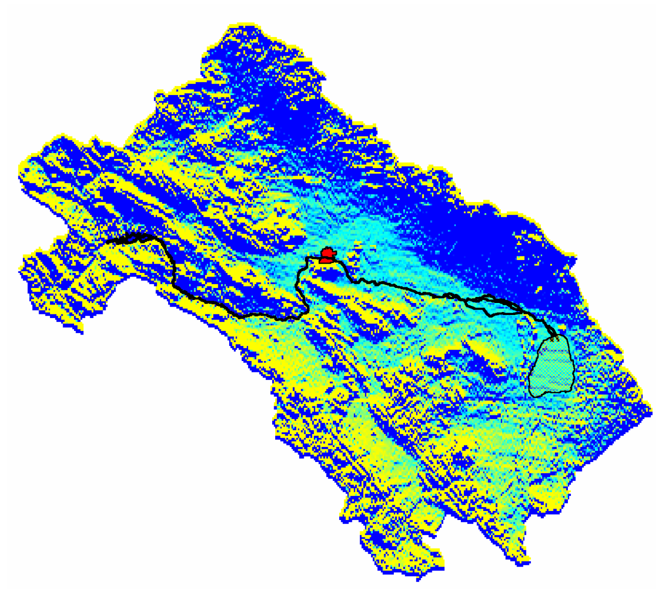
Sustainable Irrigation and Water Management in the Zayandeh Rud Basin, Iran

An Overview of the Hydrology of the Zayandeh Rud Basin

H. Murray-Rust , H. Sally,
H.R. Salemi, A. Mamanpoush



Research Report No. 3

Iranian **A**gricultural **E**ngineering **R**esearch **I**nstitute
Esfahan **A**gricultural **R**esearch **C**enter
International **W**ater **M**anagement **I**nstitute

IAERI EARC IWMI

H. Murray-Rust, H. Sally, H.R. Salemi, A. Mamanpoush. 2000. An Overview of the Hydrology of the Zayandeh Rud Basin, Esfahan Province, Iran. IAERI-IWMI Research Reports 3.

Keywords: Salinity, simulation model, Iran, agro-hydrology, irrigation

H. Murray-Rust, International Water Management Institute
H. Sally, International Water Management Institute
H.R. Salemi, Esfahan Agricultural Research Center
A. R. Mamanpoush, Esfahan Agricultural Research Center

The IAERI-EARC-IWMI collaborative project is a multi-year program of research, training and information dissemination fully funded by the Government of the Islamic Republic of Iran that commenced in 1998. The main purpose of the project is to foster integrated approaches to managing water resources at basin, irrigation system and farm levels, and thereby contribute to promoting and sustaining agriculture in the country. The project is currently using the Zayendeh Rud basin in Esfahan province as a pilot study site. This research report series is intended as a means of sharing the results and findings of the project with a view to obtaining critical feedback and suggestions that will lead to strengthening the project outputs. Comments should be addressed to:

Iranian Agricultural Engineering Research Institute (IAERI)
PO Box 31585-845, Karaj, Iran.
Phone: +98-261-241116, fax: +98-261-226277
e-mail: maryam.sal@neda.net

Esfahan Agricultural Research Center (EARC)
PO Box 81785-19, Esfahan, Iran
Phone: +98-31-757201-2, fax: +98-31-759007
e-mail: agresor@cc.iut.ac.ir

International Water Management Institute (IWMI)
PO Box 2075, Colombo, Sri Lanka
Phone: +94-1-867404, fax +94-1-866854
e-mail: iwmi@cgiar.org

An Overview of the Hydrology of the Zayandeh Rud Basin, Esfahan Province, Iran

H. Murray-Rust, H. Sally, H.R. Salemi, A. Mamanpoush

Abstract

This paper provides an overview of the hydrology and water use in the Zayandeh Rud basin based on the data available over the 11-year period 1988-1998. The inflows into Chadegan reservoir, the releases from the reservoir, and the extractions along the river for irrigation and other purposes are considered, and a rapid water balance of the basin is performed.

Inflows to the Chadegan reservoir, which serves to collect and regulate the runoff from the upper catchment of the basin to better meet the downstream water requirements for irrigation, urban and industrial uses, follow a regular pattern with moderate variability. But the limited year-to-year carryover storage in the reservoir makes the basin vulnerable to prolonged periods of drought.

Water releases from the Chadegan reservoir also show a predictable pattern, with the only deviations occurring during flood events. There is a high reliability of meeting the water requirements during periods of peak demand. But releases during the winter months, at the end of the irrigation season, are lower and more variable. This results in low discharges in the Zayandeh Rud and reduced water quality, especially in the lower reaches of the river.

A simple water-balance approach was used to estimate the proportion of return flows in the basin. An average annual value of 30% was obtained, with the magnitude of return flows being particularly important in the lower reaches of the basin. But more investigation, especially including groundwater and water quality aspects, needs to be carried out before a definitive value can be advanced.

Given the limited supply of fresh water in the Zayandeh Rud basin, further water resources development and water management improvements can only be envisaged if there is scope for real water savings in the basin. This can be assessed if a basin-wide approach, leading to a good understanding of water use (and reuse) at the farm, system and basin levels, is adopted.

Introduction

The Zayandeh Rud is a vitally important river for agricultural development, domestic water supply, and overall economic activity of the Esfahan Province in central Iran. However, population growth and greater industrial activity have increased the demand and competition for water resources in its basin. The agricultural sector has been particularly affected. Water shortages not only make it difficult to irrigate the full extent of irrigable land, but also lead to the salinization of soils in the lower portions of the Zayandeh Rud basin and a reduction in the quality of return flows into the river. The lower reaches of the river downstream of Esfahan are further polluted by ever-increasing quantities of urban and industrial effluent being returned into the river.

The IAERI-EARC-IWMI Collaborative Research project, established in 1998, addresses the question of how integrated approaches to irrigation and water management can contribute to sustaining agricultural productivity in the Zayandeh Rud basin, taking into account the multiple uses of water in the basin.

Water use, and especially the scope for further water resources development, cannot be ascertained by analyzing water utilization only at the farm or system level. Proper accounting of water availability and water use at the farm, system and basin levels is required, particularly in the context of limited supplies of fresh water and multiple uses of the available resource. Return flows from seepage, percolation and surface runoff traditionally considered as “losses” at farm and system level must all be taken into account. Molden (1997) proposed a water accounting framework where water balance components are classified into water-use categories that reflect the consequences of human interventions in the hydrological cycle.

It is also worth noting that a number of authors (Seckler 1996; Keller et al. 1996; Perry 1996; 1999) have raised questions regarding the traditional concept of irrigation efficiency, which typically relates the volume of water beneficially used (i.e., crop evaporation) to the amount of water diverted to a use. First, increases in efficiency at a local level do not necessarily lead to water savings at a basin level. Second, increases in efficiency defined in this manner are not necessarily better. For example, higher evaporation with the same diversion may lead to environmental degradation, or water may be evaporated by a less beneficial use. To get a better indication of how well water is being used and of the scope for additional beneficial use, it is perhaps preferable to compare the amount of water depleted by various uses deemed to be beneficial, to the amount of water available for use in that basin -- the concept of basin efficiency proposed by Molden and Sakthivadivel (1999).

This paper provides an overview of the hydrology of the Zayendeh Rud basin, from the point of view of the inflows into Chadegan reservoir, the releases from the reservoir, and the regulation and use of flows along the river for irrigation and other purposes. A rough water balance of the basin highlights the challenges related to managing and improving the productivity of water in a closed basin, especially in regard to the need to correctly assess the degree of return flows when seeking water management improvements.

The Zayandeh Rud Basin

Physical Description

The Zayandeh Rud basin lies in central Iran (Figure 1). It is a completely closed basin having no outlet to the sea. The river is about 350 km long and runs in a roughly west-east direction, originating in the Zagros Mountains, west of the city of Esfahan, and terminating in the Gavkhuni Swamp to the east of the city. The Zayandeh Rud provides irrigation, domestic and industrial water to Esfahan Province, which is one of the most important economic areas of Iran.

The area of the Zayandeh Rud basin is some 41,500 km^2. However, only the area upstream of the Chadegan reservoir makes any significant contribution to the streamflow. Below the reservoir there are virtually no inflows into the river, and they are so infrequent that it would be impossible to use them in any planned manner. The total water supply in the basin is augmented by the diversion of water from the Kuhrang River in Chaharmahal-va-Bakhtiari province into the upper reaches of the Zayandeh Rud. Two diversion tunnels in operation since 1986 can deliver 540 million cubic meters of water a year while a third tunnel, expected to be ready in a few years, will deliver a further 250 million cubic meters of water annually.

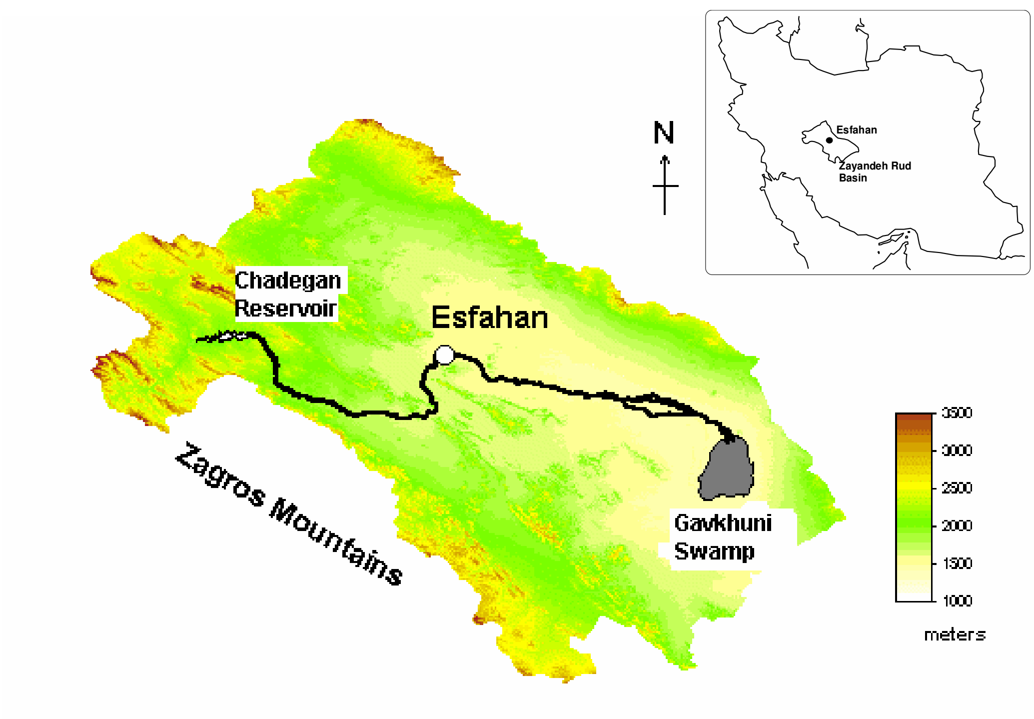


Figure 1: Location of the Zayandeh Rud basin

The Chadegan reservoir provides storage of winter and spring runoff and its releases are used to regulate flows in the river. There is a series of diversion weirs along the river, and numerous locations where urban areas and industry can extract water.

The upper catchment covers about 4,000 km^2 or less than 10% of the total catchment. The upper catchment is mountainous, with peaks rising to as much as 3,500 meters, and there is little utilization of water upstream of the reservoir. There are natural forests in the upper catchment although most of the higher land is barren.

The central and lower portions of the valley are natural arid and sub-arid areas. Steep mountain ranges rise up out of the valley floor, but the majority of the landscape consists of gently sloping alluvial fans with dry streambeds where there are occasional flash floods in rare storms. The natural vegetation here is sparse thorn bush and drought resistant grasses, and there is a high percentage of bare rock and soil.

The basin terminates in the Gavkhuni Swamp which is a natural salt pan. Much of the area surrounding the swamp is sandy and there are extensive dune areas just east of the swamp. Water entering the swamp area is extremely saline, with EC values as high as 30 dS m^{-1} during periods of low flow (Salemi et al., 2000).

Climatic Conditions

The major part of the basin receives less than 150 mm of precipitation during the year, almost all of which falls in the cooler winter months associated with fronts moving eastwards from eastern Europe. Only occasionally is there enough rainfall to generate significant runoff from the alluvial fans.

Most runoff originates from the mountains surrounding the basin, particular in the Zagros range, and most of this runoff is in the form of snowmelt rather than direct runoff from precipitation. This is illustrated by data from Kuhrang meteorological station (elevation 2285 m), located to the west of the Zayandeh Rud basin, presented in Table 1. More than 89% of the precipitation occurs between November and March, with an annual average of 70 days of precipitation. Of these 70 days about 55 experience snowfall rather than rainfall, and with cold winter temperatures that may not rise above freezing for weeks at a time, most precipitation remains in the form of ice and snow until temperatures rise in April.

The effect of spring snowmelt is that peak discharges are experienced during the time of year when agricultural demand for water is also rising. This has enabled irrigation to become an important economic activity for some centuries, and was the basis for the historical importance of Esfahan several hundred years ago.

Table 1: Average climatic conditions, Kuhrang (elevation 2285 meters), 1987-1996

	Air Temperature (oC)			Precipitation		
Month	Ave. Max.	Ave. Min.	Ave. Daily	Monthly Total	Wet Days	Days with Snow
October	18.5	4.5	11.5	47.3	5.6	0.1
November	11.9	0.1	6.0	191.2	8.6	3.6
December	4.9	-6.5	-0.8	249.5	12.0	10.4
January	0.5	-11.5	-5.5	204.6	12.9	12.4
February	2.6	-8.9	-3.1	250.3	13.2	12.6
March	5.6	-4.3	0.6	344.3	15.8	13.0
April	12.1	1.7	6.9	147.6	11.5	2.0
May	19.8	7.3	13.5	52.2	7.3	0.1
June	26.3	10.7	18.5	0.9	1.0	0.0
July	29.9	14.2	22.1	1.0	1.0	0.0
August	29.8	13.8	21.8	1.2	0.7	0.0
September	25.7	9.5	17.6	1.8	0.9	0.0
Year	15.6	2.5	9.1	1492.0	70.5	54.2

Irrigation Development

With annual potential evapotranspiration in the order of 1500 mm, it is almost impossible to practice any reliable agriculture in the Zayendeh Rud basin without irrigation. In fact, many of the areas currently utilized for irrigation, particularly those upstream of and adjacent to Esfahan City, were developed several hundred years ago using diversion weirs to feed earthern canals on either side of the river. In addition some alluvial fans have been partially irrigated using "qanats" or horizontal wells dug to reach groundwater at the base of hills, or more recently, through boreholes.

However, it has only been in the past few decades that irrigation has been developed in the form of large-scale, integrated systems with proper devices for conveyance, distribution and measurement of irrigation flows. The location of the main irrigation systems and the diversion weirs serving them are shown in Figure 2, while the main data on the irrigation systems are presented in Table 2.

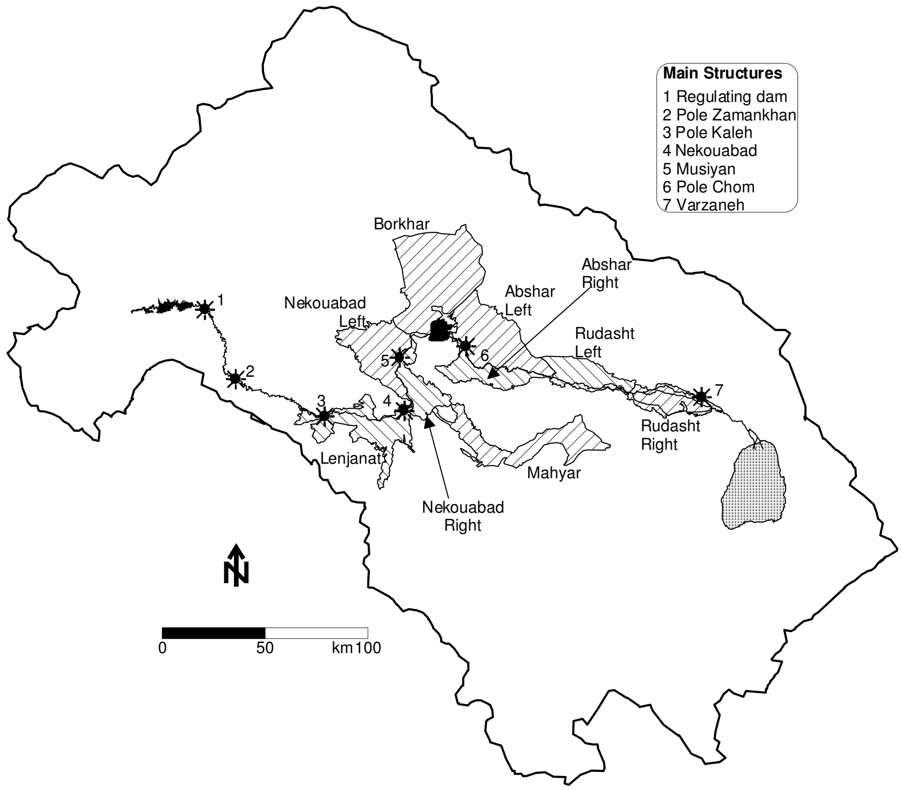


Figure 2: Main irrigation systems and regulating structures in the Zayendeh Rud basin

The Nekouabad Right and Left Bank systems were completely redesigned and reconstructed in the late-1960s and early-1970s. The main canals are regulated using 'Neyrpic' hydro-mechanical gates, while diversions to most secondary canals use 'Neyrpic' modules to deliver desired discharges. Some tertiary canals, particularly those in the older parts of the system developed long ago, remain earth canals with simple control devices, but all newer canals are concrete lined trapezoidal canals. The Abshar systems east of Esfahan are of a similar age to the Nekouabad system.

In recent years three additional areas of irrigation have been added: the Mahyar system that is south of the main valley, and is fed by a canal from a diversion on the Zayandeh Rud upstream of Nekouabad, the Borkhar system north of Esfahan town, and the extension to the Rudasht system in the eastern part of the basin. All three of these systems have had extensive groundwater development but can now rely primarily on canal water deliveries from the Zayandeh Rud.

Table 2: Main features of irrigation systems in the Zayandeh Rud basin

Name of System	Date of Construction	Designed Command Area (ha)	Design Discharge (m^3/sec)	Length of Main Canal (km)	Length of Secondary Canals (km)
a) Old Systems					
Nekouabad Right Bank	1970	13,500	13	35.3	45.0
Nekouabad Left Bank	1970	48,000	45	59.4	76.6
Abshar Right Bank	1970	15,000	15	33.5	38.0
Abshar Left Bank	1970	15,000	15	36.0	33.0
b) New Systems					
Borkhar	1997	36,000	18	29.0	Not completed
Rudasht Left & Right	In Progress [a]	47,000	50	209.2	Not completed
Mahyar	In Progress	24,000	10	120.0	Not completed

Note: [a] Rudasht is an ancient system being replaced with a new system
All new systems have conjunctive use of surface water and groundwater

Inflows into Chadegan Reservoir

Inflows into Chadegan Reservoir show a consistent annual pattern (Figure 3).

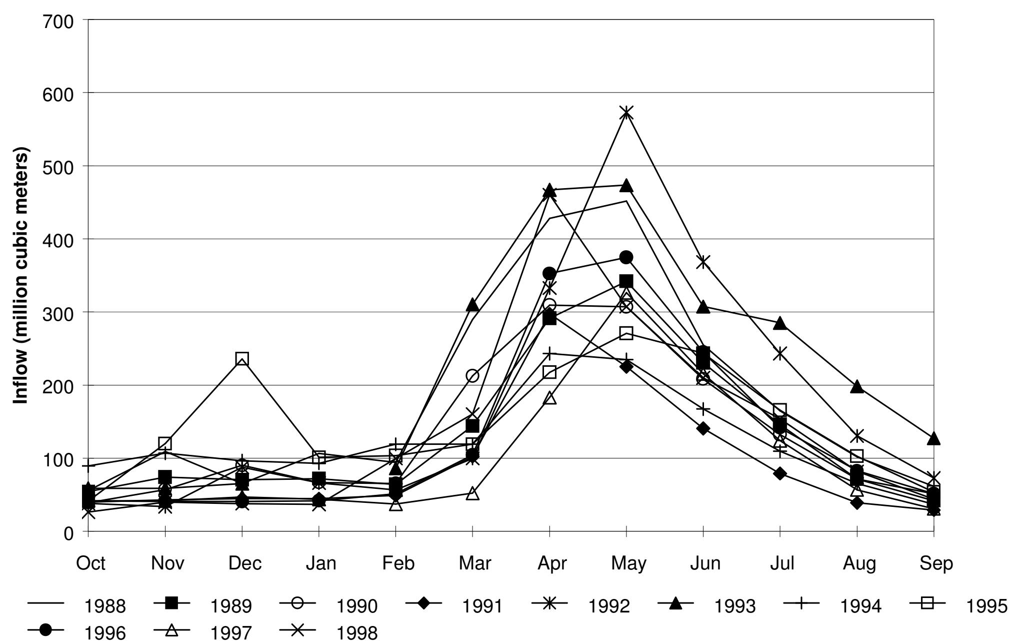


Figure 3: Average monthly inflows into Chadegan reservoir

The main period of runoff is from March to July when there is more than 150 million cubic meters of inflow into the reservoir in each month, peaking in April and May when average inflows exceed 300 million cubic meters (over 115 m^3/sec). In contrast, winter discharges are very low even though this is the period of maximum precipitation in the catchment and from August to February, inflows average less than 100 million cubic meters. Total average inflow is approximately 1700 million cubic meters per year (Table 3).

Table 3: Summary of monthly inflow data into Chadegan reservoir, 1988-1998 (in million cubic meters)

Month	Average flow	Standard Deviation	Coefficient of Variation	Maximum	Minimum
October	47.9	16.6	0.35	89.4	26.2
November	65.9	31.8	0.48	120.0	33.7
December	80.2	55.6	0.69	235.9	38.0
January	67.3	24.4	0.36	106.5	37.0
February	75.2	26.5	0.35	119.1	37.3
March	155.8	82.0	0.53	310.4	52.4
April	325.6	95.1	0.29	466.8	183.2
May	353.2	107.3	0.30	572.8	224.9
June	235.6	62.3	0.27	368.3	140.6
July	158.6	58.6	0.37	285.0	79.2
August	91.2	43.3	0.47	198.2	39.1
September	54.6	27.3	0.50	127.1	29.1
Annual	1711.2	412.3	0.24	2504.9	1134.1

Variability of annual inflows is only moderate. Annual flows during the 11 years of available records, range from 1134 to 2505 million cubic meters with a coefficient of variation of 24%. Monthly flows show greater variability, with coefficients of variation ranging from 26% to 69%. However, April, May and June, the three months with the highest average inflows, show the lowest variability (coefficients of variation about 30%) so that there is a high probability of reliable inflow during this time of the year. As would be expected, months with lower inflows show rather more variability but this is less important for water management as overall inflows are comparatively low in those months.

Although the length of data availability is comparatively short, it is possible to estimate the return periods of inflows on both an annual and a monthly basis[1]. For annual flows (Figure 4) it appears that a total inflow of about 3,600 million cubic meters has a return period of about 50 years.

[1] It must be noted that the inflow records presently available with the project team include the contributions from the trans-basin diversions from the adjoining basin. A more detailed analysis of inflows into the Chadegan reservoir will be the subject of a forthcoming paper.

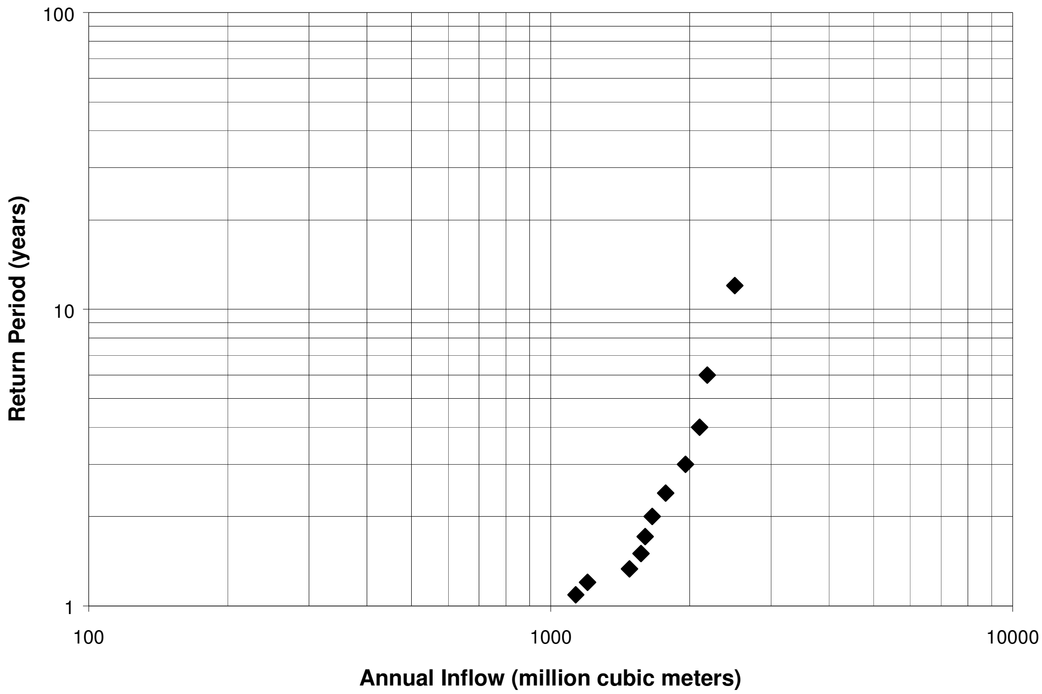


Figure 4: Empirical probability of annual inflow to Chadegan reservoir

From the empirical probability distributions for monthly inflows (Figure 5), it will be seen that the 50-year flood for May is likely to be in the order of 900 million cubic meters while for February it is only about 200 million cubic meters. Flood peaks are normally experienced during the period of annual snowmelt between April and June. The largest monthly inflow recorded during the period of available data was 573 million cubic meters in May 1992. In addition, 11 of the 12 highest flood months, when inflows have exceeded 400 million cubic meters have been either in April or May (Figure 3).

The fairly predictable inflow pattern experienced at Chadegan reservoir simplifies water management in general. The demand for irrigation water starts in April, more or less coinciding with the onset of the main snowmelt period, so that it is not necessary to have a full reservoir before the start of the irrigation season. Furthermore, the low storage levels by the end of the irrigation season makes it possible to store flood water that may occur before the onset of the winter freeze.

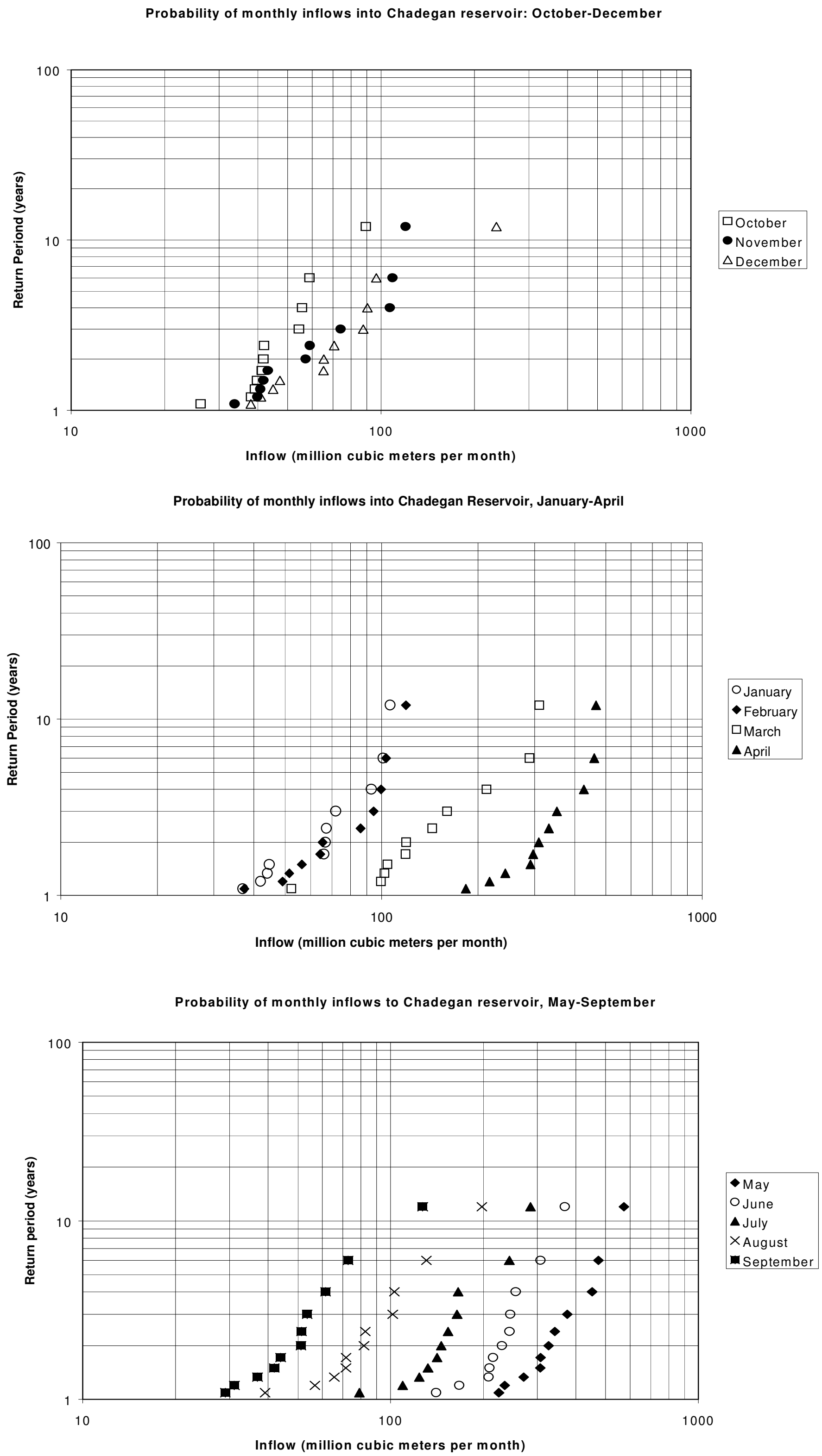


Figure 5: Empirical probabilities of monthly inflows into Chadegan reservoir, 1988-1998

Releases from Chadegan Reservoir

Figure 6 shows the general pattern of rainfall, inflow and outflow at the Chadegan reservoir.

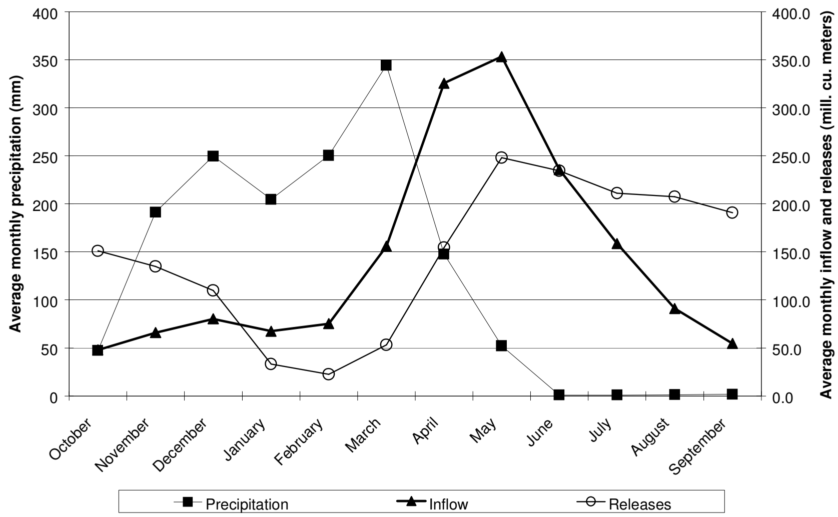


Figure 6: Average monthly precipitation, inflow and releases at Chadegan reservoir

The time lag of about two months observed between the major rainfall periods and the maximum inflow into the reservoir clearly indicates the important contribution of the snowmelt that occurs from March onwards.

The releases made from Chadegan reservoir show a very predictable pattern (Figure 7). In those periods when the reservoir storage is around 1,400 million cubic meters, then monthly releases are much higher than under normal conditions. These releases are typically made in April and May, possibly in June, and once in December as a precaution to keep reservoir levels low prior to the next snow melt season.

The three most obvious cases of flood control releases are in 1988, 1992 and 1993 when sharp peaks occurred in the release hydrograph and monthly releases exceed 250 million cubic meters. In 1995 and 1996, reservoir storage was also high but monthly releases only registered about 220 million cubic meters.

Analysis of the relationship between monthly storage and releases shows that there is a broad band into which all data points fit (Figure 8). This type of pattern indicates that there is no period when storage levels were very high but demand was very low. As long as storage is above 1,100 million cubic meters, then releases will be at least 150 million cubic meters during the next month, while if storage is less than 800 million cubic meters, releases will not exceed 125 million cubic meters. These relationships demonstrate that there is little effective year-to-year storage in the reservoir and that almost all runoff from the spring and early summer is used by the end of the summer. In this respect the reservoir has an effective runoff-delay capacity of some three months. If there were significant year-to-year storage then there would be a less clear-cut relationship between storage and releases.

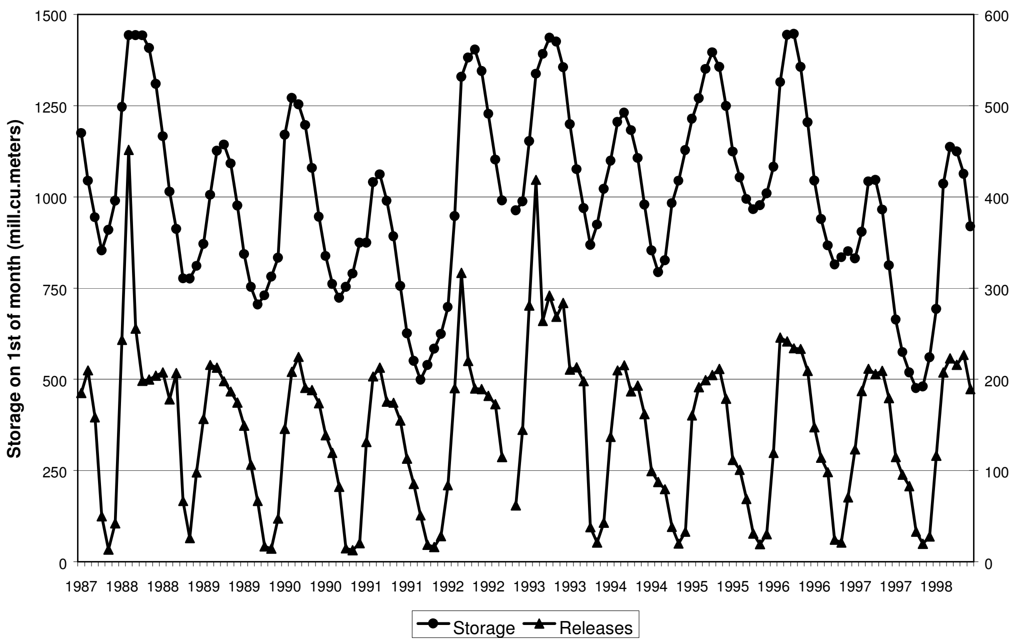


Figure 7: Chadegan reservoir: Time series of monthly storage and releases, Oct 1987-Sept 1998

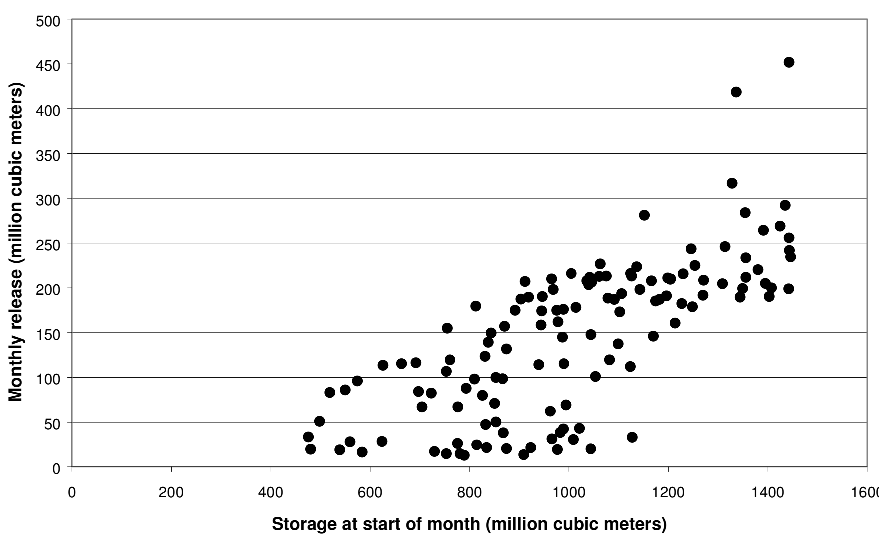


Figure 8: Relationship between storage and monthly releases: Chadegan reservoir

These data also indicate that the reservoir, and therefore the entire Zayandeh Rud basin, is vulnerable to a period of two consecutive years of drought. To date, from available records, this has not occurred. However, given that normal annual release patterns (excluding releases for flood control) require about 1,500 million cubic meters, if two successive years of inflows of 1,200 million cubic meters or less occurred, then the reservoir would not be able to meet all of the demand in the second year of a drought.

If the months when releases for flood protection are eliminated from the data set, then it is possible to define the "normal" release pattern to meet downstream demand for irrigation, urban and domestic water. This "normal" release pattern is shown in Table 4, where all the flood control issues in April, May and June have been eliminated.

Table 4: 'Normal' average monthly releases (excluding releases for flood control)

Average Monthly Releases (mill.cu.meters)			
Month	Average	Std. Dev.	Variance
Oct	143.7	40.9	28.5
Nov	122.3	43.9	35.9
Dec	103.8	57.4	55.3
Jan	31.4	15.9	50.8
Feb	19.1	4.0	21.0
Mar	44.3	25.1	56.6
Apr	130.5	23.5	18.0
May	206.6	17.7	8.6
Jun	217.6	12.5	5.7
Jul	203.5	18.1	8.9
Aug	201.5	19.8	9.8
Sep	179.0	16.0	8.9
Annual	1579.0	215.1	13.6

The effect of this operational policy is to provide very consistent releases during the period of most demand. With variability of less than 10% per month, the water flows into the Zayandeh Rud are very reliable and predictable, and deviations from the "normal" pattern are all upwards because of flood control releases.

The pattern of releases also shows that winter releases are low. There is a policy not to operate irrigation systems until April, so that during the three coldest months farmers must rely on tubewell water should they require irrigation in this period. This also means that discharges in the Zayandeh Rud are very low throughout the winter, making the river susceptible to pollution from non-agricultural sources.

The release pattern shows more variation towards the end of the irrigation season, from October to December. In years where there is more storage in the reservoir, releases in these months tend to be around 150 to 210 million cubic meters while in years when storage is somewhat lower, then the releases are reduced to the 80 to 120 million cubic meters level.

Water Use and Extractions in the Basin

The water released from the Chadegan reservoir flows along the Zayendeh Rud and is extracted at a number of points along its length for irrigation, domestic and industrial uses. The location of the major irrigation schemes and diversion structures has already been shown in Figure 2. The pattern of the average monthly volumes measured along the river is shown in Figure 9.

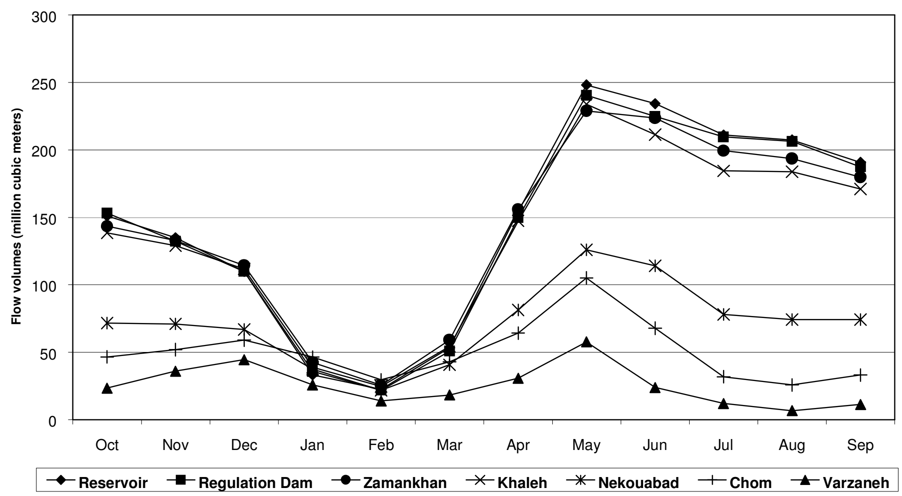


Figure 9: Average monthly volumes measured along the Zayendeh Rud

The flow pattern outside the low-flow months of January and February is practically identical at all the observation points.

There are only limited extractions between the Chadegan reservoir and the Regulating Dam just downstream, and the Regulating Dam and the Zamankhan measuring point,. Downstream of Khaleh, however, water extraction begins in earnest. The extractions along the reach from Khaleh to Nekouabad regulator plus the extractions for irrigation at Nekouabad itself account for almost half of the flow released from Chadegan.

The same pattern is repeated between Nekouabad and Chom when more than half the remaining flow is extracted from the river, either for urban and industrial use in Esfahan or for irrigation in the Abshar irrigation systems.

Further extractions for irrigation below Chom reduce flows at Varzaneh to almost nothing, apart from floodwater releases that may reach this point. In fact, average monthly measured discharges have fallen below 1 m^3/sec on numerous occasions. Worse, the quality of water reaching Varzaneh is extremely poor with high salt content and many non-agricultural pollutants.

A simple spreadsheet-based water balance type of model was used to analyze the river flows and the extractions for irrigation, urban and industrial purposes with a view to getting a better understanding of water use, and in particular, to assess the degree of water reuse in the basin.

A monthly time-step was adopted and the analysis was performed reach by reach. The response time of the river was assumed to be less than one month, so that there is no time lag in water flows between months. A reach is defined between two successive flow measuring locations along the river. Water extractions are considered to occur only in the reaches.

For each reach, a fixed extraction of 5 million cubic meters per month (or 1.9 m^3/s) was assumed for urban and industrial use. For the Nekouabad-Pole Chom reach, an additional extraction of 12 million cubic meters per month (about 4.5 m^3/s) for the city of Esfahan was included, based on a population of 2 million and a per capita requirement of 200 liters per day. Observed monthly values of precipitation were used and an effective area that is considered to contribute to the river discharge was defined for each reach.

As for irrigation, the biggest consumer of water, historical data was available in respect of the extractions by the main irrigation schemes. A few items of data were missing but these were filled by using the average values for the same months. In addition, a substantial amount of water is extracted by small-scale irrigation schemes in the river valley. Details of how the extractions by these small-scale irrigation schemes were computed are found in Droogers et al. (2000).

The model was run for the 10-year period 1987-88 to 1996-97, with a monthly time-step as mentioned above.

It was found that the amount of water withdrawn from the system (computed on the basis of the actual water flows measured at the different measurement locations along the river) is very much less than the water extracted to meet the needs of the various agricultural and non-agricultural uses within the basin. This is illustrated in Figure 10 for each of the 10 years considered[2]. The annual extractions, both net and gross, show little or no year to year variation (coefficient of variation = 0.09).

This phenomenon seems to point to the existence of substantial return flows[3] associated with the different uses of water within the basin. Otherwise, the basic water withdrawals by themselves would not be able to meet all the demands for water in the basin. The average annual return flow percentage is estimated to be 30%.

[2] The term 'net extractions' is used to refer to the difference in measured water flow between a given node and another node upstream of itself. The term 'gross extractions' refers to the extractions required to meet the different demands in a given reach.

[3] Return flow (%) = (Gross Extraction – Net Extraction)/Gross Extraction

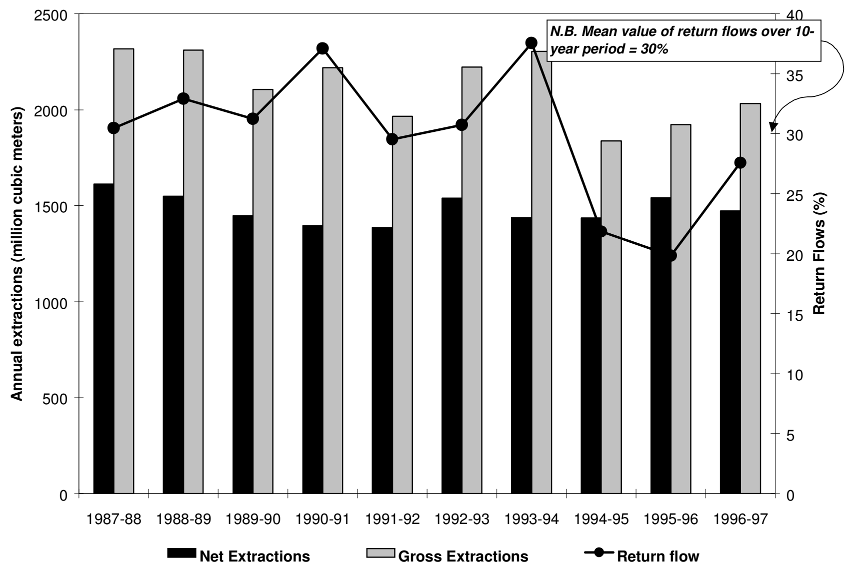


Figure 10: Average annual extractions and estimated return flows in the Zayandeh Rud basin, 1987-88 to 1996-97

Figure 11 shows the average annual extractions, and the amount of return flows in five of the reaches of the Zayandeh Rud[4]. It will be observed that in the more downstream reaches (where there is substantial irrigation), the return flow percentage is almost 50%.

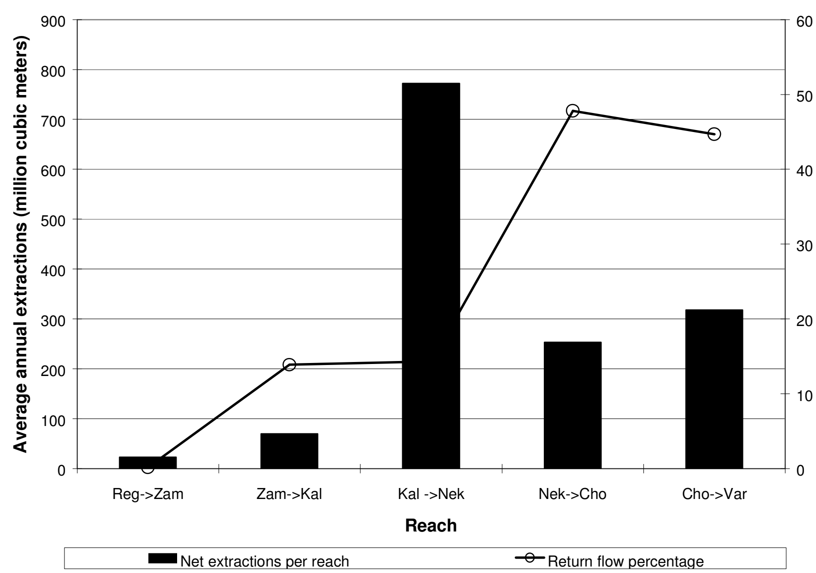


Figure 11: Estimated return flows in the different reaches of the Zayandeh Rud

It must be emphasized that the above analysis is a very rough attempt at assessing the magnitude of return flows from the various uses of water (irrigation, industrial,

[4] see figure 2 for the complete names of the reaches

domestic and urban) in the basin. A more thorough analysis, taking into account groundwater as well will have to be carried out to get a better estimate. The mixing-cell approach described by Gieske et al. (2000) to quantify both irrigation and groundwater return flows seems to be particularly promising.

Conclusion

This overview of the hydrology and water use in the Zayandeh Rud basin has brought to light a number of salient points:

- Annual inflows into Chadegan reservoir show a regular pattern with moderate variability (coefficient of variation 0.24).

- Monthly flows show greater variability with coefficients of variation ranging from 0.26 to 0.69. But the flows from April to June, the three months during which average flow is highest, have coefficients of variation that are less than 0.30, which means that there is a fairly high probability of dependable flows during this period.

- The reasonably predictable flows into Chadegan reservoir simplify reservoir management to meet demands under normal conditions, with special releases needed to ensure the safety of the dam during flood events.

- The Chadegan reservoir does not have any significant year-to-year carryover storage. Almost all the inflow during spring and early summer is released prior to the next flood season, making the reservoir (and the basin) susceptible to prolonged precipitation deficits.

- The ‘closed’ nature of the Zayendeh Rud basin is illustrated by the fact that there is normally little water reaching Varzaneh and the Gavkhuni swamp (except for flood releases that may reach these locations) situated at the tail-end of the basin. The limited supply of fresh water in the basin has serious implications for further water utilization and water management improvements in the basin.

- A simple water-balance approach was used to demonstrate the scope for reuse and return flows within the basin among its various uses. The magnitude of return flows was estimated at 30% over the whole basin, within the limitations of the approach adopted. This aspect merits further study, especially to include groundwater and water quality aspects, notably salinity.

The above points highlight the need to take an integrated, basin-wide approach when studying water management in the context of multiple uses and users of the available supplies of fresh water. A good knowledge and understanding of water availability and water use at the farm, system and basin levels are essential. Water use and the scope for real water savings cannot be ascertained by analyzing water utilization only at the farm or system level.

In light of the above discussion, there is a clear need to reconsider conventional ideas about water savings in the Zayandeh Rud basin. Apparent savings of water at the field level do not always lead to *real* savings, especially if return flows from irrigation are being reused. If the fraction of water supply depleted by evaporation and flows to sinks is already very high because of reuse, there is little scope for saving water in the river basin. On the other hand, if it were possible to achieve real water savings in irrigation, such savings could be used for expansion of irrigation, or to meet increased demands from other sectors such as urban water supply, industry, or the environment.

Acknowledgements

Numerous agencies, notably the Ministry of Agriculture and the Ministry of Energy, allowed us access to their databases and provided us with essential information for our studies. Their cooperation and support is gratefully acknowledged. The authors wish to particularly thank Mr Assadi of the Esfahan Regional Water Office of the Ministry of Energy, and Mr Ameeri, Director, of the Agricultural Master Plan of Esfahan Province and his personnel for their assistance.

Literature cited

Droogers, P., H.R. Salemi and A. Mamanpoush. 2000. Exploring basin scale salinity problems using a simplified water accounting model: the example of Zayandeh Rud Basin, Iran. *IAERI-IWMI Research Report 5*. (in press)

Gieske, A., M. Miranzadeh and A. Mamanpoush. 2000. Groundwater chemistry of the Lenjanat district, Esfahan province. *IEARI-EARC-IWMI Research Report 4.* (in press)

Keller, A., J. Keller and D.W. Seckler. 1996. Integrated water resources systems: Theory and policy implications. *IWMI Research Report 3.* Colombo, Sri Lanka: International Water Management Institute.

Molden, D.J. 1997. Accounting for water use and productivity, *SWIM Paper 1*. Colombo, Sri Lanka: International Irrigation Management Institute.

Molden, D.J. and R. Sakthivadivel. 1999. Water accounting to assess use and productivity of water. *International Journal of Water Resources Development* [Special Double Issue: Research from the International Water Management Institute (IWMI)]. 15 (1/2): 55-71.

Perry, C.J. 1996. The IIMI water balance framework: A model for project level analysis. *IWMI Research Report 5*. Colombo, Sri Lanka: International Irrigation Management Institute.

Perry, C. J. 1999. The IWMI water resources paradigm: Definitions and implications. *Agricultural Water Management*, 40(1): 45-50.

Salemi H.R., A. Mamanpoush, M. Miranzadeh, M. Akbari, M. Torabi, N. Toomanian, H. Murray-Rust, P. Droogers, H. Sally, A. Gieske. 2000. Water management for sustainable irrigated agriculture in the Zayandeh Rud basin, Esfahan Province, Iran. *IAERI-EARC-IWMI Research Report 1*. (in press)

Seckler, David. 1996. The new era of water resources management: From "dry" to "wet" water savings. *IWMI Research Report 1*. Colombo, Sri Lanka: International Irrigation Management Institute.

The following reports have been published in the IAERI-IWMI Research Report series.

1. **Water Management for Sustainable Irrigated Agriculture in the Zayandeh Rud Basin, Esfahan Province, Iran.** (2000) H.R. Salemi, A. Mamanpoush, M. Miranzadeh, M. Akbari, M. Torabi, N. Toomanian, H. Murray-Rust, P. Droogers, H. Sally, A. Gieske.
2. **Exploring field scale salinity using simulation modeling, example for Rudasht area, Esfahan Province, Iran.** (2000) P. Droogers, M. Akbari, M. Torabi, E. Pazira.
3. **An overview of the hydrology of the Zayandeh Rud Basin.** (2000) H. Murray-Rust, H. Sally, H.R. Salemi, A. Mamanpoush.
4. **Groundwater chemistry of the Lenjanat District, Esfahan Province, Iran.** (2000) A. Gieske, M. Miranzadeh, A. Mamanpoush.
5. **Exploring basin scale salinity problems using a simplified water accounting model: the example of Zayandeh Rud Basin, Iran.** (2000) P. Droogers, H.R. Salemi, A. Mamanpoush.
6. **Sustainable irrigation and water management in the Zayandeh Rud Basin. Proceedings of Workshop in Esfahan, Iran, 19-21 November 2000.** (2001) Anonymous.
7. **Assessment of irrigation performance using NOAA satellite imagery.** (2001) P. Droogers, P., W.G.M. Bastiaanssen, A. Gieske, N. Toomanian, M. Akbari.
8. **Water supply and demand in four major irrigation systems in the Zayandeh Rud Basin, Iran.** (2001) H. Sally, H. Murray-Rust, A.R. Mamanpoush, M. Akbari.
9. **Spatial analysis of groundwater trends: example for Zayandeh Rud Basin, Iran.** (2001) P. Droogers, M. Miranzadeh.
10. **Irrigated area by NOAA-Landsat upscaling techniques: Zayandeh Rud Basin, Iran.** (2002) A. Gieske, N. Toomanian, M. Akbari.
11. **Crop and land cover classification by LANDSAT 7 ETM (July 2000) for the Zayandeh Rud basin.** (2002). A.Gieske, A.R. Mamanpoush, M. Akbari, M. Miranzadeh.
12. **Field scale scenarios for water and salinity management by simulation modeling.** (2002) P. Droogers and M. Torabi.
13. **Water Supply and Demand Forecasting for the Zayandeh Rud.** (2002). H.R. Salemi and H. Murray-Rust.
14. **Water Resources Development and Water Utilization in the Zayandeh Rud Basin, Iran.** (2002). H. Murray-Rust, H.R. Salemi and P. Droogers.
15. **Groundwater resources modeling of the Lenjanat aquifer system.** (2002). A. Gieske and M. Miranzadeh.