The 1999-2001 drought in the Zayandeh Rud basin, Iran, and its impact on water allocation and agriculture[1]

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1 Introduction

Most densely populated basin in the world, especially those which include a large city, have their water resources regulated by large storage dams. The management of the dams may differ widely depending on several factors, such as the (ir)regularity/predictability of the inflow, the ratio of the storage capacity to the annual dam inflow, the priority of use (hydropower generation, or agriculture, or supply to cities; flood control), and the level of security adopted for the supply of the different uses. Despite an extensive literature on the mathematic modelling of multipurpose dams, few are managed according to the strict set of rules one may derive from such exercises. One reason is that the perception and acceptance of risk varies with time; a second reason is that political criteria often override technical criteria, especially in times of crisis. When droughts occur, it is often claimed that dam managers have released too much water and jeopardized the security of the system, leaving it more exposed to a possible extreme event. This may or may not be the case and careful examination of hydrological data is required.

The impact on agriculture of a given reduction in water supply is very hard to predict. Prediction is specially arduous in systems where farmers have developed conjunctive use of surface and groundwater. Farmers' coping strategies include changing crops, shifting calendars, improving plot level application of water, designing arrangements such as rotations at the tertiary and field level in order to save water, but also resorting to groundwater to compensate for the reduction of surface water (Molle 2003). In such a situation the relationship between supply and crop production becomes blurred. Attempts to model such irrigation systems are consequently made more complex because little is known on the temporal and spatial expression of conjunctive use. The overall degree of resilience of agriculture is therefore a complex issue that can be observed retrospectively at the macro level by examining irrigation and agricultural data.

The case of the Chadegan dam in the Zayandeh Rud river basin, Central Iran, is examined here during the 1999-2002 drought period. The Chadegan dam is the main storage reservoir in the basin and is located in the Zagros mountains. The dam was completed in 1970 and has a capacity of 1.5 Bm3 (billion m^3). Its inflow is composed of both natural runoff and the diversion from the neighbouring

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Kurang basin through two tunnels. The first tunnel was operational in the 1953 and brought an average of 338 Mm3 of additional water, while the second provides an average of 250 Mm3 since 1987. (A third tunnel is due to be completed in 2010).

The dam supplies around 150,000 ha of irrigated land along the valley and the city of Esfahan, with its two million inhabitants. The heart of the province, therefore, critically depends on the supply of the dam. Its management and capacity to weather climatic dry spells is of crucial importance. The paper first examines the characteristics and magnitude of the 1999-2001 drought in hydrological terms and whether the water crisis was worsened by inadequate management or not. It then investigates what have been the impacts of the three-year drought on water allocation and agricultural production. The macro level relationship between the decrease in water supply and in agriculture production provides important insight on the resilience of agriculture and on the efficacy of the coping strategies used by farmers.

2 Data analysis

The Chadegan dam stores water during springtime, when snow melts, and releases it until the end of the year, ensuring a degree of regulation and the cultivation of two crops in a large part of the command area. Figure 1 illustrates the annual pattern of regulation of the dam with the 1987-98 values (that is excluding the drought period).

Figure 1. Average inflow and outflow from the Chadegan dam (1987-1998)

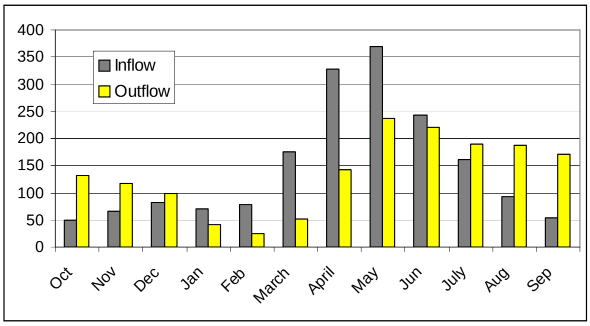


Figure 2 displays the evolution of the volume of water stored in the dam, as well as of the monthly water releases during the 1972-2002 period. It can be seen that the volumes released are relatively regular, with an overall hike after 1987 (increase in the inflow into the dam due to transbasin diversion through the second tunnel), and peaks for flood control in years when the dam is close to spilling (1976, 1987, 1988, 1993).

Figure 2: Evolution of stored (last day of month) and released water

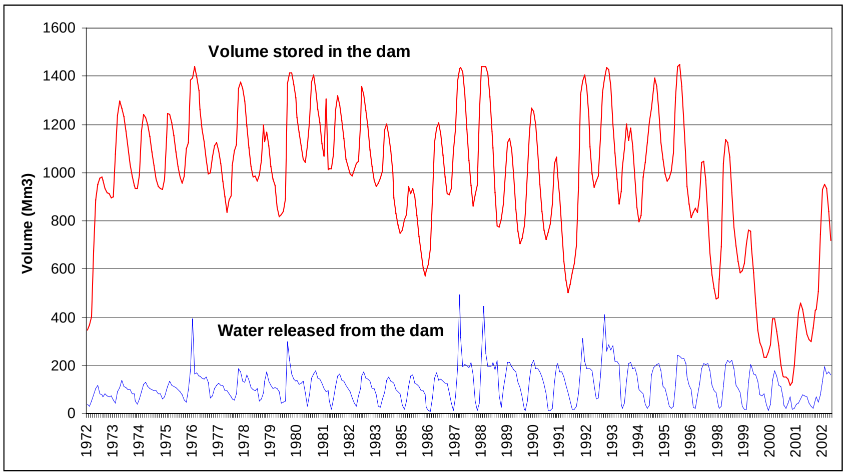
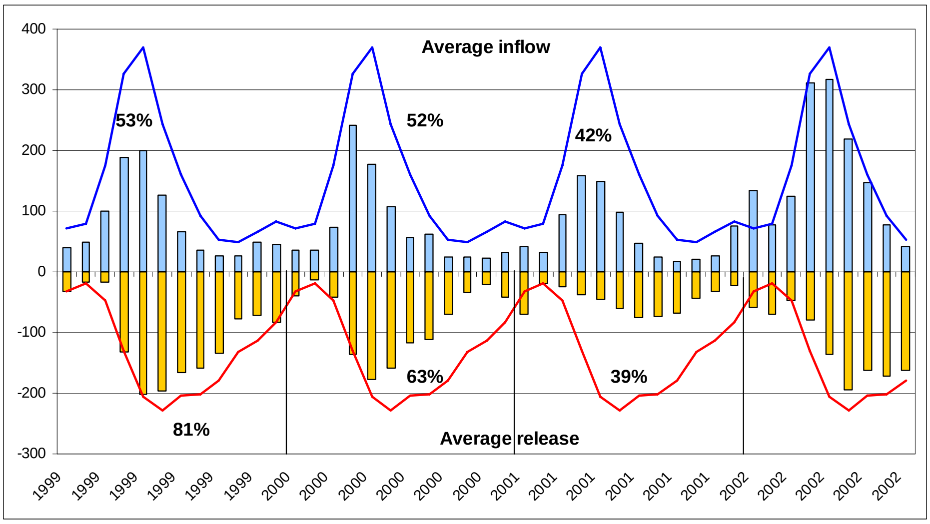


Figure 3 zooms in on the 1999-2001 drought period and examines how both monthly inflow into the dam and releases (April to March) out of it compare with average values. It can be seen that the inflow was 53%, 52% and 42% of the 1988-98 average for the three consecutive years respectively. At the same time, water releases were also reduced, but in a lower proportion, to 81%, 63%, and 39%. The third year appears as very critical, since only 39% of the water usually supplied was eventually released. Therefore it can be seen that releases in 1999 have not be attuned to the reduction in inflow, leading to an increase in the risk of shortage in subsequent years.

Figure 3: Dam inflow and dam releases during the 1999-2001 drought



This can also be seen from a longer time point of view in Figure 4, which shows that yearly releases are in general close to yearly inflow values (evaporation is limited, as is storage in the beginning of the season). The water released in 1999 was lower than the usual amount but quite large compared to the inflow observed, taking the stored volume down to 600 Mm3, thus heightening risk in case of subsequent dry year. Keeping, say, an additional 300 Mm3 in the dam would not have averted the crisis but would have eased the situation in the last year. However, if management had to be adjusted as to weather a crisis like that of the 1999-2001 three-year period, then much water would have to be kept in the dam, reducing drastically the amount of water that can be used each year. Since the cumulated inflow over the three years was as low as 2.6 Bm3, spreading the deficit over three years (assuming the situation had been known in advance) would have led to yearly releases around 850 Mm3, a far cry from the average values, and even from historical low values. It is also worth noting that out of these 2.6 Bm3, 1.1 Bm3 came through the two tunnels, which underlines the importance of the transfer from the Kurang basin for the Zayandeh Rud.

Figure 4: Comparison of yearly inflows and releases

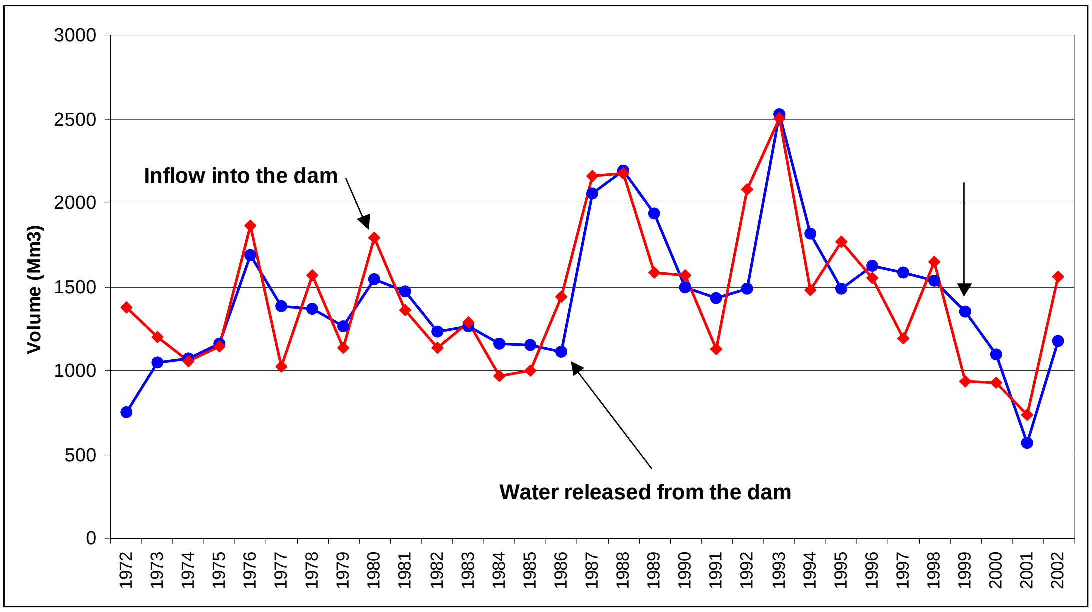
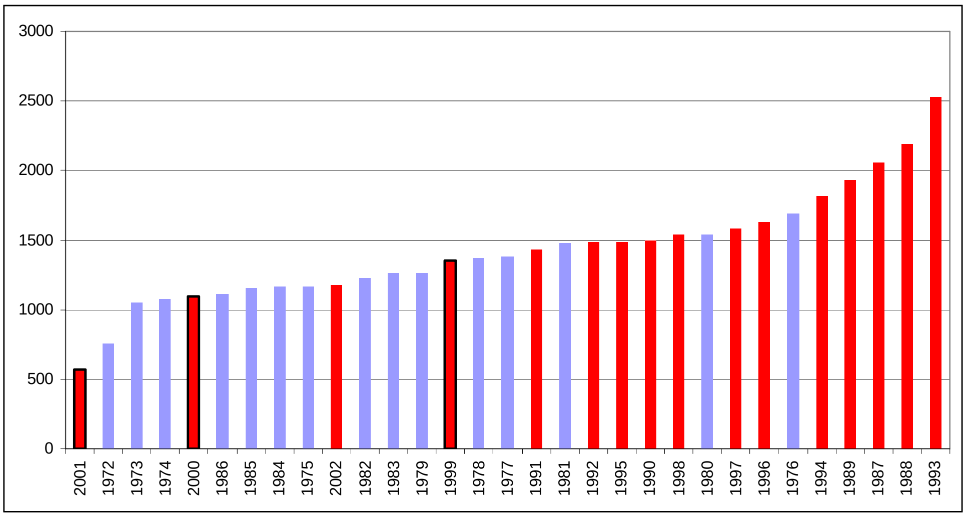


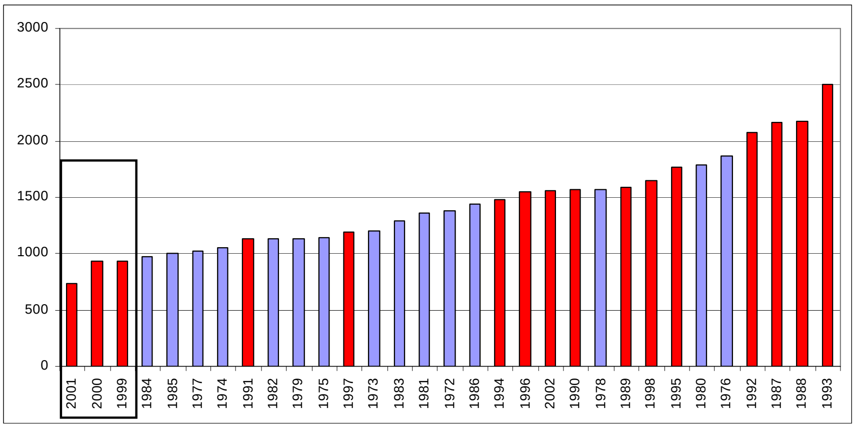
Figure 5: Average values of yearly dam releases (ranked values)



Note: bars in red correspond to years 1987, when the second tunnel was added (with an average contribution of 250 Mm3)

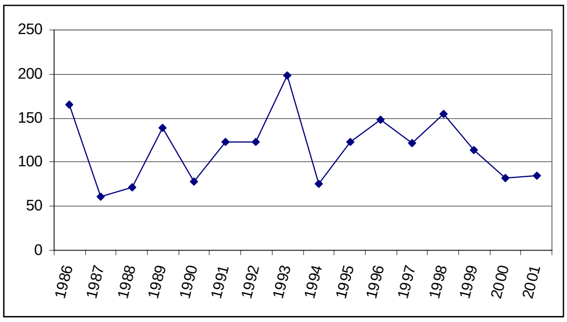
Figure 6 shows that the three consecutive inflows of the drought years were the three lowest values observed during the last 33 years, 2001 ending with an awesome value of 739 Mm3! The three-year spell can therefore be characterized as extremely exceptional.

Figure 6: Yearly inflow into the dam (ranked values)



Another way to illustrate the exceptionality of the drought is to see whether the precipitation corresponding to that period has also been exceptional or not, compared to their historical series. Figure 7 shows that rainfall has been normal in 1999 but quite low in 2000 and 2001. However these low values have also been observed in the past and the gravity of the drought cannot be sensed from rainfall alone. Esfahan rainfall data are not so significant because runoff occurs mainly in the Zagros mountain. The figure also shows the total for Khoorang……

Figure 7. Yearly rainfall in the upper basin and in Esfahan



3 Allocation of water to agriculture

This section looks at what have been the consequences of the reduced available water on the allocation to irrigated areas in the valley. We limit ourselves here to the large-scale irrigation systems supplied by the dam and shown in Figure 8.

Figure 8. Main irrigation schemes in the Zayandeh Rud basin (IWMI, AREO 2004)

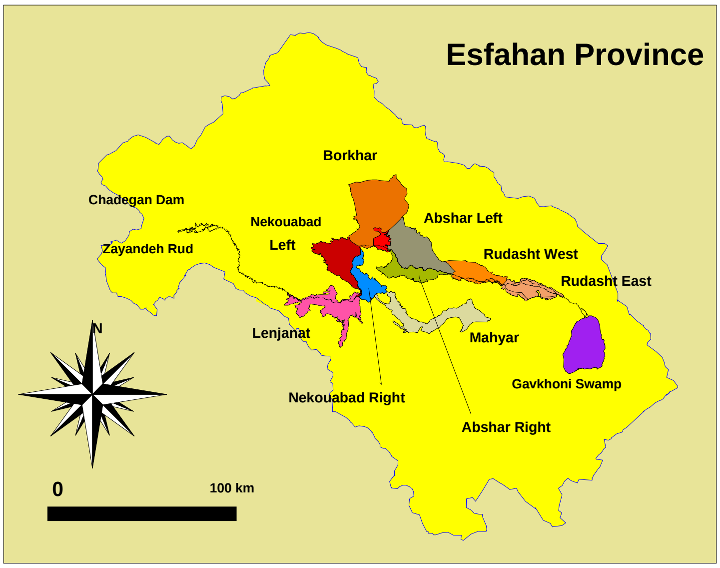
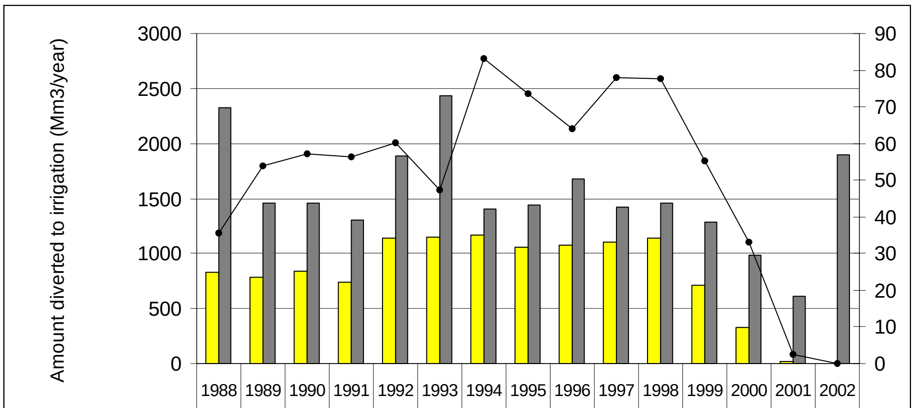


Figure 9. Total amount of water diverted to irrigation schemes



	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Diverted	831	787	837	738	1138	1153	1170	1057	1074	1104	1136	709	328	15	0
Released	2329	1461	1463	1308	1891	2433	1405	1437	1679	1418	1460	1284	987	613	1900
% diverted	36	54	57	56	60	47	83	74	64	78	78	55	33	3	0

(no release data available for 2002???; should erase the point or complement)

It can be seen from Figure 9 that the amount of water diverted to irrigation areas is around 75%[4] since 1992, after completion of Abshar Right and Left Bank areas. The drastic reduction of that percentage in 2000 and 2001 to 33 and 3%, despite dam releases being reduced to only 66 % and 41% respectively, illustrates how agriculture gets squeezed in times of shortage, while other uses get priority. In spring 2001, at the height of the drought, deliveries were ordered despite very low stocks in the reservoir. This was triggered by complaints from business owners (and dwellers) in the city, who claimed that national coverage of the crisis in the basin (children playing soccer in the river bed) was

[4] 1988 and 1993 have lower values because releases have been done for the purpose of flood control when the dam was getting close to spilling.

detrimental to the flows of tourists which normally converge to the city[5]. As the attraction of Esfahan is tightly related to the spell of its gardens and bridges, water was released to restore the magic and save the tourist season[6].

4 Impact of the drought on agricultural production

The impact of this exceptional drought on agriculture has been severe but it is instructive to try to see if curtailment of water led to reductions in production of the same order of magnitude, or whether coping strategies reduced this impact. The most serious damages have occurred in orchards supplied by wells and qanats in lateral valleys which have dried up during the period. In the village of Jalalabad, for example, located on the west of Najafabad, approximately half of the 500 ha of orchards have been lost. The discharge of the main qanat has dwindled down from 150 to 50 l/s, 40 percent of the wells dried up and the remaining ones could be used only 4 hours a day instead of 24 hours (Molle and Miranzadeh 2004).

In the main areas irrigated by diversion of the Zayandeh Rud, orchards are few and the impact has mostly been in terms of cropping areas and yield reduction. No statistics exist at the irrigation scheme level but figures for the seven districts[7] which encompass these areas provide a good proxy[8] of the impact on these areas.

Figure 10 shows a slump of 38% between 1998 and 2001 and Table 1 provides corresponding numbers for the different districts. Some districts like Borkhar (because it relied mainly on deep wells and received additional, albeit limited, canal water) show limited reduction. Districts with significant secondary valleys relying on springs and qanats (Shahrezah, Najafabad) have been much more affected (around 30%).

Table 1. Reduction in crop area in central districts

Esfahan	49%	Borkhar	7%	Khominashaar	11%
Mobaraka	29%	Najafabad	38%	Flavrjan	40%
Shahreza	36%	Total	34%		

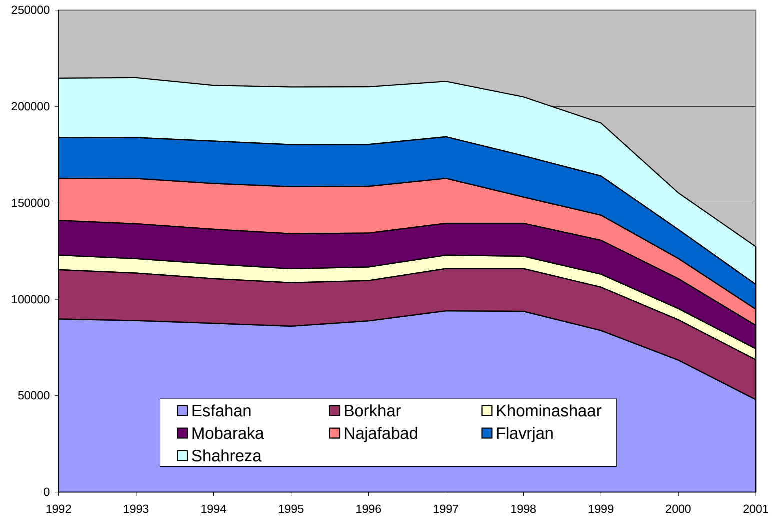
[5] During the two week holiday of the 2004 (Iranian) new year, visitors to the city were reported to number between 1.5 and 2.1 millions, that is, roughly the population of the city itself.

[6] This is why Abshar area, located downstream of the city, was able to divert a few million m^3, while upstream areas could not.

[7] Data for 2000 in Shahreza district are missing and have been interpolated based on the general trend observed in other districts. Irrigated areas that are not included in large scale schemes are supplied by qanats, springs, or wells.

[8] An unexpected difficulty with the analysis of cropping patterns in irrigation schemes is that land use data are collected by village and aggregated by districts, which do not overlap with irrigation boundaries (Sally and Mamanpoush 1999). However, since we are only considering the seven main irrigation schemes of the main valley, the aggregate of these seven districts can be considered as a reasonable proxy.

Figure 10: Evolution of cropping areas in the seven central districts



Source: Statistical yearbook by province

This reduction in area affected all crops, as can be seen in Figure 11, with the exception of trees (located in the upstream areas), because perennial crops are irrigated in priority. However, if we take the figures for the year 2002, we see that the tree area has declined from 15,366 to 13,588 ha, which suggests that the last year of the drought, 2001, has seen the loss of almost 2,000 ha of trees.

Figure 12 shows the difference in yield between before the drought (average 1997-1998) and after the drought (average 2000-2001) for eight selected crops, and identifies a decline of only 12% when they are pooled together.

Figure 11. Reduction in main crop areas (before and on the last year of the drought)

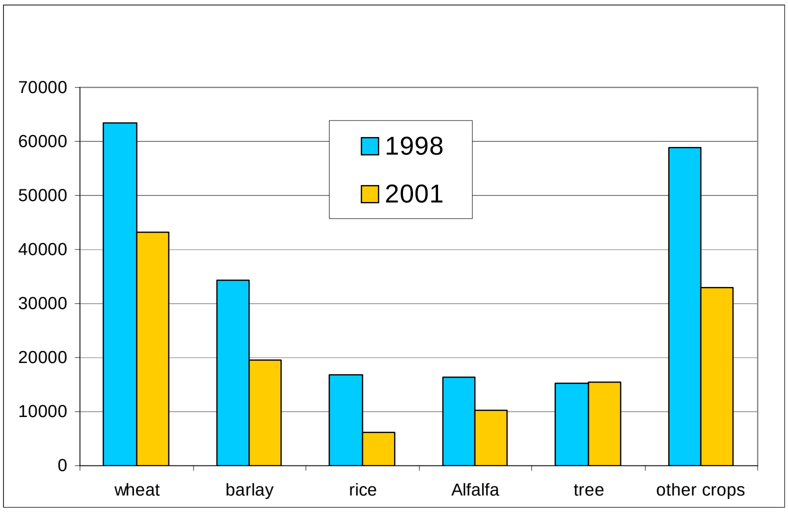
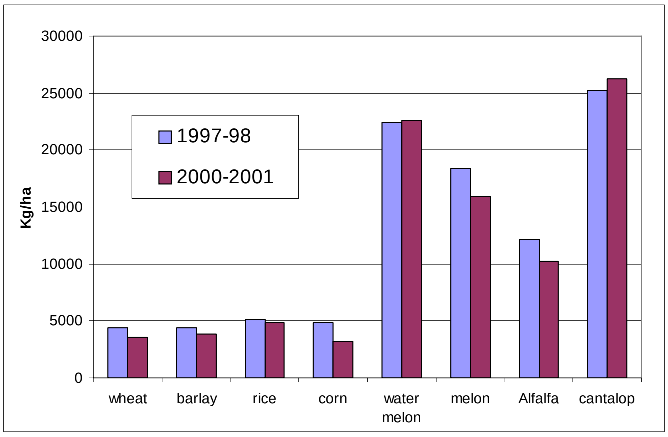
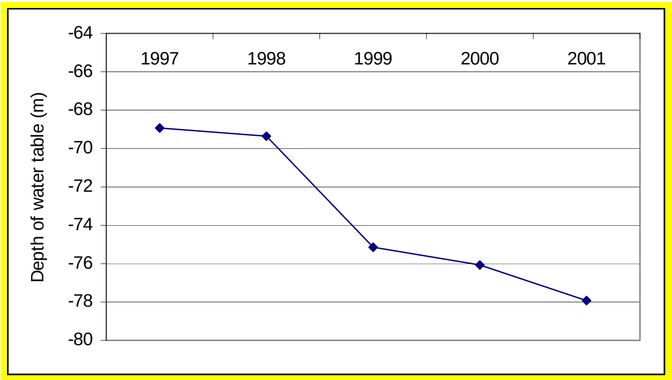


Figure 12. Reduction in average yields of main crops



The striking conclusion of this analysis is that drastic reduction of water supply in irrigation canals has been largely offset by a reduction in cropping area and an increase use of groundwater, with a limited loss in yields. Figure 13 shows the drop of the water table in a well of Nekouabad area. It suggests that the drought led to a surge in groundwater use that resulted in a drawdown of 10 meters.

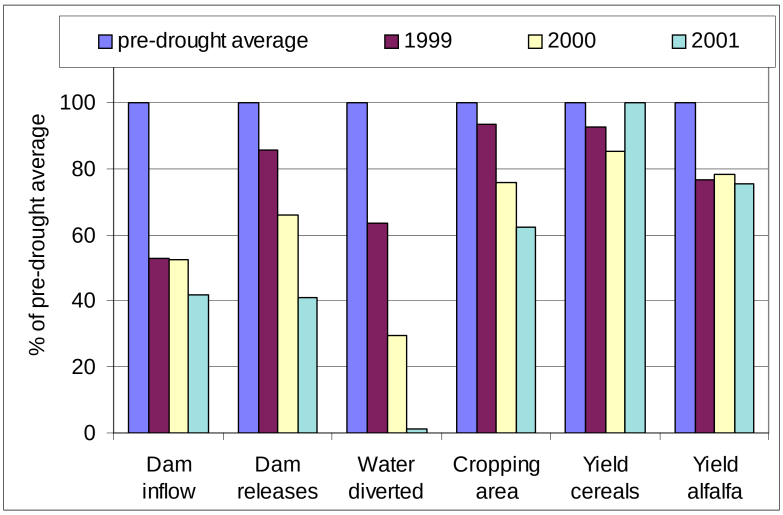
Figure 13. Drawdown of the water table in Nekouabad area



5 Synthesis and conclusion

When we combine all the above data we obtain the profile of the drought given by Figure 14. While dam inflow during the three years has been less than half of average values (and dropped to 40% in 2001), dams release have not fully been adjusted in consequence, except in 2001. Water diversion to agriculture, in contrast, with the exception of the first year, has borne the brunt of the curtailment, with a drastic zero supply in 2001. The main surprise, however, comes from the reductions in area and in yields, which appear much less than expected. This is due first of all to adjustments in terms of management (better application of water at the plot level, enforcement of rotations at tertiary level, reduction of thirsty crops like rice, etc). The drought, however, also revealed the importance of groundwater use and the high pumping capacity that can be mobilised to extend supply to plots in case of failure from supply in surface water. It allowed most farmers to withstand and go through what appears to have been the most critical climatic event of at least half century.

Figure 14. Impact of the drought on main variables



The study also demonstrated that the drought may have been worsened by the failure to reduce dam releases in 1999. However, its intensity and duration were exceptional and its impact could not have been averted even with more careful management.

These findings on the resilience and adaptive capacity of farmers to water scarcity resonates with other similar studies. The impact on agriculture of a given reduction in water supply is very hard to predict. For example, irrigation deliveries in Uzbekistan have been reduced from about 17.000 to 13.000 m^3/ha in the early 90s without significant effect on crop yield (Davis and Hirji, 2003). In central Thailand, significant growth in cropping area has occurred despite decline of supply in the dry season (Molle 2004). Two examples from China are reported by Loeve *et al.* (2003). In the 1998–2001 period, irrigated rice area declined by 34 percent in the Zhanghe Irrigation District. While this decline is large, it is much less than the 59 percent decline in total irrigation water supplied over the same period. Adaptation by farmers included water-saving practices in rice irrigation, development of alternate sources of water such as small reservoirs and groundwater, recapture and reuse of return flows through pumping or the network of reservoirs. In another scheme, water supply was reduced by 64% over three decades but the cropping area declined by 32% only. This was made possible mainly by the reuse of drainage water.

These findings first have implications for policy-makers since they suggest that farmers are able to adjust to water scarcity. Long term decline of supply to agriculture, as often occurs because of increasing supply to the urban sector, may therefore be less critical than sometimes thought. However, our attention is drawn to the fact that a great part of this adaptive capacity comes at a cost, both in financial (because of the need of pumping devices and/or wells) and environmental terms (worsening the status of groundwater in the valley). The number and development of wells in the basin is a critical issue. Wells are supposed to necessitate a permit from the administration but the existence of a large and unknown number of illegal wells is widely acknowledged. Like in many other settings of the Middle East and elsewhere, the trade-off between sustainability/control overdraft and economic growth/poverty alleviation tends to tilt towards the latter.

The description and understanding of water supply and demand in the basin is also important for managers and for modellers (IWMI and AREO, 2004). It is very important to better understand the behaviour of farmers within the irrigated areas, and in particular the characteristics of conjunctive use and the spatial distribution of the abstraction capacity. This poses challenges to the representation of irrigation systems in terms of inflow and return flow and requires an understanding of surface water/groundwater interactions, water reuse, and farmers' strategies and adaptive capacity.

6 References

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