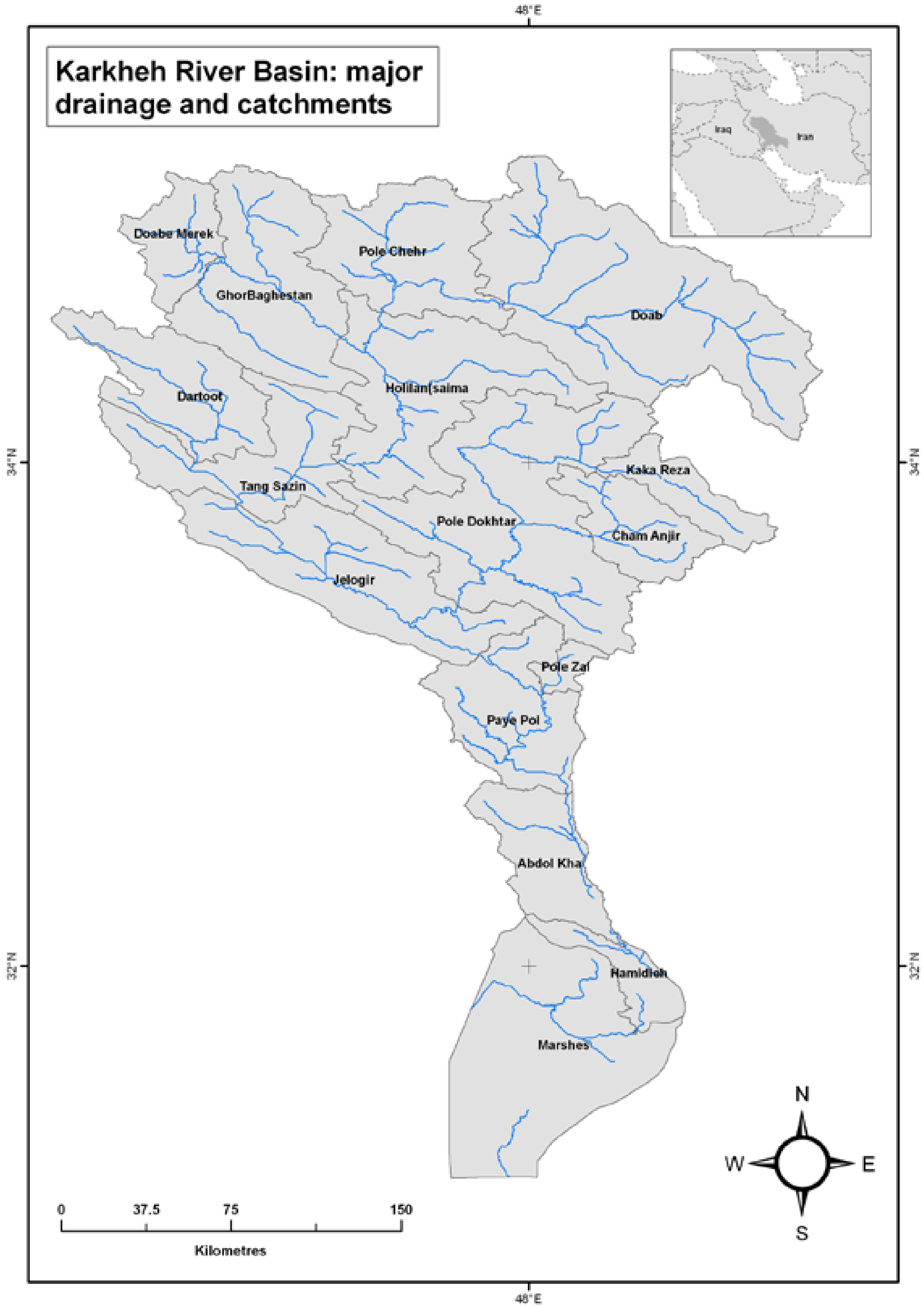

Figure 1. The Karkheh Basin, with the catchments used in the water-use account.

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

Catchment	Area, km^2
Doab	7,473
Pole Chehr	1,975
Doabe Merek	3,897
Ghor Baghestan	3,887
Holilan	4,200
Dartoot	2,563
Tang Sazin	2,871
Kaka Reza	1,093
Cham Anjir	1,634
Pole Dokhtar	6,742
Jelogir	4,075
Pole Zal	330
Paye Pol	2,668
Abdol Khan	1,872
Hamidieh	921
Marshes	6,709
Total	52,910

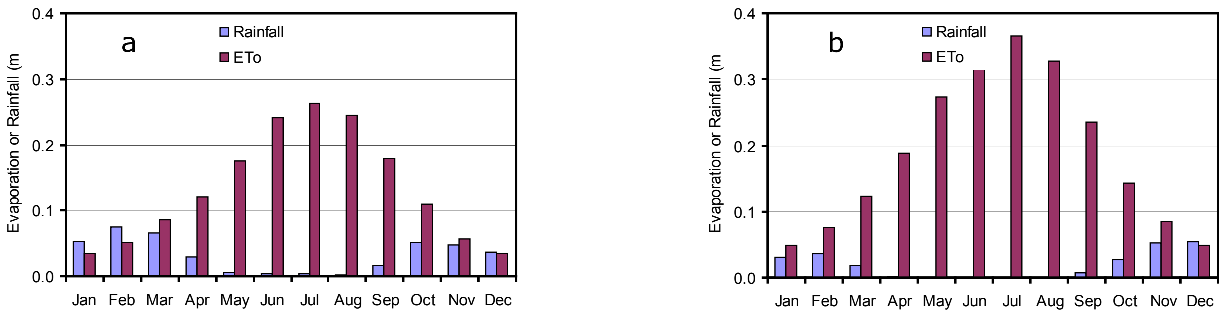

Figure 2. Monthly average precipitation and potential evaporation in the Karkheh Basin. a). Doab catchment in the north of the Basin; and b). Marshes catchment in the south of the Basin.

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.

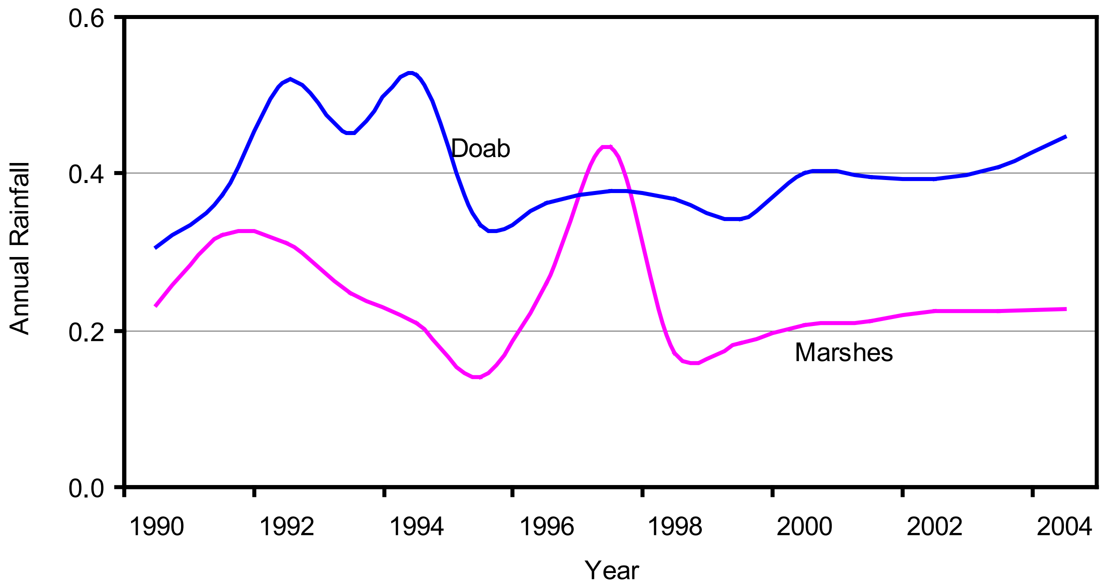

Figure 3. Annual rainfall 1990-2004 at Doab and at the Hawr Al Azim marshes.

The account is a top-down model (Sivapalan et al. 2003), based on simple lumped partitioning of rainfall into evapotranspiration and runoff, with a temperature-indexed snow-storage and melting model (Hock 2003; Konz et al. 2006; Williams 2007). This is done at the catchment level, with no spatial separation into different vegetation types. Runoff flows into the tributaries and into the Karkheh River, with downstream flow calculated by simple water balance. During high flows, some of the flow is stored in the channels.

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.

3.2.1. 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

Hereunder is a brief summary only of the input data.

4.1. RAINFALL

Rainfall and potential evapotranspiration from 1990 to 2004 were supplied by M.D. Ahmad (project leader, CPWF Karkheh Basin Focal Project). Potential evapotranspiration was available for three locations only, two in the upper part of the Basin and one in the lower part. The locations are thought to be representative of the surrounding catchments, and so the records for each location were used for several catchments. Rainfall data were available for every catchment.

4.2. REACH FLOWS

Provided by M.D. Ahmad.

4.3. LAND USE

Some basic statistics for areas of forest, grassland, and cropping (dryland and irrigation) were supplied by M.D. Ahmad. Grassland contains important areas of other land uses including barren land.

4.4. DATA LIMITATIONS

The flow from several catchments is an improbably large fraction of the precipitation. This suggests that either that there are large transfers of water into some catchments (perhaps through groundwater?), or there are errors in either the flow data or the precipitation data or both. The transfers seem to us unlikely, given that these are mountainous catchments and so there is little opportunity for water to flow (downhill) into the Karkheh Basin from surrounding basins. We are therefore more inclined to think that there are errors in the data. We shall discuss the errors in more detail in section 6.3.

5. COMPONENTS AND RESULTS IN DETAIL

5.1. FLOW

5.1.1. THE UPPER BASIN

The Upper Basin comprises all of the catchments except Abdol Khan, Hamidieh, and the Hawr Al Azim Marshes. All the catchments in the Upper Basin show an excess of precipitation over potential evapotranspiration in the winter. The flow from each catchment lags the precipitation by some months and often peaks in the spring (Figure 4). Peak flows may occur in the winter in some years, such as the winter of 1994-5. The flow was less after 1999 in a manner that appears unrelated to changes in precipitation, and this may indicate a change in land use. We have no information about a land-use change, and so have not attempted to model it.

Figures 5 to 10 show the observed and calculated flow from several catchments in the Upper Basin. All show a similar pattern, with peak flows in the spring and sometimes the winter, except for the Dartoot catchment, which has fewer winter peaks than the flows in the other catchments.

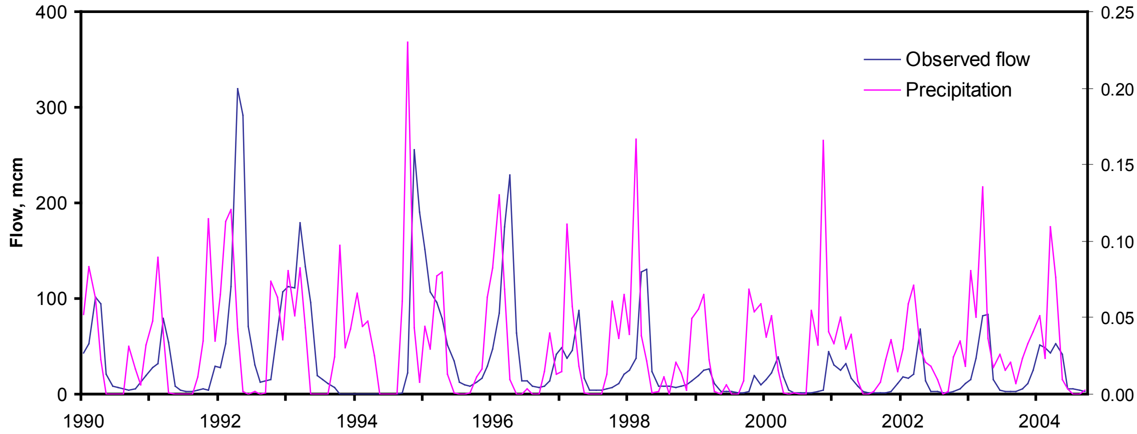

Figure 4. Rainfall and flow from the Doab catchment, 1990-2004.

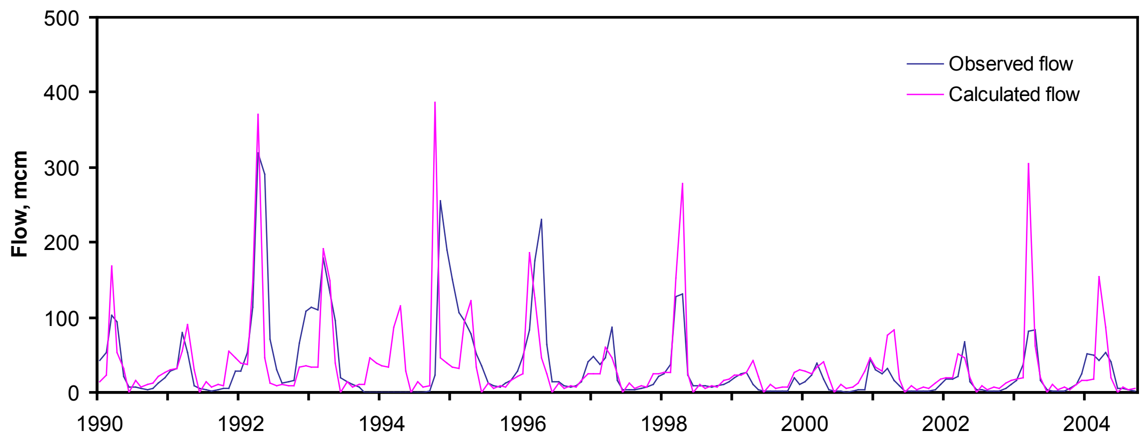

Figure 5. Observed and calculated flow from the Doab catchment, 1990-2004.

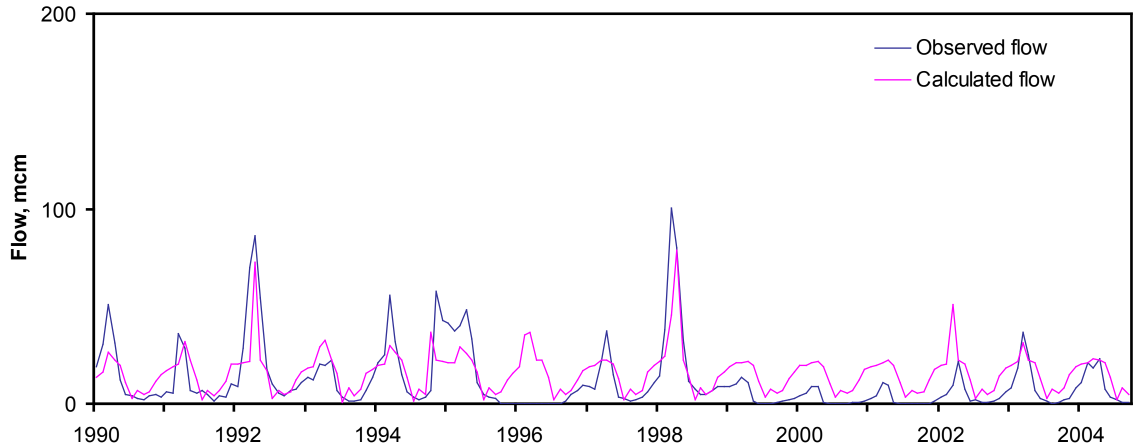

Figure 6. Observed and calculated flow from the Doabe Merek catchment, 1990-2004.

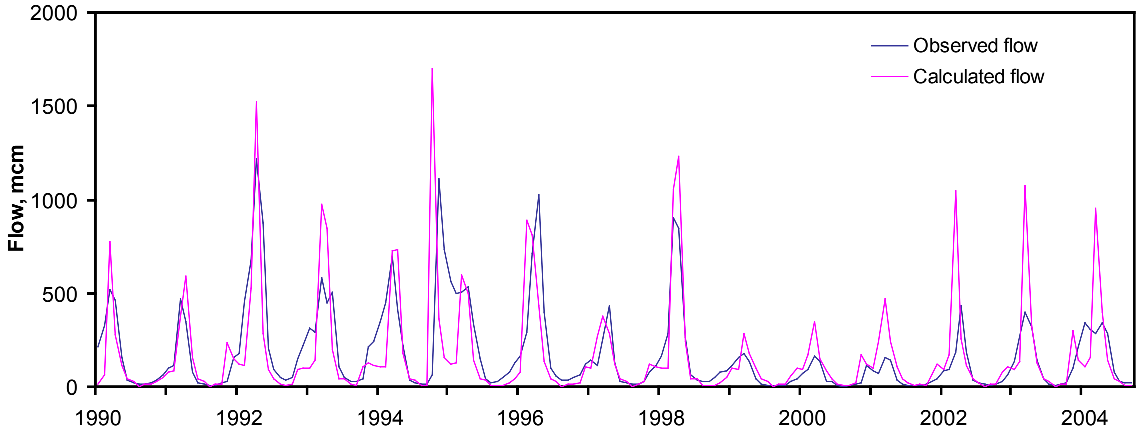

Figure 7. Observed and calculated flow from the Holilan catchment, 1990-2004.

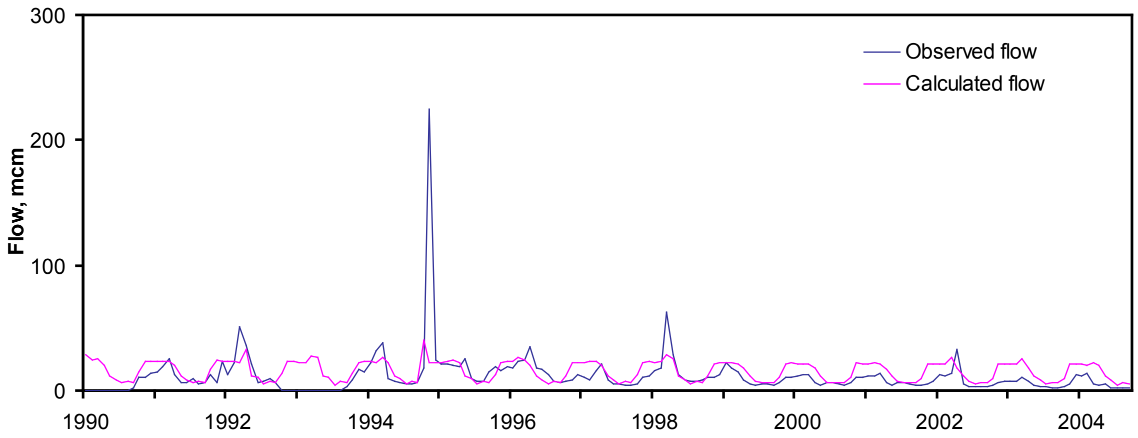

Figure 8. Observed and calculated flow from the Dartoot catchment, 1990-2004.

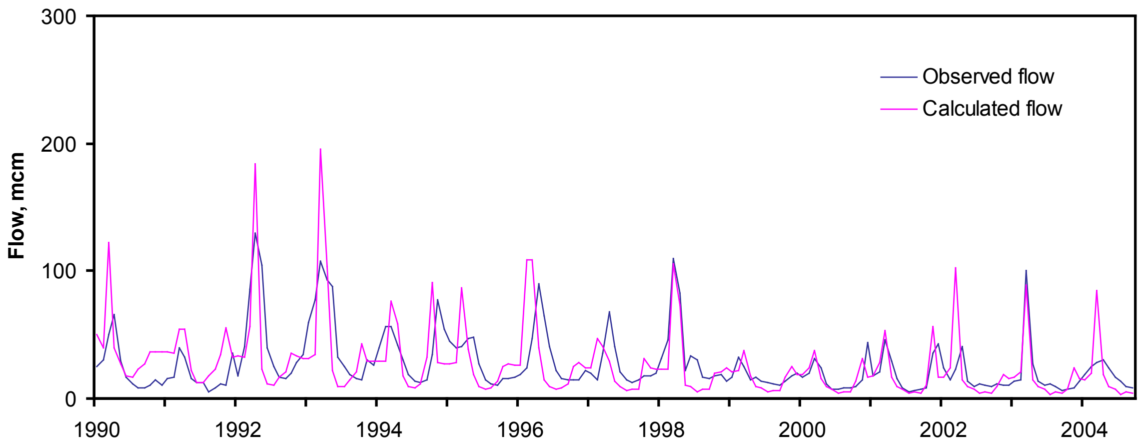

Figure 9. Observed and calculated flow from the Cham Anjir catchment, 1990-2004.

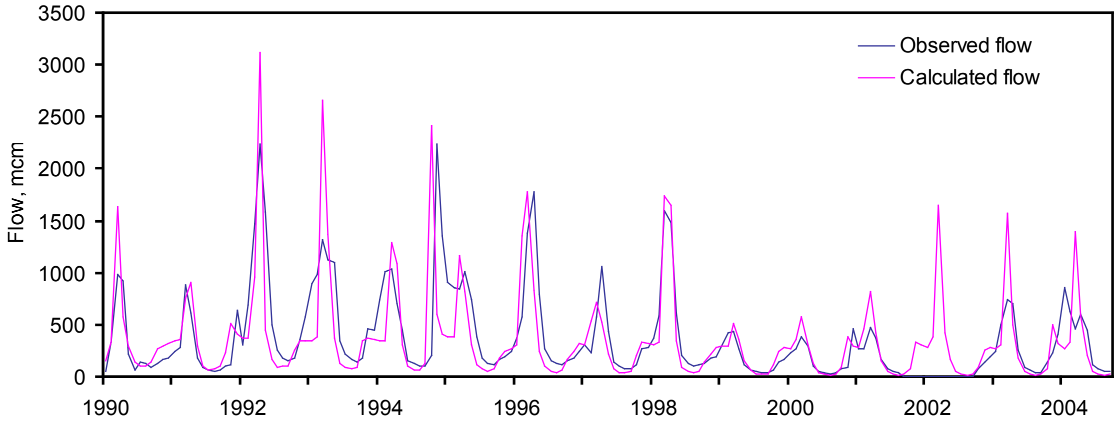

Figure 10. Observed and calculated flow from the Jelogir catchment, 1990-2004.

The comparison of observed and calculated flows is not particularly good, though the main features are modelled. As noted above in section 5.4, and discussed in more detail below, there is reason to doubt the measured flow and precipitation data. While there are undoubtedly shortcomings of the modelling, the data problems exacerbate matters and make it hard to improve the modelling.

5.1.2. THE LOWER BASIN

The Lower Basin comprises the Abdol Khan, Hamidieh, and the Hawr Al Azim Marshes catchments. The catchments in the Lower Basin have lower rainfall and higher potential evapotranspiration than those in the Upper Basin, and show little or no excess of precipitation over potential evapotranspiration even in the winter months. Flows in the Karkheh River are here dominated by flows from the upper basin. The flow at Hamidieh (Figure 11) is similar to that at Jelogir (Figure 10), except perhaps in 2003 and 2004, when the flows at Hamidieh showed neither the low flow in the summer period nor the peak flows in winter. This period is after the Karkheh Dam was commissioned, and the observations may reflect a new management regime. Since the Dam and its operation have not been modelled, this is not reflected in the calculated flow.

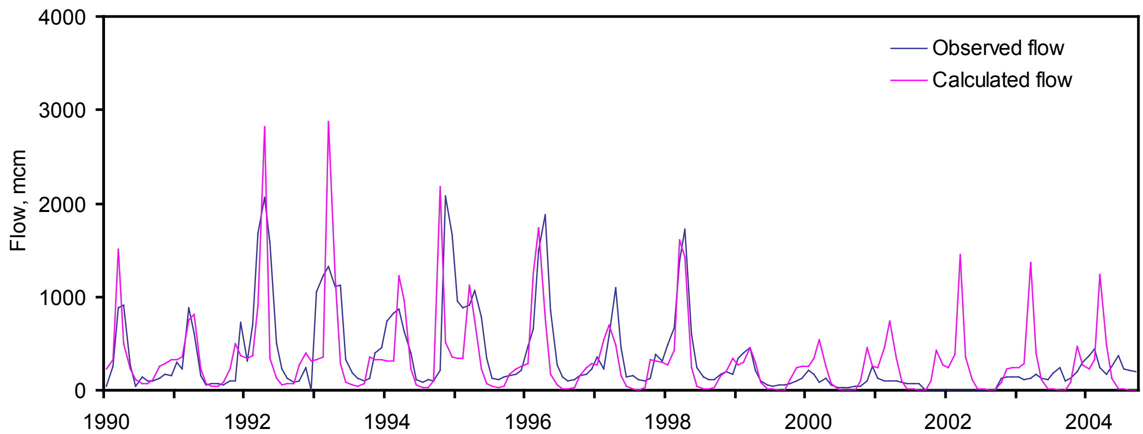

Figure 11. Observed and calculated flow from the Hamidieh catchment, 1990-2004.

The end (discharge) subcatchment has an area of 6709 km^2, and includes some of the Hawr Al Azim wetland. We have been given few data of land use for this subcatchment, so we have assumed:

- That there is 1000 km^2 of irrigation;
- That the marshes occupy up to 2000 km^2, and have a capacity of up to 20000 mcm (i.e. are 10 m deep when full to capacity);
- That the relationship between volume, V_m, and area, A_m is non-linear with the volume falling more rapidly than the area, given by:

$$A_m = A_{m\max}\left(\frac{V_m}{V_{m\max}}\right)^{c6} \quad (1)$$

where V_{mmax}, is the maximum volume;

A_{mmax} is the maximum area; and

$c6$ is a constant, taken to be 0.1.

Evaporation from the marshes is given by

$$E = c_4\, ET_0\, A_m \quad (2)$$

The calculated flow is shown below in Figure 12. There are no flow measurements.

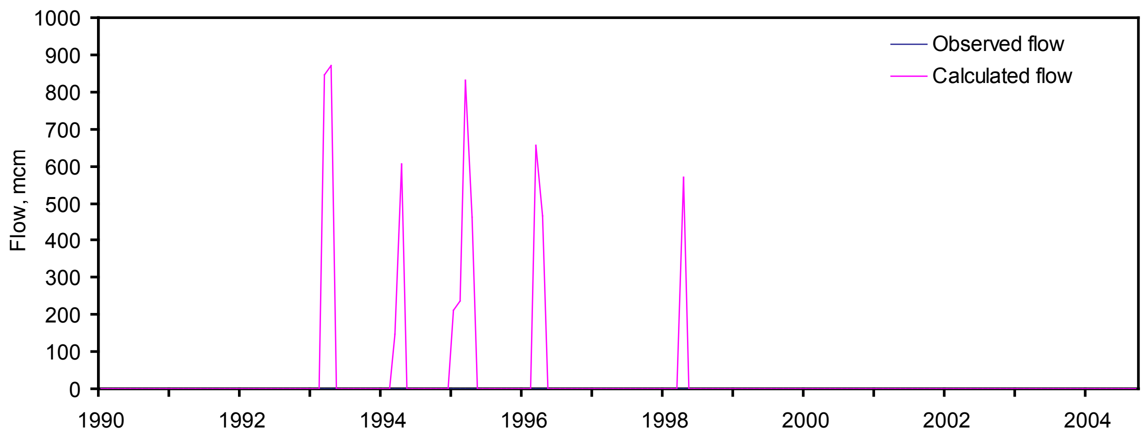

Figure 12. Observed and calculated flow from the Hamidieh catchment, 1990-2004.

The calculations suggest that the marshes may well have discharged a small volume of water into the Tigris River in wet years, but in other years there may have been no discharge, with the flow being lost to evaporation from the marshes, irrigation, and unidentified losses. The annual average discharge was, according to this calculation, about 400 mcm per year (0.4 km^3). This figure should not be treated as reliable, since we have assumed the areas and other parameters for the marshes and the irrigated area, but it gives a feel for the behaviour.

5.2. WATER USE

The mean annual input by precipitation to the Karkheh Basin totals 21,400 mcm/yr, according to the data supplied. Figure 13 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 400 mcm/yr. The evaporation and losses are mainly evapotranspiration in the Hawr Al Azim marshes. The water uses shown in Figure 13 sum to 24,500 mcm/yr, which is 3100 mcm/yr more than the rainfall. The difference is made up of storage changes and is presumed to be largely due to pumping of groundwater (M.D. Ahmad, personal communication). However, Ashrifi et al. (2004) suggest that groundwater is overpumped in only a few minor areas, and suggest that the problem may be overcome by artificial recharge ("artificial feeding").

According to the land use classification, grassland and barren land is the most extensive land use class, and uses the greatest amount of water. Irrigation, although occupying a smaller area, consumes the second largest quantity of water in the Basin. Evaporation and losses are primarily evapotranspiration in the marshes and losses from the river in the lower part of the Basin above the marshes.

The distribution of the different water uses across the Basin is shown in Figure 14. 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 – the net runoff from the whole Basin is shown in Figure 13. The figure shows the different behaviour of the runoff-generating Upper Basin and the Lower Basin where much of the flow is consumed by evaporation in the marshes and other losses. Irrigation is a major water user in most parts of the Basin.

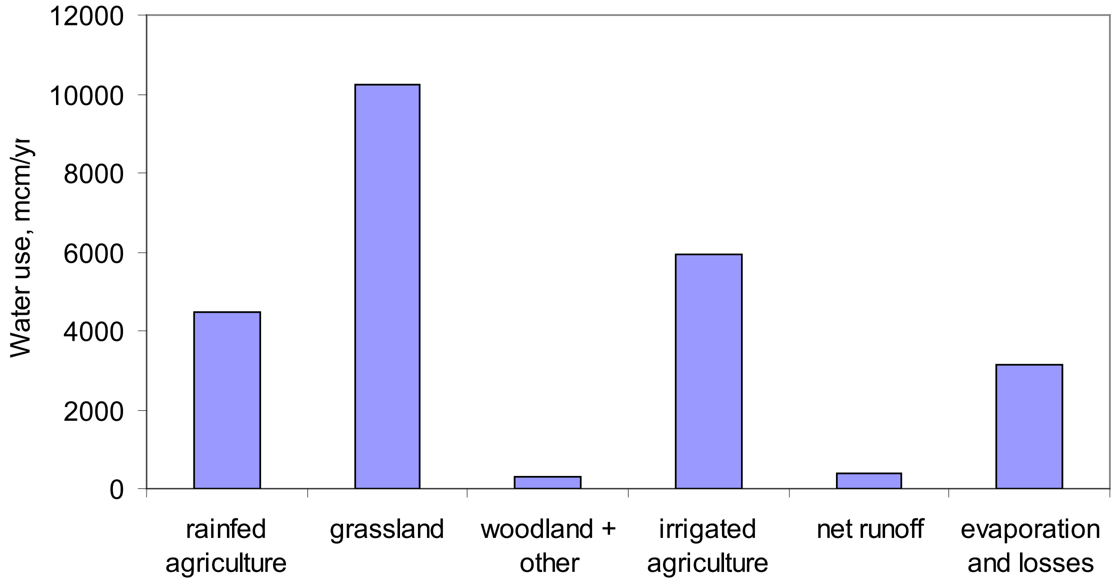

Figure 13. Major water uses (annual averages 1990-2004). Grassland includes barren land (see Section 4.3).

5.3. CATCHMENT AND BASIN HYDROLOGICAL CHARACTERISTICS

Selected hydrological characteristics will be useful for comparing the Karkheh 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 Karkheh basin is 24% (i.e. mean annual runoff is 24% 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 2).

Table 2 indicates a problem in Pole Zal, perhaps also Kaka Reza, Pole Chehr , and Paye Pol catchments. Here, the runoff ratio is impossibly high (greater than 100% in Pole Zal) or larger than is likely (in the other three catchments). Leaving aside the possibility of large transfer of water into these catchments, which seems to us unlikely, this may indicate a problem with the rainfall data, the river discharge data, or both. Experience in the Indus (Eastham et al. 2008) shows that the rainfall data are often suspect, and may underestimate the rainfall in a catchment particularly in mountainous areas. We presume that this arises at least partly from biased spatial sampling, in that the rain gauges are sited preferentially in the valleys, and miss the greater rainfall and snowfall on the mountains. Whether that is the case in this catchment, we cannot tell. A consequence of under-estimated rain could in turn be under-estimated water use by rainfed crops and other vegetation. If better and more correct climate data cannot be obtained, an alternative way to develop improved water accounts would be to develop remote sensing to estimate water use.

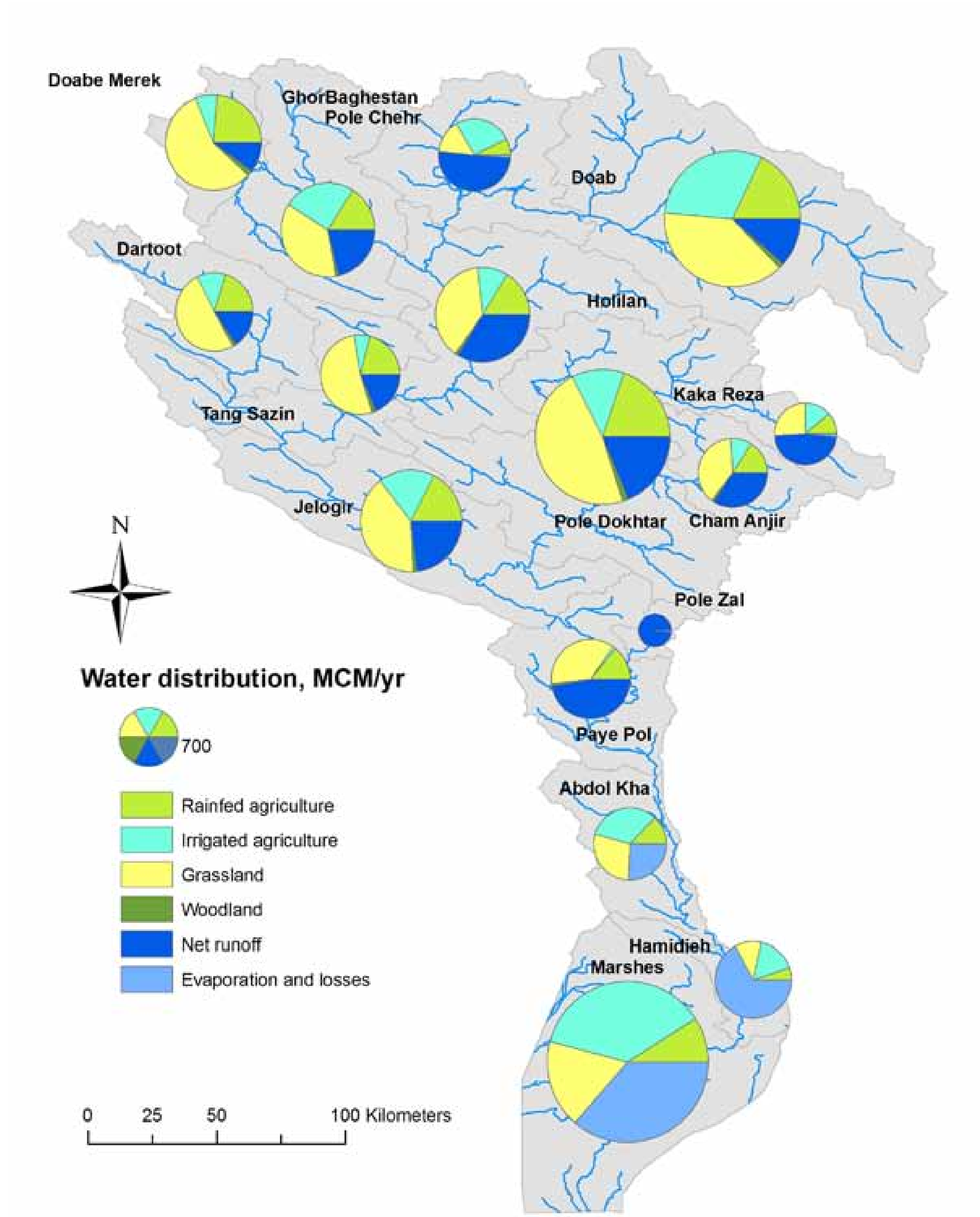

Figure 14. Major water uses (annual averages 1990-2004) in the catchments in the Karkheh Basin. Woodland contains other minor land uses, and grassland includes barren land (see Section 4.3).

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

Catchment	Runoff ratio (%)
Doab	15
Pole Chehr	58
Doabe Merek	10
Ghor Baghestan	25
Holilan	33
Dartoot	18
Tang Sazin	19
Kaka Reza	66
Cham Anjir	40
Pole Dokhtar	20
Jelogir	28
Pole Zal	118
Paye Pol	58
Abdol Khan	0
Hamidieh	0
Marshes	0
Whole Basin	24

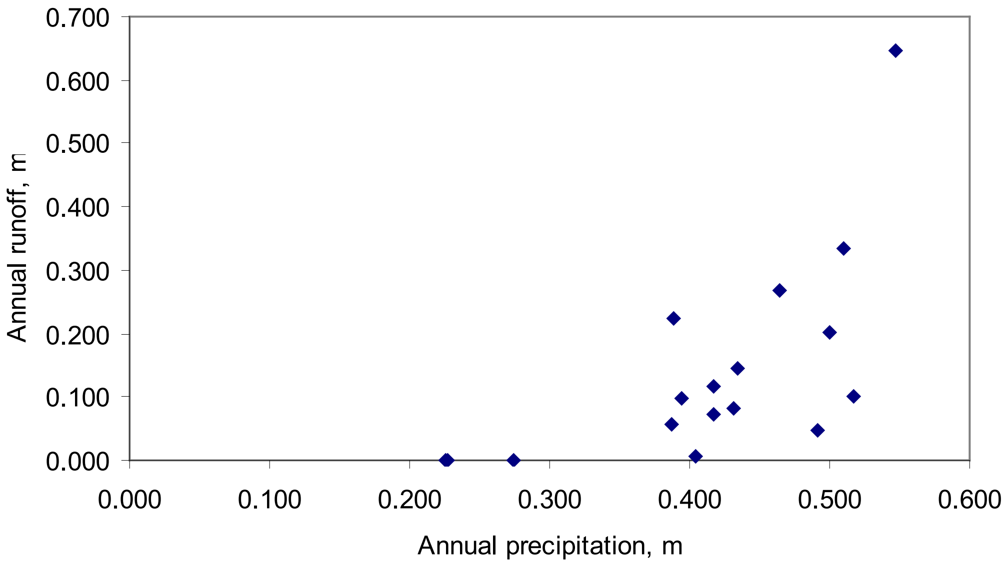

Figure 15. Runoff (annual averages 1990-2004) in the catchments in the Karkheh Basin.

The annual runoff generally increases with annual precipitation (Figure 15), but the data show considerable scatter. This may be a result of the data problems referred to above: the outlier with runoff greater than 0.6 m is Pole Zal, the catchment with the impossible runoff ratio.

6. EXAMPLE USE

As a demonstration, we examine the consequences of the Karkheh Dam. The Dam has a capacity of 7800 mcm and is just above the Paye Pol catchment. The Dam will be used to supply irrigation districts of up to 2900 km^2, which is about 1600 km^2 more than we have assumed was developed prior to the Dam. Ashrifi et al. (2004) suggest (Table 8 of their report) that as much as 2,500 km^2 of new irrigation area could be associated with the development of the Dam. We assume that the Dam discharge equals the demand from the irrigation areas downstream, which is in turn calculated from the area, the crop coefficient, the potential ET, and an irrigation efficiency, as given by equations (12) to (16) in Water-use accounts in CPWF basins: Model concepts and description (Kirby et al. 2010), plus volumes in excess of the storage capacity. The downstream irrigation districts take from the river what they require, subject to the available flow.

The consequences for flow at Hamidieh are seen in Figure 16, which indicates that the flow downstream of the dam would be modified considerably. Furthermore, the water inflow to the Hawr Al Azim marshes is predicted to reduce from the pre-dam value of about 1900 mcm/yr to about 500 mcm/yr, and the net runoff from the basin is predicted to reduce to zero. We emphasize that the example is for demonstration only. We do not know how the Dam will be operated. We have assumed no allowance of flows (either volume or timing) to the Hawr Al Azim marshes or elsewhere.

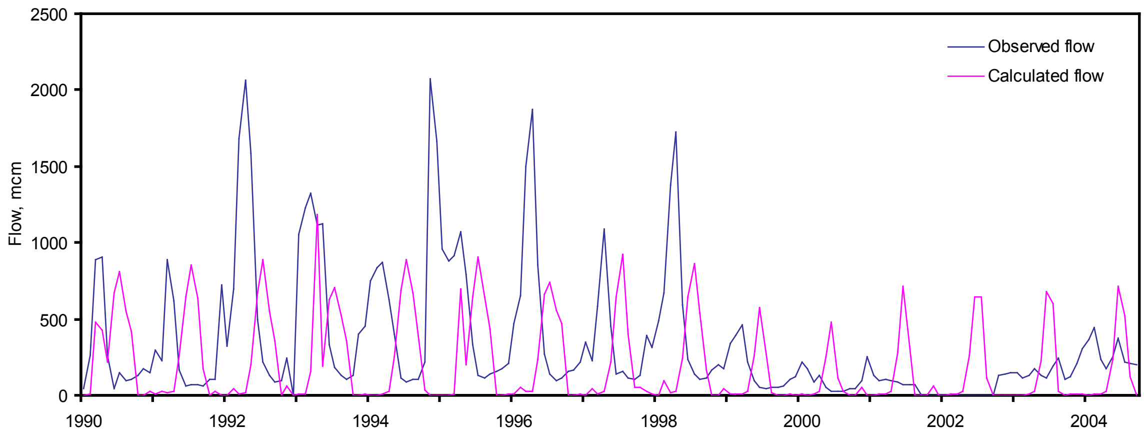

Figure 16. Flow at Hamidieh under an assumed regime of a dam at Paye Pol. The dam supplies increased irrigation areas in the lower Karkheh Basin, compared to the historical (no dam) flows.

7. CONCLUSIONS

A very simple spreadsheet model with few adjustable parameters has produced plausible simulation of runoff and river flow in the Karkheh Basin. It can be further developed to give a better representation of water use by different land uses. This would entail developing more complete and error free climate and stream-flow data, as well as land-use and crop-coefficient data. We have shown that there are some problems with the climate and stream-flow data, with some catchments apparently showing unreasonably large runoff ratios.

The Karkheh Basin has low rainfall, mostly in the winter half of the year, leading to peak river flows usually in the early spring. Despite the modest availability of water, there is considerable irrigation, and it appears that this relies on groundwater in addition to surface water diversions. It is unclear whether the groundwater use can be sustainable.

We have undertaken a preliminary scenario that simulates the impact of dam development on water availability and productivity of irrigated cropping in the lower part of the Basin. The results suggest that the upstream development will have a large impact on water availability in the lower Karkheh Basin, and hence on the prospects for irrigation and on the Hawr Al Azim marshes.

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