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80

Robbing Yadullah's Water to Irrigate Saeid's Garden

Hydrology and Water Rights in a Village of Central Iran

François Molle, Alireza Mamanpoush and Mokhtar Miranzadeh

International Water Management Institute

COMPREHENSIVE Assessment of water management in agriculture

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Cover photo by François Molle shows two farmers checking the time of the allocation to their plot.

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Summary

When pressure over water resources increases in a given river basin, these resources tend to become fully committed, with little or no outflow at the most downstream point in the basin, at least during some part of the year when river basins are said to "close." In such conditions, any decision to further tap existing water (through diversion, pumping from watercourses, drains or wells) at a given point of the hydrological cycle of the basin is almost certain to impact on preexisting users and/or on the environment. Such new developments eventually amount only to a reallocation or reappropriation of water by particular users. This fact points to an intricate and vital relationship between hydrology and water use, or in other words, between nature (with all its climatic uncertainty and complexity) and human activities (partly regulated by institutions). It also defines water as a contested resource and sets the stage for political competition and struggle between users' vested interests.

This report provides a case study from the province of Esfahan, in central Iran that, in many respects, is exemplary of these different dimensions. It describes the struggle of a village to secure the water resources without which local agriculture, and altogether life in the village, would be impossible. It illustrates the endless ingenuity of farmers in their quest for water, how land and water rights have developed, how various legal repertoires may conflict with one another, and how the intervention of the state transformed the wider hydrological cycle of the valley and affected the delicate equilibrium between population and resources that had prevailed until then. Means of accessing surface water and groundwater include qanats, diversion of the river, harvesting of lateral runoff, wells, pumping and diversion by pumping from main irrigation schemes. The report estimates the costs of accessing one cubic meter from each of these different sources and shows how political interventions or drought mitigation policies elicit solutions that are extremely costly. Water rights in the village are briefly described: they are accurately defined and give way to short-term transfers and exchanges as well as permanent transfers. The reconstitution of the history of the village allows us to analyze changes in population, land use and water use, and to interpret the relationship between the pressure over resources and villagers' strategies regarding water-resources development and use.

The study examines three nested scales: the village, the Najafabad valley and the Zayandeh Rud basin, and illustrates the most crucial aspects of closed basins, whereby any change in water use or abstraction is likely to be tantamount to proverbially rob Peter to pay Paul or, metaphorically, rob Yadullah's water to irrigate Saeid's garden. The struggle for water increases with the closure of the basin. While the solutions to local water scarcity tend to lie more and more upstream and at a wider scale, the impacts of local processes extend further and further downstream. This critical interconnectedness of actors through the hydrologic cycle is complex, sometimes unpredictable, often invisible, frequently ignored and always obscured by the variability and fluctuation of hydrological processes. Upstream/downstream and surface water/groundwater interactions get more intricate as users diversify their sources of water and intensify their use. Unchecked individual initiatives eventually add up and have a significant impact at the macro level. Macro-level interventions, in turn, critically alter the hydrological regime and the preexisting water-

sharing arrangements. In such a process, local and global interventions tend to conflict, and control over water to shift toward the state.

These points are illustrated by the interconnectedness of water resources across scales. The development of wells in the village competed with, and impacted on, both local qanats that supply the same communities and downstream ones, because of the resulting critical uptake of groundwater. The distribution of water from the Mourhab spring along the Najafabad valley was regulated by age-old agreements between riparian villages (surface water) and by the spatial distribution of qanats (groundwater), the valley aquifer functioning as a distributed underground reservoir protected from evaporation losses. This equilibrium between resources and use was fatally disrupted with the construction of a reservoir by the state, incurring high costs, losses by evaporation and a redistribution of water rights. The development of water use in the lateral valleys, in turn, impacted on the groundwater flow to the central valley aquifer and surface flows to the Zayandeh Rud river. This is compounded by the overexploitation of the aquifer and the use of deep wells for irrigating a “green belt” for the city and for other uses. Meanwhile, water diverted from the river has been increasingly distributed to lateral areas, including the Esfahan urban area and other distant cities such as Yazd. These fluxes flowing in opposite directions have both short- and long-term variations and compose a complex and not well-known hydrological pattern.

A crucial consequence of the closure of the basin is the logical *impossibility of overall water conservation,* with the exception of the case where water flowing to sinks like saline aquifers is reduced. Local conservation measures are possible but they necessarily have third-party impacts, be it on other users, next generations or on the environment. Therefore, while such local measures may benefit the users involved, they eventually amount to a reallocation of water within the basin. Shifting the benefit of water may be desirable or not, but it is rarely explicit and raises questions on water rights and on third-party impacts.

Water rights are often presented as a natural remedy to the increase in third-party impacts stemming from resource reallocation and growing uncertainty in supply. This case study serves to illustrate the difficulty in establishing such rights, first because of the incompleteness of knowledge on the resource itself, and second because of the multiscale governance issues inherent in such a definition.

More generally, the study sketched out an exploration of the human-water interface whereby institutions around water allocation and management are mediated by political, cultural and ecological contexts that interact across multiple spatial and social scales. The complexity of these macro-micro interactions, however, makes the state incapable of reordering the basin water regime by its sole action or by legislation. Constructing a sound and sustainable water regime is contingent upon allowing multilevel governance patterns that allow interest groups to negotiate arrangements that bring more certainty, social value and equity to the sharing of water. In the Zayandeh Rud basin, the challenge could be to reestablish the earlier democratic, transparent and stakeholder-controlled allocation (when *mirabs* [water chiefs] were elected), albeit in a much more complex physical and social setting than in the past, demanding both an increasing knowledge of the basin hydrology and expanded arenas of representation and negotiations.

Robbing Yadullah's Water to Irrigate Saeid's Garden: Hydrology and Water Rights in a Village of Central Iran

François Molle, Alireza Mamanpoush, Mokhtar Miranzadeh

Introduction

When pressure over water resources increases, users generally seek ways to conserve[1] water, and try to tap additional sources to increase both supply and its reliability. This generally incurs significant costs and requires a lot of ingenuity. With time, resources tend to be fully committed when river basins are said to "close," with little or no outflow at the most downstream point in the basin, at least during some part of the year. In such conditions, any decision to further tap existing water (through diversion, pumping from watercourses, drains or wells) at a given point of the hydrological cycle of the basin is certain[2] to impact on preexisting users and/or on the environment: new developments eventually amount only to a reallocation or reappropriation of water by particular users. This fact points to an intricate and vital relationship between hydrology and water use or, in other words, between nature (with all its climatic uncertainty and complexity) and human activities (partly regulated by institutions). It also suggests that water is likely to be a contested resource and sets the stage for political competition and struggle between users' vested interests.

This report provides a case study from the Zayandeh Rud basin, in central Iran, that is in many respects exemplary of these different dimensions. It describes the struggle of a village to secure the water resources without which local agriculture, and indeed life in the village, would be impossible. It illustrates the endless ingenuity of farmers in their quest for water, how land and water rights have developed, how various legal repertoires conflict with one another, and how the intervention of the state transformed the wider hydrological cycle of the valley and affected the delicate equilibrium of the population and resources that had prevailed until then. The study illustrates the most crucial aspects of closed basins, whereby any change in water abstraction is likely to be tantamount to proverbially rob Peter to pay Paul or, metaphorically, rob Yadullah's water to irrigate Saeid's garden.

The report begins with a description of the physical setting and early water use and rights to water. Then it establishes a chronology of changes in water demand and supply at the village level. The cost of water and land, as well as their exchanges and transfers, are further examined, as a way to emphasize both their relative economic values and their importance in the village community. The subsequent section

[1]Conservation here refers to a particular user who seeks to either reduce the return flow from a given amount of water he is diverting/pumping (usually, eventually depleting more of it), or—more rarely—to reduce his diversion, while achieving the same output (more water being available to downstream users from the same source but less to earlier appropriators of return flows).

[2]As pointed out by a reviewer, a new intervention in an open basin *may* have a third-party impact while that in a closed basin *always* has such an impact.

dwells on the central issue of water rights, and shows how both hydrologic and socio-institutional complexities make the definition of such rights problematic. These complexities are shown to extend across scales, from the village and the valley surveyed to the whole basin.

The Zayandeh Rud basin covers 41,500 km^2 in the center of Iran (figure 1). Its historical and

Jalalabad and the Najafabad Valley: The Setting

economic significance is attached to the city of Esfahan, with its rich and ancient history. The Zayandeh Rud originates in the Zagros mountains, where rainfall and snow are rather abundant, and traverses arid areas to empty into the swamp of Gavkhuni. The mountainous part of the basin culminates at around 2,300 meters but Esfahan and its fertile plains stand at an altitude of around 1,500 meters. While rainfall in the catchment of the dam averages 1,700 millimeters (with 55 days with snow events and 15 of rains), Esfahan receives only 130 millimeters per year, concentrated in the November-April period (figure 2). Temperatures are hot in summer, reaching an average of 30 °C in July, but are cool in winter dropping to an average minimum of 3 °C in January. Annual potential evapotranspiration is 1,500 millimeters (Murray-Rust et al. 2000). The Gavkhuni swamp, at the downstream point of the river basin, is a natural salt pan, surrounded by sandy soils and dunes. Water entering the swamp area is extremely saline, with EC values as high as 30 dS/m during periods of low flow (Salemi et al. 2000).

FIGURE 1.
The Zayandeh Rud basin and the Najafabad valley.

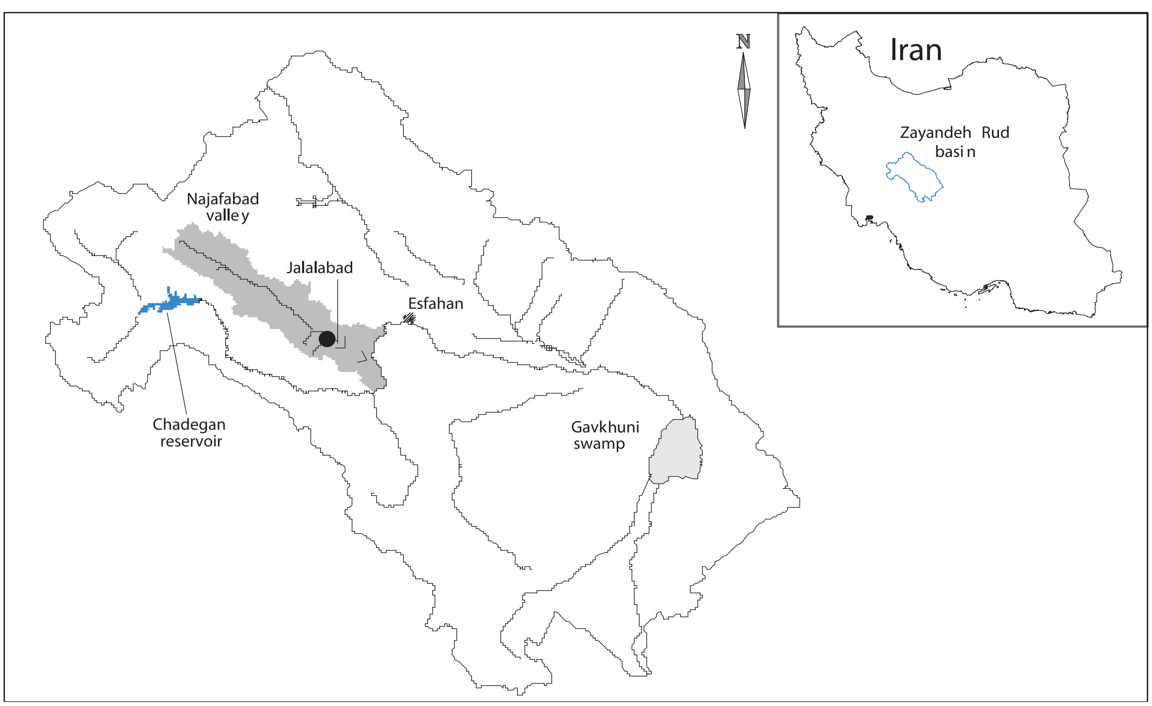
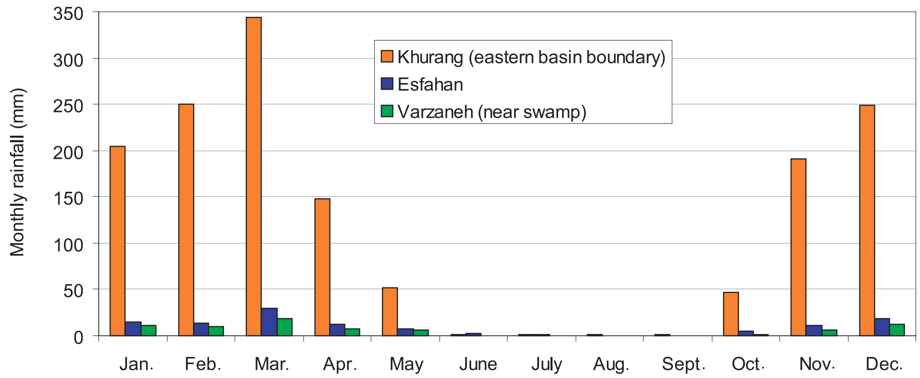
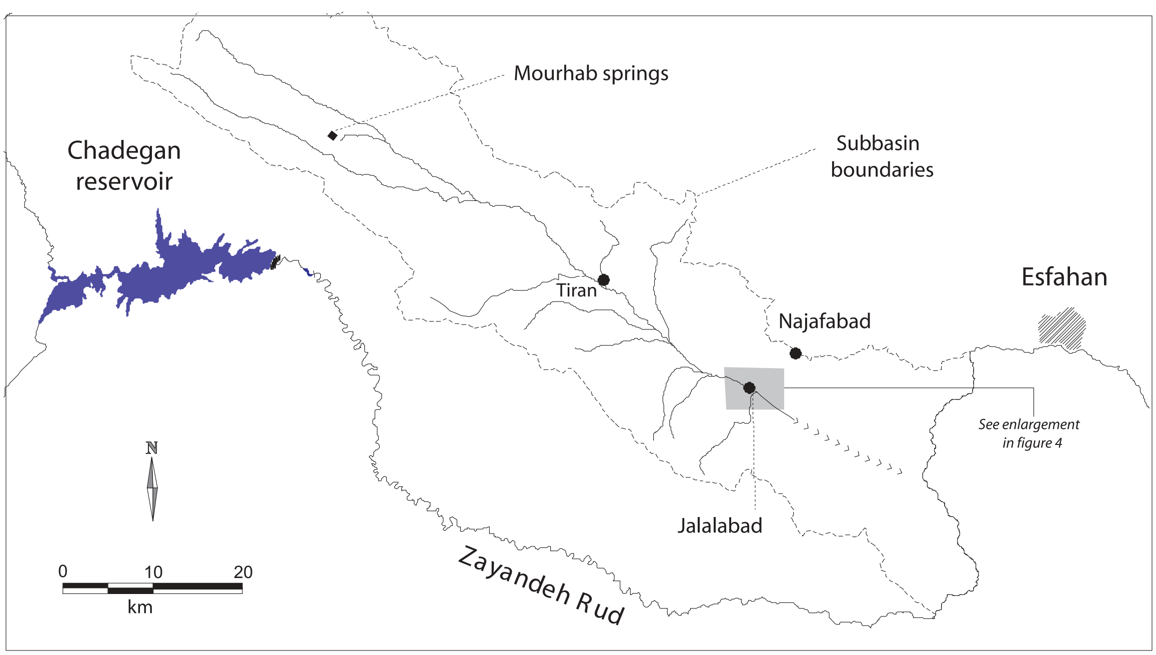


FIGURE 2.
Rainfall pattern in the Zayandeh Rud basin.



From time immemorial water has been diverted from the Zayandeh Rud to supply Esfahan and irrigate its gardens and neighboring areas. Numerous springs and *qanats* (see definition in box 1) located in the central and lateral valleys were also used. The Najafabad[3] valley, the site of the present case study, has 106 qanats totaling 266 kilometers in length and several springs (Hartl 1989), the main of which is the Mourhab spring, which in normal years

FIGURE 3.
Layout of the Najafabad valley.



[3]Najafabad itself is a rather recent city: A legend reports that during the reign of Shah Abbas a caravan had been loaded with a heavy tribute collected by the Shiite faithful and destined to the holy city of Najaf (currently in Iraq) and when passing through what is now the middle of the city the leading camel suddenly lay down and refused to move any further. Informed about the incident, Shah Abbas had declared this was a sign that the wealth carried by the caravan should not be transported to Najaf but, rather, be used to found a city (which was to bear the name of Najaf), including its water supply through the digging of 17 qanats in the valley and collection of their water by a canal (Abary 2003).

provides an average discharge of 2–5 m^3/s to the lower half of the valley (but drops to 200 l/s in autumn [figure 3]). The city of Najafabad itself had used its wealth and royal support to tap the water of 17 qanats, distant from the city by as much as 100 kilometers and collected by a canal that follows the valley and irrigates the old and lush gardens of the city.

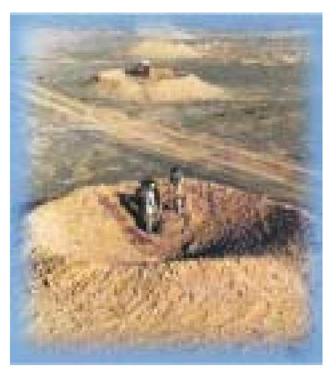
It is only with the excavation of a first tunnel bringing water from the adjacent Kurang basin (1953) and the completion of the Chadegan reservoir in 1970 (see figure 1) that supply and storage in the basin dramatically increased, ushering a new era of infrastructural development. Irrigated schemes with a command area of approximately 160,000 hectares were developed around Esfahan and were supplied with reliable water during 8 months of the year (March to October), allowing double-cropping in a large part of the area. However, in many cases, these modern schemes were superimposed on ancient systems consisting of *maadi* (run-of-the-river canals) and sometimes qanats. The gains were thus limited. Supply to the Chadegan reservoir was augmented in 1986 by additional diversion of water from the Kurang river (in Chaharmahal-va-Bakhtiari Province) into the upper reaches of the Zayandeh Rud. The two diversion tunnels can now deliver 540 million cubic meters of water and a third tunnel is under construction and should be in operation in 2005.

BOX 1.
The qanats.

"The leitmotif of the country's irrigation ecology" (McLachlan 1988), qanats are widely believed to have originated in Iran, where they were common as far back as 600 BC, although the technique can also be found from Pakistan to Spain, and as far as in Japan or California. Qanats start from a well sunk to the depth of a suitable water table. From this "mother well" a gallery with a gentle slope is dug until it reaches the surface of the ground. Every 25-50 meters or so, shafts are provided for the removal of spoil and the ventilation of the gallery (see cross-sectional sketch below). Qanats in Iran are 2 kilometers long on average but according to Mohebi (1996) they may reach 120 kilometers! In 81 percent of the qanats, the length is less than 5 kilometers. With a discharge of 30 m^3/hour, a qanat typically irrigates between 10 and 20 hectares of land (Beaumont 1989).

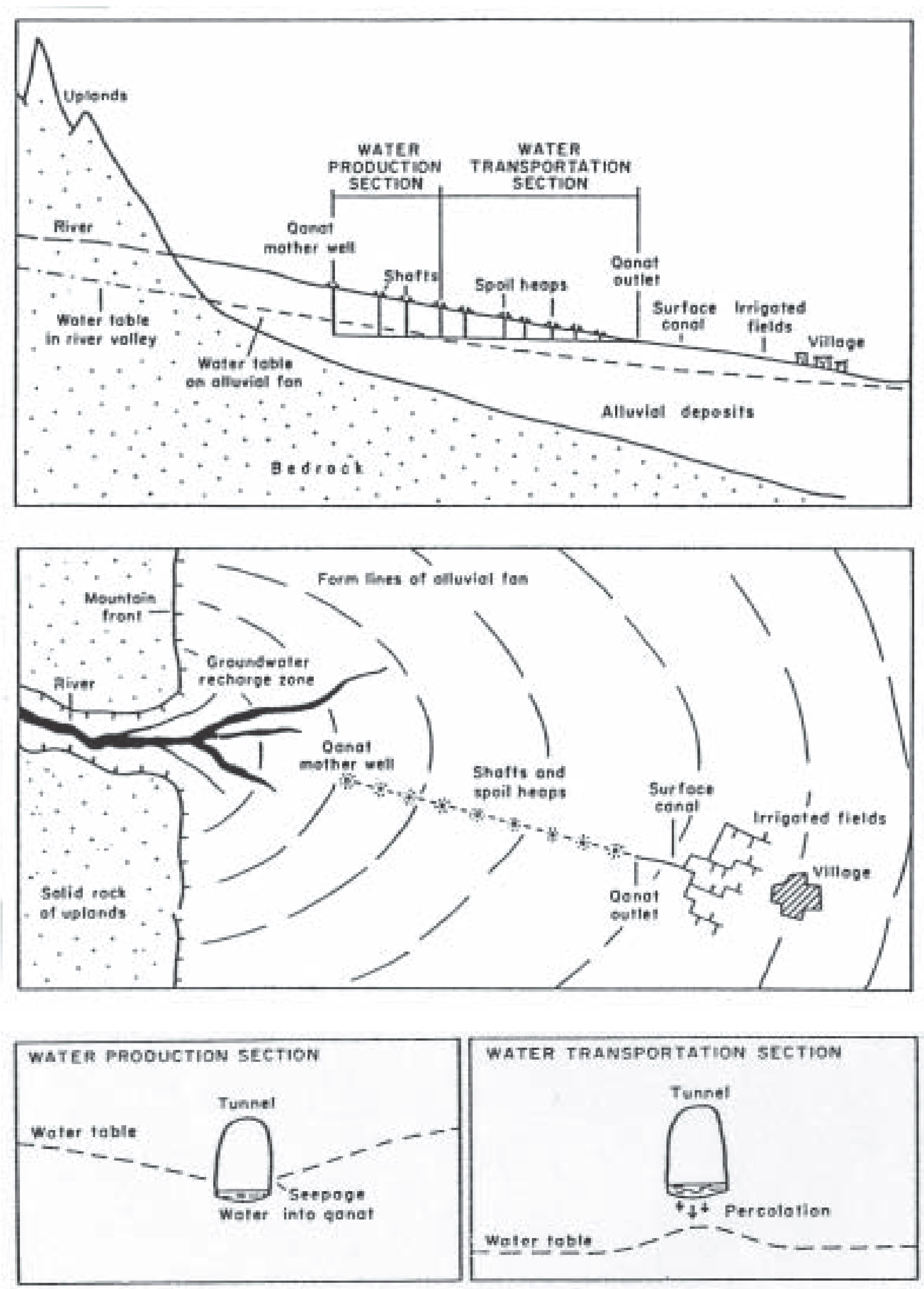
Making qanats is a very skillful operation usually performed by specialized workers called *muqanni*, who command high respect for the skills and risk attached to their work (English 1998). Estimates of the number of qanats in Iran vary between 30,000 and 50,000 (McLachlan 1988; Beaumont 1989) but a large part of them is now out of order. Statistics for the year 1999 have put their number at 27,481 (Karimi 2003).

The social cohesion of villages depending on a sole and vital source like a qanat had several managerial, legal and economic dimensions (Spooner 1974b). The demise of qanats was on the way in the sixties (Ehlers and Saidi 1989) when landlords withdrew money from annual repair of qanats to invest in wells (a more flexible and more abundant source), despite a 1943 law compelling them to take steps to repair them whenever necessary (Lambton 1953). While one of the main arguments of landlords against the land reform was the alleged incapacity of farmers to cope with the maintenance of qanats, there is no consensus on whether this did happen on a large scale (McLachlan 1988), whether it depended on local leadership (Kielstra 1989), or whether these fears were largely unfounded (Lambton 1969).



Despite a renewed interest and consideration for qanats during the post-revolution time, the emphasis on self-sufficiency and production has favored wells. The overdraft of aquifers, compounded by drought events have had, and are still exacting, a heavy toll on qanats.

BOX 1.
The qanats.



Source: Beaumont 1989.

In contrast to the main central valley whose supply of water is regulated by the Chadegan reservoir, changes in the lateral valleys of the basin, such as the Najafabad valley, have been less significant. Springs and qanats have continued to make up the bulk of water supply but they have been gradually undermined by the development of wells. These developments have also critically reduced the underground lateral recharge of the Zayandeh Rud, an aspect which is often overlooked (Morid 2003). Gieske and Miranzadeh (2003), for example, have estimated that approximately 250 million m^3 out of a yearly yield of 275 m^3 of groundwater in the Lenjanat alluvial fan aquifer are now tapped.

Jalalabad, the subject of this study, is a village of approximately 3,000 inhabitants covering 11,000 hectares. It is located in the lower reach of a 110-kilometer-long valley[4] flanked by two high mountains ending up in Najafabad, a city now forming part of the western suburbs of Esfahan, which is the capital of the province with a population of 2 million. Rainfall around the Najafabad city varies between 85 and 204 millimeters but almost half the annual precipitation can fall within 5 days (Hartl 1989). In the Safavid period (sixteenth to seventeenth centuries), the village was situated one kilometer upstream of its current location, where ruins of its destruction by Afghan invaders circa 1725 still remain. There is little doubt that settlements in this rich valley situated in the vicinity of Esfahan, and the construction of qanats, predate this event by many centuries but no particular details were readily available in the Jalalabad village.[5]

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[4] We consider in what follows only the lower reach of the Najafabad valley, from the Mourhab sources to the Zayandeh Rud. The upper reach can be dissociated for analytical purposes, since it contributes little water to the lower reach.

[5] Old people refer to Jalalabad as Aliabad.

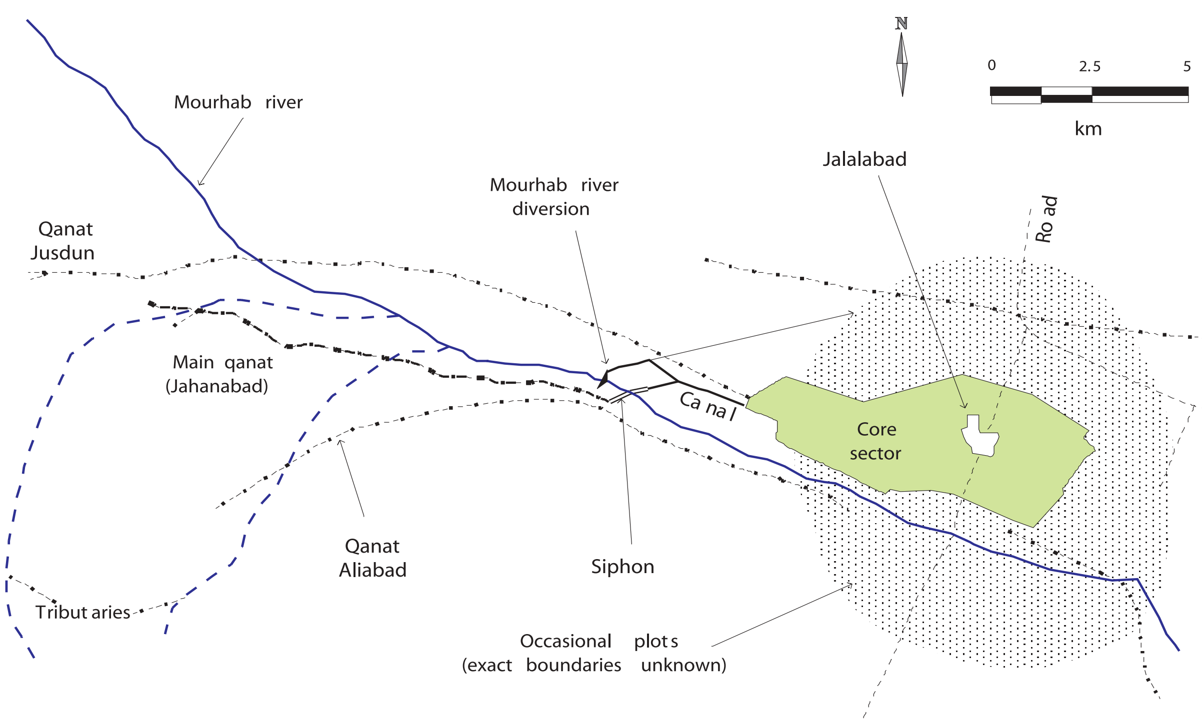
Early Water Rights and Sources of Water in Jalalabad

Water Infrastructure

Around 1900, Zélé Sultan, the Governor of Esfahan tried to revitalize the valley, which had not yet been fully resettled and put under cultivation. Some people were brought[6] in or migrated from other regions (such as the Yazd Province) and the village of Aliabad (the earlier name of Jalalabad) therefore saw an influx of population. The main sources of supply of the village until the 1960s were two qanats (figure 4) (see box 1 for further information on qanats). Aliabad qanat is located on the right of the river and was used to irrigate a tract of land that extends down to the limits of the next village (Jusdun) and was cultivated mostly with crops such as melon, watermelon, soybean and cotton. The Jahanabad qanat is a longer qanat that taps groundwater from the right bank (upstream of Aliabad qanat) but its water is channeled to the left bank through an inverted siphon ("camel-neck pipe" in local parlance) that allows the crossing of the riverbed. Its water is then directed to the gardens located along the river and divided among the farmers.

The village is also traversed by the Jusdun qanat, which emerges close to the outlet of the Jahanabad qanat. Its water is conducted along a ditch through the gardens (the ditch is now lined at the section that crosses the village itself) and empties into a shaft, which feeds an underground gallery (or short qanat) that eventually emerges 3 kilometers downstream near Jusdun. Jalalabad is entitled to use this water for domestic needs

FIGURE 4.
Early land and water use in Jalalabad (*circa* 1960).



[6]It is reported that forced migration was utilized as a punishment, particularly in Najafabad.

(including the supply to the mosque) but not to divert it for irrigation purposes. Two other qanats also follow the northern boundaries of the village (not shown). They collect water for areas located further east, beyond Najafabad itself.[7]

Agriculture in the village was limited to a core sector of orchards and cereals (wheat and barley) corresponding to the land owned by the villagers, and lateral fields, which would be irrigated to an extent depending on the observed discharge of both the river and the qanats in early spring. These areas were planted with crops such as soybean, melon or watermelon and could extend widely across the valley. The track of land irrigated by the Aliabad qanat was also planted with such crops, together with cotton (see figure 4). However, this situation improved around 1960 when both water sources and agricultural areas began to expand. This expansion is chronologically detailed in section 4.

Water rights

In the beginning of the last century, the land belonged to Sarey Modulay Akbar Mirizha, the son of Zélé Sultan (Qadjar dynasty), who had been given three villages of the lower valley (Aliabad, Jusdun and Kaley Sefid). Sarey Modulay is said to have had a particular affection for the Aliabad village and, in 1935, he sold a part of the land (2/6) to six main lineages of the village, each part constituting a dong[8] named after the main family or clan: Arbabi, Yazdi, Abedini, Kaley Sefidi, Hajbarati and Gholami. (The remaining 4/6 were bought from the state on credit by villagers in 1966, during the Land Reform).

Water rights were defined by the number of hours of the full qanat discharge allocated every 6 days[9] to a particular plot or set of plots. For convenience these plots were grouped in 12 lots of similar size that were to receive water during 12 hours (12 hours x 12 lots = 6 days). For reasons not entirely clear but said to reflect a concern for equity, each dong was given two of these lots, one located in the upper reach and the other in the lower reach (see figure 5). Only the Kaley Sefidi dong had all its land in a single lot in the middle part of the canal. Water delivery would start by the Yazdi dong at sunrise of the first day, with the first 12 hours granted to the head lot and the second 12 hours (at night) to the tail lot. On the second day, water would go to the Gholami dong, and on the following days to the four other dongs, as shown in figure 5. After 6 days, the head- and tail-end lots would swap their time slot so that those who were irrigating by day would find themselves with the night turn and vice versa. Because of the 6-day-long rotation, each week the day allotted to a particular dong is shifted back by one day (e.g., from Monday to Sunday, etc.). This system entails that the time (approximately 20 minutes for the Yazdi dong) taken by the water to flow from the head lot to the tail lot is lost; this loss is divided equally among shareholders. Altogether, the 288 half-hours of the 6-day rotation are precisely allocated (see next section).

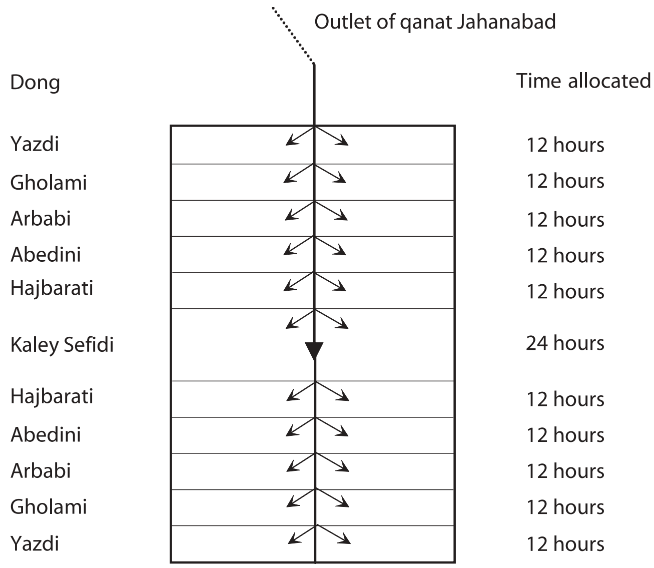
To this source of water is added the flow from the Mourhab river itself. In the seventeenth century, the village was granted a right to 2.5 of 30 parts of the Mourhab water, defined as 80 days after 21 March during which the village was allowed to divert the residual flow of the river to

[7]This case is quite frequent, since qanats in Iran are 2 kilometers long on average and need to collect water upstream of villages they frequently overlap with other villages.

[8]The dong (or the 6th part of an asset) is a traditional share in Iran. Properties are generally divided into six *dong*s.

[9]The period of 6 days corresponds to the tolerance frequency of sensitive crops, and also matches the traditional way of dividing by six. However, the literature on qanats shows extreme variation depending, among other things, on climate, soil type and cropping patterns, and the periodicity varies between 6 and 24 days (see examples in Lambton 1953; McLachan 1988; Ehlers and Saidi 1989; Beaumont 1989; English 1989; Spooner 1974b; etc.).

FIGURE 5.
Repartition of water rights (rotation over 6 days).



its fields. This right is said to have been defined by Sheikh Bahai, who codified the rights to water in the Zayandeh Rud basin at the time of Shah Abbas, in the second half of the sixteenth century during the Safavid period (Lambton 1938), but there is evidence that such regulations are much older.[10] The flow of the Mourhab river was diverted one kilometer upstream of the village and was consolidated with the qanat flow at the exit of the siphon (figure 4). In years when this consolidated flow was abundant, villagers would divert it to the land located north of the gardens and use it to grow watermelon or cotton, just as with the Aliabad qanat on the other side of the river. The sharing of water along the river according to the rights established was controlled by a *mirab* (chief of water) assisted by several overseers.

Water management

Water owners have a clear and precise sense of their ownership of water. They know exactly at which time they are allowed to make use of their long-handled spade to breach the bund of their plot and divert water into it. They know after how many minutes they must close the bund and let water flow to the next plot. They also know precisely the rights and associated times of their dong-fellows who share the 12-hour turn with them. Therefore, they commonly take care of the irrigation of their neighbor's plots, either because this has been agreed upon, or because the latter did not show up at the required time. In general, however, all villagers have motorcycles and watches and tend to be very punctual in making use of their allotment every 6 days.

[10]Ibn Rusteh (1889), for example, who wrote in the early tenth century, mentions that water use was unrestricted until the district of Alandjan, while the distribution to the following districts of Djay, Marbin, Alandjan, Baraan, Rud and Ruwaidasht was organized following "rules established by Ardashir Ibn Babak." Ibn Hawqal, four decades later, also reports that the sharing of the Zayandeh Rud water was "calculated" so that no water would be lost. Ruwaidasht and Baraan districts, for example, are reported to receive water during 9 days each month.

Their long experience with the collective and scheduled practice of irrigation, as well as the close social relationship between members of the same dong, allow for much flexibility in water management. Water transactions can occur within one of the four sectors (subareas served by the same branch canal), or even within six, considering the two sectors using only groundwater, or between sectors, according to several modalities (more on this later).

The accurate measurement of time is crucial. In ancient times, this was done by using water clocks (bowls with an orifice at their bottom that were placed floating in a larger receptacle, each sinking of the bowl measuring one unit of time). Watches became common 40 years ago but the start of the daily rotation was still based on the sunrise. It was only 20 years ago that the use of watches was fully resorted to, which marked the end of the recurrent disputes regarding time sharing.

In case the discharge in the canal is too low, then the 6-day rotation is increased to 12 days and the full flow is given to only one side during 12 hours, instead of being divided into two. In the opposite case, the excess flow is diverted to the riverbed or to some depressions where water is impounded with the aim of recharging the aquifer. Twenty years ago or earlier, they would also send part of the diverted flow to the northern part of the village, where watermelons and other field crops were grown.

Although the Qanat Committee is the guarantor of the water rights, collects the fees for payment of the Nekouabad canal water and also supervises the two crucial points where the qanat flows are divided (branch going to mazrae jadid, and main division structure at the exit of the qanat: see picture below), it has no role in water management beyond this point. Management is taken care of by the dongs themselves, which regulate their internal distribution. No one in the village is aware of the full details of the system. Repartition between dongs is strictly defined by blocks of 12 hours and therefore needs no adjustment or supervision. This striking lack of centralized control goes together with a strict adherence to the established rights and schedules. Following Spooner (1974b), this can be partly ascribed to the fact that since “any disturbance of the temporal distribution systems affects all shareholders adversely, the normal premium on social order is increased.”

Structure to divide the qanat flow

Farmer at work

Lined canal

A Chronology of Water Demand and Supply

This section records the parallel development of water supply and water uses over the last century and illustrates how the challenges posed by population growth or by the decline of some water sources were dealt with.

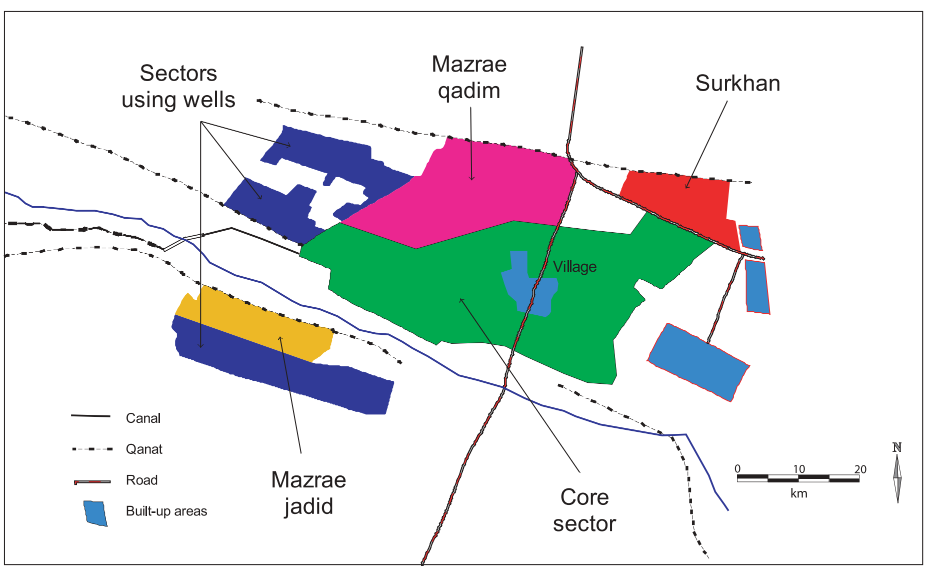
The Postwar (WWII) Period and the 1963–64 Drought

The 1950s and the early 1960s were a period of abundance of water. Population and crop areas were still limited, and villagers enjoyed a sustained discharge from the two qanats. Some villagers who had land near the left bank of the river also diverted part of the Aliabad qanat to the other bank by means of a pipe forming an aqueduct.

In the early sixties, the villagers decided to expand the cultivation area on the basis of the available water. A large area of 240 hectares north of the core area, named *mazrae,*[11] was developed (figure 6). Unlike the core sector, where each dong had both head-end and tail-end lots, the design was simplified and a mazrae was divided into six parts attributed to the six dongs. The flow from the Jahanabad qanat was divided into three parts, two parts going to the core sector, and the third part to the new sector. Individuals received new plots, in proportion to their water rights in the core sector. The same irrigation schedule with a 6-day rotation was adopted and the period of 24 hours allotted to a given dong was chosen to coincide with those in the core area, so that irrigation operations could be concentrated in one day.

This period of abundance ended abruptly. Droughts are said to be recurrent events in the valley (with an occurrence of approximately four or five in a century). However, they differ in intensity and duration, and their impact depends on the ratio of demand to supply and the existence or nonexistence of some slack. The 1963–64 drought is still very present in the

FIGURE 6.
Successive phases of expansion of the village gardens (with water rights).



[11]Mazrae means irrigated farm(land). The sector would later be named *mazrae qadim* (old), when a new area named *mazrae jadid* (new) would be opened.

memory of the older generations. It is said that most gardens were abandoned and that a large part of a population of 650 villagers left for Najafabad in quest of alternative work and other means of livelihood while around 300 remained in the village. With the hydrological conditions gradually returning to normal, however, most people returned to the village in the following years, but some established themselves in Najafabad. Many of the trees had died necessitating the planting of new trees.

A few years after the drought, just before the revolution, the continuous efforts of the villagers in maintaining and extending the gallery of the main qanat were rewarded with a fortunate find. Noting that water was squirting from the ground of the gallery, the workers dug a vertical shaft from a depth of –7 meters to –12 meters and connected with a "vein" of water that doubled the discharge of the qanat, which reached its maximum value of 180 l/s. This increase in supply in the late 1970s led to the decision to expand the gardens by opening a new sector of approximately 100 hectares at the northern limit of the village. This sector was called *Surkhan* (red) because of the color of the earth in this area (figure 5). The flow of the qanat was consequently divided into four equal parts, and the new sector allotted to shareholders based on the pattern adopted earlier for the mazrae. Likewise, the 6-day rotation was adopted again.

The Revolution and Wartime (1979–1989) and the Development of Wells

The period of the revolution is first of all marked by the continuing development of shallow wells. This was part of a policy emphasizing self-reliance and the development of production, coupled with a strong stance in favor of population growth (which reached a rate of 3.8% in the 1980s).[12] This development seems to have been based on an inadequate hydrological analysis and villagers got into the business of well digging,[13] despite reservations and awareness that qanats might be impacted. The wells did, indeed, bring a dramatic increase in water supply, probably tapping underground flows, which were directly flowing to nearby or downstream qanats, as well as recharging the main aquifers along the Zayandeh Rud itself. Two new areas were therefore collectively developed and irrigated exclusively with wells: four wells were dug in the upper part of the village, upstream of the gardens irrigated by the water of the qanat, and four others were dug on the other side of the river (figure 5). As a result, the Aliabad qanat was soon to see its discharge dwindling and eventually drying up.

In addition, villagers obtained a permit to dig 15 wells within the existing gardens, as a way to boost the available water per hectare of garden. These investments were made by farmers from the same dong, or from an association of two dongs, and the distribution network of the well water was superimposed on the existing canal network (see box 2). The water is distributed through earth canals to nearby plots (sometimes using the existing canal network but not always), and through pipes to more distant plots. The impact of well development on the discharge of qanats confirmed the intuition of farmers about the interconnectedness of the different water sources. Wells dug without licenses by individuals, in particular in the catchment area of the main qanat, were opposed by farmers and were filled in by force (this was to happen recurrently and as recently as 4 years ago).

[12]"Because of Iran's enormous natural resources and the regional and global mandates of the Revolution, a large, rapidly growing, and young population was a highly desirable asset rather than a liability" (Meyhrar 1995). Demographic statistics for this period are complex because of the flow of refugees from the fatalities of the war across the Iraqi and Afghan frontiers, and of the exodus of an estimated 1–3 million people. However, there is no doubt that the postrevolution period, with its emphasis on the virtues of early marriage and having children, fueled an unprecedented demographic boom. In 1991, the annual growth rate had dwindled down to 2.45, and reached 1.5 in the 1996 census!

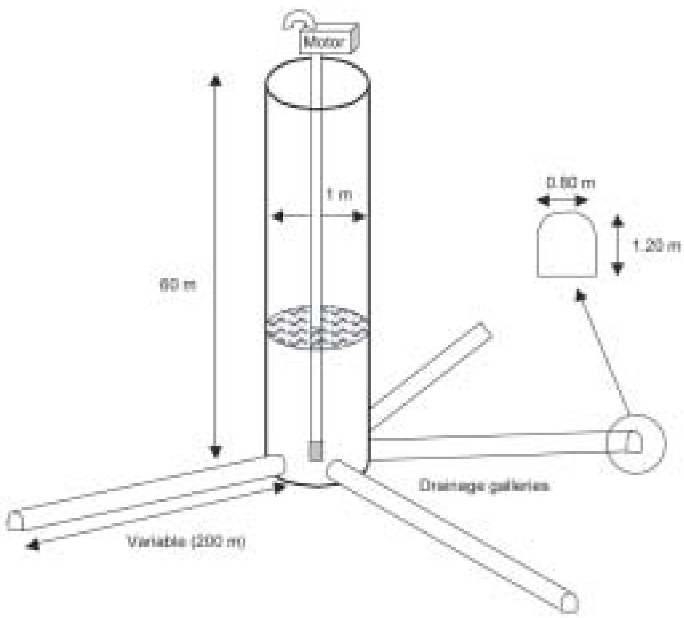
[13]Two wells had already been dug in the late 1960s in the core gardens in response to the drought.

BOX 2.
Wells and pumping stations.

Wells are excavated with pneumatic drills to a depth of approximately 60 meters. From the bottom of the pit, galleries are then dug horizontally, which serve as a mini-qanat, draining water to the central shaft.

Wells are taxed depending on their discharge: 120,000 tumans/year for 25 l/s, or 70,000 tumans for 15 l/s (1 tuman = 10 rials; 1,000 tumans = approximately €1). A representative has to go to Esfahan to pay the fee, even if the well is dry! Only decommissioned wells, sealed off and with no pumping equipment, can be exempted from payment of fees.

O&M costs include repairs, payment for an operator and a guard at night, as well as the energy costs. All these costs are distributed over the number of hours of functioning, giving a cost of approximately 14,000 tumans/hour of right over a 6-day period. Recently, all the stations were shifted from diesel engines to electric motors, and this cost was lowered down to 5,000 tumans/hour of right, but an investment of 7 million tumans per well had to be made by farmers. No official organizations, such as cooperatives, have been established and villagers manage the pumping units by themselves, both technically and financially.



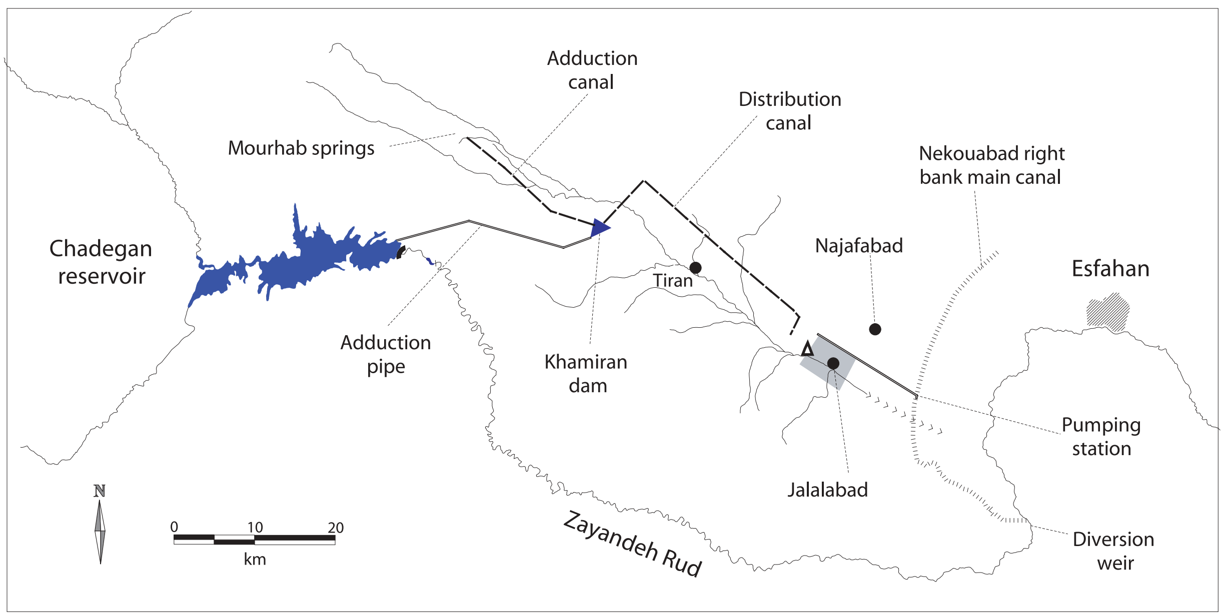
Example of intricacy in the distribution network

A pumping station (well)

Rights to well water are also defined in shares of functioning time, in proportion to the contribution of each individual to the investment. It is to be noted that not all farmers in a given dong subscribed to the investment (for lack of means or interest, or for already having sufficient water endowment), although the great majority did. When water was abundant, before the drought, the electric pumps could be operated almost with no interruption (in practice 22 hours/day). At the end of the drought, in contrast, water in the wells would dry up after 2 hours and pumping had to be interrupted until water filled it again, allowing only 8 hours of operation per day on average (some wells allowed only 2 hours of operation per day).

In the mid-1980s, a new source of water was added. Water was diverted through a pipe from the Nekouabad right bank main canal (constructed in 1970), some 10 kilometers further downstream, requiring two successive pumping stations: out of the 400 l/s brought into the area[14] a constant discharge of 60 l/s during 8 months was granted to the village (figure 7). This flow was incorporated to the qanat flow at the very entrance to the village, before its division into

FIGURE 7.
New water developments in the Najafabad valley.



different canals (see picture above). This means that the benefits of the canal water accrue to existing water-rights holders and that water is not used for other uses or expansion of the irrigated area. This water is paid for at the price of 4 tumans/m^3 (€0.004/m^3).

The substantial increase in supply brought about by the wells and the Nekouabad diversion allowed some land expansion and also intensification in the core sector. The area of the garden was increased from 200 hectares to 250 hectares. The remaining 400 hectares devoted to

[14] 140 l/s go to Najafabad, and the rest to many smaller users (hospital, etc.).

cereals and other annual crops were fully cultivated, in contrast to the earlier situation when half was left fallow each year. Ten hectares were also cultivated with rice, because of the high price it fetched.

The Revolution also marked the end of the regulation of the Mourhab river by the mirab.[15] This disruption allegedly allowed upstream villages, notably Askaran, the first served by the Mourhab water, to appropriate more than its share. The regulatory function was taken over by state organizations resulting in less transparency and eventually strengthening the power of the state to modify traditional rights, as events would soon show.

From this period also dates the expansion of chicken farms. About ten farms are located in the village but they are generally undertakings by outsiders. The village benefits little from these chicken farms since they mostly employ Afghan labor.[16] They use limited water and sell the dung to farmers.

Last, the war time (1980–88) was a confused period from the point of view of demography. While Jalalabad counts 40 martyrs for a population of 2000 at the time, it also saw the influx of a population fleeing the war zone in Khuzistan (mostly Loros). These refugees settled in the village but hardly got involved in agriculture because they commuted daily to Najafabad.

The Khamiran Dam (1993) and Its Impact

Originally undertaken by the Ministry of Jihad in the late 1980s, the Khamiran dam was probably a well-intentioned attempt to increase the storage for local use in the valley. Because of the lack of a favorable location to site a reservoir across the main valley, the Khamiran dam was constructed on a tributary of the Mourhab river, on the right hand side of the valley (see figure 7). This situation made it necessary to build a diversion weir on the river (200 meters downstream of the Mourhab springs themselves) and a 20-kilometer-long lined adduction canal on a contour line of the right flank of the valley.

Since the dam is not able to supply the upper part of the valley because of its position, another canal branching off the diversion weir takes water to the village of Askaran. Instead of the “natural” system of recharge through the stream that prevailed for centuries, the dam is now supplying water to downstream villages through another lined canal approximately 40 kilometers long. This canal, however, stops short of supplying Jalalabad and the villages further downstream. The dam was completed in 1992 and has a capacity of 6.8 million m^3. It was built by the Ministry of Jihad and Agriculture but was eventually taken over by the Ministry of Energy, which imposed water fees higher than those proposed by the Ministry of Jihad.

To increase the value and usefulness of the Khamiran dam and extend the benefits of the Chadegan reservoir to other valleys, a plan was drawn to pump water from the latter over the mountain ridge into the former (see figure 7). In 1991, the Karvan pump station was constructed for that purpose but it faced severe technical problems and its operation was discontinued after 3 or 4 years (Newson and Ghazi 1995).

The dam had a dramatic impact on the hydrology of the valley. First, with the Mourhab itself now fully diverted, the flow in the river stopped. Villagers in Jalalabad report that in ancient times the river would provide abundant

[15]Ibrahim Totkha, the then mirab, known for his strict enforcement of the ancient rules of water sharing, was accused of having participated in a counterrevolutionary attack on Najafabad with people from Tiran (his hometown) and was later executed.

[16]In addition to cheap labor, Afghans are also accommodated within the farm and thus serve as guards against thievery during the night.

fishes during spring and sometimes early summer, that it was often not possible to walk across it, and that they even happened to play on its frozen water during the winter time (40 years ago). Second, the lack of flow in the river dried up the main source of recharge of the aquifer, and qanats, springs and some wells started to falter. For example, the Jusdun qanat is believed to have dried up because of the dam. Similarly, the qanats in the villages of Jafarabad, Methiabad, Asfhan, etc., also dried up. It was only in years of abundant rainfall and snow, when the dam ended up spilling, that the situation tended to return to normal, albeit not fully, clearly demonstrating to villagers the negative impact of the reservoir.[17]

These changes overrode the traditional rights on the Mourhab. Because some villages, like Nezhatabad, had developed quite lately they were deprived of rights but with these new changes they were allocated part of the water coming from the dam. Other former rights holders, like Jalalabad villagers, lost the benefit of the river. Even, those villages like Tiran, which formerly had 6 of the 15 parts of the river, had to pay[18] for the very water they had freely enjoyed for centuries. The dam resulted in the canceling and redistribution of rights. It is hard to tell without further analysis what the change in the water balance of the valley has been but the losses by evaporation (1 million m^3,[19] out of a maximum storage capacity of roughly 7 million m^3) and the stopping of the earlier river flow from the valley into the Zayandeh Rud suggest that the overall supply is unlikely to have been increased.[20] The crucial point not to be missed is that the dam, at a high financial cost, disrupted the delicate and continuous recharge of the valley aquifer provided by the river flow. Consequently, the longstanding balance between this recharge and the tapping of the aquifer through the qanats, already significantly altered and jeopardized by the development of wells, was critically disturbed. Qanats, and even some wells, were further undermined.

This change did not remain unchallenged. Villagers organized themselves and demonstrated against this change in Tiran and other places. These demonstrations ended up with some fatalities but to no avail, the dam being eventually used as planned. In Jalalabad, the drop in water supply from the Mourhab resulted in the loss of approximately 3 months of river water, corresponding to the ancient diversion rights. (During such months the diverted flow generally largely exceeded the flow from the qanat).

In 1996, a strip of land along the riverbank of approximately 150 hectares, named mazrae jadid, was planted with almond trees and put under irrigation (figure 6). Part of the water rights of the core sector was reallocated to this new land. However, as will be seen later, this decision was driven by considerations other than the need for more land (or a favorable water/land ratio).

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[17]The relation between the qanats and the valley aquifer are complex: while some qanats mainly tap aquifers recharged by lateral runoff from the mountain infiltrating the sides of the valley, many have part of their course close to the river and sometimes even cross it underneath. They are, thus, also tapping the valley aquifer.

[18]The village of Khamiran, at the foot of the dam, is paying 2 million tumans for a discharge supposed to be 40 l/s, but still maintained at 20–25 l/s, that is, 2.4 tumans/m^3 at full supply but 4.8 tumans l/s in reality. Aziabad, the last village to receive water, upstream of Jalalabad, is reported to pay 1.6 million tumans for 60 l/s, or 1 tuman/m^3 at full supply.

[19]This order of magnitude is calculated based on an average water area in the dam taken as half of the maximum area.

[20]It may be that the dam, through its impact on groundwater flow to the lower reach of the valley, has increased the water made available to the valley itself, but if this is the case it occurred to the detriment of farmers tapping the aquifer, at the juncture between the Najafabad valley and the Zayandeh Rud valley.

The 1999–2001 Drought and Its Aftermath

The 3-year drought that hit the region during 1999–2001 (but which for some farmers started even 2 or 3 years earlier, as discharges started to decline) was of exceptional severity. The 3 years not only ranked lowest as regards the inflow into the Chadegan dam since its completion in 1970, but these exceptionally dry years also happened consecutively (Molle and Mamanpoush 2004).

Most qanats in the Mourhab valley, including Aliabad and Jusdun qanats in the village, dried up. Wells with insufficient depth or located far from the river also dried up. The upper well sector had to be abandoned, as its four wells ran out of water. (The agricultural area of Qarib Khan, 2 kilometers upstream of Jalalabad and farmed by another village, underwent the same fate). Two of the four wells of the right bank well sector better resisted and most of the area could be saved.

The raising of sheep by approximately 100 families was also severely impacted by the drought because of the scarcity of fodder. The owner of a major herd estimated that the number of sheep in the village decreased from 3,000 to 1,500.

The drought also made it clear that the Nekouabad water delivered by the pipe could not be considered as fully reliable. Indeed, the Ministry of Energy was unable to maintain allocation at the nominal level of 60 l/s and reduced it to approximately 40 l/s (while the full fee was maintained). In 2003, despite the return to normal conditions in the Chadegan reservoir, the incoming water was still at 40 l/s but farmers had no means to question this situation.

This dramatic situation of stress on all available water resources led to a desperate search for remedial measures. First, most of the main distribution canals in the village were lined (at a cost of 2 million tumans or €2,000). Second, work on the furthering of the Jahanabad qanat was undertaken in 2000 and is due to continue for several years.[21] The work concentrates on the second branch (see figure 8), which now crosses the bed of a right bank tributary in two locations and is going to intersect the main branch, although at a much higher depth.

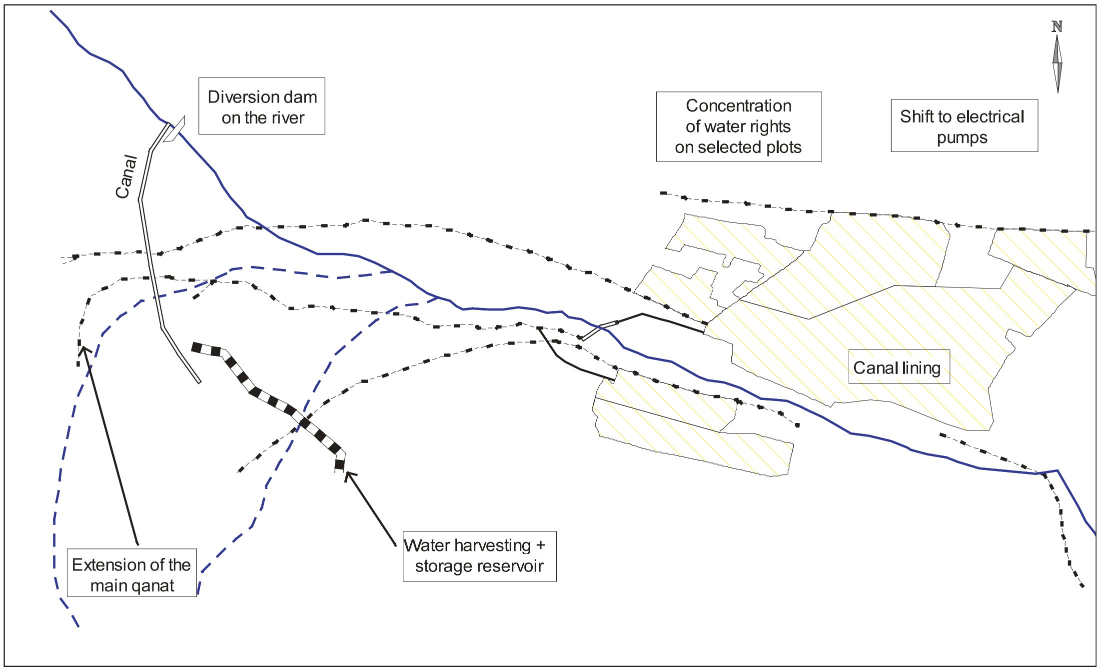
Another ambitious initiative aimed at damming the Mourhab water, in order to capture whatever flow might occur in the future. Since no proper storage is possible in the valley itself because of its flatness, the river is diverted to a lateral earth dam (similar to the Khamiran scheme), which has a rather long bund and is also able to collect lateral runoff. The dam is said to have a capacity of 400,000 m^3 filled only by half during 2002, when rainfall was particularly abundant. This work on the qanat and canal lining amounted to 36 million tumans (€36,000) and was paid by the government through the Ministry of Jihad and Agriculture.

Another solution to soothe the financial squeeze experienced by farmers was the financing, from 1997 onward, of electric pumps, replacing the diesel-engine-driven ones, at a cost of 5–7 million tumans/well. From 2000, this shift was subsidized by the government (40% of costs); it allowed the decrease of operational costs, from 14,000 tumans to 5,000 tumans/hour of right (in 6 days).

With the lack of water, water management was altered and farmers concentrated their water rights in some plots or some trees, leading to an increase in transactions in land and water rights (see section 6). They also endeavored to improve the application of water. In orchards

[21]Six persons work on a shaft, and two shafts are used at the same time to evacuate the spoil of the excavation. During the 2 months preceding the survey, the qanat was extended by 17 meters. A length of 0.80 centimeter gives approximately one cubic meter of spoil paid at 55,000 tumans.

FIGURE 8.
Remedial initiatives taken by villagers against the drought.



formerly irrigated by the basin, furrows and circular depressions around the trees were soon to appear.

In 2002 and 2003, the situation was on the way to recovery but the supply from all sources, qanat, canal and wells, was still under half of the potential or "normal" value. Wells, in particular, have not recovered yet and those which could be operated a total of 8 hours a day during the drought can now be used 10 hours a day. Approximately half of the gardens, however, have been lost. Discouragement was running high but a few gardens were started to be planted anew.

Synthesis

This short retrospective can now be synthesized to show a successive phase of adjustment between supply and demand, principally driven by population and hydrological change.[22] It is also possible to draw charts showing the evolution of the ratio between three variables: population, cropping area and available discharge.

The population in the village was around 400 in 1950 and 650 when the 1964 drought hit the village. Over half of the inhabitants left during that event but most returned during the following years. The population built up to 1,300 in 1978 and to 2,000 in 1985. At present, the population of the village is estimated at 3,000 but many people reside in the village and work outside during the day. In compensation, it is estimated that a much higher number of families live in Najafabad or elsewhere, but partly retain rights and activities in the gardens of the village. This expansion of the "village" in Najafabad was a lengthy process but could not be captured for lack of data. The population variable thus tends to lose its meaning as the economy diversifies

[22]A more complete study should consider other factors, such as economic factors, which determine the return to land and water and therefore the minimum area to sustain a family. Such historical data, however, are hard to collect and we limit ourselves here to the examination of plain ratios between land, water and population.

with the people toing and froing daily between the village and the city. For lack of more precise information, however, we have considered that the two opposite effects cancelled each other and retained the nominal population as an indicator to be combined with land and water to express pressure over resources.

Changes in cultivated area and available discharge cannot be accurately reconstituted. In particular, it is hard to account for yearly variations and to estimate the average extent of the lateral areas that were cultivated in accordance with the water available each year. Another difficulty is that the crop mix is also unknown and, considering the average area under cultivation, it does not capture the fact that cereals and gardens do not really compete for water since their water requirements are largely staggered, or the fact that rice[23] cultivation requires much more water than dry cereals.

Although it is not possible to represent year-to-year variability (but the recent and the 1964 drought are considered) or to obtain very accurate values of these variables, the estimates collected are plotted with the aim of outlining qualitative trends that can support the analysis.[24] Figures 9, 10 and 11 plot ratios between these three variables. Dotted and solid lines represent estimates with and without considering the Aliabad qanat, respectively.

It can be seen from figure 9 that the ratio of population to land was rather stable until 1970, then rose slightly until the 1999 drought where the loss of gardens reflected negatively. It is possible that the increase in the last three decades mirrors growing pressure over land resources, as determined by water supply. It is also possible that this evolution is overrated (because of the non-consideration of the occasional peripheral plots) or compensated for by a growing garden/cereal ratio that ensures growth in water productivity. It is therefore probably more correct to conclude that the growth in pressure over land resources has been in fact very moderate, as new water resources have allowed expansion of agriculture. Figure 10, in fact, shows that the available water per hectare of land remained around 0.1 l/s/ha until the Revolution, when the increase in the qanat discharge, wells and other sources gradually allowed the ratio to double, before collapsing dramatically during the drought. Last, the ratio of water to population (figure 11) declined (with a discontinuity during the first drought), especially during the seventies, before increasing and leveling off. Evolution in recent years is however uncertain and inconclusive because the number of people relying on agriculture is not known with accuracy.

[23]Some villagers with enough water rights grow rice since the price of rice is much higher than that of other cereals, but this cultivation is limited.

[24]Tabulated data used for this analysis are given in the appendix.

FIGURE 9.
Evolution of the population/irrigated area ratio.

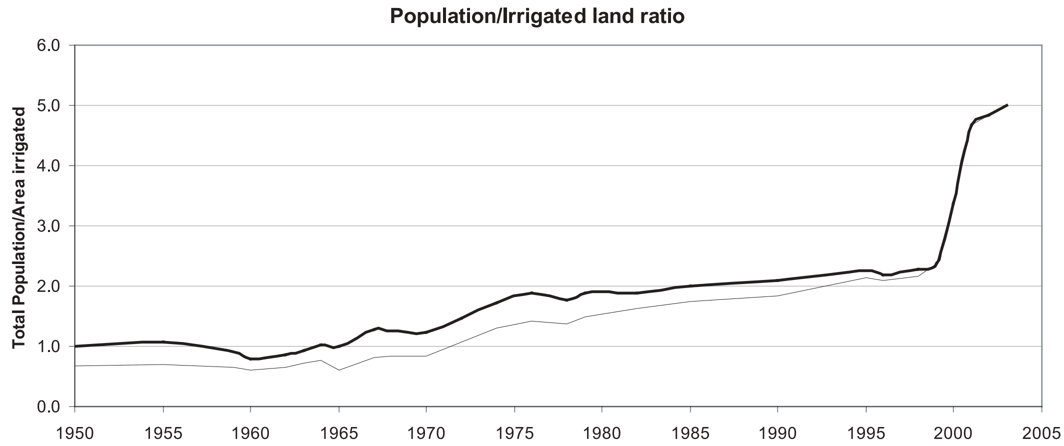


FIGURE 10.
Evolution of the discharge/irrigated area ratio (l/s/ha).

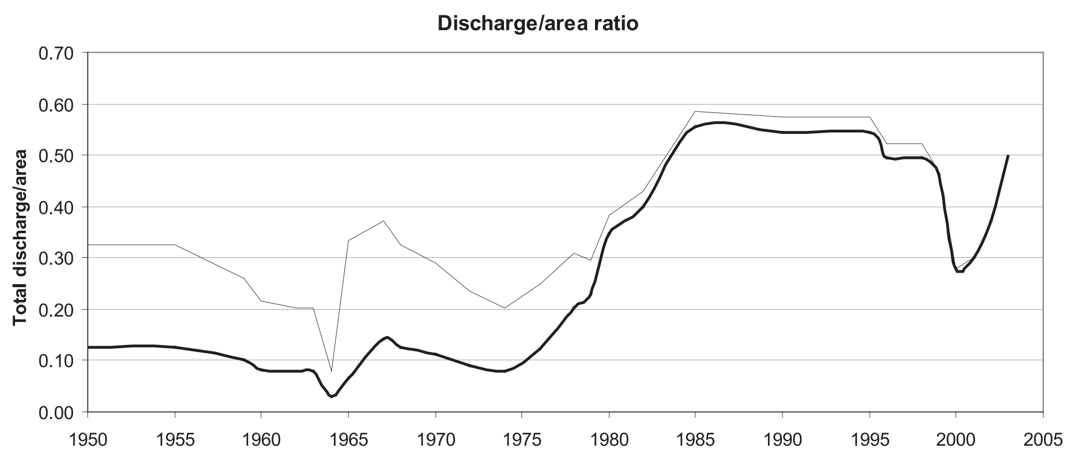
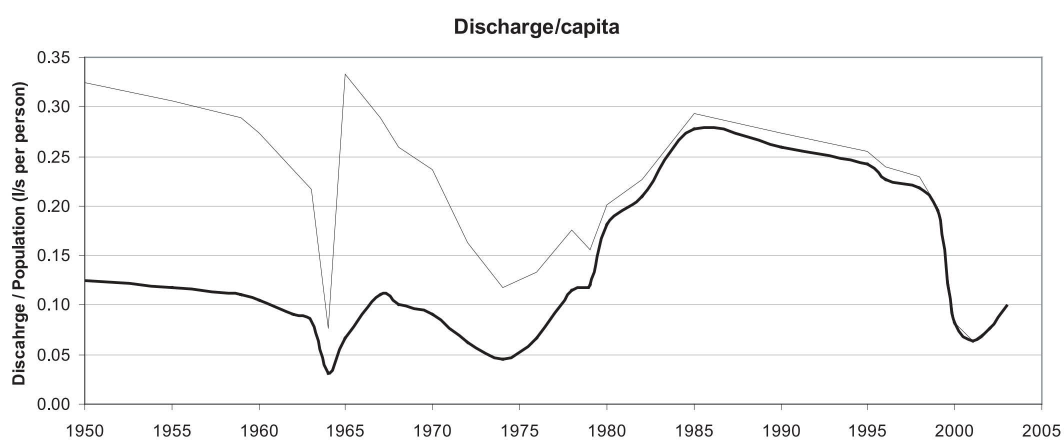


FIGURE 11.
Evolution of the discharge/capita ratio.



Cost of Land and Water and Gross Agricultural Incomes

Cost of Water

The various sources of water used by Jalalabad through the years can be compared in economic terms, with regard to both the investment and operational costs. This provides hints on the financial efforts that the state or villagers were ready to make in order to keep water supply in line with demand and population growth.

It is, of course, very difficult to assess the investments in the digging and maintenance of the qanats along centuries. As a proxy of maintenance costs, we may take the ongoing work aimed at furthering the galleries, which corresponds more or less to what is needed to counterbalance the decline in discharge by increasing the drainage area. This work (at the moment paid by the state) of 4 million tumans/year compared with a discharge of 100 l/s gives a cost of 1.9 tumans/m^3. (Since 1,000 tumans amount to one Euro, the following costs are given in tumans and can easily be converted.) This can be compared with the "spot-market" price of one hour of water right (4.6 tumans/m^3), which, however, now also includes the contribution of the Nekouabad water.

These costs have first increased with the operation of wells. The actual cost of a 60-meter deep well, with its horizontal drainage galleries, is estimated at 25 million tumans,[25] which corresponds to an investment of 60 tumans/m^3 of water made available per year. To this must be added 15 tumans/m^3 for the later shift from diesel to electric pumps. Operational costs are very low because of the subsidized rate of rural electricity[26]: as mentioned earlier, they were 8 tumans/m^3 with diesel motors, and are now 3 tumans/m^3 with the shift to electricity.

The price of water from the Nekouabad canal is of the same order of magnitude (4 tumans/m^3) and the sunk costs (6.4 tumans/m^3 made available each year) are also limited (but this is the part paid only by farmers). Comparatively, the new dam constructed in the village to collect lateral runoff and capture the residual water of the Mourhab amounts to an investment[27] of 360 tumans/m^3 of stored water. This shows how relief measures decided at the height of the drought are extremely political and favor emergency/relief considerations over economic aspects.

Last, the cost of the Khamiran dam was estimated at 53 million tumans (1990) and that of the feeder canal filling it at 64 million tumans (1991). If we consider the cost of the irrigation canals and the feeder canal to be of the same order of magnitude it gives us around 1.57 billion tumans in actualized value (2001). The cost of the cubic meter made available per year is therefore very high (274 tumans/m^3).

It is also interesting to compare these costs with those of the water brought by tankers, which the villagers bought at 700 tumans/m^3 during the most critical period of the last drought.

Table 1 summarizes all these costs. Investment costs are given in tumans/m^3 made available each year (on average), without considering the life duration of each source. It is important to stress that these values are orders of magnitude rather than accurate numbers, because actualization of the costs was not very

[25]But only 5 million tumans for the main pit, galleries being added gradually.

[26]The costs of electricity (per Kwh) are as follows: 19 rials for agriculture, 112 rials for domestic use, 168 rials for general use and 215 rials for industrial use (rounded values).

[27]We have considered here that the dam would, on average, fill up to only a fourth of its capacity (based on last year's observations); even if we double this value, the investment cost remains very high.

precise. However, they suffice to show big differences between sources. The table shows that the Khamiran dam and the water-harvesting dams were very expensive ventures. In the former case, the cost to the farmers is very low because of the subsidies implicit in the non-charging of sunk costs and O&M expenditures. Canal water is also subsidized, and its investment costs underrated.

TABLE 1.
Comparative costs of sources of water (tumans/m^3, or €10^{-3}/m^3, 2001 values).

Source of water	Mourhab river	Jahanabad qanat	Well[a]	Nekouabad canal	Reservoir	Tanker	Khamiran dam[b]	Canal/ uplands[c]
Investment[d]	~0	?	93 (72)	6.4[e]	360		274	289
Running costs (to farmers)	~0	1.6	3 (8)	4	?	700	2?	?

[a] For a well with a discharge of 20 l/s and used 20 hours/day (running costs include tax). Values in parentheses correspond to cost for diesel engines. Other values are for electric engines.

[b] Calculation has been made considering that the active storage available is 70 percent of the total capacity.

[c] Estimate for the failed project to bring Nekouabad water to the village uplands (see later).

[d] In tumans/m^3 made available each year on average (no consideration on the life duration of the investment).

[e] Part of the investment paid by farmers.

Price of Land

The price of land is extremely variable depending on the location, the presence of fruit trees and whether water rights are attached to it and sold altogether or not. One hectare is worth only 2 million tumans in the upper part of the village (well sector), but 11 million tumans near the village, where gas, electricity and other facilities are available. The price of a hectare of land is 15 million tumans in the core sector but only 5 million tumans in the mazrae qadim, and 4 million tumans in the Surkhan sector near the road. This is the price of bare land: if trees are planted, the cost is much higher, depending on the type and age of the trees. For almond trees, for example, the 1,000 trees to be found in one hectare are worth 8,000–9,000 tumans each (for fully developed trees), amounting to 8–9 million tumans/hectare, more than the price of most plots.

Cost of Production and Return

The different costs for accessing water can be compared with estimates of agricultural income. As is common, the benefits drawn from the different crops are in direct proportion to the investment costs and of risk (both for production and marketing).

Almonds. Generally, 90 to 100 almond trees are planted in one *jerib.*[28] The yield and the price depend on the variety. The *mormakha* variety is more expensive than pistachio itself and fetches 5,000 tumans/kg of dried almonds, but each tree produces only 2 kilograms. The *mamaye* and *rebi* varieties fetch much lower prices (1,500 and 1,200 tumans/kg, respectively) but are less sensitive to pests and produce almost twice more. The gross benefit of one jerib of rebi can be taken at 200,000 tumans, and the net benefit at around 170,000 tumans.[29]

[28]One jerib is one tenth of a hectare, and is the unit commonly used in the village.

[29]Not including family labor. Labor exchange is very common but extra labor is needed for land preparation and harvest. Wage laborers (often Afghans) are paid 3,500 to 4,000 tumans per day, which can be compared to the amount of 5,000 tumans paid in the construction sector.

Pomegranate trees. Pomegranate trees require very little input and are very drought-resistant (they can stand 18 days without irrigation). They produce 100 t/ha (10 t/jerib) yielding a gross income of 150,000 tumans/year/jerib, or 100,000 tumans after deducting costs.

Cereals. Barley is sold at only 100 tumans/kg. Yields vary with the availability of water but an average can be taken at 600 kg/jerib, giving a gross product of only 60,000 tumans. The corresponding gross income for wheat is 68,000 tumans (or around 60,000 tumans in net value, family labor not computed).

Other fruits. Fruit trees such as cherry, plum or apricot yield a better income but are sensitive to water stress. They need water every 6 days, while almonds may stand a frequency of 12 days. Walnuts are also offered high prices but the yield is uncertain, depending notably on frost. Under the present conditions of water scarcity, there are only a few trees, which are reserved for home-consumption. The profitability of a good garden is exemplified by half a hectare of orchard planted with high-quality walnut trees and miscellaneous trees, which brought its owner a net benefit of 5 million tumans/year.

Overall, it can be seen that the magnitude of per hectare income is around 600,000 tumans for cereals and 1–2 million tumans for fruit trees (with higher values however for high-value fruits such as walnuts, or peach, cherries, etc., usually cultivated in small quantities). This can be compared to the cost of water: if we consider an application of between 5,000 and 15,000 m^3/ha, the total (variable) cost of water from the canal/qanat or wells (taken here at 4 tumans/m^3) is between 20,000 and 60,000 tumans, a small fraction of the farm income (under 10%).

A typical qanat water right is half an hour/jerib, which is sold at 360,000 tumans (12,000 tumans/minute), which means from 1 to 6 years of agricultural income from that jerib. Qanat water is relatively cheap compared to land (with barren land in inner gardens at 5 to 15 million tumans/jerib), in particular because the supply from wells is higher than that from the qanat.

Land and Water Transactions

Because of the individuation of land and water rights in the village, the relative easiness in reallocating given amounts of water spatially and the close social bonds between villagers, water transactions are quite frequent.

Transactions within a Sector

The most common transaction is between dong-fellows. A farmer who, for example, is harvesting one plot may choose to “lend” his right to another farmer who needs more water, and who will return it at a later opportunity. The borrowing farmer may respect the order of the successive operations and just direct the “borrowed” flow to his own plot. If his plot is distant, however, which will happen, for example, if his time slot within the 12-hour period is quite a long time before or after that of the lender, then he will incur significant losses in time and in infiltration. He may therefore choose to inform the farmers whose turns fall between their two turns that he wishes to shift their time in order to concentrate two water rights on his plot. If his plot is located downstream of the lender’s, then those concerned farmers will be asked to shift their irrigation back by the amount of time he borrowed. If his plot is located upstream of the lender’s, then the successive farmers will have to delay their starting time by the same period of time. In that particular case, however, the problem is easier to resolve because the farmer will just have to divert the existing flow at some point further upstream. He will have to deduct from his time-right the time taken by water to make its way to the point where it had been interrupted but this is quicker since the canal is already wet. The most common case, however, is that of exchanges between neighbors. Since gardens are irrigated every two to four 6-day turns and other crops each with one or two turns, depending on the heat and the month, farmers cede their rights when they do not irrigate and add their neighbors' rights to their own when they irrigate.

A second (rare) case may occur when a farmer has plots in both the upstream and downstream lots of the dong. This may happen if he has bought some land or married a woman endowed with land in the other lot. In that case, he may shift a right, say one hour, of one lot to the other but he has to incur the burden and losses associated with directing the flow to a remote plot. (Only the Kaley Sefid dong enjoys more flexibility, since all farmers' plots are in the middle lot). Transfers from one dong to another are not possible because they would disrupt the whole division in lots of 12 hours.[30]

Transactions between Sectors

The dong-fellows generally have land in all six sectors, which increases the work needed for water management and also allows the reallocation of water from one sector to another. Two farmers of the same dong may exchange water on the same day (as opposed to the preceding case where the borrower returns water on a subsequent day), since a given farmer will have his irrigation operations concentrated on the day attributed to his dong.[31] One hour can be given to a dong-fellow in one sector and compensated for by one hour received in another sector. Typically, this happens during drought when farmers choose to concentrate the meager flow into some particular gardens.

Types of Transaction

The above examples refer to on-the-spot swapping operations that allow both flexibility in the reallocation of water and a better response to varying and spatially distributed crop requirements. If one farmer is not interested in an exchange he may simply sell or buy a right for one rotation. This happens frequently and the price is usually 2,000–2,500 tumans/hour. During the peak of the drought, however, the price was observed to reach 4,000 tumans/hour for a discharge that was almost one-fourth of the usual discharge, which corresponds to an increase of 700 to 800 percent that well-illustrates the shift in the marginal value of water.

These reallocations can also be agreed upon for a longer period. For example, the owner of a garden destroyed by the drought may choose to wait for a year or two before planting new trees. More often he will use the freed water on his other plots but if he is a resident of Najafabad or absentee owner he may simply rent out his right to a dong-fellow for a season or two. The price is calculated on the basis of the time of one hour multiplied by the number of rotations per year (approximately 40). The purchaser has to inform his dong-fellows about the transaction, so that time slots may be rearranged to allow the concentration of rights on his plot.

Well water rights are also ceded for one year at a price of 20,000 tumans/hour of right.

The transfer can also be permanent. The water-right owner can simply transfer his right to

[30]This only happens between plots that belong to two successive and adjacent dongs.

[31]If he has plots in several dongs which, again, can occur because of marriage or land purchase, he will have to be present on the field on several days.

a purchaser by declaring the transaction to the Qanat Committee,[32] where it will be duly registered. However, the transaction can only be between members of the same dong and within the same sector, so as not to disrupt the apportion of one day per dong. The price of one minute of qanat water (now increased by canal water) is 12,000 tumans. It must be noted that the water right is not attached to land. In effect, several owners have sold their water rights after the drought and let their land fallow, while retaining ownership on it (which can be a good strategy, since the built-up area of the village is expanding). Land, of course, is generally sold with its water right attached but not necessarily so. With the abandoning of many gardens during the drought, twenty cessions of water rights, mostly of farmers residing in Najafabad, were recorded. An hour of right to well water can also be sold, at the price of 800,000 tumans (or 40 times its value for one season). It must be noted that this price is lower, around 600,000 tumans, when the land is sold concomitantly (at a price that varies, as mentioned earlier).

Although transactions are frequent they are limited by several factors. Often, farmers have several plots planted to different crops in the same section and rebalance demand and supply within their own set of plots. Planting cereals alongside a permanent garden is a good water-management strategy because these winter crops need water in spring, while gardens will require more water during summer. When water gets really scarce, farmers may choose either to spread it over the totality of their plots, or to concentrate it on some plots, on some parts of a given plot, or on given crops (for example, pomegranate trees can stand two rotations without water, that is, 18 days, while other trees cannot).

It is also noteworthy that only the right expressed in terms of time is registered. The succession of irrigation operations and other internal arrangements are not written down. They are sanctioned by custom and do not give rise to any conflict. Only buying/selling transactions are recorded. Interestingly, the transfer by inheritance, by far the most common, does not result in such records. The Islamic law, which governs the distribution of inheritance to children by granting one part to a female and two parts to a male, is generally applied. Most villagers therefore do not have personal documents that directly show their ownership of land or water but they are all able to exhibit the initial document given to their ancestor by Sarey Modulay in the beginning of the twentieth century. The portion of this land inherited by a particular individual after several generations, plus the derived land on the more recent sectors, are said to be well known by all and is never questioned. This striking self-regulating aspect of land- and water-rights application and transactions, with no felt need for a centralized control, gives a measure of the centrality of such rights in village life. The recognition and individuation of rights are probably a result of the large (private) investments required to mobilize water resources, either through qanats or through wells (Spooner 1974a).

It is important to understand that the initial land and water rights, as codified in 1935, determine all the further developments made based on the qanat water, as well as on whatever water source is added to it, including wells, which are rightly seen as partly feeding on the same resource. These rights have been of course modified and fragmented by inheritance and sales, including sales to outsiders. This has engendered a dual system of land property, whereby a plot can be bought either with or without a “right to extension.” In the former case, the purchaser will be considered as a core-sector

[32]This committee is nominated by the Village Council, which has 6 members elected by the population every 4 years.

shareholder and will get shares of land in any further development/extension that uses qanat water. In the latter case, he will remain the owner of the part of his water right that will be directed to a possible newly opened area but not of the corresponding land share. This land, on the contrary, will be allotted to the former owner of his plot, who kept his right to extension. In practice, the owner of the new plot without water and the owner of the water share without land are led to strike a deal, so that one will sell his asset to the other (the transaction may also involve a third party). As a result of this distinction in right, the price of land "with extension" is 50 percent higher than the price without it. Land transactions are registered in front of witnesses and receive the seal of the Village Council. Water-rights deals, in contrast, are merely noted down in a book by the Qanat Committee.

Land- and Water-Rights Linkages

The development of the mazrae qadim and *sourkha* sectors was the result of a perceived excess of water and, since the right to ownership of these possible extensions had been specified in the initial land grants, villagers gained ownership of the new irrigated lands.

In contrast, the more recent development of the mazrae jadid on the right bank of the river and the reallocation of a fraction of the two parts of water allocated to the core sector were not due to a perceived excess of water but to a strategy to occupy and appropriate land. A crucial aspect of the politics of water in the village is the actual law on land. Villagers may occupy and reclaim barren land within the limit of the village, and can claim ownership of the land after demonstrating that within 2 years they can turn it green (or use it for some other productive use, such as chicken farming, industries, etc.). This, of course, necessitates finding access to a source of water. At present, the most common situations or cases are those where a) some water-rights holders reallocate their water spatially because the original use is no more possible (typically the encroachment of Najafabad city upon its old gardens: see next section; b) some people are granted permits to dig wells; c) water-rights holders decide to spread their water over a larger area; and d) state-sponsored projects may tap resources on which the state has control, notably the Zayandeh Rud water diverted to the irrigation canal system. The second case is exemplified by the two areas in the village irrigated exclusively with wells, while the third case is illustrated by the successive expansions from the core sector to the three added ones. The fourth case is exemplified below by the project of development of the village highlands.

The law, however, does not confine this right to villagers alone. Outside investors and also the state can make use of their right to occupy land. The lack of definition of "groundwater rights" makes it possible for particular individuals to be granted permits to dig wells. The rule that forbids digging or drilling a well within a radius of 500 meters of a preexisting well may not be strictly adhered to, and it is also too crude to prevent third-party impact on all hydrological situations, in particular on qanats. Having heard of government projects to occupy the area upstream of the village (the vicinity of the ruins of the old village, which is also the drainage area of the two qanats), the villagers decided to first occupy the stretch of land along the river (mazrae jadid), the closest to the village and also the part to which the qanat water could be more easily diverted. This was done by planting almond trees and by constructing, at their cost (14 million tumans), a canal receiving water directly from the outlet of the main qanat (before the transfer, via siphon, of its water to the other bank of the river). The qanat flow was redivided, from four into five parts, and the 180 hectares of the new sector were apportioned to the 450 shareholders[33] in proportion to their water rights in the core area. This, of course, reduced the per jerib discharge in the whole area and entailed an untimely weakening of water security just before the drought. In order to occupy and secure the land located further upstream, they also planned to develop drip irrigation in that area but were not given the permits for the two wells that would have been necessary. This was done with the full understanding that the wells would most probably affect their own qanat, but was judged preferable to waiting for somebody else to be granted a permit.

Recent developments showed that this premonition was not baseless. The villagers got the information that a joint venture between investors of Najafabad and a foreign company to produce flowers in greenhouses for export was being planned and that the area of production could be located in the disputed area. This strengthened the determination of the villagers, notwithstanding a sense of resignation that led one farmer to comment "they would end up without water and working as employees for 'them'."

Another way to capture water is to activate political support[34] and links with line agencies to propose and push for development projects that may tap state-controlled resources, such as the water supplied to irrigation by main canals. Such claims are usually supported by equity considerations put forward by people whose villages are not located in areas that benefited from earlier large-scale development projects. This, however, may be risky as the following example will show.

Seven years ago, the village was promised a discharge of 200 l/s, to be pumped from the Nekouabad right bank main canal[35] to irrigate 3,000 hectares of good soil located in the mountain that overtops the village. Villagers invested 60 million tumans in land development out of the 170 million requested before realizing that the project was not forthcoming. While they had been promised that the 170 million would be paid by the Ministry in exchange for the land (worth 270 million) occupied by an electric station south of the village,[36] the whole project collapsed with the outbreak of the drought. Villagers had formed an association of 1,100 members[37] who were ready to invest in the new venture and had accepted to relinquish their rights to land for the benefit of the government, on the promise that they would be granted ownership after 2 years of cultivation. With water not forthcoming, irrigation and agriculture became impossible and the land rights remained with the government. The project would have incurred significant costs for adduction but the villagers were ready to pay for the 450 million tumans needed (7 years ago). Costs are now estimated at 1.2 billion tumans and there is no news about the 200 l/s originally targeted for the village since the drought has

[33]Because of the division of land, more people were actually concerned but they remained under the representative of the family for the sake of simplicity.

[34]For example, the former Minister of Information was born in Jalalabad; the Minister of Agriculture is from the Najafabad district, etc.

[35]Before the revolution (1979), and probably after the construction of the Nekouabad left bank main canal in 1970, at a distance of 10 kilometers, there were already projects to bring water from the canal (that is from the Zayandeh Rud) through a pipe. Another project was to bring water from the Chadegan dam, which was realized only in the 1990s but which eventually failed.

[36]As mentioned by one villager, "it is not easy for the Ministry of Energy to pay money but it is easy to give water." This intuition hints at the power of the ministry to allocate water without close scrutiny on third-party impacts, because of the absence of a quantitative definition of water rights.

[37]Since the new land was not supposed to be developed based on the qanat water, the benefit of the project was not confined to ancient rights holders but opened to all. Altogether, 110 individuals without ancient rights applied for land in this project.

shown how scarce water could be. Faced with such a gridlock, villagers have decided to hire a lawyer to take their case to court. It is worth noting that farmers are well aware of the competition for the Zayandeh Rud water (through the Nekouabad canal) and that the rush for securing an allotment of water is seen as a critical and strategic move in the context of a total basin closure. Interestingly, they are also aware that the Zayandeh Rud water is being piped out of the basin to the cities of Yazd, and in the future to Kashan,[38] and are convinced that this would not have been possible if they had "bought" the water of the Nekouabad canal in time.

Another example also well illustrates the mobility of land and water rights. The encroachment of Najafabad city upon its old garden area has freed a part of the water supply coming from the 17 qanat collector (now allegedly flowing to the Zayandeh Rud), and rights holders, with the help[39] of the Department of Agriculture of the district, have planned to use part of this water to develop 3,000 hectares of almond trees in the middle of the valley. However, with the drought, the collector's discharge was reduced from 1 m^3/s to a tenth of this value, with 12 out of the 17 qanats having dried up. Only 850 hectares have been planted so far but shareholders are expected to be granted the authorization to dig one well for each of the dry qanats, which will compound the overall decline of groundwater resources. It must be noted that the strategy of Najafabad's landowners is not only to make productive use of their water rights (a share of the collector's discharge) but also to get access to land, whose value is likely to increase in the future. Since whoever is demonstrating that he can turn barren public land green is granted ownership, Najafabad gardeners were able to get hold of a land 30 kilometers distant by reallocating part of their water rights.

All these examples show the diversity of strategies to access land by spreading water use or to access water by spreading land use. They involve different actors, villagers, investors and various government agencies, and result in a constant redefinition of the land and waterscapes. These issues and their implication for allocation and rights are examined more closely in the following section.

Hydrology and Water Rights: Lessons Drawn and the Challenges Faced

The Quest for Water

Several important lessons can be drawn from the story of Jalalabad. The first one is the ingenuity deployed by villagers for centuries to tap the water resources necessary for life and agriculture. This applies first to the development of the qanats. The development of the Jahanabad qanat has been quasi-continuous; branches have been made longer and deeper, connections with riverbeds or deeper aquifers established and siphons or aqueducts constructed across rivers. Surface water was diverted to different fields, depending on its abundance, or trapped so that it may infiltrate and recharge local aquifers. Surface water has also been recently stored in a lateral reservoir, which is also a water-harvesting device aimed at recharging groundwater. Villagers have developed hybrids between wells and qanats to take

[38]Qom, a very thirsty city too, is also mentioned but it seems that official plans are to divert water from another basin.

[39]A share of 20 percent of the investment is paid by the government while the rest is to be paid by the farmers.

advantage of power-driven pumping devices. They have struggled to obtain additional water from the state, through pipe connections to the Nekouabad right bank irrigation canal, lobbied for similar projects in order to occupy and develop the highlands of the village, or struggled to get a share from the Khamiran dam. As we have seen above, new challenges to the control of water are still appearing.

These endeavors on the supply side have been paralleled by efforts on the demand side, including water transactions, blending of crops with staggered requirements, establishment and use of furrows instead of flood irrigation during the drought, concentration of water rights, etc.

Socio-Hydrologic Breakdown

The second lesson is the evidence of the breakdown of the delicate balance between the hydrological cycle and the uses of water in the valley. This breakdown happened in two steps: first, the development of wells, second the construction of the Khamiran dam.

After the nationalization of water resources in 1968, the growing intervention of the state came together with a modernist ethos, whereby traditional village irrigation was considered as primitive, backward and inefficient (McLachlan 1988; Ehlers and Saidi 1989). Modernization required technology and modern water-lifting devices, and the development of pumps and wells was considered very advantageous compared with qanats, because the fluctuating discharge of the latter was considered to hinder agriculture. This considerably boosted the expansion of wells which started in the late 1950s. While in the 1950s the contribution of tube wells was negligible and existing qanats were providing 60 percent of all supplies and serving 1,200,000 hectares of irrigated land in the whole of Iran, by the mid-1970s wells were already providing 8 billion m^3 against 9 billion m^3 by qanats (McLachlan 1988).

Qanat discharges are determined by the height of the water table, which determines the length of the water-bearing section (Beaumont 1989). Wells, in contrast, ensure a more or less constant discharge irrespective of the water table depth (at least in a certain range and in the short term) and this flow can be increased by galleries and the use of more powerful pumps. They are not only hardly sensitive to variations in the groundwater stocks but may also abstract more water out of the aquifer than it comes in as recharge. The “mining” of aquifers has little short-term impact but proves unsustainable after a few years, especially when a drought occurs, as we have seen earlier.

The history of the destruction of qanats by wells is documented by several studies (e.g., Ehlers and Saidi 1989) and well illustrated by the Najafabad valley, as well as by the Borkhar area: the qanats of the Borkhar area, a flourishing cultivated area north of Esfahan, were destroyed by the ensuing spread of deep wells sunk to irrigate summer crops and orchards (Lambton 1969). This does not mean, however, that wells should have been disregarded, nor outlawed from the outset. It is likely that, in some areas, the potential of groundwater was higher than what the qanats were extracting. For the Najafabad valley for example, if we ascribe to each of the 106 qanats of the valley the average discharge of 32 l/s found by Hartl (1989) for a sample of these qanats, we arrive at a total discharge of approximately 3.5 m^3/s. It is probable that wells have been used to tap more available resources but insufficient control of their number and location eventually led to competition with the qanats.

The second fatal step was the construction of the Khamiran dam, probably based on the common (yet radically wrong in that context) idea that surface storage is beneficial because it may regulate water that would otherwise flow downstream untapped and non-beneficially. In effect, traditional water sources (spring and qanats) feed on the huge natural water-storage facility provided by the alluvial aquifer of the valley. This natural reservoir has overwhelming advantages over a dam: a) it incurs no loss by evaporation; b) it is distributed all along the valley, allowing access to almost all villages; c) this distribution is free and requires no intervention; and d) water use had been quite finely attuned to the resource.

The failure to fully appreciate these advantages probably paved the way for a decision which had all the attires of a modernist solution (engineering- and technology-oriented, capital-intensive and state-controlled) but produced disastrous effects. With the diversion of the Mourhab, as it has been mentioned earlier, the constant replenishment of this distributed reservoir was interrupted and water concentrated in one point; the intervention incurred high capital costs; the balance of supply and use was disrupted; the reservoir undergoes evaporation losses; earlier investments in affected wells and qanats were cancelled; traditional rights were impaired and access effectively redistributed; those who received water had to pay for it; allocation became unclear and users lost control over it; and the ecology of the river was fatally impacted.

Conflicting Legal Repertoires

The third lesson is the interference of the state and the confusion of legal repertoires. The Civil Code, following the Islamic Law, gives priority to established owners of land over newcomers and upstream over downstream users of water. Prior appropriation rights were protected by a clause stipulating that the use of water by newcomers should not impact on the interest of existing users. The need to protect springs, wells and qanats was addressed by defining a *harim*, or a prohibited area for extraction around these sources. A Qanat Law for the protection and construction of qanats was enacted in 1930 under Reza Shah but it did not have much effect. The law predated the introduction of power-operated deep or semi-deep wells and was not updated to deal with these new developments. McLachlan (1988) reports that the "legal frameworks from Islamic Law and the Civil Code that surrounded water use were powerfully supplemented by customary practices ('*urf*)… These local regulations governed to a large degree the access to, and use of, water in irrigation within what was a complex organization of supply in an uncertain physical environment."

The nationalization of water resources was introduced in 1967 as the tenth point of the "White Revolution" and Regional Boards were established to assess and control water use and to charge consumption. The state thus gained wide power of control and taxation of private/communal ownership.[40] In several instances, the state took over the management of minor schemes and abolished customary rights, with mixed results (Lambton 1969; Ghazi 2003), but this seems to have happened on a case-by-case basis. Water management in the Najafabad valley was apparently not altered.

All in all, the right to groundwater, as regulated by the granting of permits by state authorities, became a state affair and was administered centrally, with limited knowledge of local hydrology, transparency, and control by interested populations. Regulation of the diversion of surface water, too, became insulated from

[40]As usual, this measure seems to have been justified by the alleged ability of water fees to control "wasteful application" and induce shifts from subsistence to commercial crops, a rhetoric endorsed uncritically by McLachian (1988). Water charges, in fact, remained as politically acceptable levels and were never high enough to induce such shifts (see Perry 2001). In the words of McLachian (1988), "with this income the disincentives to the official agencies of supplying water to the irrigation sector were removed."

stakeholders. Instead of the mirab whose actions had to be patent and who enforced rights sanctioned by tradition, now the state allocates water with little recourse available to users to question this allocation. For example, the share of water going to Askaran, the most upstream village, is defined by the regulation of a hydraulic structure, which can be tampered with and which may easily be subject to local arrangements between operators and the villagers. Likewise, 2 years after the drought, most villages are still not receiving the agreed-upon discharge from the dam (or from the Nekouabad canal, as for the case of Jalalabad), despite conditions in the dam having returned to normal. No insurance or reasons are given that discharges will be restored to their initial values. In a similar fashion, the redistribution of water in the Najafabad Valley after the construction of the Khamiran dam was a non-transparent process with no direct participation of the population concerned. The village of Khamiran, for example, could divert 30 l/s from the Mourhab and 50 l/s from its qanats. Both sources have dried up after the construction of the dam and they now pay 2 million tumans for a discharge of 40 l/s from the dam, unilaterally reduced to 20-25 l/s during the drought.

This situation is also illustrated by the Zayandeh Rud itself. With the superposition of concrete canals over the network of ancient maadi, the state has largely overridden the riparian rights enshrined in the sixteenth century document attributed to Sheikh Bahai. Despite some modification in the 1930s, when rice cultivation was temporarily banned, this regulation had been enforced for centuries and its enactment, in spite of its official seal, had been done in what would nowadays be termed "stakeholder" consultation and participation. The introduction of the edict states that

(…) "the competent authorities of the State should appoint a few persons of the reliable and aged men to establish, under the signatures of the exalted and honourable *mostawfis* and the confirmation of the *kadkhodas* and *rish-safids* of the *boluks* [districts], which share the water of the Zayandeh Rud, honestly and to the best of their knowledge, the shares and lot of each village and hamlet in each *boluk*, according to its capacity and need, and to enter in the registers under guarantee, so that regulation (of the waters) should be put into execution" (Lambton 1953).

Another ancient source quoted by Spooner (1974a) stresses that the mirab "must prevent the powerful from trespassing on the weak with regard to the shares of water," and referee water disputes "with the confirmation and approval" of the local leaders. In sum, the situation at the moment is one in which the state controls large-scale irrigation networks as well as groundwater permits, more often than not in conflict with traditional rights. Interestingly, however, these are not fully abolished, judging from the way water is taxed. Farmers who draw water from two maadi near the Kaley (head) bridge, for example, get water from the first one free but pay for water from the second. The reason is that the first maadi branches off the Zayandeh Rud a few hundred meters upstream of the bridge, while the second branches off a few meters downstream of it. Since the rights defined by Sheikh Bahai applied only to maadis diverting water after the bridge, the upstream diversion is disregarded and not taxed. Likewise, the price of the Khamiran dam water supplied to the different villages, which also depends upon whether the village formerly held rights or not, is higher if the village had no rights! It is ironical in some sense that while overriding ancient rights, the state keeps referring to them for the only purpose of taxation. This can be seen as a compromise between preexisting rights and the complete redefinition of rights.

Robbing Yadullah's Water…or the Tricky Logic of Closed Basins

The last and most important lesson to be learned is that in a closed basin any local increase in water abstraction, be it from surface water or underground water, is likely to decrease the supply of another user somewhere else in the basin. Because the closure of river basins results in a growing interdependence of the users within the basin, one must carefully analyze how the paths of the different surface-water and underground flows are interrelated and how any local intervention that modifies the quantity, quality or timing of one of these flows impacts the whole system. What is stored, conserved or depleted at one point dictates what is available at another point, further downstream (Molle 2003). Whenever an individual, a village or the state taps a new source of water or alter the allocation of an existing one, it is tantamount, in reality, to a mere reallocation: in other words, *one may be almost sure to be robbing Yadullah's water to irrigate Saeid's garden*. The spatial and temporal features of these implicit or explicit reallocations (and the identification of who wins and who loses) are often tricky and sometimes unexpected. Several examples, found at nested levels, can be drawn from the preceding discussion.

The prime example is of course that of wells which deplete local aquifers. Well development is tantamount, at least partially, to a reallocation of water from qanat (sometimes spring) owners to the well owners. These owners may be the same persons, as in the case of the development of the right-bank well sector, which has dried up the Aliabad qanat. But they may also be very different people. The flower-farm project upstream of Jalalabad would entail the reallocation of water from villagers to a capitalist joint venture between investors of Najafabad and a foreign company.

The development of wells in lateral valleys also reduces the groundwater flow to downstream areas. Farmers understand that groundwater is not a static resource and the issue is "pumping water before it flows downstream," as one of them expressed. The same also applies to surface water, with the new reservoir that captures any possible flow in the Mourhab (part of it, however, is reinjected locally into the aquifer by infiltration).

The construction of the dam is a good example of storing the surface water (in the reservoir), which used to diffuse to the valley aquifer and be distributed all over it, to further reallocate it only to some villages. The result of the dam, together with the wells and the qanats, is probably a drastic, although invisible, reduction of the groundwater flow to the Zayandeh Rud itself, since water is "retained" in the valley. This flow formerly contributed to the recharge of the river and to the amount of water used downstream for irrigation. According to groundwater balances of the Najafabad Valley, 28 percent of current water use is unsustainable (mining of groundwater resources), and only 9 percent of groundwater leaves the basin, presumably for the main valley (Morid 2003). Although early rights focused on the river, the overall balance between demand and supply that resulted from these rules, in fact, implicitly incorporated these underground flows.

Along the Zayandeh Rud itself, of course, water supply has been dramatically changed by the Chadegan dam and the successive tunnels, while demand increased with the expansion of irrigation and other uses. However, there are numerous examples of reallocation. The upper reach of the river, for example, comprises a narrow and steep-sided valley but numerous pumping stations abstract water and supply it to almond orchards located on the plateau, and equipped with drip-irrigation they supply it to locations sometimes 150 meters higher than the river! These orchards are estimated at 10,000 hectares (IWMI and AREO 2004) and are now developing on a large scale and, in the absence of formal rights, they only deplete the resource that was to be used downstream.

A less-obvious example of reallocation is provided by the development of large “green belts” around the city, along the ring-road. These trees have allegedly been planted “for the environment,” that is, to help greening the city surroundings. They are generally irrigated by drippers and water is sourced from deep wells. A vague feeling seems to prevail that this is done using underground water that was more or less waiting to be tapped. In reality, this underground water is flowing towards the river and is also contributing to the base flow of the river. Again, the impact is on downstream irrigators and the environment. This example shows how water for agriculture can be reallocated almost “invisibly” to provide amenities to city dwellers (and urban-based decision makers). A more visible variant of this is the direct pumping from the Zayandeh Rud river to irrigate the University Campus, the zoo and its surrounding park.

Canal lining also increases local use to the detriment of return flow users. The Najafabad’s collector, that follows the valley, has been lined, increasing the flow to Najafabad but reducing groundwater recharge. This also applies to the canal that distributes qanat water in Jalalabad: the benefit is local (less losses and less costs to pump water back to the fields), but subsurface flows are reduced.

The upstream/downstream and surface/underground are complex and sometimes yield counterintuitive consequences. For example, Jalalabad farmers may be upset by the fact that farmers in Nezhatabad, one but the last village to be supplied by the Khamiran dam, receives enough water to grow rice, while they were not granted a share of the dam (paddy fields usually dry up in a lapse of time of between half a day and three days and, therefore, diversion to these fields is very high). In fact, these losses are very beneficial to them since they replenish the aquifer that flows downstream towards their village (although the benefit is probably significantly reduced by the wells that locally recycle part of this infiltrated water).

Pumping from the Nekouabad canal is also attractive. A discharge of 400 l/s is delivered to users in the Jalalabad area, but there are several other users. For example, generally, factories have no problem in getting supply from the canal since their demand is seemingly limited and the Ministry of Power can sell water to them at a much higher price. Since the canal is allotted a given amount of water and has a capacity limited by design, the combined impact of these diversions is to reduce supply to agriculture.

In general terms, water use is becoming more and more local, as users increasingly tap water resources (surface water and underground water) closer to their source. Consequently, basin flows are reduced with the exception of the supply of the Chadegan dam. However, for each increase in supply, there seems to be a host of demands and water-use projects are waiting to be implemented.

The study thus provides a handful of instructive and graphic examples of how water gets redistributed:

- From underground to underground (wells impacting on qanats and springs).
- From surface to surface (the Nekouabad canal water piped to Jalalabad).
- From surface to underground (diversion of Mourhab water and harvesting lateral runoff into a storage dam that recharges local aquifers in Jalalabad).
- From underground to surface (the aquifer recharges along the Mourhab now transformed into stored surface water; the seepage of Najafabad’s adductor transformed into [increased] surface supply through canal lining).

- From underground/surface to surface/underground flow (lateral aquifers were contributing to the base flow of the Zayandeh Rud; the river now recharges the lateral aquifers).

If these interventions induce hydrological changes, they also work across scales, and across levels of social and political control. The excavation of tunnels has introduced trans-basin diversions into the basin; the construction of the Chadegan reservoir and the modern irrigation schemes have transformed the hydrological regime of the Zayandeh Rud that, in turn, has changed the underground flow between the main and lateral valleys. These flows have been, and still are, altered by overabstraction of groundwater by wells that, in turn, have affected qanats and springs, and the surface lateral flows to the river. This interconnectedness across scales has critical implication for societies, since they link macro-level management and decision making to local processes. The corresponding establishment of multilevel governance patterns is a challenge (not specific to the Zayandeh Rud basin) that is bound to take several decades to be addressed effectively.

As exemplified earlier, while some interventions, such as the diversion to main irrigation schemes, are well quantified, the overall web of interactions is not, and many of these interventions have consequences rendered invisible both by the hydrologic complexity and by the year-to-year variability of flows, which mask long-term trends. A wet year is likely to pop up and show that resources are abundant, or at least sufficient, to satisfy users; but a dry year, or a drought, is all the more likely, in turn, to show that resources are overcommitted and the slack needed to absorb or dampen irregularities is lacking.

Another consequence of the closing of a river basin cannot be overemphasized. Since all water resources in the basin are committed, water savings at the basin level are logically impossible. Local conservation measures are possible but they necessarily have third-party impacts, be it on other users, next generations (mining of aquifers) or on the environment. This evidence is still not fully appreciated by decision makers, and official statistics still stress the low efficiency of irrigation schemes, reported to range from 28 to 42 percent in the Esfahan Province (Keshavarz and Heydari 2003). The case of the lower Colorado, where an alleged win-win agreement between the Southern California Metropolitan Water Authority (MWA) and the Imperial Irrigation District (IID) took place in 1998, is a good example of excessive optimism. This celebrated arrangement includes the lining of the All-American canal by MWA and the right of usufruct of an estimated 100 million m^3 conserved through this intervention granted to MWA (CGER 1992). In fact, it is apparent that the so-called “savings” are detrimental to the recharge and quality of the aquifer, which is tapped by Mexican farmers on the other side of the border, in the Mexicali Valley, thus resulting in further decline of this resource (Cortez-Lara and Garcia-Acevedo 1999). Win-win hydrologic situations often have a forgotten “lose” side somewhere else.

Future Waterscapes in the Village

Changes in the economy, demography and the resource base of the village, most of which are shaped by macro evolutions that transcend its boundaries, are likely to govern the main evolutions of the village.

The most critical problem is the current economic crisis, which increases population pressure over resources. Unemployment of youth is very high in the village and this has brought drug-addiction problems and raised crime to levels hitherto unheard of. One nearby textile factory is about to close, compounding the situation. The population is still on the rise, despite a sheer drop in fertility but emigration seems to be limited.

Nowadays, more than half of the farmers do not live in the village but reside in their great majority in the nearby city of Najafabad. This is because many of their children have moved to the city and settled there and they have followed them rather than staying alone. On the other hand, some strangers to the village, usually Najafabadi willing to make investments, have also bought gardens but they do not reside in the village. Their number is less than 10 percent of the total number of farmers. Absentee owners either pay some employees to take care of their farm or rely on relatives or neighbors to do so.

Because of the sharp difference between income derived from gardens and from annual crops, the loss of approximately half of the gardens has severe implications on the village economy. Whether water supply will soon return to pre-drought levels or whether recovery will be affected by more dry spells will determine if and when orchards will be reestablished. Villagers seem undoubtedly to be attached to their gardens. This is true because of the investments made but more for sentimental reasons, as illustrated by a landowner who emigrated to the United States but returned to see his garden after the drought. Owning a garden is considered socially prestigious (Kielstra 1989). However, it can be feared that creeping and enduring water scarcity will hamper recovery and discourage many to invest in their gardens. The very slow recovery of wells is an ominous sign that another severe drought might be fatal. Selling water rights may thus be an increasingly adopted option, with concentration of rights in more limited and secured gardens.

The options explored by the Jalalabad villagers to ease pressure over water resources include the following strategies:

a) Augmenting the discharge of the Jahanabad qanat is the easiest and most straightforward option under their control. This strategy has been highly rewarded in the past, with the discovery of a water "vein" that doubled the discharge of the qanat. Furthering the part of the gallery situated within the aquifer increases supply, and the subsequent gain in depth is also an insurance against further drops in the water table.

b) Another solution to water scarcity explored by the Jalalabad villagers is the purchase of the Jusdun qanat. The qanat is currently dry but this is partly due to its poor maintenance and the collapse of some parts of the gallery. This has raised the pressure in the upper reach of the qanat and has created a reemergence in the pit located in a riverbed crossed by the qanat.[41] Since Jusdun is now supplied with water from the Nekouabad canal, its villagers do not bother spending money to maintain their qanat and Jalalabad has declared its interest in buying it and in making the necessary investments to restore it.

c) A last option is to battle to obtain the extension of the delivery canal coming from the Khamiran dam down to the village and a share of its supply. The villagers have brought their case forward to Esfahan, in the Ministry of Energy, and have been orally promised 10 l/s from the dam as compensation to their right to the Mourhab water. Since nothing has been achieved, they recently decided to hire a lawyer to further their case. In addition,

[41]Since the top of the shaft located in the depression of the riverbed is much lower than the others, a "spring" has appeared in the (usually dry) river. The eagerness of the search for water can be sensed by the fact that, during our visit to this place, a farmer from a nearby village was observing the reemergence accompanied by an engineer who was expected to advise on the best way of tapping it.

they intend contesting the case of the village highlands, where investments have been made but where the government's contribution has not been forthcoming.

d) On the demand side, agricultural strategies include change in crop type, crop insurance,[42] improvement of irrigation at the plot level, or adoption of micro-irrigation. This solution is put forward by governmental line agencies. The creed that technology saves water, however, is missing the point. Such a shift, just like the lining of the canals during the drought, would reduce infiltration losses and also the amount of water in the aquifer tapped by the very villagers through their wells, as well as by downstream users, through wells and qanats. Micro-irrigation would only increase and concentrate depletion of water in the village while compounding the situation elsewhere. This option, however, is likely to spread in the future since it is the logic of the individual that prevails, and since third-party impacts are not recognized or, sometimes, not identified. In addition, it fits an image of modernization that officials are eager to embrace and propose. One may envision a future where greenhouses and more capital-intensive ventures will gradually develop at the expense of traditional farming. While such a shift would be desirable in terms of economic efficiency, it is unlikely to benefit all farmers across the board, and its social value is uncertain.

The Challenge of Water Rights

The absence of clear water rights means that interventions, reappropriation and redistribution, with their impacts across scales and social groups, are a sizeable reality. The three main losers of this lack of overall control over resources use in the Zayandeh Rud are, not surprisingly, those most commonly and primarily affected in closing basins: the downstream users, the next generations and the environment, the latter two being the "stakeholders" who typically have less bargaining power. Next generations are affected by the mining of aquifers and the gradual depletion of groundwater resources. The environment bears the brunt of the reduction of flows at a time where more water is generally needed to dilute pollution. Downstream "users" include the last irrigation sectors of the Rudasht and the Gavkhuni swamp. Salinity of soil and water in Rudasht has been shown to be on the rise and prone to increase in the future (IWMI and AREO 2004; Morid 2003). Environmental degradation (electric conductivity of water draining from Rudasht typically at 6-12 dS m^{-1}) (Salemi et al. 2000) can be contrasted with the affluent past of the area. Ibn Hawqal (1889) reported that, in the tenth century, the districts of Ruwaidasht and Baraan constituted "an important region in which ten mosques can be found. Harvests are abundant and all the supply of Esfahan comes from it."

It is tempting to think that because of the closure of the basin and growing competition for water, the formalization of rights is both needed and inevitable. Property rights are widely seen by neoclassical economists as an endogenous response to conflicts, where they restore

[42]For a yearly amount of 5,500 tumans/jerib of almond trees, the indemnity in case of crop loss (as occurred last year because of frost) is as high as 70,000 tumans/jerib (more than what the yearly income would be).

certainty and legibility and reduce transaction costs. This could be substantiated by the opening sentence of the sixteenth century firman on the Zayandeh Rud water mentioned earlier: "The royal command was given that, since differences had arisen in the villages and the water shares of the Zayandeh Rud of Esfahan…"

However, there are several difficulties to such an establishment, and this applies not only to the Zayandeh Rud basin but also to most situations. The first reason, alluded to earlier, is the complexity of hydrology and the lack of quantitative representation and knowledge about the different fluxes of water, notably those of groundwater. The second is the variability and unpredictability of these hydrologic processes, which have drastic implications on how the definition of rights would incorporate this variability. The third reason is political, whereby state actors may prefer, or at least content themselves with, a more fuzzy allocation process at their discretion rather than an open one with painstaking consensus-building and negotiations. Just like in the case of the Nekouabad canal discussed earlier, it is always possible to accommodate an additional use (e.g., the demand of water by the city of Yazd, which lies out of the basin) since the corresponding discharge is limited with regard to the average supply. The impact of such a use is thus likely to be distributed over a large area. The supply from the river will be slightly reduced (say, by 1 or 2%) but this impact will be imperceptibly spread over all irrigation areas.

There are two caveats, however. First, several such relatively minor reallocations combined together will eventually have a more sizeable impact. Irrigation areas are likely to respond by withdrawing the shortfall from aquifers, in an (already) unsustainable way. Second, this disregards what happens in situations of drastic shortage, when agricultural use is severely curtailed and when commitments to urban supply see their relative weight in demand gaining predominance. In 2001, for example, diversions to agriculture were totally interrupted, despite water releases from the dam still amounting to 39 percent of yearly average values (Molle and Mamanpoush 2004). Because nonagricultural uses have little flexibility, crises become more frequent and more visible, since they impact on cities.

It is tempting, once fuzziness in water allocation has been identified, to prescribe a clarification couched in terms of water rights, a policy recommendation that has become fashionable in the last few years. However, establishing formal water rights cannot be achieved by fiat and is predicated upon crucial prerequisites (Molle 2004). More pragmatically, water allocation is a process that needs to be oriented towards greater transparency and participation, informed by hard data and improved hydrologic knowledge, and negotiated by the groups of users concerned.

The conflict between state allocation and traditional rights does not mean that the latter should disappear, nor that they should be immutable. The change in supply brought about by the Chadegan dam and the successive tunnels certainly allows for growth in demand and use, and is quantitatively large enough to warrant a redefinition of rights. What is missing, however, is a mechanism to define new rights and make societal choices in a transparent and negotiated manner, with due consideration to environmental services. It is thus essential to understand the interconnectedness of uses and the third-party impact of the decisions taken.

As mentioned above, the challenge of establishing negotiated patterns of allocation or water rights is one of multilevel governance. National-level issues include political (and conflicting) decisions about trans-basin diversions and arrangements to share water between provinces. For example, the Chaharmahal-va-Bakhtiari Province, which has part of its border with the Esfahan Province made up by the Zayandeh Rud itself, is supporting extensive development of an irrigated almond orchard based on the idea that the river is also "ours." Within the Esfahan Province, the Ministry of Power has large discretionary power on the allocation of Chadegan dam water, and accommodates demands and requests from MPs or other political constituencies (Ghazi 2003). The city of Esfahan itself may take decisions about surface water use that are not consistent with basin management ("green ring," etc.). At a more local level, farmers tend to deplete as much surface water and underground water as available to them before it flows downstream. Establishing a sound water regime at the basin level is thus a monumental task that needs governance patterns that are yet to emerge.

Conclusions

The study of Jalalabad has illustrated the quest for water of a village and its multiple adaptations to water scarcity and relative imbalances between population, demand and supply. The value and centrality of land and water were illustrated by the strong social control upon ownership and transactions, as well as by the prices fetched and the marginal cost of providing additional supply.

The struggle for water increases with the closure of the basin. While the solutions to local water scarcity tend to lie more and more upstream and at a wider scale, the impacts of local processes extend further and further downstream. This critical interconnectedness of actors through the hydrologic cycle is complex, sometimes unpredictable, often invisible, frequently ignored, and always obscured by the variability and fluctuation of hydrological processes. Upstream/downstream and surface water/groundwater interactions get more intricate as users diversify their sources of water. Unchecked individual initiatives may add up and have a significant impact at the macro level. Macro-level interventions, in return, critically alter the hydrological regime and preexisting water-sharing arrangements. In such a process, local and global interventions tend to conflict, and control over water to shift toward the state.

A consequence of the closure of the basin that, despite being obvious, cannot be overemphasized is the logical *impossibility of overall water conservation*. Local conservation measures are possible but they necessarily have third-party impacts, be it on other users, next generations or on the environment. Therefore, while such local measures may have benefit for the users involved, they are eventually *tantamount to reallocation* of water within the basin. Shifting the benefit of water may be desirable or not, but it is rarely explicit and raises questions on water rights and on the third-party impacts.

The study has sketched out an exploration of the human-water interface whereby institutions around water allocation and management are mediated by political, cultural and ecological contexts that interact across multiple, spatial and social scales (Sneddon et al. 2002). The complexity of these macro-micro interactions, however, makes the state incapable of reordering the basin water regime by its sole action or by legislation. Constructing a sound and sustainable water regime is contingent upon allowing multilevel governance patterns that allow interest groups to negotiate arrangements, which bring more certainty, social value and equity to the sharing of water. In the Zayandeh Rud basin, the challenge could be to reestablish the earlier democratic, transparent and stakeholder-controlled allocation (when mirabs were elected), albeit in a much more complex physical and social setting than in the past, demanding both an increasing knowledge of the basin hydrology and expanded arenas of representation and negotiations.

Appendix. Change in population, cultivated area and water availability.

Year	Popul.	Core area (ha)	Extension (ha)*	Qanat Jusdun (l/s)	Qanat Aliabad (l/s)*	Qanat Jahanabad (l/s)	Mourhab (l/s)	Wells (l/s)	Canal (l/s)	Total discharge (l/s)	Q/area	Q/Pop	Pop/area	No of wells	Average discharge	Time of use
1950	400	400	200	80	50	90	40	0	0	130	0.13	0.13	1.0	0		
1955	425	400	200	80	50	90	40	0	0	130	0.13	0.12	1.1	0		
1959	450	500	200	80	50	90	40	0	0	130	0.10	0.11	0.9	0		
1960	475	600	200	80	50	90	40	0	0	130	0.08	0.11	0.8	0		
1962	550	640	200	80	50	90	40	0	0	130	0.08	0.09	0.9	0		
1963	600	640	200	80	50	90	40	0	0	130	0.08	0.08	0.9	0		
1964	650	640	200	30	25	40	10	0	0	50	0.03	0.03	1.0	0		
1965	300	300	200	80	35	60	40	0	0	100	0.07	0.07	1.0	0		
1967	450	350	200	80	45	90	40	0	0	130	0.14	0.11	1.3	2		
1968	500	400	200	80	50	90	40	0	0	130	0.13	0.10	1.3	2		
1970	550	450	200	80	50	90	40	0	0	130	0.11	0.09	1.2	2		
1972	800	550	200	80	50	90	40	0	0	130	0.09	0.06	1.5	2		
1974	1,100	640	200	80	50	90	40	0	0	130	0.08	0.05	1.7	2		
1976	1,200	640	200	80	50	90	40	29	0	159	0.12	0.07	1.9	2	25	14
1978	1,300	740	200	80	50	160	40	29	0	229	0.20	0.11	1.8	2	25	14
1979	1,400	740	200	50	50	150	40	29	0	219	0.23	0.12	1.9	2	25	14
1980	1,600	840	200	30	50	150	40	131	0	321	0.35	0.18	1.9	9	25	14
1982	1,800	950	150	30	50	150	40	219	0	409	0.40	0.21	1.9	15	25	14
1985	2,000	1,000	150	30	30	150	40	335	60	585	0.56	0.28	2.0	23	25	14
1990	2,100	1,000	150	30	30	150	0	365	60	575	0.54	0.26	2.1	25	25	14
1995	2,250	1,000	50	30	30	150	0	365	60	575	0.54	0.24	2.3	25	25	14
1996	2,400	1,100	50	30	30	150	0	365	60	575	0.50	0.23	2.2	25	25	14
1998	2,500	1,100	50	30	30	150	0	365	60	575	0.50	0.22	2.3	25	25	14
1999	2,600	1,100	0	5	30	100	0	365	50	515	0.46	0.20	2.4	25	25	14
2000	2,700	800	0	0	0	50	0	133	40	223	0.28	0.08	3.4	20	20	8
2001	2,800	600	0	0	0	40	0	100	40	180	0.30	0.06	4.7	20	20	6
2002	2,900	600	0	0	0	50	0	133	40	223	0.37	0.08	4.8	20	20	8
2003	3,000	600	0	0	0	50	0	208	40	298	0.50	0.10	5.0	20	25	10

* The extension area and the additional discharge from the Aliabad canal are indicated but not considered in the calculations because of the too high uncertainty and variability of these terms.

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