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Scale, governance and the management of river basins: A case study from Central Iran

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ABSTRACT

Aquatic socio-ecological systems show pervasive cross-scale interactions and problems of fit between ecosystems and institutions. Nested bio-hydrological processes within river basins are prone to third-party impacts, and equitable/sustainable management of water resources requires adequate governance patterns that both cover relevant scalar levels and handle cross-scale interactions. This paper provides the example of the Zayandeh Rud basin, in central Iran, and describes the historical evolution of water use at three different nested scales. It shows how the gradual overallocation of water resources (basin closure) and the manipulation of the hydrological cycle by the state and other actors have resulted in a constant spatial and social redistribution of water use and associated benefits and costs. State-centered modes of governance characterized by the priority to large-scale infrastructure, vested political and financial interests, lack of attention to local processes and hydrological interconnectedness, and the neglect of environmental degradation, must give way to forms of comanagement that better articulate the different levels of control and governance.

1. Introduction

Social–ecological systems have attracted significant scholarly attention in recent years. Examination of the conditions favoring their robustness (Anderies et al., 2004) and resilience (Folke et al., 2007) has singled out cross-scale interactions and the fit between ecosystems and institutions as two central issues worthy of investigation (Görg, 2007; Young, 2002): most resource management systems have external linkages and drivers at different scales and Berkes (2002, p. 317) argues that "it is useful to start with the assumption that a given resource management system is multiscale and that it should be managed at different scales simultaneously." Cross-scale interactions permeate not only ecological and societal processes but also their linkages and Anderies et al. (2004) argue that failure of the links between resources, governance systems, and their associated infrastructures reduces the robustness of a social–ecological system, that is, its capacity to cope with uncertainty and disturbance.

We are concerned here with the long-term sustainability of aquatic ecological systems and, following Sneddon et al. (2002), with the ways these systems are influenced "by human social relations mediated by political-economic, cultural, and ecological contexts that themselves interact across multiple spatial scales." When dealing with water-dependent socio-ecological systems, with the river-basin level as a starting point of the analysis, the vexing societal problem of sharing scarce resources is compounded by the whimsical, fluctuating and fluid nature of the resource itself and by both the interconnectedness of ecosystems and the interdependence of humans who rely on the same basin hydrological cycle (Bakker, 2003; Molle, 2007). The challenge is to devise governance patterns that can handle this complexity: we need to work out the fit between particular ecological processes and the levels of decision and responsibility (Adger et al., 2005; Wilbanks, 2006) and, more importantly, to ensure the consistency of the links between these levels of decisions and parallel cross-scale bio-hydrological processes.

One such task is to regulate the evolution of water use and abstraction at different scales while controlling both local and cumulated impacts on third parties. When pressure over water resources increases, water tends to become fully committed and depleted within the basin; consequently, river-basin outflows tend to fall below the level required to meet downstream requirements, including (depending on the situation) diluting pollution, flushing out sediments or sustaining estuarial or coastal ecosystems. In such cases, river basins are said to be closing, when flows are inadequate during a few dry months, or closed, when this situation extends to most of the year (Molden et al., 2005; Molle et al., 2007a; Molle and Wester, 2009).

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The concept of basin closure calls forth two sets of crucial questions: first there is a need to understand what the societal mechanisms are that tend to produce closed or 'overbuilt' basins, a phenomenon that has been both illustrated by well-known rivers such as the Colorado, the Jordan, the Yellow, the Indus or the Syr-Daria and shown to be expanding to basins located in comparatively more favorable climatic contexts, such as the South of India or Thailand (Molle et al., 2007a). This questions the cultural, financial and sociopolitical factors that underpin large-scale water resource (over)development, notably dams and irrigation schemes, and must explain "why enough is never enough" (Repetto, 1986, Molle, 2008). Massive social and environmental changes wrought by such developments put such an inquiry squarely in the field of political ecology, with a special attention to how the distribution of power shapes competing discourses and decision making, and to how the costs, benefits and risks generated by interventions on the hydrological cycle—both by the state and other actors—are spread spatially and socially (Worster, 1985; Robbins, 2004; Sneddon et al., 2002; Adger et al., 2005; Molle, 2007).

A second set of questions concerns the actual apportionment and distribution of water and how management incorporates, and responds to, hydrologic variability and uncertainty. Water sharing may be more or less responsive to this variability, and diversely transparent/equitable and technically efficient. Again, patterns of governance are likely to reflect the distribution of power and the relative weights of the state, economic sectors, and the civil society.

Although many communal and/or ancient water distribution systems have proved to be socially controlled and resilient (Coward, 1980; Chatchawan and Lohmann, 1991; Ostrom, 1992), effects of basin closure coupled with expansion of state power, often through the reshaping of waterscapes by large-scale interventions, have made them increasingly dependent on decisions taken, and processes unfolding, at other scales. More generally, basin closure and over-commitment of water resources increase both cross-scale hydrological interdependence between users and the entanglement of governance and legal management regimes, with state regulation often overlapping or conflicting with rules established locally (Bruns and Meinzen-Dick, 2000).

Because of its distributed, fluid and fluctuating nature, the hydrological cycle possesses a unique potential for generating externalities that will travel across space and time and social groups and be greatly magnified by the increasing manipulations associated with basin closure. We feel it is of great importance to make explicit the growing intricacies of cross-scale interactions as basins close and their relationships with patterns of governance, illustrated here by the particular historical trajectory of the Zayandeh Rud basin, in central Iran. Echoing concerns that political ecology sometimes neglects the documenting of environmental change (Walker, 2005), we first dwell on the analysis of how waterscapes have been reshaped with time. The paper is organized into four main sections that successively review the physical setting of the basin, ancient water management, recent changes in water resources development and use, and the socio-ecological breakdown that ensued. The comparison between ancient and present times, together with the analysis of three nested scales allows us to unpack the coevolution of water use and governance as the basin closes and highlight currents mismatches. The information used in this multi-level analysis has been collected throughout the 2000s through the various research activities carried out in the Zayandeh Rud as part of the Comprehensive Assessment of Water Management in Agriculture and referred to in the text. Data on Jalalabad village, in particular, has been collected from archival data and through semi-structured interviews of villagers.

2. The Zayandeh Rud and Mourhab Valleys

The Zayandeh Rud basin covers 41,500 km^2 in the center of Iran (Fig. 1). Its historical and economic significance is attached to the city of Esfahan, with its rich and long history. The Zayandeh Rud originates in the Zagros mountains and traverses arid areas before emptying into the swamp of Gavkhuni, a Ramsar site. The mountainous part of the basin culminates at around 2300 m but Esfahan and its fertile plains stand at an altitude of around 1500 m. While annual rainfall/snow in the upper catchment averages 1700 mm, Esfahan receives only 130 mm per year, concentrated in the November–April period. Annual potential evapotranspiration is 1500 mm (Murray-Rust and Droogers, 2004). The Gavkhuni swamp includes temporary wetlands along the lower course of the river and a natural salt pan, where the river terminates and where water eventually evaporates or percolates.

From time immemorial water has been diverted from the Zayandeh Rud, literally the 'life-giving river', to supply Esfahan and irrigate its gardens and surrounding agricultural areas. Agriculture largely depended on snowmelt from the mountain. Numerous springs and *qanats* – underground horizontal galleries excavated to collect groundwater and convey it to the surface located in the central and lateral valleys were also used. (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)).

It is only with the excavation of a first tunnel bringing water from the adjacent Kuhrang basin (1953) and the completion of the Chadegan reservoir (see Fig. 1) in 1970 that supply and storage in the basin dramatically increased, ushering in a new area of infrastructural development which, added to existing areas, totaled approximately 160,000 hectares (ha) of double-cropped irrigated land around Esfahan. Supply to the Chadegan reservoir was augmented in 1986 by a second tunnel from the Kuhrang river basin, and a third tunnel is soon to come under operation.

In contrast to the main central valley, whose supply of water is regulated by the Chadegan reservoir, water use in the lateral valleys of the basin has remained centered on springs and qanats. The 110-km long Mourhab valley (also called the Najafabad valley), for example, has 106 qanats totaling 266 km in length and several springs (Hartl, 1989), the most important of which is the Mourhab spring, which in normal years 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) (see Fig. 1). In the 1970s, however, the spreading of wells and pumps has led to an increasing use of groundwater and, subsequently, to a competition with qanats, both in the main and lateral valleys.

Jalalabad is a village with a population of approximately 3000 and 11,000 ha of extension, out of which up to 1100 ha can be irrigated. It is located in the lower reach of the Mourhab valley which ends up in Najafabad, a city now forming part of the western suburbs of the capital of the province, Esfahan. Rainfall around Jalalabad varies between 85 and 204 mm but almost half of the annual precipitation can fall within 5 days (Hartl, 1989).

We can thus distinguish between four different and nested scales: the scale of the village and its local management of different sources of water; the scale of the lateral valley, with its surface and underground water flows nourished by springs, snowmelt and occasional flash floods; the scale of the river basin itself, where the Zayandeh Rud is supplied by the Chadegan dam and also by whatever flows accrue from lateral valleys; and the national scale where, for example, decisions to redistribute water through interbasin transfers are taken: we will focus on the first three levels and examine, first of all, how they are physically connected by water

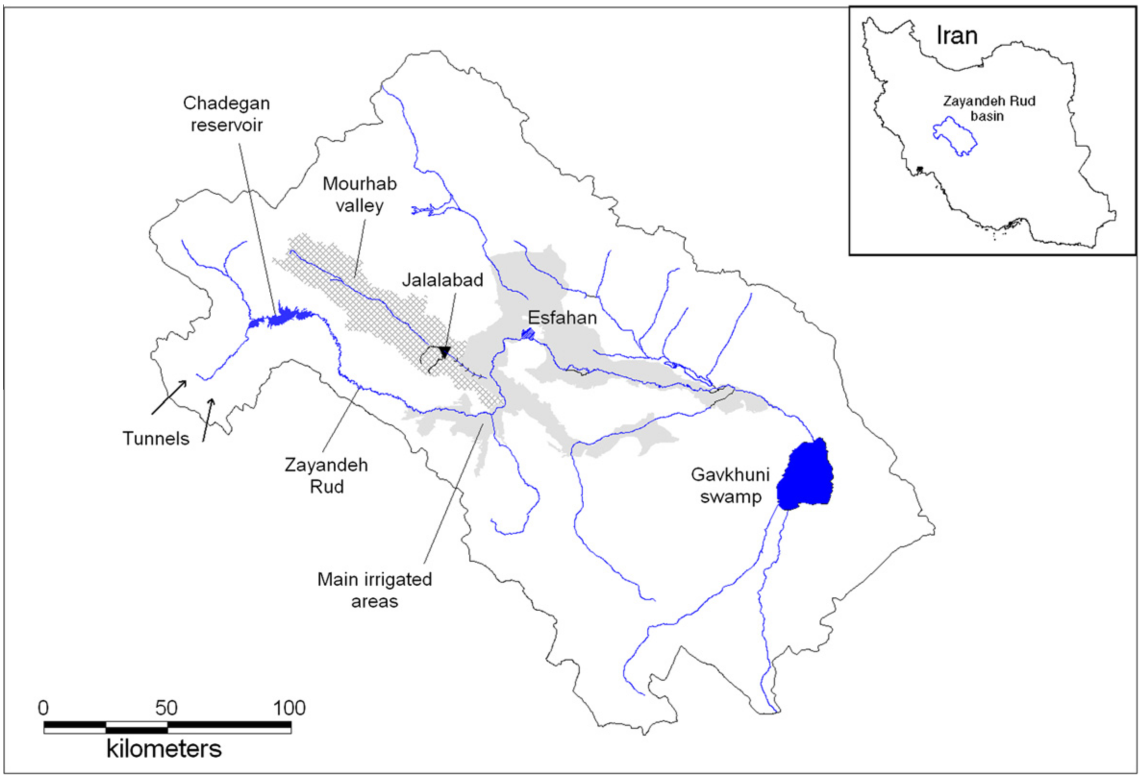

Fig. 1. The Zayandeh Rud basin and the Mourhab Valley.

fluxes and, second, how this interconnectedness is paralleled and dealt with in terms of management and governance.

3. Early water rights and uses of water in the Zayandeh Rud river basin

Although water use around Esfahan is as old as the city itself and although we have records of water management dating back to the third century (Hossaini, 2006), historical documents on water use are scarce. Ibn Rusteh (1889), for example, who wrote in the early tenth century, mentions 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 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." Rudasht and Baraan districts, for example, were reported to receive water during 9 days each month.

The earliest known detailed regulation of the Zayandeh Rud has been unearthed by Lambton (1938). Riparian rights in the sixteenth century are described in detail in an edict (*tumar*) attributed to Sheikh Bahai, which specifies the water apportioned each month to each district (*boluk*) and village. The river was managed by a *mirab* and six assistants selected by 33 *boluk* representatives, with the help of appointed *maadi salars*, heads of each of the main run-of-the-river diversion canals (*maadi*) that were branching off the river. These managers were paid by users, proportionally to the amount of water received, and were dispensed with if their service was judged to be unsatisfactory. 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 referees water disputes "with the confirmation and approval" of the local leaders. According to Hossaini (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." 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). Despite some modifications in the 1930s, this regulation has been enforced for centuries and, in spite of its official seal, has been enacted following principles that would nowadays qualify as subsidiarity and "stakeholder empowerment." 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* 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).

The situation seems to have been the same in lateral valleys. Rules defined protected areas in order to avoid conflicts between qanat users (Foltz, 2002). Qanats were considered as private property of those who had invested in their excavation. In the Mourhab valley, the city of Najafabad used its wealth to build and tap the water of 17 qanats, distant from the city by as far as 100 km and collected by a canal that followed the valley and still irrigates today the lush gardens of the city. The use of surface water, on the other hand, was also socially controlled. In the 1960s, the surface water of the Mourhab River (name after its main spring) 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*.

In Jalalabad, the main sources of supply of the village until the 1960s were two qanats, in addition to whatever surface water could be diverted according to the rules. In the beginning of the last century, the land belonged to the son of Zélé Sultan who sold part of it to the six main lineages of the village. Up to present days, qanat water rights are 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. 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." Out of equity, each clan was given lots 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. The flow of the Mourhab River was diverted 1 km upstream of the village and was consolidated with the qanat flow. In years when this consolidated flow was abundant, villagers would divert it to the land located north of the village orchards and use it to grow watermelon or cotton.

In sum, the emerging picture is that of nested user-controlled systems of governance which involved village ditch managers, system overseers and valley *mirab* (both in the main and the lateral valleys) who were all nominated and paid by the users in their jurisdiction, with well-accepted and -enforced rules for sharing the resource. The cultivation area and irrigation doses were attuned to the available river water 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 indiscriminately was not critical because the density of qanats was regulated, lateral valleys would contribute surface flow to the Zayandeh Rud in excess months or years and a sub-superficial flow at least during a large part of the year.

4. Recent water resources development in the basin

4.1. Large-scale state intervention

Although a first interbasin tunnel, excavated in 1953, diverted water from the Kuhrang to the Zayandeh Rud basin (bringing in 340 million cubic meters per year [Mm^3/yr]) and increased the flow in the river, it was only in 1970, with the completion of the 1500 Mm^3 capacity Chadegan reservoir, that regulation of the water regime was made possible. This date also almost coincides with the nationalization of water resources in 1968 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 infrastructures, was newly established. Yet, in many cases, these modern schemes were superimposed on the ancient network of *maadi* and sometimes on qanats, and the gains were thus limited, although double-cropping became possible in most of the valley. 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 the river, instead, was barred at two points (Nekouabad and Abshar) by major regulators that distributed water to 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 trans-basin tunnel from the Kuhrang river in 1986, another 250 Mm^3 were made available annually. This spurred the rehabilitation of the old Rudasht scheme, at the tail end of the valley, and the extension of the irrigated area by 40,000 ha (Borkhar and Mayhar). Part of these districts was already irrigated with groundwater but overexploitation generated problems of declining water quality that new surface water was first supposed to mitigate; whatever freshwater available in excess would be used to expand cultivation.

There is no significant year-to-year carryover storage in the Chadegan reservoir because almost all of the floodwater entering the reservoir is released prior to the next flood season. This maximizes the production from irrigated agriculture and part of the variability in supply is handled by resorting to groundwater. This buffering role of aquifers has been critical in the 1999–2001 drought, especially in 2001 when no water was supplied to agriculture which, however, cultivated 60% of the total area, based on wells (Molle et al., 2007b). Yet, the function of the aquifers is gradually weakened by their decline and they will not be able to compensate for dwindling surface water supply in the long run.

The increased available supply, in addition to being committed to new irrigation areas, also met the increasing needs of Esfahan, with its population totaling 2 million and a growth at 2–3% per year, and of neighboring industries. The industrial sector now needs over 100 Mm^3. An additional 280 Mm^3 will soon be made available through the third Kuhrang tunnel, and further 150 Mm^3 will be developed from a series of local springs throughout the karstic portions of the basin (Murray-Rust and Droogers, 2004). Yet part of this water is already committed to supplying cities in much drier areas (Yazd, Rasfanjan, Kerman) located outside the basin.

State investments and regulation did not remain confined to the main valley: they also expanded into lateral valleys. In the Mourhab valley, the Ministry of Jihad undertook the construction of a dam—the Khamiran dam—in the late 1980s, with the objective of increasing storage and local water use. For lack of a favorable location to site a reservoir across the Mourhab, the Khamiran dam was constructed in 1992 with a storage capacity of 6.8 Mm^3 on a tributary of the Mourhab, on the right-hand side of the valley. This situation made it necessary to build a diversion weir on the river, 200 m downstream of the Mourhab spring itself, and a 20-km-long lined adduction canal along a contour line of the right flank of the valley that could convey spring water into the dam (see Fig. 2).

Instead of the natural system of aquifer recharge through the stream that prevailed for centuries, the dam is now supplying water to downstream villages through a 40 km long canal. This canal, however, stops short of supplying Jalalabad and the villages further downstream. 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 Fig. 2). 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 1979 Revolution also marked the end of the regulation of the Mourhab river by the *mirab*. The regulatory function was taken over by state agencies resulting in less transparency and eventually strengthening the power of the state to modify traditional rights, as events would soon show.

4.2. Local water resource development and the dissemination of wells

Notwithstanding these state-initiated projects, villagers at the local level have also been actively looking for ways to respond to

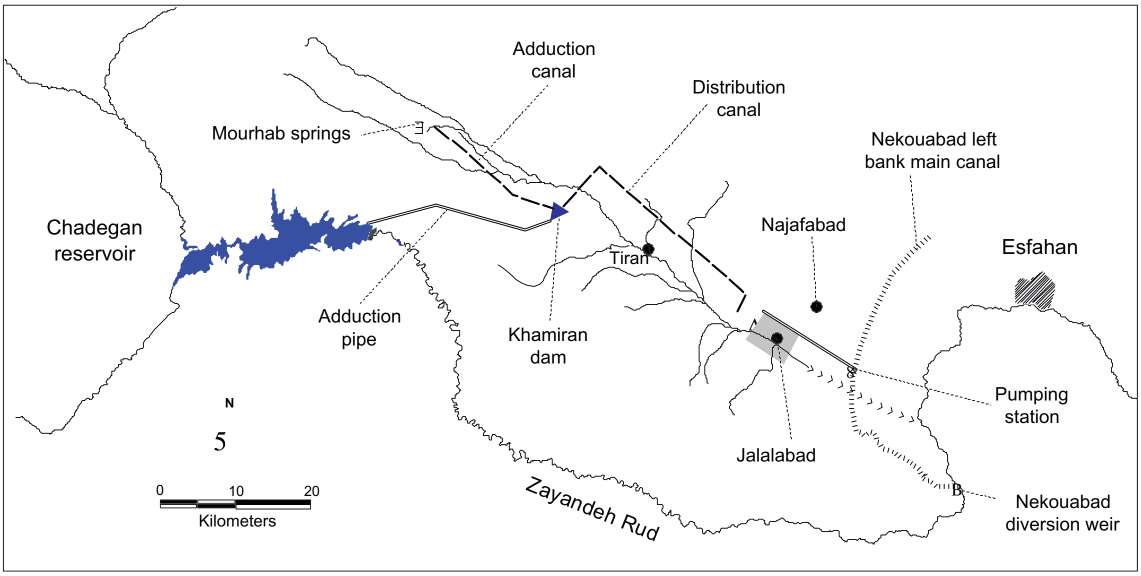

Fig. 2. New water developments in the Mourhab valley.

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 to hinder the intensification of 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 1,200,000 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 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). This development seems to have been based on inadequate hydrological analysis, 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 dramatic increase in water supply. Jalalabad received an authorization for sinking eight wells in the village that were used to expand the garden area. In addition, villagers obtained a permit to dig fifteen 60 m-deep wells within the existing orchards, as a way to boost the available water per hectare of garden. These investments were made by farmers from the same irrigation unit and the piped network used for distributing the well water was superimposed on the existing network of earth canals. As a result, one of the two qanats used by the village soon saw its discharge dwindling and eventually drying up. The impact of well development on the discharge of the qanats confirmed local knowledge about the interconnectedness of the different water sources. Digging of wells without licenses by individuals, in particular in the catchment area of the main qanat, is opposed by farmers who close the wells by force (this has happened recurrently and as recently as 4 years ago).

In the late 1970s, 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 and connected it 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 led to the decision to expand the gardens by opening a new sector of approximately 100 ha.

In the mid-1980s, a new source of water was added. Complaining that the Khamiran dam had impacted their right to the Mourhab's water, villagers obtained an allotment of water diverted through a pipe from the Nekouabad left bank main canal, some 10 km further downstream, requiring two successive pumping stations: out of the 400 L/s brought into the area a constant discharge of 60 L/s during 8 months was granted to the village (Fig. 2). This flow was incorporated to the qanat flow at the very entrance to the village, before its division into different canals. This means that the benefits of the canal water accrued to existing water rights holders and that water was not used for other uses or expansion of the irrigated area.

During the 1999–2001 drought, many qanats in the Mourhab valley and wells with insufficient depth or located far from the river dried up. In Jalalabad, the flow of the qanat dwindled down to 50 L/s and only part of the wells resisted, allowing a few hours of supply each day. Half of the orchards of the village were destroyed and the number of sheep in the village decreased from 3000 to 1500. The drought also made it clear that the Nekouabad water delivered by the pipe could not be considered as fully reliable, since the nominal flow of 60 L/s was reduced to approximately 40 L/s.

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. Second, work on the furthering of the qanat was undertaken. Third, a concrete weir (funded by the government) was built across the Mourhab in order to capture whatever flow might occur in the future and divert it to a lateral earth dam that also serves as a water-harvesting structure. Last, with the lack of water, farmers concentrated their water right in some plots or some trees, leading to an increase in transactions in land and water rights, and endeavored to improve the application of water: in orchards formerly irrigated by the flooding of basins, furrows and circular depressions guiding water around the trees were soon to appear.

5. Hydrologic and social breakdown

These changes in water development and use, and in water governance at various scales, engendered a hydrologic and social breakdown of the rather stable system that had prevailed before the construction of the Chadegan dam and the taking over of water management by the state apparatus.

5.1. Disruption of the water regime

Closure of the Zayandeh Rud basin became apparent in the sixties, when flows to Gavkhuni dropped to close to zero (Murray-Rust and Droogers, 2004). The Chadegan dam (1972) allowed a better redistribution of water during summer and the late 1970s enjoyed a relative improvement of the situation, with groundwater levels coming up in many areas and some discharge accruing to the wetlands and the lake. Yet, any amount of excess water was rapidly tapped by overextended irrigation areas and the whole water was consumed. Likewise, the additional supply of the 1986 tunnel only allowed 3 years of 'slack,' and the mew supply of water was rapidly committed. Overextension of irrigated areas, competition with other uses (compounded by the 1999–2001 drought) and discretional water allocation by the state made supply uncertain and led to a massive buildup of wells.

Wells developed in parts of the central valley that were exclusively irrigated by 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). While the discharges of qanats are determined by the height of the water table, 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 may also abstract more water out of the aquifer than it comes in as recharge. For the Mourhab 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 only: it is thus probable that wells have allowed farmers to tap more available resources than earlier through qanats but insufficient control of their number and location eventually led to competition with the latter, duplication of investments, and overdraft of groundwater. While the 'mining' of aquifers had little impact in the short term, the abstraction of deeper water later resulted in increased costs and salt contents, and more shallow wells drying up, as well as in the undermining of qanats and springs (an history documented by several studies on various countries: e.g., Ehlers and Saidi (1989), for Iran; and Mustafa and Usman Qazi (2007) and Lightfoot (1996), for examples from Baluchistan and Morocco, respectively).

While the Mourhab valley was affected by the development of wells, the second decisive event was the construction of the Khamiran dam. 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 and the diversion of the Mourhab spring had a dramatic impact on the hydrology of the Mourhab valley and the flow in the river virtually stopped.

The dam project was 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. Indeed, 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: (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; (d) water use had to be quite finely attuned to the available resource. In addition, the remaining flows, if any, were not lost as perceived, but used further downstream in the main valley.

The failure to fully appreciate these advantages probably paved the way for a decision which had all the trappings of a modernist solution (engineering- and technology-oriented, capital-intensive and state-controlled) but produced disastrous effects. With the diversion of the Mourhab, 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 underwent evaporation losses; earlier investments in affected wells and qanats were partly 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.

Regulation of the diversion of surface water in the Mourhab valley became insulated from stakeholders. Instead of the *mirab*, who enforced rights sanctioned by tradition in a transparent way, the state now 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. This allegedly allowed Askaran to appropriate more than its share by colluding with operators. On the contrary, 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.

Water quality has also undergone critical evolutions, mostly because of industrial and urban effluents (partly reused in agriculture after basic treatment). But increasing reuse of return flows within and between schemes augments the salinity of water as it moves downstream, impacting soil and crop yields.

5.2. Interconnectedness in closed basins

While water users in river basins with abundant water will generally little impact others users, the closure of river basins results in the growing interdependence of users within the basin. What is stored, pumped, conserved or depleted at one point dictates what is available at another point, further downstream (Molle, 2003). In a closed basin, whenever an individual, a village or the state taps a new source of water, or alters the allocation or the return flow of an existing one, reallocation is likely to occur. In other words, one may be almost sure to be robbing Peter to pay Paul. 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. One must therefore 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. Several examples 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 or may not be the same persons: while farmers' wells partly impact their own qanats (and those of nearby downstream villages) reallocation between social groups may occur: in Jalalabad, for example, a flower-farm projected just upstream of the village by a capitalist joint venture between investors in Najafabad and a Dutch company would result in a shift in resource, if the later were to be granted a permit to drill wells. The development of wells also reduces the groundwater flow to downstream areas. Farmers understand that groundwater is not a static resource and the issue is "pumping groundwater before it flows downstream," as one of them expressed.

The construction of the Khamiran dam is a good example of storing the surface water which used to diffuse to the aquifer all along the valley to reallocate it to specific villages. The cumulative impact of the dam, the wells and the qanats results also into a drastic, although invisible, reduction of the groundwater flow to the Zayandeh Rud itself, since water is 'retained' and used in the valley. Other underground flows that also contributed to the base-flow of the river (and allowed irrigation downstream of Esfahan) were tapped by deep wells in and around the cities to irrigate large "green belts" of trees planted "for the environment." This example shows how water formerly used by agriculture in the main valley can be reallocated almost 'invisibly' to provide benefits to upstream farmers and amenities to city dwellers (and urban-based decision makers). Depletion of groundwater both in the main and lateral valleys has inverted the net underground gain to the Zayandeh Rud: Gieske and Miranzadeh (2003), for example, have estimated that approximately 250 million m^3 out of an annual yield of 275 m^3 of groundwater in the Lenjanat alluvial fan aquifer are now tapped. Further down the valley net fluxes have been inverted and it is, in all likelihood, the river which now recharges the valley aquifers, an "invisible" change which is often overlooked (Morid, 2003).

Reallocation is also occurring on the upper reach of the Zayandeh Rud river. Numerous private pumping stations abstract water to supply 10,000 ha of almond orchards located on the plateau, 150 m above the valley bottom (Murray-Rust and Droogers, 2004). These orchards are still growing and, in the absence of formal rights, they only deplete the very resource that was not only allocated to downstream irrigated areas but had provided the rationale for investment in costly irrigation facilities.

Conservation efforts also impact water pathways. Canal lining in Jalalabad 'saves' water that can then be spread on a larger area, increasing local water depletion and benefits to the detriment of return-flow users. The canal that collects qanat water for Najafabad all along the valley has also been lined to offset declining supply, thus increasing the flow to Najafabad but, at the same time, decreasing groundwater recharge along the valley.

The study thus 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 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.

5.3. Shifting governance and conflicting legal repertoires

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 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. (Water management in the Mourhab valley was apparently initially not altered). This interference of the state created confusion in the 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. 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 need to protect springs, wells and qanats was addressed by defining a *harim*, or a prohibited area for extraction around these sources (Foltz, 2002). Nevertheless, the Law for Fair Distribution of Water, ratified in 1983 established that the use of groundwater through digging wells and qanats or through the expansion of these systems are conditional upon requesting and receiving a permit from the Ministry of Power (Hoogesteger, 2005). The right to access groundwater became administered centrally, with limited knowledge of local hydrology, transparency, and control by interested populations. This opened the way for bribery and for powerful people to obtain well permits through influence.

The confusion in the legal repertoires is also illustrated by the apportionment of the Zayandeh Rud water. At the inter-provincial level, 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 irrigated almond orchards downstream of the dam based on the perception that the river is also "theirs." This directly withdraws water that was allocated to downstream areas. Likewise, the decision by the central government to divert part of the river to supply other dry cities through long-distance pipes signals the superimposition of overriding extra-local decisions. The same can be said about tourist and urban development around the dam that both extract water from the lake and pollute it.

Within the basin, the Ministry of Power has large discretionary power over the allocation of the Chadegan dam water, and accommodates demands and requests from Member of Parliaments or other political constituencies (Ghazi, 2003). For example, factories have in general 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. Interests of construction and landscaping companies notoriously involved in kickback practices are also more easily catered for (Foltz, 2002). The imbalance created in the Jalalabad area by the Khamiran dam also had to be "corrected" by withdrawing water from the Nekouabad canal (see Fig. 2); the planning of this costly pumping scheme spurred other local demands (hospital, urban areas, etc.) which were added to the discharge delivered to Jalalabad. Since irrigation canals are allotted a given amount of water and have a capacity limited by design, the incremental and combined impact of these diversions is to reduce supply to agricultural areas.

That priority in allocation is given to nonagricultural uses was well illustrated in 2001 when, at the peak of the drought, diversions to agriculture were zeroed during the whole season and cultivators left with their sole groundwater resources, despite water releases from the dam still amounting to 39% of yearly average values (Molle et al., 2007b). 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 tightly related to the spell of its gardens and bridges, water was released to the Zayandeh Rud to restore their magic and save the tourist season.

In the main valley, the superposition of concrete canals over the network of ancient *maadi*, led to the state largely overriding the riparian rights enshrined in Sheikh Bahai's regulation. The administration, yet, could not fully erase these rights and a study of water allocation within schemes showed 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. Some villages that had developed quite lately were deprived of rights and 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 redistribution of water in the Mourhab valley after the construction of the Khamiran dam was a nontransparent 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 €2000 for a discharge of 40 L/s from the dam, unilaterally reduced to 20–25 L/s during the drought. Tiran village, which formerly had 6 of the 15 parts of the river, and other villages had to pay for the very water they had freely enjoyed for centuries. The dam resulted in the canceling and redistribution of 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 affected in closing basins (Molle and Wester, 2009): 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 salts. The next generations are affected by the mining of aquifers and the gradual depletion/contamination of groundwater resources. Downstream "users" include the last irrigation sector of Rudasht and the Gavkhuni swamp. Salinity of soil and water in Rudasht is on the rise, yields are the lowest in the valley, and some plots are now left uncultivated (Murray-Rust and Droogers, 2004; Morid, 2003). Environmental degradation in the area can be contrasted with its affluent past, strikingly, in the tenth century. Ibn Hawqal (1889) reported that the 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). As benefits from water use have been shifted upstream, salts – mobilized by increasing recycling of water – have moved and concentrated downstream. Cross-scale linkages reflect the distribution of power (Adger et al., 2005) and attendant governance frameworks.

Evidence of fuzziness in water allocation often translates into an experts' prescription couched in terms of *water rights*, a policy recommendation that has lately become fashionable, notably among neoclassical economists who see property rights as a response to conflicts that restores certainty and legibility, and reduces transaction costs. However, establishing formal water rights cannot be achieved by fiat and is predicated upon crucial technical and institutional prerequisites (Molle, 2004). Difficulties include the complexity of hydrology and the lack of quantitative knowledge about the different fluxes of water, notably those of groundwater; the variability and unpredictability of these hydrologic processes; the need of devices that allow quantitative allocation and monitoring at several levels; and political reasons, since decision makers may prefer a fuzzy allocation process left to their discretion to an open process with painstaking consensus-building and negotiations.

Just as 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 cities of Yazd and Rafsanjan, which lie out of the basin but are home to former Presidents Khatami and Rafsanjani) since the corresponding discharge is limited with regard to the average supply: 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; and the cumulated effect of such relatively minor reallocations, once visible, will be ascribed to a "growing demand" that needs to be met by the development of additional water resources.

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 the resource available, its variability, pre-existing water rights, hydrological cross-scale linkages and environmental needs.

Resource depletion and mismanagement are clearly linked to what Berkes (2002) has called "cross-scale institutional pathologies." The challenge of establishing negotiated patterns of allocation is one of multi-level governance. National-level issues include political (and conflicting) decisions about trans-basin diversions and arrangements to share water between provinces; or the claims of the Chaharmahal-va-Bakhtiari neighboring Province to Zayandeh Rud water. Within the Esfahan Province, the Ministry of Power retains large discretionary power on the allocation of Chadegan dam water. The city of Esfahan itself may take decisions about surface water use, which are not consistent with basin management and water availability ("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 structures that are yet to emerge and are not easy to define. As Pahl-Wostl (2007) puts it "there is no sound basis for deriving the kind of regime properties needed for integrated and adaptive management" but there is an agreement that purely state-centric regimes have failed. In Iran, participation of the civil society is still weak (Namazi, 2000) and the government prefers to ride the wave of privatization: a few years ago it contracted out the operation and maintenance of irrigation systems to private companies, cleverly referred to as the *mirab*: like in many other countries, the ideology of efficiency that favors private rather than state operators has allowed former staff from state agencies to form their own companies and to perform the same service, albeit at a higher cost and private benefit to themselves, and with no increase in accountability.

6. Conclusions

This case study of the Zayandeh Rud river basin, seen here as a social–ecological system, illustrates the breakdown that occurs when ecological processes and responsibility lay at different scales, and when there is a failure to fully account for cross-scale linkages (Adger et al., 2005; Wilbanks, 2006). Our account has shown a continuous and implacable race between supply and unregulated/expanding use that brought the basin to closure, increased its sensitivity to extreme events, affected existing rights, and resulted in third-party impacts.

Basin closure generated a critical indiscriminately of actors through the hydrologic cycle that 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. Unbridled well drilling tends to exhaust aquifers and cancel the historical investments and rights vested in the qanats. Unchecked individual or local initiatives 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, interventions at different spatial levels end up proving inconsistent with one another and being sources of conflict. Storage and diversion dams, canals, long-distance water transfers, pumping or treatment stations, water harvesting structures, wells or qanats, all technological artifacts become instruments of a constant reshuffling of access to water and spatial-cum-social redistribution of benefits and costs.

The overall spatial pattern is a gradual shift of use and benefits upstream, while salts and scarcity concentrates downstream: the now degraded Gavkhuni Ramsar site and the lush gardens of Rudasht of bygone days are the obvious hallmarks of that shift of water use to upstream urban areas and tourist resorts around the lake. The lateral valleys, too, have gradually zeroed their contribution to the main valley in terms of both surface and underground water flows, and more water has been "retained" upstream by dams, harvesting structures, and wells. In social terms, it is apparent that negative impacts tend to concentrate on marginal or weak and distant constituencies: the downstream users, de-capitalized farmers with no access to groundwater, the next generations and the environment. A political ecology framework is well adapted to examining the relationships between environmental change, power to reorder the hydrological regime, and the attendant patterns of access to and use of resources.

All the recorded evolutions and disturbances to the system have not been matched with a capacity to reorganize and adapt governance. Available resources, however augmented they were through dams or interbasin transfers, were not allocated based on a sound consideration of hydrological linkages and annual variability. On the contrary interventions – most notably the overexpansion of irrigated areas – were partly motivated by private political or financial benefits which, added to unregulated and uncoordinated local actions such as well drilling, removed any 'slack' in the system, leaving it vulnerable to droughts and prone to social/environmental third-party effects. This confirms "the potential for an accumulation of small actions, each on their own perhaps quite harmless, to destabilize important natural and social systems" (Folke et al., 2007).

This also questions the role of the state. While it could be considered as the guarantor of social and environmental justice the state has first typically engaged in a "hydraulic mission" (see Allen, 2001 and the October 2009 special issue of *Water Alternatives*), where large-scale infrastructure development was an objective in itself, often oblivious of economic or hydrologic realities. Existing or generated spatial imbalances were then "fixed up" in an ad hoc (and capital-intensive) manner, using pumps and pipes to circumvent the law of gravity (e.g. transferring water from the Chadegan dam to the Mourhab valley, from the Nekouabad canal up to Jalalabad, or from the Zayandeh Rud to distant cities outside the basin). These ad hoc interventions have, locally, both undermined some existing water use systems (e.g. Mourhab valley) and allowed for the intensification of others (double-cropping in the main valley), with associated effects on their respective resilience. But part of ecological transformations also escaped the state because of their local nature but also because legal instruments such as the 1983 law on groundwater and its permit system typically *overestimate* the power of the state to regulate expansion of local uses and interventions. No doubt, the increase in population, the decline in farm size, and a range of social/economic difficulties also reduce both the willingness and the capacity of the state to regulate water use in a context where land is abundant and where any possible "excess" of water that can be tapped at some point will be readily absorbed by expanding cultivated lands.

While the complexity of macro–micro interactions surely makes it difficult for the state to establish adequate water management, constructing a sound and sustainable water regime requires recognition that the state is incapable of reordering the basin water regime by its sole action or by legislation. A sound regime is contingent upon the enabling of multi-level governance patterns, which allow interest groups to negotiate arrangements that bring more certainty, social value and equity to the sharing of water (Bache and Flinders, 2004; Andersson and Ostrom, 2008). It is apparent that such an evolution does not emerge precisely because it is adverse to the interests of those who find personal or political benefits in perpetuating state-centric governance and expansion of capital-intensive infrastructure, and who dominate decision-making. This does not mean that the power of centralized management agencies should be undermined or handed over to the private sector. Rather the nested nature of hydrological scales and the now overriding importance of dam management and bulk water allocation call for forms of comanagement (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 well 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.

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