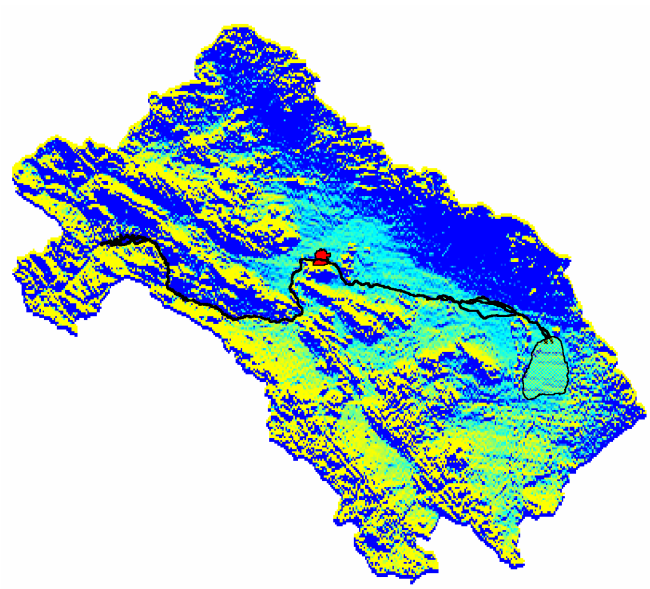
Sustainable Irrigation and Water Management in the Zayandeh Rud Basin, Iran

Water supply and demand in four major irrigation systems in the Zayandeh Rud Basin, Iran

H. Sally, H. Murray-Rust,
A.R. Mamanpoush, M. Akbari



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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:

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Water Supply and Demand in Four Major Irrigation Systems in the Zayandeh Rud Basin, Iran

Hilmy Sally, Hammond Murray-Rust, A.R. Mamanpoush, M. Akbari

Abstract

This paper examines the performance of the Zayandeh Rud basin, temporally (on a monthly basis) and spatially (between systems) by comparing irrigation water supply and demand in four of the major irrigation systems in the basin, namely Nekouabad Right and Left, and Abshar Right and Left.

Estimating water supply has been a fairly straightforward exercise using the precipitation and water release data available with the relevant government agencies. But the estimation of water demand proved to be more difficult due to the absence of data on irrigated areas and cropping patterns. An empirical interpolation procedure was devised to derive this information from the available district-level agricultural statistics for Esfahan province. The first results obtained proved to be promising and form the basis for the supply-demand analysis presented in this report. The validity of this approach may be further assessed against satellite image-based estimates of irrigated areas.

Nevertheless, this situation highlights the importance of systematic, regular monitoring to provide reliable data on irrigated areas, crops, water deliveries and operational practices. The absence of such basic information will hamper efforts to evaluate and improve irrigation system performance.

The results of this study illustrate the difficulty of regulating water deliveries to match demands. In general, deficits in water supply in summer are followed by substantial surplus in winter. In a water-short, closed basin like the Zayandeh Rud, it is vitally important to make the most productive use of the available water resources. All of the water is fully committed and depleted by various uses within the basin and additional water needs can only be met through gains in water productivity.

It is suggested that the crucial role of groundwater in maintaining high levels of cropping intensities and the conjunctive use of surface and ground water merits further study in order to get a more comprehensive picture of the overall water supply and demand in the Zayandeh Rud basin.

Introduction

The Zayandeh Rud basin is water-short and closed. In other words, all of the water is fully committed and depleted by various uses within the basin. In such circumstances, it is vitally important that the water resources of the basin are used as productively as possible. In particular, the performance of the irrigation systems within the basin must be such that the productivity of water used for agricultural purposes is maximized, and that all water users get a fair share of the available water.

At irrigation system level, performance can be assessed in terms of the ratio of the water consumed by evapotranspiration to the water delivered to the head of the irrigation system, because there is a direct link between evapotranspiration, biomass production and yield. If a high percentage of delivered water is utilized for beneficial purposes, then we can deduce that there is a high level of performance. More detailed descriptions on irrigation performance assessment and water productivity are available in Molden and Sakthivadivel (1999), and Molden et al. (1999).

Performance at both basin and system level can also be assessed by determining the extent to which actual performance compares with the performance expected in the design stage, or prior to the start of an irrigation season. Quite often, irrigation system managers have to make informed guesses about the actual cropping pattern that will emerge during a season when they make water allocations to their systems. An obvious way of doing this is to examine previous cropping patterns, calculate likely water requirements based on empirical formulae (e.g. FAO-Cropwat), and arrive at a probable scenario of water demand. Operating the irrigation system in such a way that the water deliveries during the season meet these demands is an important challenge faced by irrigation managers.

This paper examines the performance of the Zayandeh Rud basin, temporally (monthly and annually) and spatially (between systems) by comparing irrigation water supply and demand in four of the major irrigation systems in the basin, namely Nekouabad Right and Left, and Abshar Right and Left. The importance of systematic, regular monitoring to provide reliable data on irrigated areas, crops, water deliveries and operational practices is highlighted. In the absence of such basic information, meaningful performance assessment and subsequent improvements to system management will be difficult to achieve.

The Zayandeh Rud Irrigation Systems

General description

The Zayandeh Rud irrigation systems depend on the release of water from Chadegan reservoir situated some 120 km upstream of Esfahan city, in the upper catchment of the 41,500 km^2 river basin (Figure 1). For the first 80 kilometers or so of its 350-km length, there is very little scope for irrigation along the Zayandeh Rud because the river is incised into the foothills of the Zagros Mountains. However, about 40 kilometers upstream of Esfahan the valley widens out and there is a sufficiently wide alluvial plain

to permit large-scale irrigation. The river terminates in the Gavkhuni Swamp, which is a natural salt pan. There are no discharges of utilizable water flowing out of the basin, illustrating the closed nature of the Zayandeh Rud basin.

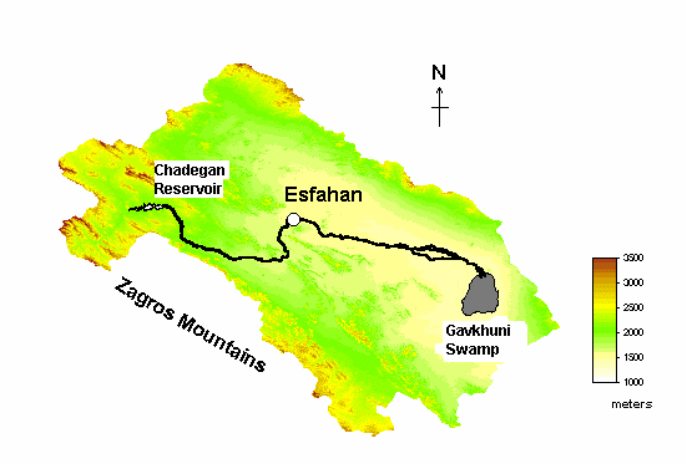

Figure 1: The Zayandeh Rud basin

There has been a long tradition of locally managed irrigation in the flood plain close to the river. But many of these traditional systems have either fallen into disrepair or have been absorbed into newer surface or groundwater based systems (Salemi et al., 2000). Modern surface irrigation started in the 1970s with the completion of Chadegan reservoir and the construction of major diversion weirs at Nekouabad and Abshar that serve to regulate the water supply to four irrigation systems located on the left and right banks of the river. The overall layout of the different irrigation systems in the basin is shown in Figure 2 and their main characteristics are given in Table 1.

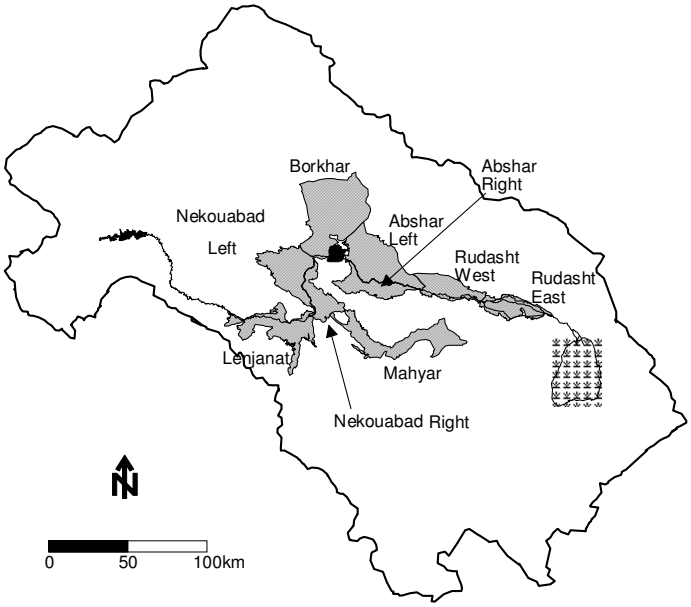

Figure 2: Main irrigation systems in the Zayandeh Rud basin

A locally constructed weir has served the Rudasht area for many decades but is being modernized at the present time, and a new irrigation network is being constructed in the Borkhar area north of Esfahan and in Mahyar, south of the city. In Lenjanat, Borkhar and Mahyar there has been development of groundwater resources for irrigation using deep tubewells over the past couple of decades, and these are being supplemented by new surface water deliveries from the Zayandeh Rud. These new areas were made possible by transbasin diversions of water into the Zayandeh Rud basin to supplement storage in the Chadegan reservoir.

Table 1: 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

In this paper, attention is focused on the performance of 4 schemes, namely Nekouabad Right and Left, and Abshar Right and Left, which have been in operation since the 1970s. The Borkhar, Mahyar and Rudasht (East and West) systems, parts of which are still under development and have only just begun to benefit from Zayandeh Rud surface irrigation water, have not been included in this analysis.

Crops and cropping calendars

The statistics of the Ministry of Agriculture reveal that over 40 types of crop are grown in the basin. The most common ones are wheat, barley, rice, fruits and horticulture.

Figure 3 illustrates a typical cropping calendar, considering only the main crop types.

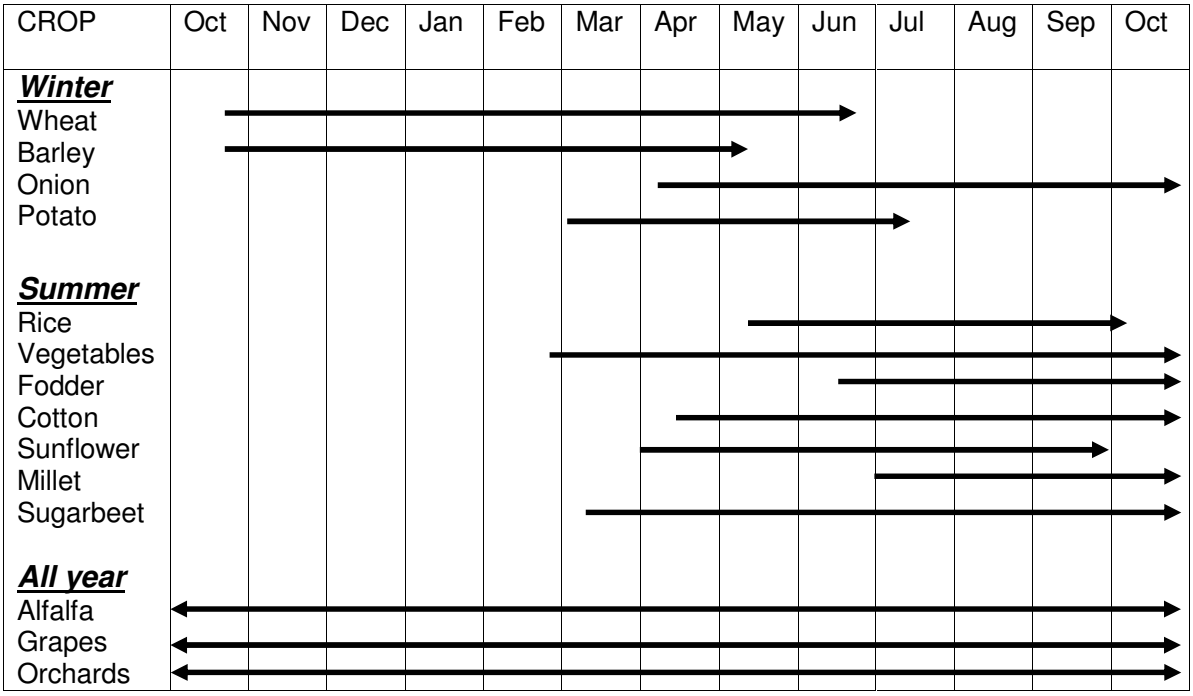

Figure 3: Typical crop calendar, Zayandeh Rud basin

Water Supplies

Data for the releases from Chadegan reservoir and the diversions into each of the main irrigation networks were obtained from the provincial office of the Ministry of Energy. The data covering the 12-year period from 1987-88 to 1998-99 are provided in annex 1. Figures 4 and 5 show the results of the analysis of this data to estimate the total annual water supply to each irrigation system and the corresponding water availability.

From figure 4 it will be seen that there is relatively little year-to-year variation in the amounts of water diverted into each of the major irrigation systems. The average annual releases from the Chadegan reservoir are a little more than 1500 million cubic meters except when large releases have to be made for flood protection, such as in 1992-93. As pointed out in Murray-Rust et al. (2000), the operational pattern of the reservoir very closely reflects the expected irrigation issues.

Figure 5 shows the theoretical water availability in the major irrigation systems in the Zayandeh Rud, based on their respective design irrigation command areas. It will be observed that the average availability of water in the Nekouabad Left Bank system (about 3 mm/day) is less than that in the other systems (more than 4 mm/day). The much larger design command area of Nekouabad Left Bank (48,000 ha) could be one reason for this. Precipitation contributions have not been included at this stage, but will be added to the irrigation releases in the supply-demand comparisons that will be performed later on in this paper.

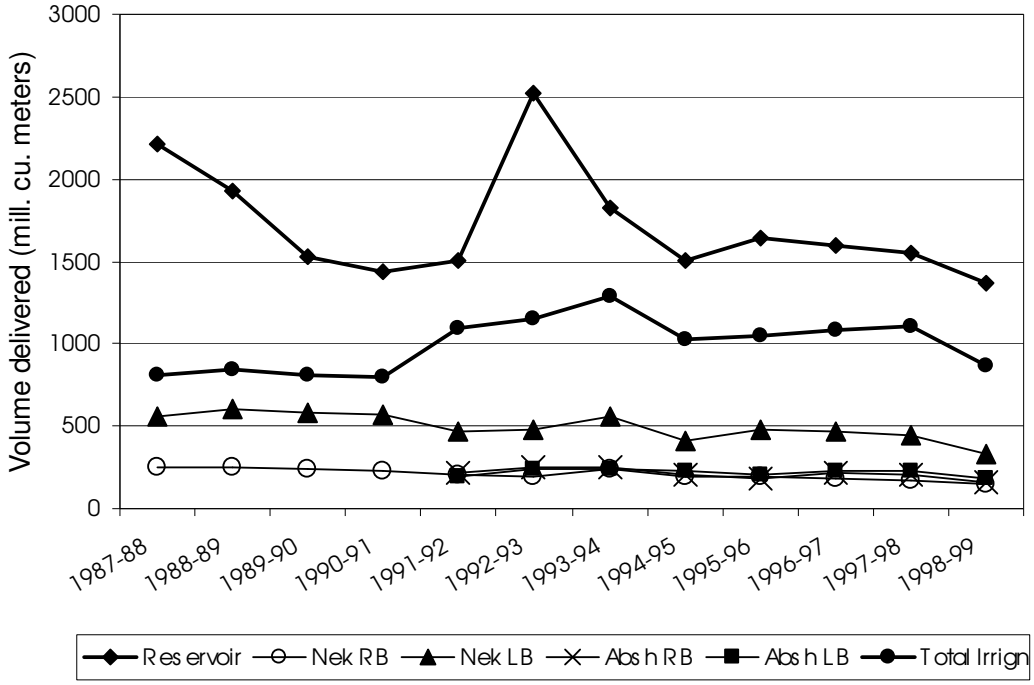

Figure 4: Annual water releases from Chadegan reservoir and water delivered to major irrigation systems in Zayandeh Rud basin

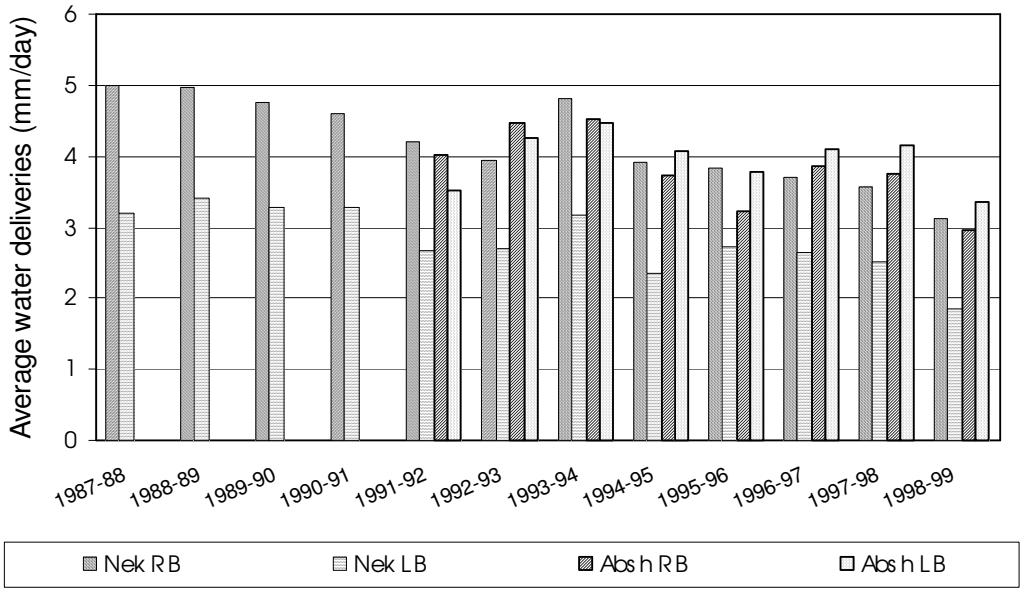

Figure 5: Annual availability of water in major irrigation systems

Figures 6 and 7 show average monthly releases into each system, from which it is clear that there are three separate water delivery conditions. From January to March of each year, hardly any water is issued to any system. Water releases increase significantly from April onwards and peak releases occur between May and September, coinciding

with the hottest and driest part of the year. From October to December water deliveries are at an intermediate level, reflecting the need for continued irrigation for some crops but at a lower level.

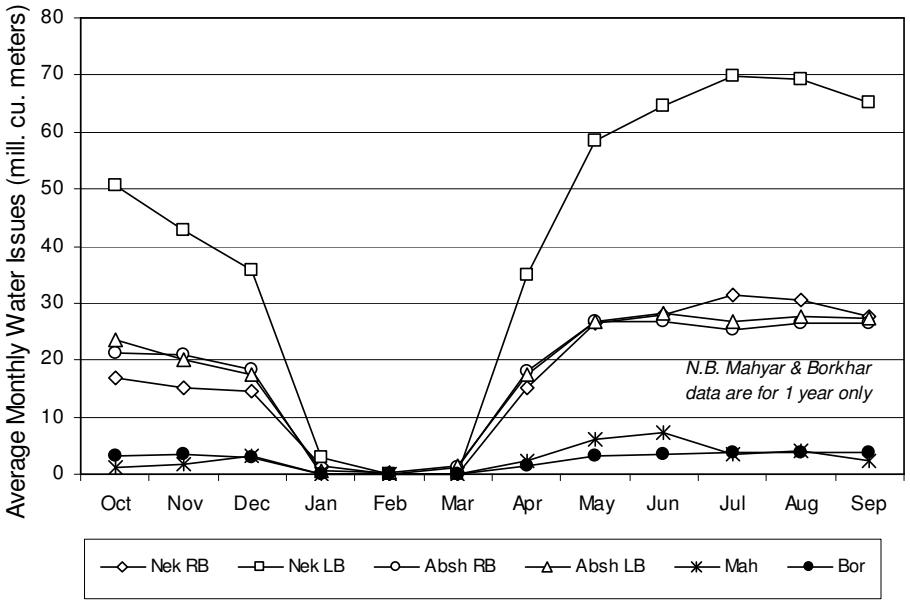

Figure 6: Monthly average irrigation releases to Zayandeh Rud irrigation systems

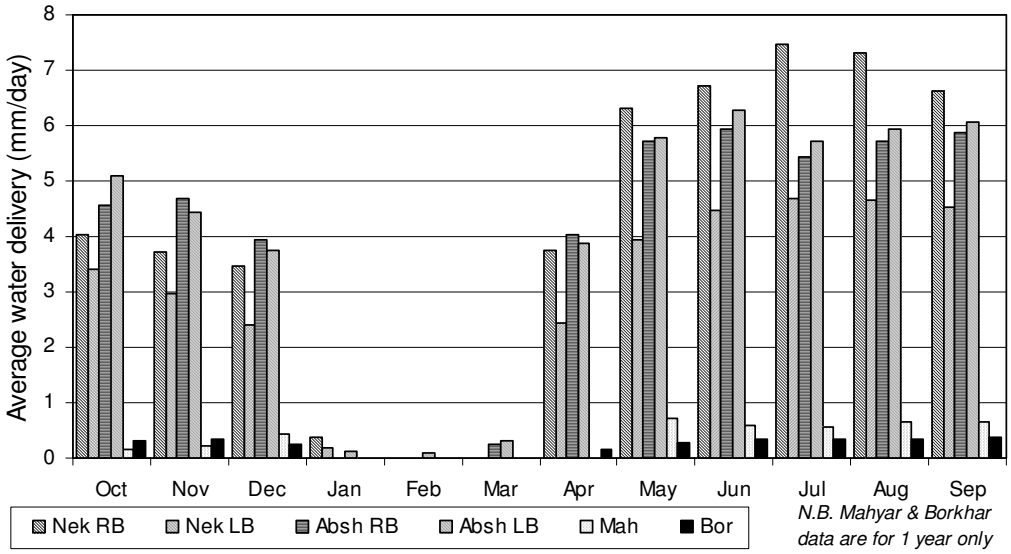

Figure 7: Monthly irrigation water availability in Zayandeh Rud irrigation systems

Assessing Demand for Irrigation Water

Data availability

While estimating the water *supply* to the irrigation systems has been a straightforward exercise, on account of the availability of relevant data, the estimation of water *demand* proved to be more difficult.

In order to do this, we would normally require data on irrigated areas, types of crops, cropping calendars, and crop water demand for each crop. It will then be possible to calculate the total water requirement for each system, and to compare this with the amount of water diverted at the head of the system.

Data on cropping patterns, cropping calendars and estimated cropping intensities were available at the Provincial offices of the Ministry of Agriculture. This is based on data collected village by village, which are then aggregated into homogeneous agricultural zones and administrative districts.

We will note straightaway that (a) the data collected concerns ALL crops, within the irrigation systems as well as outside, and (b) the data is neither collected nor readily available on an irrigation system level basis. The first point can be rapidly addressed because practically all crops in the basin will be irrigated and any differences are unlikely to be very significant. The second point too should not, in principle, pose any major obstacle, provided that we are in a position to clearly identify the relationship of each village to the different irrigation systems.

Using village-level data to estimate cropping patterns

A first attempt was made to determine the cropping patterns for the different irrigation systems from the village-level data. This turned out to be a very time-consuming and fastidious task (3 months of work for analyzing one year's data).

Some analysis conducted on the cropping pattern finally developed for 1991-92 is given in the following table:

Table 2: Cropping pattern estimated from village-level data, 1991-1992
(Derived from village-level data collected by Ministry of Agriculture: Mamanpoush, 21/09/2000)

	Crop Areas (ha)			
	Nekouabad-Left	**Nekouabad-Right**	**Abshar-Left**	**Abshar-Right**
Wheat	2807	1803	4542	5235
Percentages	*20.6%*	*19.5%*	*43.8%*	*36.9%*
Barley	921	1730	1207	1562
Percentages	*6.8%*	*18.7%*	*11.7%*	*11.0%*
Rice	1771	2844	387	2398
Percentages	*13.0%*	*30.7%*	*3.7%*	*16.9%*
Vegetable	2635	1416	1366	1978
Percentages	*19.4%*	*15.3%*	*13.2%*	*14.0%*
Fodder	1762	842	2854	2954
Percentages	*12.9%*	*9.1%*	*27.6%*	*20.8%*
Trees	3714	629	2	48
Percentages	*27.3%*	*6.8%*	*0.0%*	*0.3%*
Total (ha)	**13610**	**9264**	**10359**	**14176**
Design area (ha)	48000	13500	15000	15000
Annual crop intensity (%)	28.4%	68.6%	69.1%	94.5%
Water issues (m^3x10^6)	467.78	208.26	193.34	220.54
Equivalent depth (mm)	3437	2248	1866	1556
Water availability related to design area (mm)	975	1543	1289	1470

Based on this cropping pattern, the cropping intensities (C.I.) obtained are extremely low (except for Abshar Right). On the other hand, the equivalent water depths delivered to the different systems seem to be unreasonably high compared to the water availability for that particular year.

These results thus seem to indicate that the cropping patterns determined by this approach are probably not reliable. Given the total number of villages and crops involved, it is possible that some villages and crops get left out and the contribution of villages to the irrigation systems do not get properly included.

Estimating cropping patterns from district-level data

In light of the above situation, it was considered worthwhile attempting to verify if the use of the aggregated administrative district-level data would give better estimates for cropping patterns with less time and effort.

The irrigation system and administrative district boundaries were overlaid using the available ILWIS maps to determine the proportion of area of each system that belonged to each of the administrative districts in the Zayandeh Rud basin. This enabled to determine a weighting factor for each irrigation system belonging to a particular district. Applying this factor to the recorded crop area of that district will give an estimation of

how this cropped area are distributed among the irrigation systems that fall within that district (see table 3 below).

Table 3: Coefficients to distribute district-level crop area data among irrigation systems within that district

Administrative district	Irrigation systems within the district	Proportion of cropped area of the district attributable to the different irrigation systems	
		(ha)	(%)
Borkhavan	Borkhar	58775	100
Esfahan	Nekouabad Right Bank	75	0.05
	Borkhar	19475	11.77
	Abshar Left Bank	52250	31.57
	Abshar Right Bank	22475	13.58
	Rudasht West	24750	14.95
	Rudasht East	22675	13.70
	Mahyar	23800	14.38
Shahreza	Mahyar	17500	100.00
Mobarakeh	Lenjanat	21500	64.52
	Nekouabad Right Bank	9575	28.73
	Nekouabad Left Bank	575	1.73
	Mahyar	1675	5.03
Lenjanat	Lenjanat	20300	97.95
	Nekouabad Left Bank	425	2.05
Khomeynishar	Nekouabad Right Bank	375	3.38
	Nekouabad Left Bank	5050	45.50
	Borkhar	5675	51.13
Najafabad	Nekouabad Left Bank	20075	100.00
Flavarjan	Nekouabad Right Bank	10375	44.43
	Nekouabad Left Bank	12975	55.57

The assumptions here are that (a) all the crop area in a given district can be attributed to one or more of the irrigation systems, and (b) the crop areas are distributed among the irrigation systems in a particular district in the same proportion as their overall boundary areas. As stated in the previous section, the first assumption is not unreasonable given that almost all crops in the basin are irrigated. As for the second assumption, the degree of uncertainty is not expected to be any worse than that associated with using the basic village-level data, especially taking into account the large saving of time and effort. The results obtained will tell us if this approach is promising or not.

The more than 40 crops included in the district-level information were re-arranged into 10 categories of representative crops (more categories may be selected, if necessary). A simple spreadsheet model was developed to estimate overall cropping patterns using this approach. The following table shows the cropping patterns obtained for the four irrigation systems being studied for 4 years for which crop data were available: 1992-93, 1995-96, 1997-98, and 1998-99.

Table 4: Overall cropping patterns in four major irrigation systems in Zayandeh Rud basin determined from district-level data

System	Alfalfa	Barley	Fodder	Orchard	Onion	Potato	Rice	S-beet	Wheat	Other	Total
1992-93 (units: ha)											
Nek LB	1737	4118	185	7981	1244	1178	3906	1007	9104	8568	39029
Nek RB	855	1890	44	1220	292	816	2939	277	3551	3063	14948
Abs LB	3031	1200	1623	664	695	379	789	1818	11208	10190	31596
Abs RB	1304	516	698	286	299	163	340	782	4821	4383	13591
All systems	*6927*	*7724*	*2551*	*10151*	*2529*	*2536*	*7973*	*3885*	*28684*	*26203*	*99163*
1995-96 (units: ha)											
Nek LB	2412	3429	490	8269	786	2798	6123	190	7906	7425	39828
Nek RB	878	1543	90	1165	460	963	4129	106	2810	2859	15002
Abs LB	2999	5051	2084	759	452	267	1231	1105	9787	4287	28023
Abs RB	1290	2173	896	327	194	115	530	475	4210	1844	12054
All systems	*7579*	*12196*	*3560*	*10520*	*1892*	*4142*	*12013*	*1876*	*24713*	*16415*	*94907*
1997-98 (units: ha)											
Nek LB	1778	2230	426	5471	1215	1384	5408	37	6497	4253	28699
Nek RB	903	1605	76	1122	637	816	3899	81	3140	2406	14685
Abs LB	3047	5272	2494	679	717	311	1272	1123	10103	4595	29612
Abs RB	1310	2268	1073	292	308	134	547	483	4346	1976	12737
All systems	*7037*	*11375*	*4069*	*7564*	*2976*	*2645*	*11126*	*1724*	*24085*	*13131*	*85733*
1998-99 (units: ha)											
Nek LB	1676	2030	432	5451	1207	1927	4667	30	5605	4243	27268
Nek RB	834	1484	76	1048	711	1183	3330	59	2474	2756	13956
Abs LB	2435	4587	2473	710	717	312	1042	603	9996	3674	26550
Abs RB	1048	1973	1064	305	308	134	448	259	4300	1580	11420
All systems	*5993*	*10075*	*4044*	*32012*	*2943*	*3557*	*9487*	*951*	*22375*	*12254*	*103692*

The values obtained for irrigated areas and cropping intensities by this method appear to be more realistic compared to the results derived from the village-level data, and have also been obtained with far less time and effort. But we still do not know if they accurately reflect the ground reality. In order to check this, comparisons with available estimates of irrigated areas based on satellite imagery have been attempted in table 5.

Table 5: Comparison of irrigated area estimates obtained using different methods

Estimation Method	Nekouabad-Left	Nekouabad-Right	Abshar-Left	Abshar-Right
District level data, 1995-96	39 828	15 002	28 023	12 054
NOAA+NDVI, Feb+Sept 1995	30 320	16 675	39 013	16 238
Difference	+31.4%	-10.0%	-28.2%	-25.8%
District level data, 1998-99	27 268	13 956	26 550	11 420
District level data, August 99	16 292	7 895	10 430	4 486
Landsat 7, August 1999	27 912	12 922	22 874	12 382
Difference, August 1999	-41.6%	-38.9%	-54.4%	-63.8%

The results of the NOAA image analysis of February and September 1995 (Droogers et al.) are representative of the crop situation in the 1994-95 hydrological year. So, comparing these values against the irrigated areas of 1995-96 obtained from the district-level statistics is not really valid but is indicative of the general degree of agreement between the two approaches.

On the other hand, the comparison for August 1999 show that the district-level statistics approach greatly under-estimates irrigated area. This is not entirely surprising. There maybe inadequacies in the sampling techniques used to compile the district-level statistics and only official irrigated areas may be included. On the other hand, the satellite images will produce information on total cropped area. Similar differences in results between irrigated areas derived from published agricultural statistics and from remotely sensed images were obtained in an IWMI collaborative project in Turkey (GDRS & IWMI, 2000). The effects of such under-estimations in irrigated areas would normally translate into excess in water deliveries over the water demand computed for the period in question.

Comparisons of the irrigated areas estimated from district-level statistics against the results of satellite image analysis for more years will allow us to be in a better position to judge the validity of this administrative district based approach for estimating cropping patterns in the irrigation systems.

Water demand computations

The potential evapotranspiration of the 10 crops chosen to be representative of the more than 40 grown in the basin were estimated using the FAO-CROPWAT program. The data records for the Kaboutarabad meteorological station for the years 1992-93, 1995-96, 1997-98 and 1998-99 were used for this purpose. The crop water requirements thus obtained were then applied to the estimated crop areas and cropping patterns to get the water demands of each of the 4 irrigation systems for the 4 years being studied.

Comparison of Supply and Demand

The information now available makes it possible to compare water supply and water demand in the irrigation systems. It must be noted that the water supply is made up of the actual water deliveries to the different systems plus the rainfall occurring in the relevant periods. Tables showing the results obtained for the 4 years, 1992-93, 1995-96, 1997-98 and 1998-99 are provided in Annex 2.

Figures 8, 9, 10 and 11 provide comparisons of the monthly water supply (irrigation releases plus rainfall) and demand for each of the 4 irrigation systems for the 4 years that have been studied: 1992-93, 1995-96, 1997-98, 1998-99.

Figures 12, 13, 14 and 15 illustrate the monthly water surplus and deficits in these systems for the same 4 years.

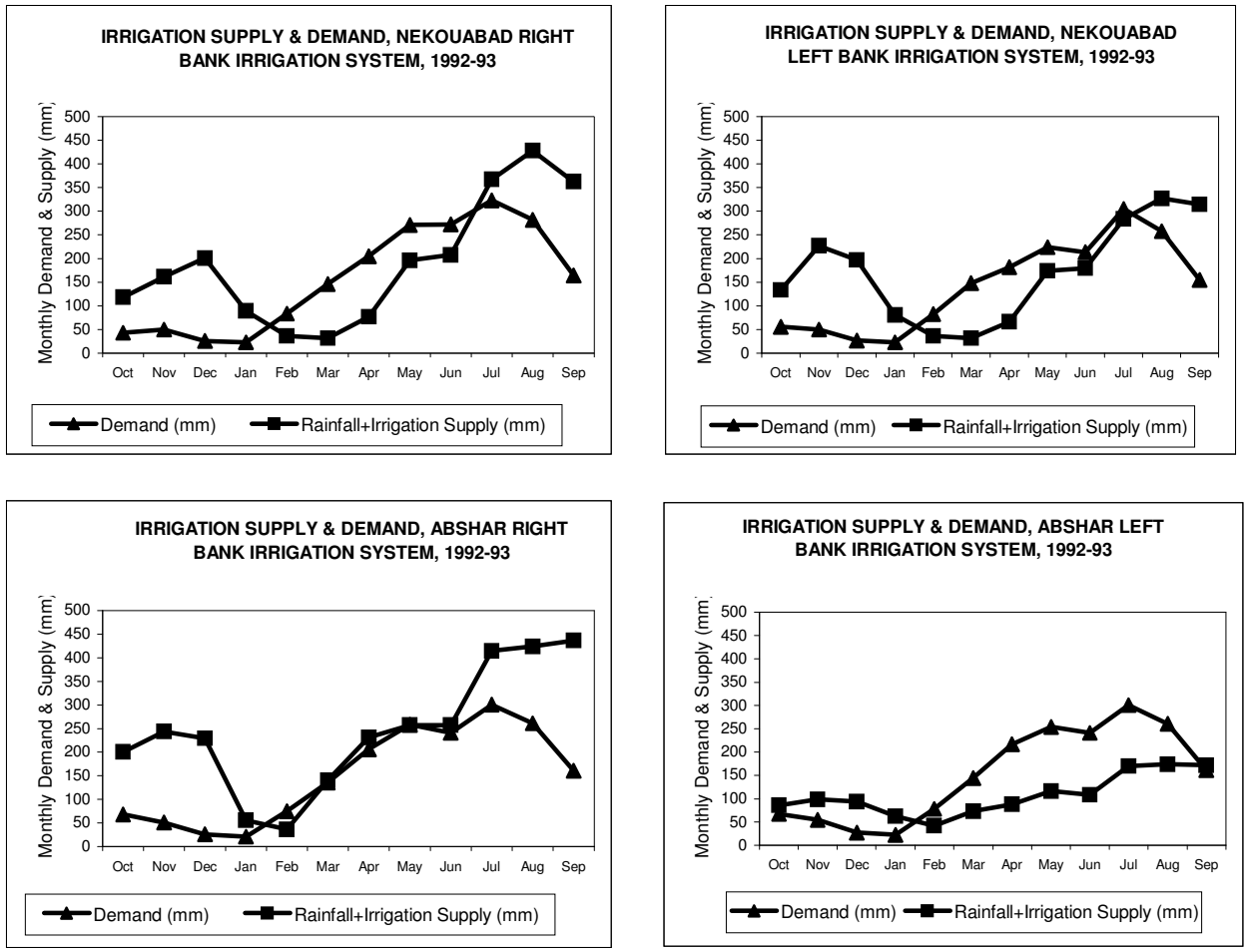

Figure 8: Irrigation supply and demand volumes in four major irrigation systems in the Zayandeh Rud basin, 1992-93

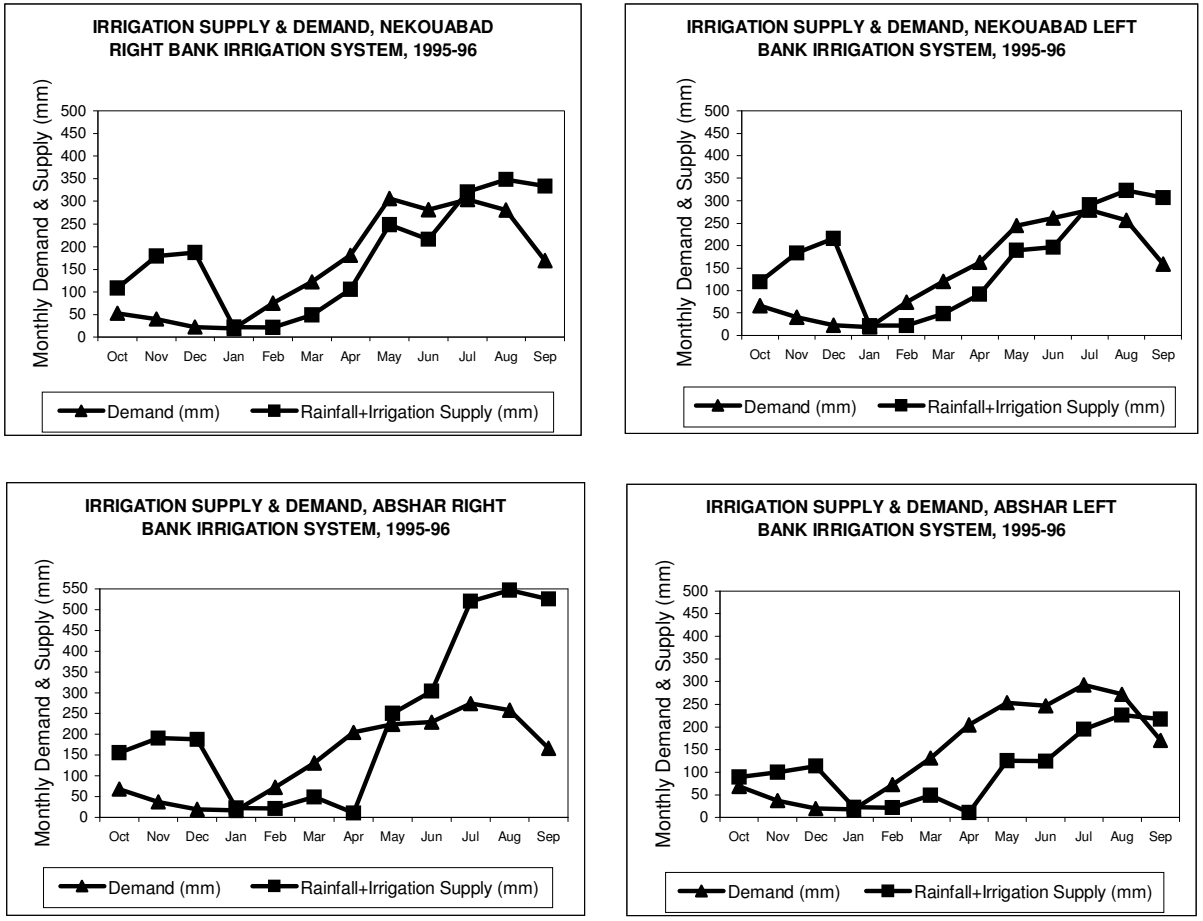

Figure 9: Irrigation supply and demand volumes in four major irrigation systems in the Zayandeh Rud basin, 1995-96

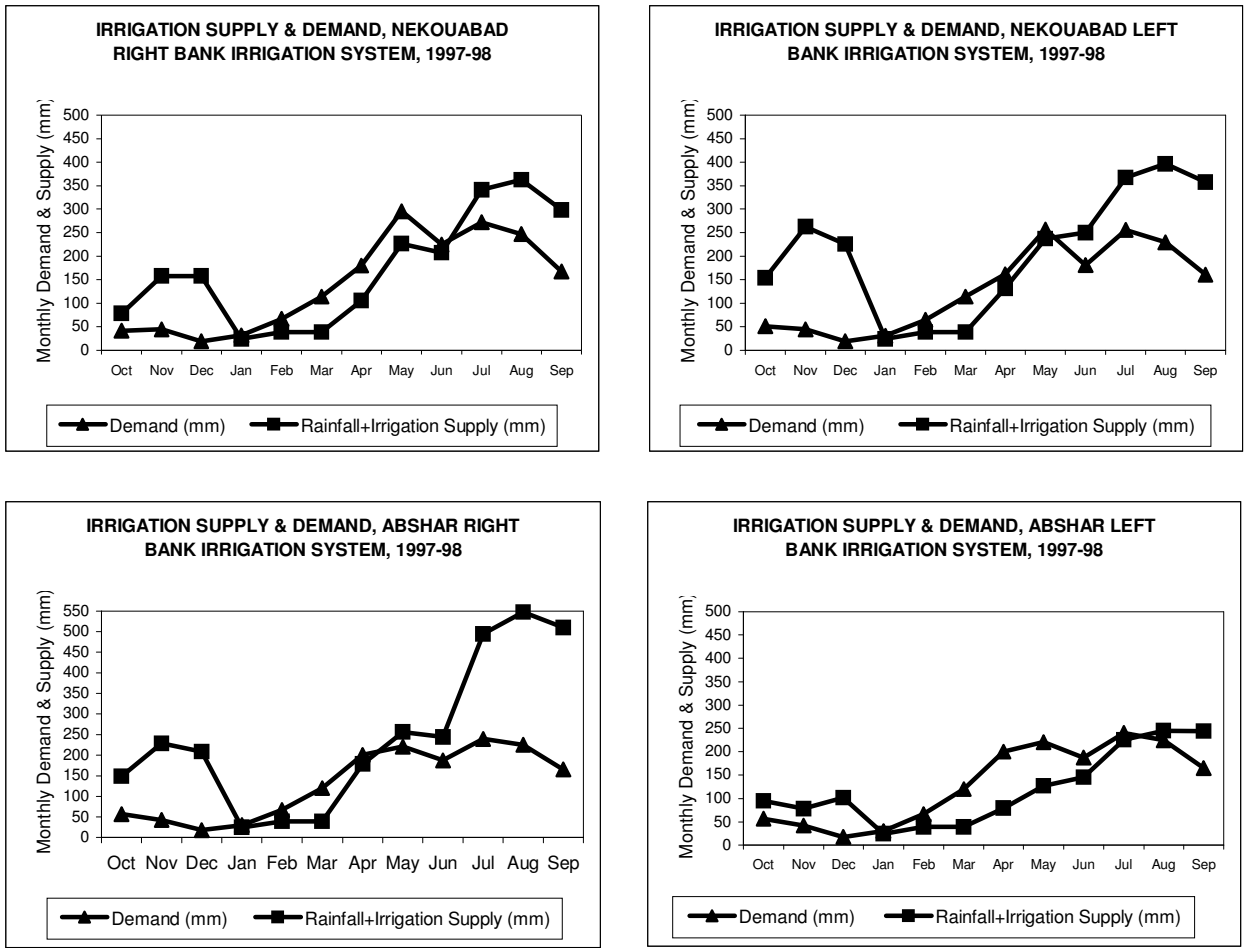

Figure 10: Irrigation supply and demand volumes in four major irrigation systems in the Zayandeh Rud basin, 1997-98

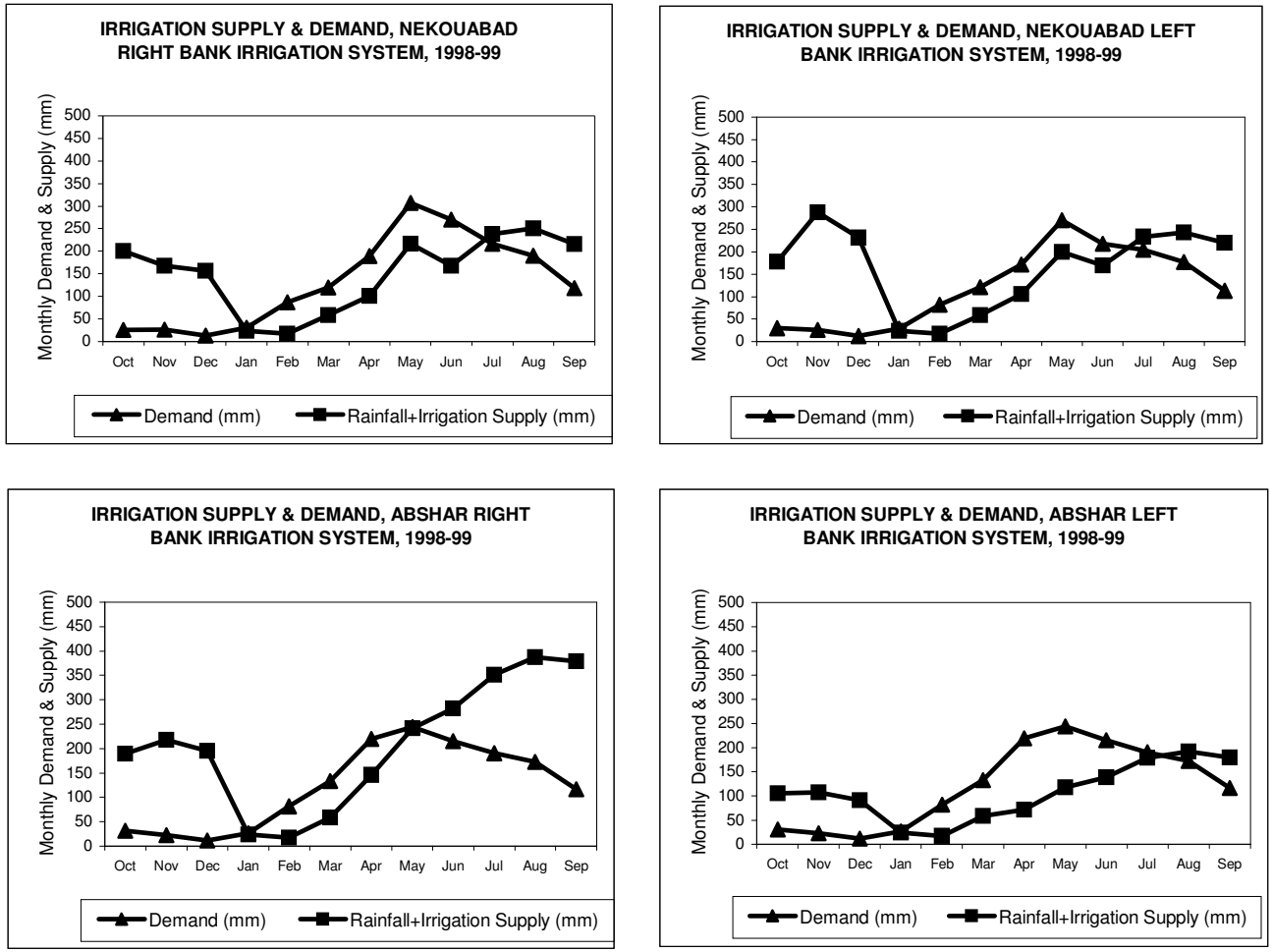

Figure 11: Irrigation supply and demand volumes in four major irrigation systems in the Zayandeh Rud basin, 1998-99

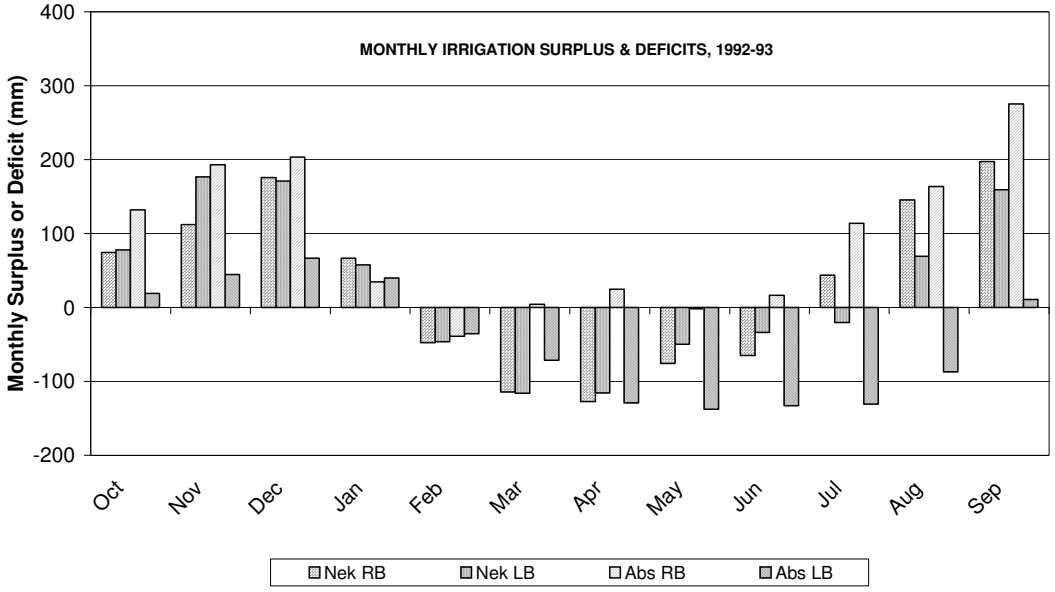

Figure 12: Monthly water surplus and deficits in four major irrigation systems in the Zayandeh Rud basin, 1992-93

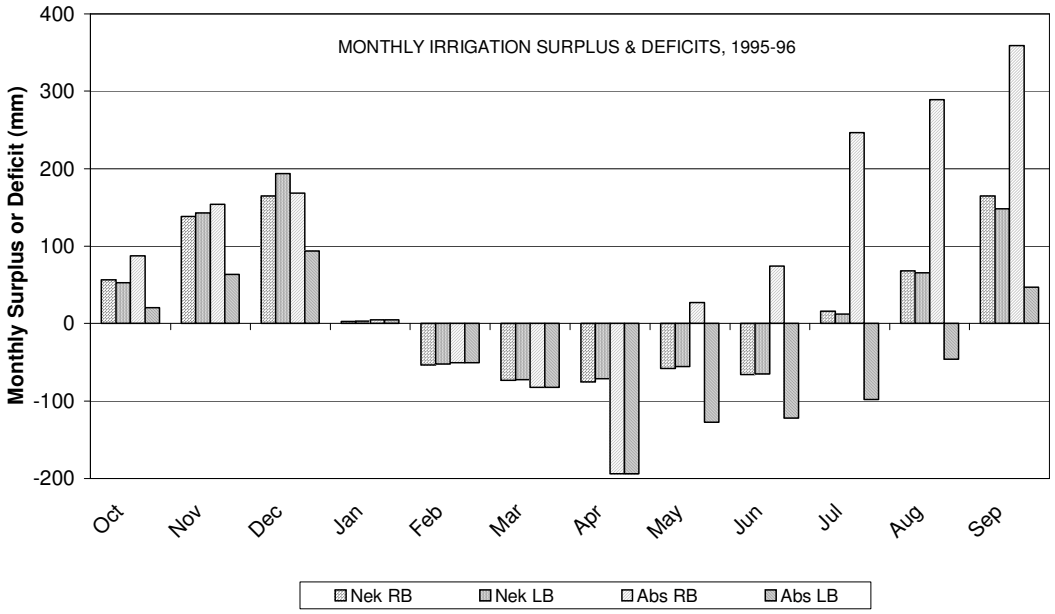

Figure 13: Monthly water surplus and deficits in four major irrigation systems in the Zayandeh Rud basin, 1995-96

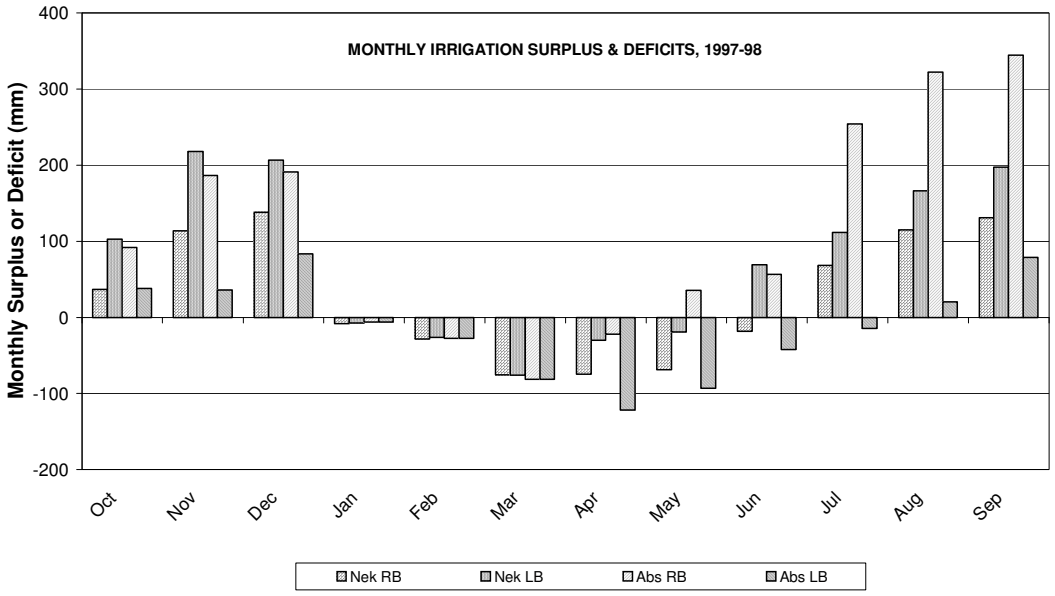

Figure 14: Monthly water surplus and deficits in four major irrigation systems in the Zayandeh Rud basin, 1997-98

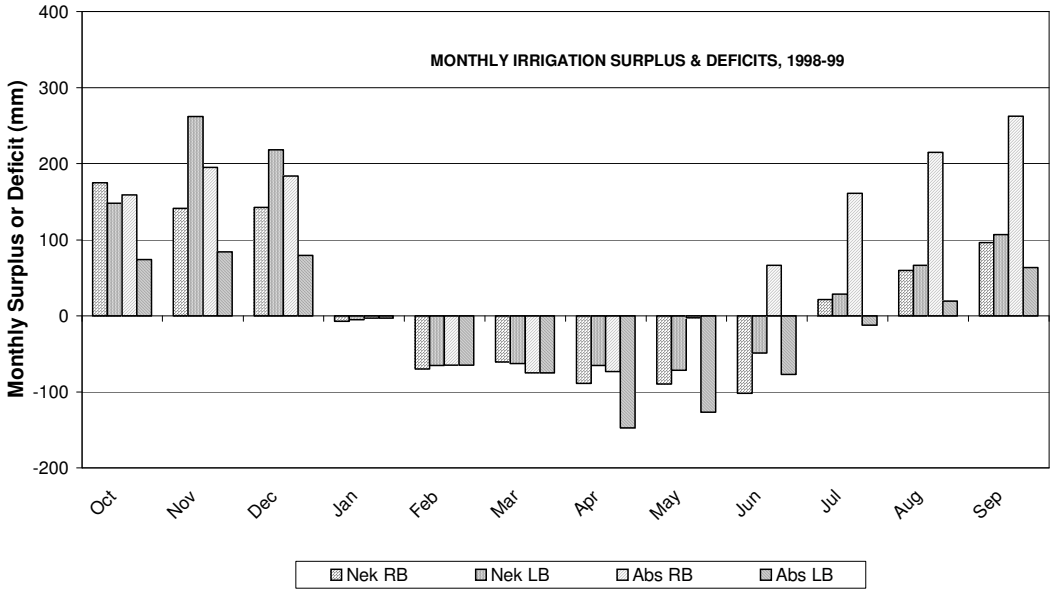

Figure 15: Monthly water surplus and deficits in four major irrigation systems in the Zayandeh Rud basin, 1998-99

Discussion

Analysis of the graphs and tables of water supply and demand highlight the case for improved management of irrigation water deliveries into the Zayandeh Rud irrigation systems by better matching of variations in supply and demand and taking into account the available canal capacities. Some of the specific observations that can be made in this respect are as follows:

- The 16 graphs of irrigation supply and demand (4 systems x 4 years) indicate that in all the four systems studied, although the water deliveries show an increasing trend almost reflecting the increasing demand from January to about June, the supply actually falls short of demand.

- In the remaining six months of the year, there appears to be a phenomenon of 'over-correction', generally resulting in surpluses of water supply over demand. In all the systems studied, the water supply exceeds demand in the first three months of the hydrological year, from October to December. The largest deficits occur between February and May.

Table 6: Summary of annual surplus and deficits in irrigation water deliveries

System	Surplus (+) or Deficit (-) *(units: million cubic meters)*			
	1992-93	1995-96	1997-98	1998-99
Nekouabad Right Bank	+11.98	+8.81	+14.91	+7.41
Nekouabad Left Bank	+23.66	+18.26	+139.97	+54.77
Abshar Right Bank	+80.24	+47.13	+78.35	+53.23
Abshar Left Bank	-155.83	-137.85	-68.41	-68.84

- Of the 4 systems, the Abshar Right Bank receives the largest surplus of water supply over demand. This is especially so during summer when the water releases are far in excess of the needs of the actual cropping pattern; the areas actually cropped are less than the design area, on which the water releases to the systems are based.

- On the other hand, the Abshar left bank system shows an opposite trend. It has the largest deficits and the smallest surpluses when compared to the other systems in a given period. The actual cropped areas in this system are much more than the design command area. As the irrigation releases are based on the design area this will naturally result in deficits.

- Similarly, the Nekouabad right and left bank systems have large extents of rice, cultivated from May to September. But both systems have deficits in surface water at the start of the cropping season.

- In this study, conveyance and distribution losses in the canal network between the diversion point and farmers' fields have not been taken into account. Water issues at the head of the system have been compared to crop water requirements, based on the estimated cropping pattern for the year. This is not unreasonable, given that water

'lost' through seepage and percolation is re-used in the system. Drainage out of the system has also not been considered; this is an aspect worthy of further investigation.

- We have also assumed that all the rainfall in a particular month is effectively contributing to irrigation supply. In fact, this maybe too optimistic. Most of the rainfall occurs between January and March and if rainfall is not taken onto account, the deficits observed during this period would be even greater.

An interesting question arising from this discussion is *'what strategies do farmers and system managers adopt to respond to these deficits in surface irrigation supply?*' In particular, it will be of considerable interest to study the extent to which farmers use groundwater to supplement surface irrigation supplies, and the interactions between these two sources of water.

Conclusion

This paper set out to study irrigation water supply and demand in four major irrigation systems in the Zayandeh Rud basin, namely Nekouabad Right and Left, and Abshar Right and Left. While water supply information was readily available, the estimation of water demand proved to be more difficult due to the absence of data on irrigated areas and cropping patterns.

To overcome this difficulty, this information was finally derived from the available district-level agricultural statistics for Esfahan province. But these data cover all crops and are not specifically focused on the irrigation systems. Hence, a simple spreadsheet-based model was devised to derive the required information on irrigated areas and irrigated crops from the available records. This approach yielded credible results with far less time and effort compared to aggregating village-level data. But the validity of this approach has to be further verified against satellite image-based estimates of irrigated areas. But the challenge of identifying crop types and cropping patterns will still remain.

This clearly highlights the importance of carrying out systematic, regular monitoring to provide reliable data on irrigated areas, crops, water deliveries and operational practices. In the absence of such basic information, meaningful performance assessment and improvements to system management will be difficult to achieve. Crop-based irrigation system management will also help to better match water deliveries to actual demand.

An obvious question that arises is whether the oversupply of water during the autumn and winter months from the surface irrigation network is 'wasted'? Much of this probably goes to recharging of groundwater that can be subsequently re-used when there is a shortfall in surface irrigation supply. Groundwater is also used to irrigate crops outside the official command areas of the systems. Analysis of changes in groundwater levels and of well discharge records in combination with the surface irrigation operations will provide a much better picture of overall supply and demand of irrigation water in the Zayandeh Rud basin.

This study has been limited to the four older irrigation systems in the Zayandeh Rud basin. It can be extended to include the newer irrigation systems in the basin, as and when they come into operation.

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Annex I: Water releases in Zayandeh Rud basin

Table I.1. Monthly water releases from Chadegan reservoir (units: m^3x10^6)

Month	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99
Oct	185	208	149	139	113	182	211	99	112	147	115	113
Nov	210	178	106	119	86	173	213	88	101	114	96	101
Dec	158	207	67	82	51	115	198	80	69	98	83	85
Jan	50	67	17	15	19	33	38	38	31	25	33	31
Feb	14	26	15	13	16	62	21	20	19	21	20	16
Mar	42	98	47	20	28	145	43	33	30	71	28	16
Apr	243	157	146	131	84	281	137	161	119	123	116	134
May	451	216	208	203	190	419	210	192	246	187	208	205
Jun	256	213	225	213	317	264	215	199	242	212	223	199
Jul	199	198	191	176	220	292	187	205	234	206	216	168
Aug	200	187	188	174	190	269	193	211	233	209	227	162
Sep	204	175	174	155	189	284	162	179	209	179	189	137
Total	2212	1928	1533	1441	1503	2517	1828	1504	1646	1593	1553	1367

Table I.2. Monthly water deliveries to major irrigation systems (units: m^3x10^6)

NEKOUABAD RIGHT BANK												
Month	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99
Oct	20.87	18.40	22.51	17.93	15.90	16.46	16.59	11.23	15.18	11.33	10.93	24.63
Nov	19.96	18.14	17.80	17.14	14.86	13.48	19.09	14.21	12.76	11.40	11.44	11.15
Dec	19.61	19.22	15.85	17.93	11.78	15.77	18.79	11.60	11.02	11.60	10.23	10.26
Jan	3.93	7.60	0.00	0.00	0.00	2.77	4.62	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apr	24.71	24.19	26.27	14.13	10.80	7.82	15.47	17.90	9.37	11.95	10.37	9.29
May	30.41	31.71	30.28	31.49	31.10	20.51	29.98	23.79	23.37	21.87	21.67	20.92
Jun	32.14	32.14	29.98	32.23	29.64	24.93	31.36	26.44	26.82	25.41	25.25	19.28
Jul	32.14	32.14	31.19	33.26	33.31	31.15	34.82	31.19	31.08	32.88	31.10	21.29
Aug	32.14	32.14	30.11	32.66	31.98	32.79	34.82	30.57	30.45	29.99	30.02	19.74
Sep	31.45	29.64	30.37	30.20	28.90	27.78	30.93	25.91	29.13	25.91	24.87	17.00
Annual	247.36	245.33	234.36	226.96	208.26	193.44	236.47	192.84	189.18	182.34	175.88	153.56
NEKOUABAD LEFT BANK												
Month	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99
Oct	62.81	65.92	56.85	59.96	50.98	48.47	55.21	33.85	44.06	43.93	41.99	43.03
Nov	48.73	59.66	46.83	54.26	37.32	46.87	45.10	34.37	34.34	34.21	34.95	34.99
Dec	44.19	52.44	32.31	51.75	24.06	38.32	40.00	24.34	34.26	31.10	27.90	27.89
Jan	6.48	9.07	0.00	0.00	0.00	5.01	13.13	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apr	50.63	60.05	61.17	45.88	3.11	19.35	40.87	30.54	24.88	33.39	28.12	21.16
May	63.59	66.27	77.24	67.65	64.80	53.22	67.91	45.85	54.86	50.11	49.16	41.35
Jun	69.98	69.64	77.33	70.37	79.88	57.37	67.91	54.69	65.71	59.31	61.65	39.63
Jul	72.10	73.09	77.93	75.95	78.02	65.19	74.48	65.35	75.72	70.55	68.06	41.83
Aug	69.98	73.87	75.08	75.00	69.38	71.28	78.97	63.89	74.80	72.39	67.78	39.55
Sep	71.58	70.03	71.45	74.22	60.23	68.43	72.23	58.09	71.30	67.05	61.47	35.83
Annual	560.09	600.05	576.20	575.04	467.78	473.52	555.81	410.98	479.92	462.05	441.08	325.26
ABSHAR RIGHT BANK												
Month	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99
Oct			nd	nd	27.99	24.36	25.92	17.06	17.75	19.61	17.97	19.39
Nov			nd	29.81	18.92	23.33	23.85	18.85	16.98	18.53	21.05	18.27
Dec			nd	28.86	14.00	20.74	19.70	15.87	13.79	17.84	17.72	16.23
Jan	nd	nd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	nd	nd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	nd	nd	0.00	0.00	0.00	11.38	0.00	0.00	0.00	0.00	0.00	0.00
Apr	nd	nd	nd	nd	21.70	24.97	24.91	23.06	0.00	18.86	18.55	13.26
May	nd	nd	nd	nd	27.05	27.59	32.14	26.45	24.05	27.19	25.87	22.65
Jun	nd	nd	nd	nd	29.73	28.12	32.14	27.78	25.40	27.41	21.30	22.15
Jul	nd	nd	nd	nd	26.52	28.13	30.00	22.17	26.30	26.68	26.96	16.07
Aug	nd	nd	nd	nd	26.78	28.13	29.73	26.33	27.04	27.86	29.12	17.38
Sep	nd	nd	nd	nd	27.86	28.93	29.73	27.18	25.96	27.81	27.19	17.00
Annual	nd	nd	nd	nd	220.54	245.66	248.11	204.74	177.27	211.78	205.72	162.40
ABSHAR LEFT BANK												
Month	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99
Oct		nd	nd	nd	20.74	24.36	25.14	20.27	23.39	25.01	26.61	23.65
Nov		nd	nd	19.98	18.66	22.03	22.29	17.33	20.75	21.19	16.66	20.83
Dec		nd	nd	16.64	14.52	18.14	19.96	16.83	16.62	19.03	18.06	17.41
Jan	nd	nd	nd	1.81	1.04	1.34	1.30	0.00	0.00	0.00	0.00	0.00
Feb	nd	nd	nd	1.30	1.04	1.34	0.00	0.00	0.00	0.00	0.00	0.00
Mar	nd	nd	nd	1.85	1.30	10.02	0.00	0.00	0.00	0.00	0.00	0.00
Apr	nd	nd	nd	nd	18.75	21.22	21.16	24.27	0.00	21.41	18.94	14.73
May	nd	nd	nd	nd	26.25	27.86	30.27	27.86	26.70	21.32	28.84	25.55
Jun	nd	nd	nd	nd	23.84	27.59	34.82	29.81	27.82	28.12	29.49	25.28
Jul	nd	nd	nd	nd	20.89	26.78	31.87	28.65	28.45	28.99	28.56	18.75
Aug	nd	nd	nd	nd	22.77	26.78	28.39	29.46	32.57	30.80	30.27	20.03
Sep	nd	nd	nd	nd	23.57	26.52	29.73	29.20	31.23	29.68	30.29	18.75
Annual	nd	nd	nd	nd	193.34	233.98	244.92	223.70	207.52	225.55	227.72	184.97

nd: no data

Annex II: Supply-demand comparisons

Nekouabad Right Bank, 1992-93								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	13927	6.08	44	16.46	118	0.0	118	74
Nov	8338	4.14	50	13.48	162	0.0	162	112
Dec	8338	2.14	26	15.77	189	12.1	201	175
Jan	8338	1.90	23	2.77	33	56.2	89	67
Feb	8338	6.97	84	0.00	0	36.3	36	-47
Mar	9432	13.79	146	0.00	0	32.0	32	-114
Apr	10944	22.38	204	7.82	71	5.9	77	-127
May	10944	29.69	271	20.51	187	8.3	196	-76
Jun	11992	32.68	273	24.93	208	0.0	208	-65
Jul	8485	27.42	323	31.15	367	0.0	367	44
Aug	7670	21.63	282	32.79	428	0.0	428	145
Sep	7670	12.65	165	27.78	362	0.0	362	197
Annual		181.47		193.44		150.8		
Nekouabad Left Bank, 1992-93								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	36173	20.30	56	48.47	134	0.0	134	78
Nov	20672	10.37	50	46.87	227	0.0	227	177
Dec	20672	5.53	27	38.32	185	12.1	197	171
Jan	20672	4.77	23	5.01	24	56.2	80	57
Feb	20672	17.08	83	0.00	0	36.3	36	-46
Mar	22857	33.75	148	0.00	0	32.0	32	-116
Apr	32082	58.26	182	19.35	60	5.9	66	-115
May	32082	71.87	224	53.22	166	8.3	174	-50
Jun	31870	68.08	214	57.37	180	0.0	180	-34
Jul	22951	69.87	304	65.19	284	0.0	284	-20
Aug	21773	56.18	258	71.28	327	0.0	327	69
Sep	21773	33.80	155	68.43	314	0.0	314	159
Annual		449.85		473.52		150.80		
Abshar Right Bank, 1992-93								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	12130	8.33	69	24.36	201	0.0	201	132
Nov	9563	4.88	51	23.33	244	0.0	244	193
Dec	9563	2.45	26	20.74	217	12.1	229	203
Jan	9563	2.05	21	0.00	0	56.2	56	35
Feb	9563	7.17	75	0.00	0	36.3	36	-39
Mar	10508	14.29	136	11.38	108	32.0	140	4
Apr	11092	22.89	206	24.97	225	5.9	231	25
May	11092	28.68	259	27.59	249	8.3	257	-2
Jun	10916	26.30	241	28.12	258	0.0	258	17
Jul	6793	20.41	300	28.13	414	0.0	414	114
Aug	6630	17.29	261	28.13	424	0.0	424	163
Sep	6630	10.68	161	28.93	436	0.0	436	275
Annual		165.41		245.66		150.80		
Abshar Left Bank, 1992-93								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	28199	18.96	67.2	24.36	86	0.0	86	19
Nov	22232	12.09	54.4	22.03	99	0.0	99	45
Dec	22232	6.01	27.0	18.14	82	12.1	94	67
Jan	22232	5.00	22.5	1.34	6	56.2	62	40
Feb	22232	17.27	77.7	1.34	6	36.3	42	-35
Mar	24429	35.26	144.3	10.02	41	32.0	73	-71
Apr	25787	55.94	216.9	21.22	82	5.9	88	-129
May	25787	65.48	253.9	27.86	108	8.3	116	-138
Jun	25377	61.33	241.7	27.59	109	0.0	109	-133
Jul	15792	47.44	300.4	26.78	170	0.0	170	-131
Aug	15413	40.20	260.8	26.78	174	0.0	174	-87
Sep	15413	24.84	161.2	26.52	172	0.0	172	11
Annual		389.81		233.98		150.80		

Nekouabad Right Bank, 1995-96								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	14050	7.37	52	15.18	108	0.9	108.9	56
Nov	7137	2.89	41	12.76	179	0	178.8	138
Dec	7137	1.61	23	11.02	154	32.8	187.2	165
Jan	7137	1.36	19	0.00	0	22.1	22.1	3
Feb	7137	5.36	75	0.00	0	21.7	21.7	-53
Mar	8206	10.01	122	0.00	0	48.6	48.6	-73
Apr	9831	17.82	181	9.37	95	10.6	105.9	-75
May	9831	30.13	306	23.37	238	10.9	248.6	-58
Jun	12417	34.97	282	26.82	216	0	216.0	-66
Jul	9697	29.55	305	31.08	320	0.2	320.7	16
Aug	8734	24.54	281	30.45	349	0	348.6	68
Sep	8734	14.76	169	29.13	334	0	333.6	165
Annual		180.37		189.18		147.80		

Nekouabad Left Bank, 1995-96								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	37353	24.65	66	44.06	118	0.9	118.9	53
Nov	18697	7.61	41	34.34	184	0	183.6	143
Dec	18697	4.20	22	34.26	183	32.8	216.0	194
Jan	18697	3.52	19	0.00	0	22.1	22.1	3
Feb	18697	13.77	74	0.00	0	21.7	21.7	-52
Mar	21685	26.20	121	0.00	0	48.6	48.6	-72
Apr	30740	49.99	163	24.88	81	10.6	91.5	-71
May	30740	75.26	245	54.86	178	10.9	189.4	-55
Jun	33434	87.39	261	65.71	197	0	196.5	-65
Jul	26018	72.57	279	75.72	291	0.2	291.2	12
Aug	23220	59.53	256	74.80	322	0	322.1	66
Sep	23220	36.97	159	71.30	307	0	307.0	148
Annual		461.66		479.92		147.80		

Abshar Right Bank, 1995-96								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	11440	7.810349	68	17.75	155	0.9	156.1	88
Nov	8903	3.279241	37	16.98	191	0	190.8	154
Dec	8903	1.706935	19	13.79	155	32.8	187.7	169
Jan	8903	1.535314	17	0.00	0	22.1	22.1	5
Feb	8903	6.440809	72	0.00	0	21.7	21.7	-51
Mar	9493	12.43631	131	0.00	0	48.6	48.6	-82
Apr	10014	20.46896	204	0.00	0	10.6	10.6	-194
May	10014	22.41808	224	24.05	240	10.9	251.0	27
Jun	8371	19.20472	229	25.40	303	0	303.4	74
Jul	5057	13.84171	274	26.30	520	0.2	520.3	247
Aug	4942	12.7661	258	27.04	547	0	547.1	289
Sep	4942	8.22642	166	25.96	525	0	525.3	359
Annual		130.13		177.27		147.80		

Abshar Left Bank, 1995-96								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	26593	18.16	68.3	23.39	88	0.9	88.9	21
Nov	20695	7.62	36.8	20.75	100	0	100.3	63
Dec	20695	3.97	19.2	16.62	80	32.8	113.1	94
Jan	20695	3.57	17.2	0.00	0	22.1	22.1	5
Feb	20695	14.97	72.3	0.00	0	21.7	21.7	-51
Mar	22067	28.91	131.0	0.00	0	48.6	48.6	-82
Apr	23278	47.58	204.4	0.00	0	10.6	10.6	-194
May	23278	58.97	253.3	26.70	115	10.9	125.6	-128
Jun	22356	55.12	246.6	27.82	124	0	124.4	-122
Jul	14653	42.88	292.6	28.45	194	0.2	194.4	-98
Aug	14386	39.16	272.2	32.57	226	0	226.4	-46
Sep	14386	24.47	170.1	31.23	217	0	217.1	47
Annual		345.38		207.52		147.80		

Nekouabad Right Bank, 1997-98								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	13883	5.85	42	10.93	79	0.1	78.8	37
Nov	7252	3.22	44	11.44	158	0.6	158.3	114
Dec	7252	1.43	20	10.23	141	17.1	158.2	138
Jan	7252	2.34	32	0.00	0	24.2	24.2	-8
Feb	7252	4.86	67	0.00	0	38.6	38.6	-28
Mar	8150	9.28	114	0.00	0	38.6	38.6	-75
Apr	9909	17.82	180	10.37	105	0.8	105.5	-74
May	9909	29.29	296	21.67	219	8.5	227.2	-68
Jun	12202	27.46	225	25.25	207	0	206.9	-18
Jul	9139	24.91	273	31.10	340	0.8	341.1	68
Aug	8322	20.53	247	30.02	361	1.2	361.9	115
Sep	8322	13.98	168	24.87	299	0	298.8	131
Annual		160.97		175.88		130.50		
Nekouabad Left Bank, 1997-98								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	27281	13.96	51	41.99	154	0.1	154.0	103
Nov	13339	5.92	44	34.95	262	0.6	262.6	218
Dec	13339	2.60	19	27.90	209	17.1	226.2	207
Jan	13339	4.18	31	0.00	0	24.2	24.2	-7
Feb	13339	8.61	65	0.00	0	38.6	38.6	-26
Mar	14760	16.90	114	0.00	0	38.6	38.6	-76
Apr	21447	34.76	162	28.12	131	0.8	131.9	-30
May	21447	55.04	257	49.16	229	8.5	237.7	-19
Jun	24625	44.60	181	61.65	250	0	250.3	69
Jul	18555	47.51	256	68.06	367	0.8	367.6	111
Aug	17171	39.45	230	67.78	395	1.2	395.9	166
Sep	17171	27.58	161	61.47	358	0	358.0	197
Annual		301.11		441.08		130.50		
Abshar Right Bank, 1997-98								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	12078	6.87	57	17.97	149	0.1	148.9	92
Nov	9241	3.87	42	21.05	228	0.6	228.3	186
Dec	9241	1.65	18	17.72	192	17.1	208.8	191
Jan	9241	2.79	30	0.00	0	24.2	24.2	-6
Feb	9241	6.11	66	0.00	0	38.6	38.6	-28
Mar	9858	11.80	120	0.00	0	38.6	38.6	-81
Apr	10458	20.95	200	18.55	177	0.8	178.2	-22
May	10458	23.04	220	25.87	247	8.5	255.9	36
Jun	8738	16.37	187	21.30	244	0	243.8	56
Jul	5465	13.11	240	26.96	493	0.8	494.0	254
Aug	5331	11.99	225	29.12	546	1.2	547.4	322
Sep	5331	8.82	165	27.19	510	0	510.0	344
Annual		127.37		205.72		130.50		
Abshar Left Bank, 1997-98								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	28081	15.97	56.9	26.61	95	0.1	94.9	38
Nov	21485	9.00	41.9	16.66	78	0.6	78.1	36
Dec	21485	3.83	17.8	18.06	84	17.1	101.1	83
Jan	21485	6.49	30.2	0.00	0	24.2	24.2	-6
Feb	21485	14.20	66.1	0.00	0	38.6	38.6	-27
Mar	22919	27.43	119.7	0.00	0	38.6	38.6	-81
Apr	24315	48.71	200.3	18.94	78	0.8	78.7	-122
May	24315	53.56	220.3	28.84	119	8.5	127.1	-93
Jun	20314	38.05	187.3	29.49	145	0	145.2	-42
Jul	12705	30.49	240.0	28.56	225	0.8	225.6	-14
Aug	12394	27.88	225.0	30.27	244	1.2	245.4	20
Sep	12394	20.51	165.5	30.29	244	0	244.4	79
Annual		296.13		227.72		130.50		

Nekouabad Right Bank, 1998-99								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	13037	3.35	26	24.63	189	11.6	201	175
Nov	6630	1.76	27	11.15	168	0	168	141
Dec	6630	0.89	13	10.26	155	1.5	156	143
Jan	6630	2.05	31	0.00	0	23.8	24	-7
Feb	6630	5.76	87	0.00	0	17.1	17	-70
Mar	7872	9.39	119	0.00	0	58.5	59	-61
Apr	9631	18.26	190	9.29	96	4.5	101	-89
May	9631	29.56	307	20.92	217	0	217	-90
Jun	11477	31.01	270	19.28	168	0	168	-102
Jul	9079	19.71	217	21.29	235	3.9	238	21
Aug	7895	15.01	190	19.74	250	0	250	60
Sep	7895	9.39	119	17.00	215	0	215	96
Annual		146.15		153.56		120.90		
Nekouabad Left Bank, 1998-99								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	25854	7.76	30	43.03	166	11.6	178	148
Nov	12140	3.14	26	34.99	288	0	288	262
Dec	12140	1.56	13	27.89	230	1.5	231	218
Jan	12140	3.52	29	0.00	0	23.8	24	-5
Feb	12140	10.02	83	0.00	0	17.1	17	-65
Mar	14097	17.06	121	0.00	0	58.5	59	-63
Apr	20755	35.55	171	21.16	102	4.5	106	-65
May	20755	56.26	271	41.35	199	0	199	-72
Jun	23392	51.11	219	39.63	169	0	169	-49
Jul	18219	37.31	205	41.83	230	3.9	233	29
Aug	16292	28.76	177	39.55	243	0	243	66
Sep	16292	18.43	113	35.83	220	0	220	107
Annual		270.49		325.26		120.90		
Abshar Right Bank, 1998-99								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	10894	3.36	31	19.39	178	11.6	190	159
Nov	8374	1.93	23	18.27	218	0	218	195
Dec	8374	0.96	11	16.23	194	1.5	195	184
Jan	8374	2.25	27	0.00	0	23.8	24	-3
Feb	8374	6.85	82	0.00	0	17.1	17	-65
Mar	8768	11.68	133	0.00	0	58.5	59	-75
Apr	9382	20.58	219	13.26	141	4.5	146	-73
May	9382	22.89	244	22.65	241	0	241	-3
Jun	7857	16.92	215	22.15	282	0	282	66
Jul	4621	8.81	191	16.07	348	3.9	352	161
Aug	4486	7.74	172	17.38	387	0	387	215
Sep	4486	5.21	116	17.00	379	0	379	263
Annual		109.17		162.40		120.90		
Abshar Left Bank, 1998-99								
Month	Area (ha)	Demand ($x10^6$ m^3)	Demand (mm)	Irrigation Supply ($x10^6$ m^3)	Irrigation Supply (mm)	Rainfall (mm)	Irrign+Rain (mm)	Surplus (+) or Deficit (-) (mm)
Oct	25325	7.80	30.8	23.65	93	11.6	105	74
Nov	19468	4.48	23.0	20.83	107	0	107	84
Dec	19468	2.23	11.5	17.41	89	1.5	91	79
Jan	19468	5.23	26.9	0.00	0	23.8	24	-3
Feb	19468	15.92	81.8	0.00	0	17.1	17	-65
Mar	20384	27.16	133.3	0.00	0	58.5	59	-75
Apr	21811	47.84	219.3	14.73	68	4.5	72	-147
May	21811	53.22	244.0	25.55	117	0	117	-127
Jun	18265	39.34	215.4	25.28	138	0	138	-77
Jul	10742	20.48	190.7	18.75	175	3.9	178	-12
Aug	10430	17.99	172.4	20.03	192	0	192	20
Sep	10430	12.12	116.2	18.75	180	0	180	64
Annual		253.81		184.97		120.90		

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.
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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.