9 Buying Respite: Esfahan and the Zayandeh Rud River Basin, Iran

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Introduction

Oases pose a particular challenge to water resources development: they are tightly dependent upon the sources of water that they are able to access and strongly constrained in their growth by the utter scarcity that comes with aridity. Some of the oases – think of Marrakesh, Samarkand or Baghdad – are located in desert or semi-desert areas but are supplied by a river that starts its course in rainier, and often distant, regions. For such large cities, the time eventually comes when expansion of both the city and its surrounding fields and orchards, which thrive on the association of sun, water and dry air, encounters the limits established by nature.

Esfahan, in central Iran, is one such city. The story of Esfahan, with its rich and long history, and of its lifeblood, the Zayandeh Rud River, vividly illustrates the challenges faced by societies in situations of water scarcity. In the past, user communities have developed robust institutions to share springs, *qanats* (human-made underground galleries that drain aquifers), intermittent streams, or river flows. Yet, basin closure – a state where all resources are fully committed and where water only reaches the terminus of the basin in exceptional years – coupled with the expansion of state power, characterized by the reshaping of waterscapes by large-scale interventions, has made local systems dependent on decisions taken at other scales. Competition for resources and basin closure generate both increased hydrological interconnectedness between users and entanglement of governance and legal management regimes.

This chapter first describes the physical and human setting of the Zayandeh Rud, then reviews ancient and recent water resources development in the basin, and finally reflects on the hydrological, social and institutional consequences of basin closure. The Zayandeh Rud basin provides a vivid account of an oasis buying respite by implementing successive water imports from neighbouring basins. It also offers a textbook illustration of both the process of continuing river basin overbuilding and its consequences.

Physical and Human Context

The Zayandeh Rud basin covers 41,500 km^2 in the centre of Iran (Fig. 9.1). The river rises in the bleak and craggy Zagros mountains, which reach over 4500 m, traverses the foothills in a narrow and steep valley, and then bursts forth onto the plains at an altitude of some 1800 m. However, the splendour of the river is short lived: reduced towards the east by

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natural seepage losses, evaporation and more recent extractions for irrigation, and urban and domestic uses, the river eventually dies out in the Gavkhuni lake, a vast expanse of white salt that forms the bottom end of the basin, lying at an altitude of over 1200 m. In this naturally confined (or endoreic) basin, the flows reaching the lake are now much reduced compared with natural conditions, and there are extended periods when no water flows in the tail reach of the river (Fig. 9.1).

The total length of the river is some 350 km, but it is the central 150 km of the flood plain to the east and west of Esfahan that provides the basis for intensive agriculture and large settlements. Along this strip soils are deep and fertile, predominately silts and clay loams, and slopes are gentle, ideal for the irrigated agriculture built up over many centuries. The river indeed forms an oasis in the desert (Murray-Rust and Droogers, 2004).

The climatic conditions in the mountains are markedly different, as shown by data from Kuhrang, which lies just to the west of the Zayandeh Rud basin (Fig. 9.1). Situated at an elevation of almost 2300 m, precipitation averages 1500 mm, much of it in the form of snow, and snow remains on the ground throughout winter, only melting when temperatures warm up from April onwards (Murray-Rust and Droogers, 2004). In contrast, the city of Esfahan only receives 130 mm of rainfall each year, on average (Fig. 9.2).

The primary source of water in the basin is, thus, the upper catchment of the Zayandeh Rud. Lateral tributaries joining the river in the plains are mostly non-perennial, have little regional importance and do not reach into the main part of the basin, except during winter months and rare flash floods, although subsurface runoff accrues to the main stream. Runoff generated in the upper basin is strategically

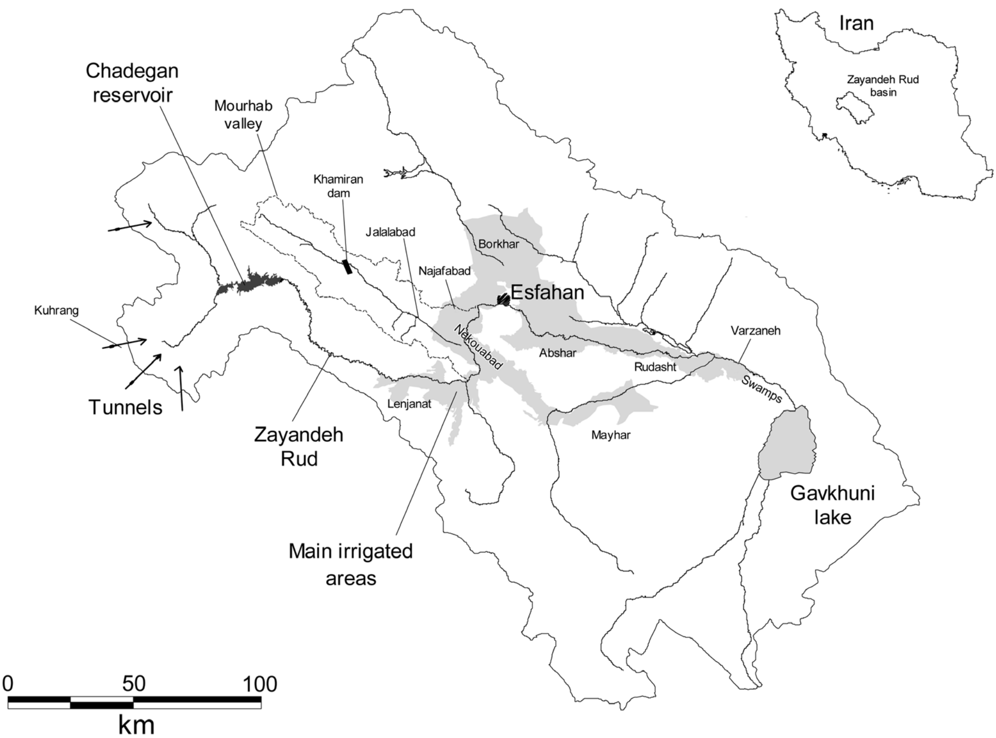

Fig. 9.1. The Zayandeh Rud basin.

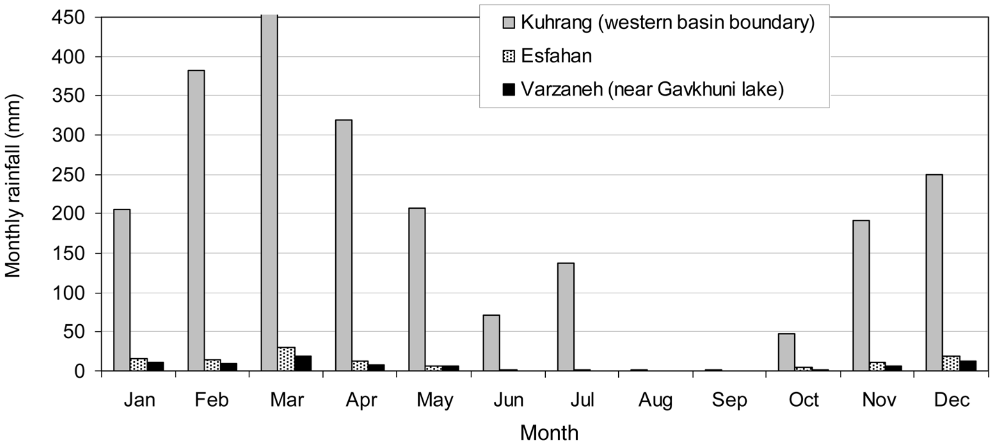

Fig. 9.2. Average monthly rainfall: Kuhrang, Esfahan and Varzaneh (1988–1999).

stored in the Chadegan reservoir, constructed just above the point where the Zayandeh Rud enters the flatter parts of the basin (Fig. 9.1). From September until February, inflows only average between 50 and 75 Mm^3 per month (20–30 m^3/s), reflecting both the dry conditions of summer and then the cold conditions dominated by accumulation of snow in the upper parts of the basin. From March onwards snowmelt increases and discharges normally peak in April or May, with average flows of 125–150 m^3/s. In June and July, the discharge slowly declines to the low-flow conditions. The peak flows from April to June provided the basis for widespread downstream irrigation using simple diversion structures.

The Zayandeh Rud basin has seen a dramatic population increase in the past 45 years. According to the 1956 census, the population in the basin was some 420,000, while in 2000 the total population was estimated at 2.3 million. This is an annual growth rate of 5.9%. Figure 9.3 shows population growth in the basin and in Esfahan since 1956, projected to 2020 with a 2% annual growth rate from 1996 onwards. Growth has not been uniform. The fastest growth was between 1956 and 1986, averaging close to 7% a year, but in the past 15 years it has slowed down to 2–2.5% a year. Initially, Esfahan city grew faster than the rest of the basin, but this is no longer the case: The growth rate of Esfahan is close to 2%, while outside the city it has risen to 2.5–3% a year.

Early Water Use in the Zayandeh Rud River Basin

Although water use around Esfahan is as old as the city itself and although there are records of water management dating back to the 3rd century BC, when Ardeshir of Babak (the founder of the Sassanid dynasty) sent an engineer to fix the 'disorders [that] appeared in the regulation of the Zayandeh Rud waters' (Hossaini Abari, 2006), historical documents on water use are scarce. Rusteh (1889), for example, who wrote in the early 10th century, mentioned that water use was unrestricted up to the district of Alandjan, while the distribution to the downstream districts of Djay, Marbin, Alandjan, Baraan, Rud and Rudasht was organized following 'rules established by Ardeshir Ibn Babak'.' Hawqal, four decades later, also reported that the sharing of the Zayandeh Rud water was 'calculated so that no water would be lost'.

The earliest-known detailed regulation of the Zayandeh Rud was unearthed by Lambton (1938). Riparian rights in the 16th century are described in detail in a *tumar* (an edict) attributed to Sheikh Bahai, which specifies the water apportioned each month to each *boluk* (district) and village. The river was managed by a *mirab* elected by 33 *boluk* (representatives), who selected six assistants, who, in turn, appointed *maadi salars*, heads of each *maadi* (main run-of-river diversion canal) that branched off the river. According to Lambton (1953), the introduction of the edict states that:

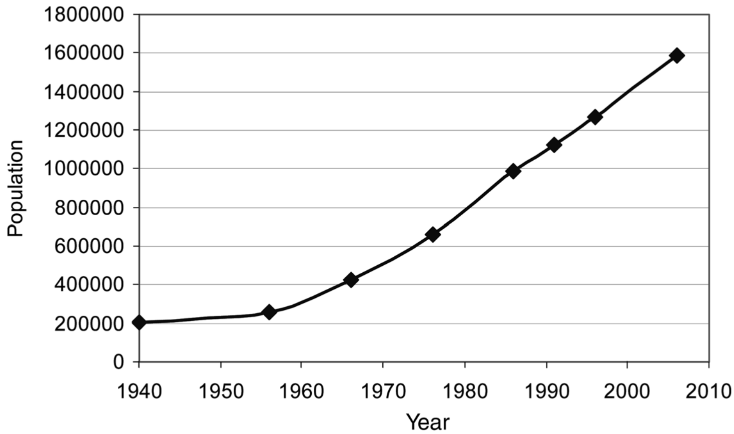

Fig. 9.3. Population growth in the Zayandeh Rud basin, 1956–2020.

> (…) 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 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.

Water was divided into 55 primary shares, which were further subdivided 'into 276 secondary shares associated with the major irrigation canals or *maadi* and into 5105 tertiary shares at the village level' (Hossaini Abari, 2000). Managers were paid by users, in due proportion to the amount of water received, and were dispensed with if their services were judged to be unsatisfactory (Hossaini Abari, 2006). Where there was no *maadi*, water could be lifted from the river or from drains using animal-driven Persian wells (Murray-Rust and Droogers, 2004). The application of the *tumar* was discontinued by invasions and some rulers, but was renewed in 1927, when about 500 rights-holders met to demand the reinstatement of the rules. With some modifications in the 1930s, these were enforced until the early 1970s (Pirpiran, 2007).

In lateral valleys, such as the Mourhab valley, which rejoins the Zayandeh Rud's left bank west of Esfahan (see Fig. 9.1), the use of surface water was also socially controlled. In the 1960s, the water of the Mourhab River was allocated according to rules that villagers also trace back to Sheikh Bahai. The rules determine which village can divert which proportion of the river flow during which period, and they were equally enforced by a powerful *mirab*.[1]

The village of Jalalabad, located in the lower part of the Mourhab valley (see Fig. 9.1), provides a very good picture of water rights and management at the village level (Molle *et al.*, 2004). The main sources of supply to the village until the 1960s were two *qanats*, in addition to whatever surface water could be diverted from the Mourhab River according to the rules. Land was apportioned among the six main lineages of the village in the beginning of the last century, and up to the present, *qanat* water rights have been defined at the plot level, in terms of minutes of use per 6-day turn. These rights can be reallocated among plots, temporarily lent, ceased or leased, or permanently sold and transferred. No one in the village is aware of the full details of the system. This striking lack of centralized control goes together with a strict adherence to the established rights and schedules. Spooner (1974b) posits that 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'. Out of equity, each lineage was given plots both at the beginning and at the end of the canal system. Maintenance of the ditches was undertaken collectively and that of the *qanat* was entrusted to specialized workers; these workers, as well as the water masters, were paid by the users themselves, a system still in use.

More generally, *qanats* were considered as the private property of those who had invested in their excavation. Owners could be individuals, groups of families, or wealthy merchants, as in the case of Najafabad city, which used its wealth to tap the water of 17 *qanats* distant from the city by as far as 100 km and collected by a canal that follows the Mourhab valley and, even today, irrigates the lush gardens of the city. Rules have defined protected areas to prevent conflicts between *qanat* users (Foltz, 2002). Areas like those of Borkhar, north of Esfahan, were well known for their high density of *qanats* (see Fig. 9.4).

Ancient water-use systems thus involved village ditch managers, system overseers and valley *mirabs* (in both the main and the lateral valleys), who were all nominated and paid by the users in their jurisdiction, with well-accepted and well-enforced rules for sharing the resource. The cultivation area and irrigation doses were attuned to the available river flow and to the discharge of the *qanats*, which, served as 'phreatic barometers' (Lightfoot, 2003), their flow varying in line with the level of the aquifers. Likewise, gardens formed the core of the irrigated area but were not overextended so that they could stand water shortages. In case of excess surface water, short-cycle crops were cultivated on adjacent lands; this was the way to deal with the variability of the resource. As far as one can judge from available evidence, the system appears to have been strongly based on local governance and quite resilient. Hydrological interconnectedness was not critical because the density of *qanats* was regulated, and lateral valleys would contribute both surface flow to the Zayandeh Rud in excess years and a subsurface flow at least during a large part of the year.

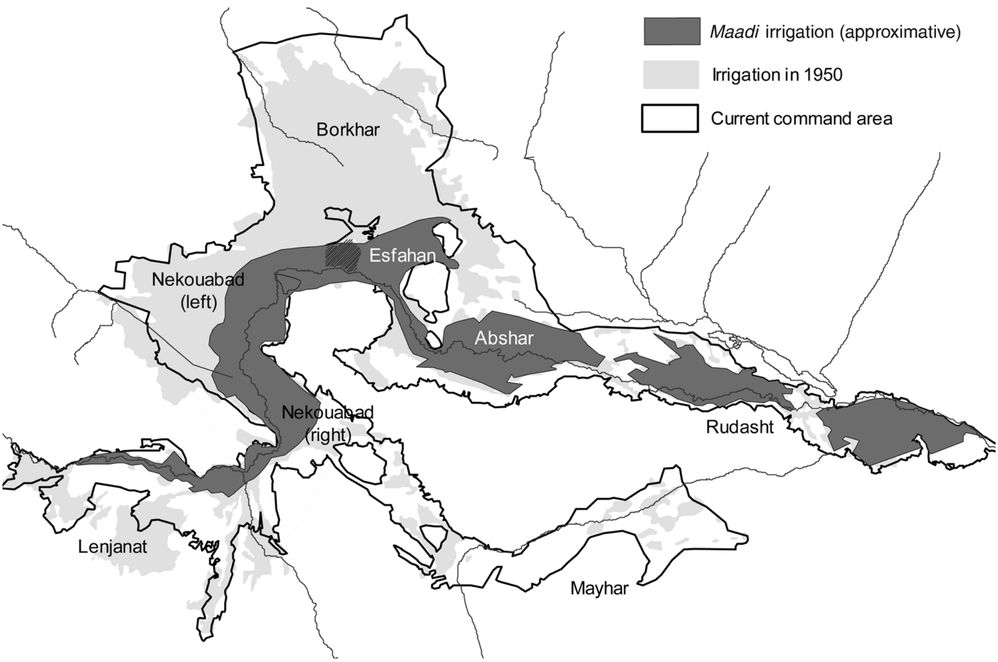

Fig. 9.4. Ancient and current irrigation areas in the main plain.

Recent Water Resources Development in the Basin

Large-scale state interventions

Agricultural and urban development in the Zayandeh Rud basin has always been constrained by water availability. But, the history of the basin's water development is not (yet) a story of limits. It shows that demand – largely generated by expansion of irrigation schemes – always exceeded supply, despite the successive increases in available water brought by reservoirs and interbasin transfers. 'New' water was, each time, committed outright.

The basin resources were first augmented in 1953, when a first interbasin tunnel diverted water from the Kuhrang River to the Zayandeh Rud basin, adding 340 Mm^3/year to a natural runoff of about 900 Mm^3 (Abrishamchi and Tajrishy, 2002). In 1970, the completion of the 1500 Mm^3 capacity Chadegan reservoir (see Fig. 9.1) allowed the regulation of the water regime. With these two works, water supply and storage in the basin dramatically increased. This date also almost coincides with the nationalization of water resources in 1968 (and the establishment of regional water authorities, subordinate to the Ministry of Energy) and signals the new power acquired by the state to control the lifeblood of the region and to design the expansion of the irrigation area in the valley, where an area of 76,000 ha provided with modern hydraulic infrastructure was established. Yet, in many cases, these modern schemes were superimposed on the ancient network of *maadi* and *qanats*, and the gains were thus limited, although double-cropping became possible in most of the valley (Fig. 9.4). The *maadi* system and its attendant social organization and local knowledge were thus overridden and replaced by a state agency in charge of operation and maintenance. The intakes of most *maadi* were obstructed and instead the river was barred at two points (Nekouabad and Abshar) by major regulators that distributed water to new, large main canals, one on each bank of the river. Likewise, overseers and heads of *maadi* were replaced by state-appointed technicians.

With the opening of a second interbasin tunnel from the Kuhrang River in 1986, another 250 Mm^3 was made available annually.[2] This spurred the rehabilitation of the old Rudasht scheme, at the tail-end of the valley, and the extension of the irrigated area by some 40,000 ha (Borkhar and Mayhar schemes). Part of these two districts was already irrigated with groundwater, but overexploitation had generated problems of declining water quality, which new surface water was first supposed to mitigate; whatever fresh water was available in excess would be used to expand cultivation.

The increased available supply, in addition to being committed to new irrigation areas, also met the growing needs of Esfahan (with its population now totalling 1.6 million, and a growth rate that reached 5% in some years) and of neighbouring industries. The industrial sector now needs over 100 Mm^3 annually.

In 2009, an additional 260 Mm^3 will be made available through the third Kuhrang tunnel, together with 200 Mm^3 diverted from the Dez River upper catchment (the Lenjan tunnel). This will more than double the natural annual runoff (see Fig. 9.1). Another tunnel, the Behesh Abad tunnel, is under study. It would bring 700 Mm^3 downstream of the Chadegan dam but would require a very costly 75-km-long tunnel (Abrishamchi and Tajrishy, 2002; Morid, 2003).

The evolution of surface water supply and use is shown in Fig. 9.5. Inflow into the valley (measured at Pol-e-Kaleh station) is completely diverted and consumed, except in wet years, when part of it reaches the Gavkhuni lake (flow at Varzaneh). The additional inflow to be brought by the two new tunnels is likely to be fully allocated and consumed as soon as it is made available. At best, within a few years, they will help to replenish aquifers if farmers can use more surface water instead of groundwater.

There is no significant year-to-year carry-over storage in the Chadegan reservoir because almost all of the flood water entering the reservoir is released prior to the next flood season. This maximizes the production from irrigated agriculture (at the expense of security in supply), and part of the variability in supply is handled by resorting to groundwater. This buffering role of aquifers was critical in the 1999–2001 drought (see later) (Molle *et al.*, 2008). Yet this role is gradually weakened by the decline of the aquifers, and they will not be

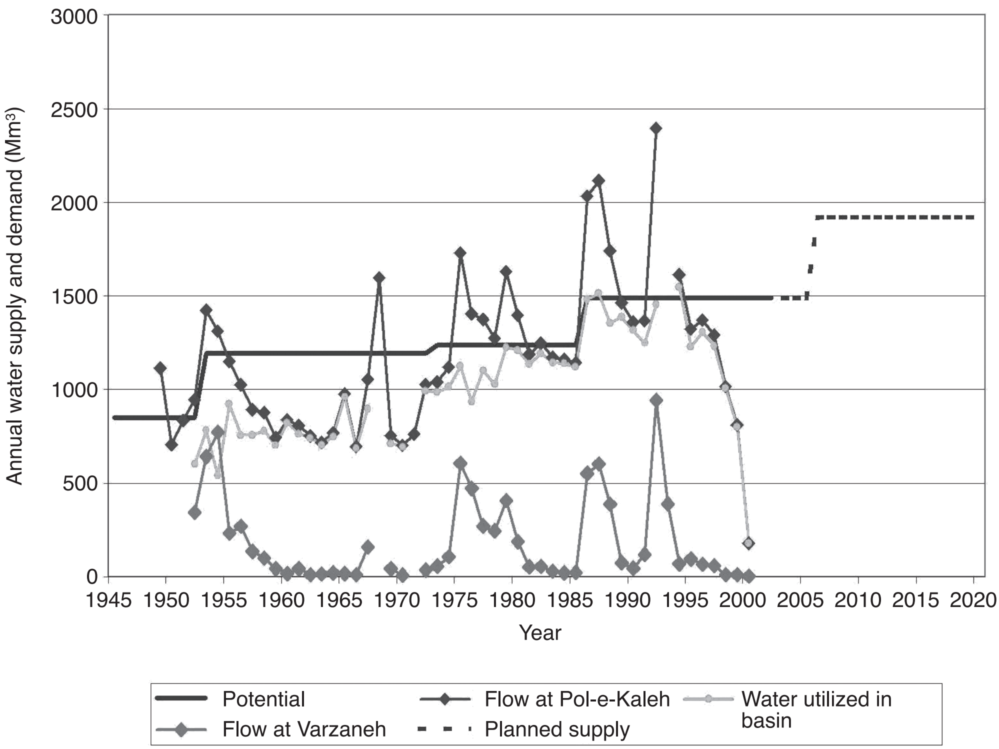

Fig. 9.5. Evolution of supply and use of surface water in the Zayandeh Rud basin (Murray-Rust and Droogers, 2004).

able to compensate for dwindling surface water in the long run.

State investments and regulation did not remain confined to the main valley: they also expanded into lateral valleys, such as the Hana and Mourhab valleys. In the latter, for example, in the late 1980s the Ministry of Jihad undertook the construction of the Khamiran dam, with the objective of increasing storage and local water use (Molle *et al.*, 2004). The dam was completed in 1992 and has a capacity of 6.8 Mm^3. Instead of the natural system of aquifer recharge through the stream, which had prevailed for centuries, the dam is now supplying water to downstream villages through a lined canal approximately 40 km long. 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 up to pump water from the reservoir over the mountain ridge into the Khamiran dam. In 1991, the Karvan pump station was constructed for that purpose, but it faced severe technical problems and its operation was discontinued after some 3 years (Newson and Ghazi, 1995).

Local water resource development

Notwithstanding these state-initiated projects, villagers at the local level have also been actively looking for ways to respond to population growth by increasing supply from aquifers, through *qanats* or wells. The growing intervention of the state after 1968 came together with a modernist ethos that considered traditional village irrigation 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 seen as very advantageous compared with *qanats*, because the fluctuating discharge of the latter was considered as hindering 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 serving 1.2 million ha 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).

The post-revolution period was 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 favour of population growth (which reached a rate of 3.8% in the 1980s). This development seems to have been based on inadequate hydrological analyses, and villagers got into the business of well-digging despite reservations and awareness that *qanats* might be impacted. In Jalalabad, for example, the wells did bring a substantial increase in water supply. Jalalabad received an authorization to sink eight wells around the village, and these were used to expand the garden area. In addition, villagers obtained a permit to dig 15 wells within the existing orchards, as a way to boost the available water per hectare of garden. As a result, however, the discharge of one of the two *qanats* used by the village soon started to dwindle and eventually dried up. The impact of the development of wells on the discharge of the *qanats* confirmed local knowledge about the interconnectedness of the different water sources.

Studies conducted by the Esfahan Water Authority (EWA) in 2000 revealed that several aquifers were being overexploited, especially in some of the irrigated areas (Morid, 2003). Presently about 21,200 tube wells, 1726 *qanats* and 1613 springs exploit a total of 3619 Mm^3 of groundwater annually. This is more than twice the surface water diversions, which (although both sources are partly interdependent) gives an idea of the importance of groundwater in the Zayandeh Rud basin.

Socio-hydrological Interconnectedness

Despite the periodic transfer of additional water from neighbouring basins, these changes in water resources development and use point to a constant overcommitment of resources. The increase in the abstraction capacity, notably because of the overdevelopment of irrigated areas, created a very tight river basin system, where some water paths disappeared or were reversed and where users in the basin are increasingly interdependent. What is stored, conserved or depleted at one point dictates what is available at another point further downstream; externalities travel across the basin in a way that is blurred by the irregularity and partial invisibility of the hydrological cycle (Molle, 2003). This section illustrates several social/spatial competitions and allocation conflicts which result from this growing interconnectedness.

Upstream versus downstream

In the absence of clear and enforced water rights, upstream areas are in an advantageous position. In closed basins, new upstream abstraction merely shifts the benefits of water use from downstream to upstream areas. A typical example of such a shift in the Zayandeh Rud basin is occurring between the Chadegan reservoir and Lenjanat (the beginning of the main plain; see Fig. 9.1). Traditionally, irrigation was restricted to the narrow valley bottom (to areas which, altogether, might nevertheless amount to 40,000 ha) and occurred through gravity. Numerous private, large diesel pumps now abstract water to supply 10,000 ha of nut and almond orchards located on the plateau, 150 m above the valley floor (Murray-Rust and Droogers, 2004). These orchards, often irrigated with drippers, may be in the order of 10,000 ha and are rapidly expanding. One bank of the river belongs to the Chaharmahal-va-Bakhtiari province, which – in the absence of interprovincial allocation agreements – is supporting this development, based on the perception that the river is also ‘theirs’.

Other upstream capture of resources is apparent in the unbalanced share of water delivered to the different irrigation schemes (see Fig. 9.4). The Nekouabad schemes receive, on average, 39% of the total irrigation supply, although they only make up 18% of the irrigated area. Expansion of irrigation facilities to the Borkhar and Mayhar schemes has also reduced the amount of water flowing downstream. Increasing water scarcity (and resulting soil salinization) in the downstream area can be contrasted with its affluent past: strikingly, in the 10th century, Hawqal (1889) reported that the [tail-end] districts of Rudasht 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*' (emphasis added). Benefits from water use have clearly been shifted upstream.

Wells versus *qanats*

A prime example of reallocation is, of course, that of wells depleting local aquifers. Development of wells is tantamount, at least partially, to a reallocation of water from *qanat* (sometimes spring) owners to the well owners, and – oftentimes – from collective to individual use and management. These owners may or may not be the same persons, but those with the financial capacity to drill wells tend to get the upper hand. The development of wells eventually reduces groundwater flows to downstream areas. Jalalabad's farmers, in the Mourhab valley, understand that groundwater is not a static resource and that the issue is 'pumping groundwater before it flows downstream', as one of them expressed.

The history of the destruction of *qanats* by wells, in Iran and elsewhere, is documented by several studies (e.g. Ehlers and Saidi, 1989; see also Lightfoot, 1996 and Mustafa and Usman Qazi, 2007, for examples from Morocco and Baluchistan, respectively). It is likely, however, that in some areas the potential of groundwater was higher than what the *qanats* were extracting, but insufficient control of their number and location eventually led to competition with the *qanats*. The *qanats* of the Borkhar area, for example, a flourishing cultivated area north of Esfahan, were destroyed by the spread of deep wells sunk to irrigate summer crops and orchards (Lambton, 1969).

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 depth of the water table (at least in a certain range and in the short term). They are not only less sensitive to variations in the groundwater stocks but may also abstract more water out of the aquifer than what comes in as recharge. The 'mining' of aquifers had little short-term impact but proved to be unsustainable after a few years, especially when the 1999–2001 drought occurred.

Lateral plains versus the main plain

Depletion of groundwater in both the main and lateral valleys has inverted the total net underground flow to the Zayandeh Rud. In the Mourhab valley, for example, the cumulative impact of the Khamiran dam and the wells and the *qanats* on the groundwater flow to the Zayandeh Rud itself has been dramatic, although partly invisible, since water was 'retained' in the valley. Likewise, Gieske and Miranzadeh (2003) have estimated that approximately 250 Mm^3 out of an annual yield of 275 Mm^3 of lateral groundwater flow to the Lenjanat alluvial fan aquifer is now tapped. These examples show how base-flow water formerly used by agriculture downstream in the main valley was reallocated almost 'invisibly' to provide benefits to upstream farmers.

Further down the valley it is, in all likelihood, the river which now recharges the valley aquifers, an aspect which is often overlooked (Morid, 2003). By drawing down the water table, well users (including the city that sank deep wells to irrigate large 'green belts' of trees planted 'for the environment') not only tap underground flows that used to contribute to the base flow of the river but also 'drag' water from the river bed to lateral aquifers, to the detriment of irrigation downstream of Esfahan.

City versus agriculture

As in many regions of the world, the combination of water scarcity and urban sprawl results in water being reallocated out of agriculture to the domestic and industrial sectors. In the Zayandeh Rud basin such reallocation is left to the discretion of the Ministry of Power, which controls the allocation of the Chadegan dam water and accommodates demands and requests from MPs or other political constituencies (Ghazi, 2003). For example, factories generally have no problem in getting supply from irrigation canals since their demand is allegedly limited and the Ministry can sell water to them at a much higher price. The interests of construction and landscaping companies notoriously involved in kickback practices are also more easily catered for (Foltz, 2002).

That priority in allocation is given to non-agricultural uses was well illustrated in 2001, when, at the peak of the drought, diversions to agriculture were reduced to zero during the whole season and cultivators were left solely with their groundwater resources, despite water releases from the dam still amounting to 39% of yearly average values (Molle *et al.*, 2008). Power asymmetries were made patent when business owners (and angry residents alike) in the city asked for water to be released from the dam, claiming that national coverage of the crisis in the basin (children playing soccer in the river bed) was detrimental to the flow of tourists which normally converged to the city. As the attractiveness of Esfahan is strongly related to the spell of its gardens and bridges, water was released to the Zayandeh Rud (literally the 'life-giving river') to restore their magic and save the tourist season.

Greater Esfahan, with its population of 1.6 million and its current annual growth rate at 2.3%, receives an increasing share of water, estimated at 250 Mm^3/year. In the 1970s, the Zayandeh Rud basin was the focus of specific government policies to increase industrial production outside Tehran. Esfahan was seen as a prime location, particularly as the Chadegan reservoir had just been completed and it was assumed that water supplies would be readily available. Between 1975 and 1977 four major industries were developed (defence industries, Mobarekh steel mill, Esfahan oil refinery and Sepahan cement factory), with a total annual demand of 60 Mm^3. A polyacrylic factory was added in 1980, with a demand of an additional 5 Mm^3. The war with Iraq halted industrial development, but from 1988 to 1991 more industrial enterprises were established, with a total demand of 39 Mm^3. Total industrial demand is therefore at least 104 Mm^3 (Murray-Rust and Droogers, 2004).

But water is also committed to cities located in much drier areas (Yazd, Rasfanjan, Kashan) and outside the basin. Yazd receives 90 Mm^3 annually through a pipeline, and diversions of 42 Mm^3 to Kashan and Sahr Kurd will soon start (Abrishamchi and Tajrishy, 2002; Morid, 2003). While these cities are more distant from the Zagros 'water-tower' and their situation is somewhat worse, these transfers are also political decisions, which are probably not unrelated to the fact that Yazd and Rafsanjan are home to former Presidents Khatami and Rafsanjani.

Human use versus nature

Abstraction of all the water available in the river has been the rule since the mid-1960s, when the basin closed and the flow to the Gavkhuni swamp and lake was limited to flood periods and excess years (see Fig. 9.5). As a result, the Gavkhuni swamps, an important wetland for migratory birds and registered as a Ramsar site, became degraded. Salinity of soil and water in Rudasht – the tail-end agricultural area – is on the rise; yields are the lowest in the valley, and some plots are now left uncultivated (Morid, 2003; Murray-Rust and Droogers, 2004).

More generally, reduced diversions to irrigation also means that percolation and leaching of salts have been reduced, while the groundwater used as a substitute is also often of poor quality. Soil management becomes a central issue as more soils are threatened by salinization and by becoming sodic.

With insufficient discharges in the river, river health has also been impacted, and the values of biological oxygen demand from Esfahan downstream are classified as 'bad' (i.e. higher than 10) and reach 23 (Pourmoghaddas, 2006).

Groundwater exploitation versus next generations

Following the construction of the Chadegan reservoir, it appeared that water table levels have risen in many areas, not least in Rudasht, at the tail-end. However, data over the past 10 years indicate that groundwater levels are dropping in all parts of the irrigated areas of the basin, and in some areas they are dropping dramatically. In Najafabad, just west of Esfahan, fruit trees planted 10–15 years ago based on groundwater irrigation are dying due to rapidly declining groundwater, resulting in older wells drying up due to the drilling of larger, deeper wells for urban and industrial water supplies.

While wells have spread in areas formerly exploited through the use of *qanats*, they have also developed in irrigation schemes. Within the irrigation systems, the decline of aquifers has been more or less constant in the past 6 years. In Nekouabad left and right banks, average decline has been 2.5 m/year and 1.5 m/year, respectively, almost certainly exacerbated by domestic and industrial installation of wells. In Abshar it has declined by some 0.4–0.6 m/year, in Borkhar by 0.8 m/year, and even in Rudasht, where water quality is poor, groundwater tables have dropped by 0.25 m/year. This suggests that somewhere around 250–600 mm/year are being pumped for agriculture and are not being recharged (Murray-Rust and Droogers, 2004).

Aquifers definitely have a crucial buffering role in compensating for deficient surface water supply in dry years. A fascinating measure of their importance was provided in 2001, when no water was delivered to irrigated areas but the cropping area was still at 60% of its value in a normal year (Molle *et al.*, 2008). This role, however, can only be sustained if aquifers are replenished; it is hard to imagine, at the moment, why and how this could occur. In addition, it is also unclear to what extent the overdraft of the aquifer can continue without incurring changes in the water's salt content.

Main Issues and Responses to Basin Closure

Allocation mechanisms and basin governance

The problems of competition highlighted above signal a situation in which water is constantly reallocated through the decisions of both local actors (e.g. spread of wells) and the state (e.g. construction of irrigated schemes, export of water, etc.), with negative consequences in terms of equity and environmental sustainability, and externalities concentrating on downstream rural users, the environment and the next generations. Overallocation (due to an abstraction capacity far above available resources) and reallocation (whether implicit or explicit, intended or not) are due to both the lack of control/monitoring of who gets what and when, and the absence of a system of entitlement or rights.

The Civil Code, following Islamic Law, gives priority to established owners of land over newcomers, and upstream over downstream users of water (Ghazi, 2003). Prior appropriation rights were protected by a clause stipulating that the use of water by newcomers should not impact on the interests of existing users. However, 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 need to protect springs, wells and *qanats* was addressed by defining a *harim*, or an area with extraction around these sources prohibited (Foltz, 2002). While these socially controlled modes of water exploitation were efficient at the scale of communities, they were eroded by the lack of control and hydrological criteria regarding the drilling of wells.

The nationalization of water resources was introduced in 1967 as the tenth point of the Shah's 'White Revolution', and regional boards were established to assess and control water use and to charge for its consumption. The 1968 Water Law was intended generally to end the traditional system of water rights, based primarily on the riparian doctrine, and replace it with a system of rights based on water-use permits for the purposes of beneficial and reasonable use of these resources (Beaumont, 1974). The state thus gained wide power of control and taxation of private/communal ownership. 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.

In the valley itself, with the superimposition of concrete canals over the network of ancient *maadi* in the early 1970s, the state largely overrode the riparian rights enshrined in Sheikh Bahai's regulation. Yet the administration could not fully erase these rights, and a study of water allocation within schemes has shown that ad hoc distinctions were made between canals built in former *maadi* areas and those in newly reclaimed areas (Hoogesteger, 2005). In the Mourhab valley, traditional rights on the river water were equally eroded. The redistribution of water in the Mourhab valley after the construction of the Khamiran dam was a non-transparent process with no direct participation of the population concerned.[3] Some villages that had developed quite lately and had no right to water were allocated part of the water coming from the dam. In contrast, other former rights-holders, like Jalalabad, lost the benefit of the river.

The examples given above make it clear that some sort of basin-level coordination body is needed to analyse hydrological data, establish transparent allocation schemes (through a system of entitlements or otherwise), discuss priorities and development plans, and integrate representatives from the different socio-economic sectors. Such participation is, however, unlikely to be very effective under present circumstances, since representation of the civil society is still weak (Namazi, 2000). The state is likely to retain full control of the decision-making power of such a vital resource. Establishing a sound water regime at the basin level is thus a monumental task, which needs governance patterns that are yet to emerge.

Limited scope for (real) efficiency gains

In a basin with hardly any water reaching its terminus, water can only be 'saved' by limiting unproductive evaporation. There are not so many opportunities to achieve such a reduction. Conventional conservation efforts impact water pathways and merely reallocate water: canal lining in Jalalabad 'saves' water, which can then be spread over a larger area, increasing not only local production but also water depletion, to the detriment of downstream users who were tapping subsurface flows. The canal that collects *qanat* water for Najafabad city has also been lined to offset declining supply, thus increasing the flow to Najafabad but, at the same time, decreasing groundwater recharge in the Mourhab valley.

Little is known about the efficiency of large-scale irrigation in the valley. In Iran, as elsewhere, gravity irrigation is stigmatized as a process wasteful of precious resources and micro-irrigation is held as a natural solution to this state of affairs. In the particular setting of the valley, however, it is dubious that much improvement can be brought about: there already exists extremely efficient recycling of 'losses' at the plot level (pumping of groundwater), at the scheme level (pumping from drains) and at the valley level (the return flow from one scheme – 30% of gross diversion values on average – is part of the supply to the following one).

Micro-irrigation is believed to reduce unproductive soil evaporation, but even this benefit is unclear and has been found by some researchers to be sometimes illusory (Burt *et al.*, 2001).[4] In any case, there are also a number of constraints to the adoption of micro-irrigation. First, not all crops (e.g. rice or lucerne) are suitable for such a technique; second, the investment cost is very high and can never be offset by whatever saving in the water bill (Perry, 2001); and third, such investments only make sense for high-value crops for which security of supply is essential (as such, they are more likely to be adopted where groundwater is abundant and used).

Efficiency gains have also been sought in improvements of scheme management. A few years ago the government contracted out the operation and maintenance of irrigation systems to parastatal enterprises, cleverly referred to as the *mirab*: as in many other countries, the ideology of efficiency that favours private rather than state operators has allowed former staff from state agencies to form their own companies and to perform the same service but with some private benefit to themselves (although workers who moved along from one structure to the other lost their former state privileges and saw their working hours increase markedly; see Hoogesteger, 2005). Possible efficiency gains are undocumented but the administration claims that costs have been cut by 15–20%.

Groundwater control

The control of groundwater use has been problematic, even though the drilling of new wells is checked by the local farmers themselves (who do not want to see more local abstraction) and by a control of the activities of drilling companies. The right to access groundwater is officially regulated by the granting of permits by state authorities. Permits have been administered centrally, with limited knowledge of local hydrology, transparency and control by interested populations. This has opened the way for bribery and for powerful people to obtain well permits thanks to their political clout.

Control of groundwater abstraction is an intractable problem worldwide. As supply in public schemes becomes deficient, farmers resort to wells as a compensation. It would be politically very hard for the state to parallel its failure to deliver reliable water by a crackdown on self-funded private wells; indeed, the administration acknowledges that illegal drilling of wells is a pervasive problem (Hoogesteger, 2005). Overcommitment of resources and the resulting decline of supply to agriculture are likely to reinforce the shift to groundwater and the dropping of water tables.

Water quality, waste water and health

With reduced flows and recurring shortages, and pollution from both agriculture and industries, the health of the Zayandeh Rud River has been affected. The solute content of the irrigation return flow into the aquifers and the river, combined with urban and industrial effluents, is much higher than that of the water flowing in the river. The mixing leads to progressively increasing levels of salinity (measured as EC, electrical conductivity) and total dissolved solids (TDS) along the Zayandeh Rud.

Pourmoghaddas's (2006) study of water quality in the Zayandeh Rud between 1989 and 1999 (not including drought years) shows that the average value of EC is around 250 mS/m before the river enters the plain, rising to 700 mS/m after receiving industrial effluents and to 1200 mS/m in Esfahan, increasing to 4500 mS/m as the river receives return flow from the Abshar irrigation scheme, and peaking at 19,600 mS/m in the terminal reach of the river. The pattern is similar for non-agricultural pollution. The concentration of the major cations and anions follows the same increasing trend as one goes downstream. The concentration of heavy metals (Pb, Ni, Cd) increases tenfold as the river passes through Esfahan, to levels of 0.1 mg/l for Pb, 0.07 mg/l for Ni and 0.02 mg/l for Cd (four times WHO's standards) (Vahid, 1996). A sharp decrease in dissolved oxygen (DO) is observed at the Pole Chom station, where effluent of the wastewater treatment plant discharges into the river.

A hydrochemical analysis of groundwater from boreholes along the Zayandeh Rud River reveals the same pattern, which is not surprising as the aquifers are recharged both by the river water and by return flow and leakage from the irrigation schemes. A detailed hydrochemical study of a small subcatchment (Lenjanat) along the Zayandeh Rud upstream of Esfahan over a 10-year period has shown that the groundwater composition is subject to long-term trends (Gieske *et al.*, 2000). In some parts of the aquifer, salts are being slowly flushed out, whereas in other parts concentrations are rising. It appears that the groundwater composition is slowly changing in response to expanding or variable cultivation practices. Other studies on shallow wells (1.5–9.5 m) also showed that pollution has been transferred from the river to aquifers (Pourmoghaddas, 2006).

Such levels of pollution may create public-health hazards, as during the 1999–2001 drought, when the treatment station of Esfahan could not handle the quality of the incoming water, resulting in serious health problems in the city. The effluents of Esfahan are also increasingly reused by agriculture, but the health impacts are not well known at the moment. Tourist and urban development around the Chadegan dam not only extracts water from the lake but also pollutes it in return, impacting the quality of water at its source. In sum, degraded water quality results in various health and environmental impacts, which tend to get worse both in the long run and in times of shortage.

Vulnerability to droughts

When basin water resources are overcommitted and fully depleted there is no more slack in the system and all the hydrologic variability in supply is passed on to users. Since urban uses receive priority, agriculture (not to mention the environment) has to cope with a supply that basically varies each year and bears the brunt of climatic variability. The 1999–2001 drought has put this fact in sharp relief (Molle *et al.*, 2008). The third year was very critical, since diversions of surface water decreased down to 39% of average values, with the irrigation share at only 3% of its pre-drought average. Yet, contrary to this dramatic drop in supply, cropping areas were curtailed by 39% only, although there was a degree of shift to crops with lower water requirements and average yields were slightly affected (by 12%).

Farmers have responded to the drought and to pervasive water scarcity in the past 20 years in different ways, as illustrated by a study of farmers' coping strategies in the Abshar irrigation system (Hoogesteger, 2005). At the outlet level, some user groups defined priority rules (e.g. priority to smallholdings) to allocate limited water; in others, some farmers ceded their share to others and left their land fallow; elsewhere, farmers joined together to drill collective wells. At the individual level, farmers' responses included: increased use of groundwater by drilling or deepening of wells; use of untreated effluents from Esfahan; a shift to less-sensitive crops, such as fodder maize; migration to other regions unaffected by the drought to rent land; and lease or sale of land (Molle *et al.*, 2008). Despite this adaptive capacity, recurring shortages tend to affect the weakest farmers and to drag them out of business in a context of high unemployment.

Reopening the basin?

The history of the Zayandeh Rud basin has shown repeated resorts to water import as a means of solving the recurring and marked imbalances between supply and demand. At first sight this would appear to merely result from population growth (Esfahan sheltered refugees from western provinces during the war with Iraq, when its population grew at an annual rate of close to 7%), industrial development and the needs of agriculture. This latter sector, although subject to irregular supply, still totals 66% of water diversions in an average year and there are serious questions about the reasons for continuing investment in irrigation infrastructure.

It seems somewhat contradictory that while large-scale irrigation systems established 30 years ago (the Nekouabad and Abshar schemes), let alone the traditional systems that go back hundreds of years, are struggling to get sufficient water, new irrigation developments continue apace in the basin. Many of the reasons 'why enough is never enough' (see Molle, 2008, for an examination of the societal drivers of basin overbuilding) possibly apply to the present case. The financial and political benefits accruing to a set of decision makers and entrepreneurs may have played a role in the extension of canals to Borkhar and Mayhar areas (Foltz, 2002). At a minimum, the design hypotheses and justifications for such works, in a context where water is increasingly exported to large cities in neighbouring basins, are likely to have been dubious.[5] While in the current situation of high unemployment agriculture remains a sector which cannot be neglected, it is also not clear what categories of farmers benefit most from these investments.

All in all, it may well be that this benefit will be very limited, since supply is likely to be limited and intermittent. A perverse consequence of such overdevelopment of irrigation infrastructure, however, is that it 'mechanically' generates water scarcity, exposes 'beneficiaries' to the precariousness of uncertain supply, and creates the political conditions for justifying further development. With this logic at work, further and highly costly imports of water are expected to be effected. It can be equally feared that the next abundance of water will be absorbed by waiting fields in the Borkhar and Mayhar areas, and perhaps in new areas, which will be planned to raise the design economic benefits of the new transfer.

While the basin is buying respite at a high cost[6] (although this cost is largely shifted to the national level), one may wonder what the limits of such a process are. It is already apparent that 'donor basins' are complaining about the diversions and that these are only made possible because of the overriding decision-making power of the central government. During the drought, for example, people in the lower Dez basin (of which the Kuhrang is a tributary) suffered shortages and severe health problems. Diversions also take their toll on hydropower generation, since the Kuhrang feeds into the Karun and its four dams (the first hydropower complex in the country). These externalities imposed on donor basins should certainly be considered in order to get a clearer picture of the full costs of these transfers.

Conclusions

No doubt sprawling urban oases with growth dynamics that largely lie beyond the question of water availability are faced with critical challenges. In the Zayandeh Rud basin, increase in population, decline in farm size and agricultural income, environmental degradation and growing sectoral competition for water appear to be at loggerheads with the finite and circumscribed nature of the water generated in the Zagros mountains. Yet, while oasis culture is characterized by frugality and attention to nature's limits, the Zayandeh Rud basin seems to have developed without a sense of limits. Esfahan and its surroundings have been planned to become major urban and industrial poles during both the Shah and the post-revolution periods; irrigation infrastructure has been repeatedly overdeveloped, leading to suboptimal cropping intensities and forcing farmers to complement canal supply with groundwater. At each step of the Zayandeh Rud basin development, these contradictions were – albeit briefly – dissolved by the construction of a dam or by an interbasin transfer which 'reopened' the basin. Despite these interbasin transfers, which double the availability of surface water in the basin (in 2009), and a total use of groundwater estimated at 3500 Mm^3/year (i.e. 72% of all water use), only less than 2% of the natural flow of the river reaches the Gavkhuni marshes (Management and Planning Organization, 2002). Considering the overdraft of aquifers signalled by dropping water tables (on average, 2.5 m/year), water use in the basin exceeds renewable resources. By all definitions, the Zayandeh Rud basin is closed.

In such arid areas where land is abundant, any possible excess of water will be readily absorbed by waiting fields or expanding cultivated land if no regulation control is exercised; likewise, unchecked drilling of wells will also tend to exhaust aquifers and, in places, cancel the historical investments and rights vested in the *qanats*. Imperative demands from neighbouring desert cities with even less available supply also contribute to sucking up whatever additional water is made available. The basin has thus been buying respite by ever-increasing capital investments in tunnels, but this logic now collides with the financial costs of the works required and the externalities generated on donor basins.

The spatial pattern of water resources development induced a gradual shift of benefits upstream: the Gavkhuni Ramsar site and the lush gardens of Rudasht of bygone days are the obvious victims of that shift of water use to upstream urban areas, almond tree orchards and tourist resorts around the lake. The study provides instructive and graphic examples of how water gets redistributed between surface water and groundwater, upstream and downstream, the lateral and the main valleys, wells and *qanats*, between villages, and between rural and urban users. All human interventions induce hydrological changes that travel across scales and time, and across levels of social and political control. This interconnectedness across scales has critical implications for societies, since it links macro-level management and decision making to local processes.

The absence of clear allocation rules or water rights means that interventions, re-appropriation 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 affected in closing basins: the downstream users, the next generations and the environment, in decreasing order of bargaining power. The environment bears the brunt of the reduction of flows at a time when more water is generally needed to dilute pollution and to leach the salt. The next generations are affected by the gradual and continued depletion of groundwater resources. Agriculture, as the residual user, has to deal with a supply that basically varies each year. There is no slack in the system and the only buffering capacity or flexibility is provided by declining aquifers.

A consequence of the closure of the basin that cannot be overemphasized is the logical impossibility of overall water conservation, except where unproductive evapotranspiration can be reduced. Local conservation measures are possible but they necessarily have third-party impacts. Therefore, while such local measures may have benefits for the users involved, they are – just like additional abstraction or diversions – eventually tantamount to a mere 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 equity, water rights and third-party impacts.

The complexity of social and hydrologic macro–micro interactions 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 enabling multi-level governance patterns, which allow interest groups to negotiate arrangements that bring more certainty, social value and equity to the sharing of water. This does not mean that the power of centralized management agencies should be eliminated. Rather, the nested nature of hydrologic scales and the overriding importance of dam management and bulk allocation call for forms of co-management (Sneddon, 2002), with management power and responsibility 'shared cross-scale, among a hierarchy of management institutions, to match the cross-scale nature of management issues' (Folke *et al.*, 2007).

In the Zayandeh Rud basin, the challenge could be to re-establish the earlier stakeholder-controlled allocation (when *mirabs* were elected). An 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. According to Hossaini Abari (2006), 'the management of the Zayandeh Rud was entirely in the hands of local people; the system was democratic and the government or state governors rarely had a direct role', while Ghazi (2003) underlines its strict enforcement. Whereas this management seems to embody what would nowadays qualify as subsidiarity and 'stakeholder empowerment', it must now be carried out 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.

Notes

1 The valley probably remained relatively under-populated since the invasion and the destruction wrought by the Afghans (circa 1725). Around 1900, Zélé Sultan, the governor of Esfahan, tried to revitalize the valley by bringing people in from other regions (such as Yazd province). It is thus doubtful that water-sharing rules were established in the 16th century, but this shows the mythical role acquired by Sheikh Bahai in the celebration of past water wisdom in the area (Pirpiran, 2007).

2 There are large discrepancies in the average volumes transferred, according to source: Murray-Rust and Droogers (2004) refer to 250 Mm^3, and Abrishamchi and Tajrishy (2002) to 160 Mm^3. Morid (2003) reports that tunnels Kuhrang 1 and 2 (together?) divert 300–400 Mm^3 of water per year.

3 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 had a dramatic impact on the hydrology of the Mourhab valley. It was probably based on the common – yet radically wrong in the present context – idea that surface storage is beneficial because it may regulate water that would otherwise flow downstream unused. But springs and *qanats* feed on the huge natural water storage provided by the alluvial aquifer of the valley. This natural reservoir has overwhelming advantages over a dam: (i) it incurs no loss by evaporation; (ii) it is distributed all along the valley, allowing access to almost all villages; (iii) this distribution is free and requires no intervention; and (iv) water use was quite finely attuned to the available resource. In addition, the remaining flows, if any, were not lost, as often perceived, but used further downstream in the main valley.

4 A smaller fraction of the soil surface is saturated after irrigation, thus reducing soil evaporation losses, but more frequent irrigation increases the

average humidity content of the top layers; the two effects cancel each other.

5 Satellite images confirm that the Borkhar and Mayhar areas only have interspersed cultivation and are therefore irrigated far under their design levels.

6 While the Kuhrang 1 and Kuhrang 2 tunnels are 2.8 km long each, the Kuhrang 3 and Lanjan tunnels are 23 km and 15 km long, respectively. The Behesh Abad tunnel, under study, would be 75 km long (Abrishamchi and Tajrishy, 2002). This gives a measure of the corresponding increase in costs solely for the drilling of tunnels.

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