The ‘closure’ of river basins: trajectories and societal responses

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Abstract

The development of societies is to a large extent dependent upon their resource-base, notably water resources. Access to water depends on available technology and engineering feats such as river diversion structures, canals and dams. As growing human pressure on water resources brings actual water use closer to potential ceilings, societies usually respond by adopting conservation measures and by reallocating water towards more beneficial uses.

This paper reviews various conceptualizations found in the literature of development of river basins over time. A typology of societal responses to water scarcity is then presented. It emphasizes the need to distinguish between responses devised by the state at the global level and those of individual farmers and small groups or communities. Whether these responses occur sequentially is examined by referring to several empirical situations which illustrate that a multilinear evolutionist framework can only crudely represent the specific historical evolutions and patterns that are encountered. A few elements which appear to be crucial in shaping responses are then singled out.

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1 Introduction

The evolution of societies, and in particular the development of their productive activities, is partly determined by available natural resources. Water resources, defined within their river-basin environments, are mobilized for domestic use and food production, and are, therefore, of paramount importance. In early times, when population density was still low, people adapted agriculture to abundant land and water resources. Crops, cropping calendars and elaborate subsistence techniques were attuned to natural conditions of soil, topography, climate and hydrology. Gradually, entire landscapes and waterscapes were crafted, especially under conditions in which it was easy for a small group of individuals to work together to construct a temporary diversion of river water, or under conditions in which early states exercised tight control over large populations to develop large-scale schemes for flood control or irrigation.

In the face of growing human pressure and in the course of time, the supply of natural resources reaches capacity. River basins, and often land frontiers, “close,” in the sense that most water resources are committed or depleted with very few remaining untapped. Water needs come to exceed water availability in river basins and people find that their productive activities are constrained by water shortages. This prompts crises that, in turn, lead to technological innovations and to adjustments and interventions, both in institutions and in the economy. Societal adaptations to changing relationships between people and water-basin resources seem to move through a unilinear sequence of stages, similar to those that Rostow (1962) has theorized for economic growth .

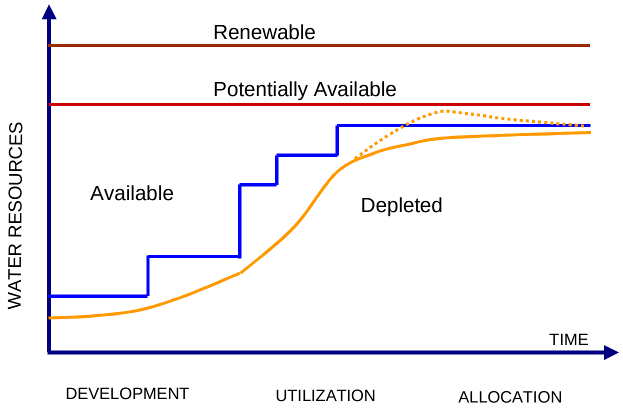
This sequential model of the evolution of the river-basin society has the merit of providing a generic framework to address an issue of worldwide relevance. It also has a great heuristic value in that it brings into sharp focus the crucial phenomenon of basin closure, making it understandable and straightforward. At the same time, its simplicity may not allow us to capture the contingency and deeper heterogeneity of the processes that underlie the historical development of societies. This paper first reviews several approaches to conceptualizing river-basin development. It then shows that distinguishing between several categories of water sources provides additional insight into how water resources are put into use and controlled. A typology of responses to water scarcity and a review of some crucial aspects of river basin development are then used to devise a new framework that is inclusive enough to describe the evolution of a wide variety of river basins and to avoid reducing them to a single, oversimplified model.

2 Common frameworks on River-Basin Development

The literature provides a few (and recent) attempts to theorize about the phases of water resources development. Molden et al. (2001b), for example, distinguish between three phases: development, utilization and allocation (Figure 1).

In the first phase of basin *development*, water use is limited to rain-fed agriculture and some run-of-river water utilization. Dams are constructed in the most convenient locations, either to produce energy and/or to irrigate, while domestic supply remains quantitatively negligible. Large-scale irrigation systems may be constructed. The amount of water effectively used for agriculture and other beneficial uses is less than the available water, much of which simply flows onward to the sea or to the next downstream basin. Water management tends to be based on demand and conflicts rarely arise. Water quality remains good and releasing more water from reservoirs easily mitigates pollution. Ecological systems and environmental functions are not significantly altered.

Figure 1. Schematic development of river basins.



Source: Adapted from Molden et al. 2001b.

In the next phase, the *utilization phase,* shortages of water begin to appear in the driest years and during unusually dry seasonal spells. Storage dams are added to the river as a safeguard against shortages, but adequate sites tend to be rare. Improving management, rehabilitating infrastructures and saving water become critical issues, while pollution problems and competition within irrigated areas become apparent. As the basin nears closure, sectoral allocation becomes a point of tension (*allocation phase*). Efforts are directed at allocating water towards the most economically valuable uses and new institutions evolve to address inter-sectoral competition and manage river-basin resources in an integrated fashion.

The description of Molden et al. draws on earlier works of Keller et al. (1998) and Keller (2000), which also break down river-basin development sequences into three phases, each one being subdivided into two further subphases. The first phase (*exploitation*) includes tapping of easy resources (small rivers, shallow aquifers) and, later, the construction of large-scale storage capacity and the pumping from deep aquifers. When the available water resources in a basin approach full development, the *conservation* phase begins. Saving in quantity generally results in problems of water quality (pollution, salinity) that also need to be addressed. Despite these efforts, a third phase, or the *augmentation* phase, usually starts when the basin is fully closed, whereby additional supply I sought from neighboring basins or from the sea (desalinization).

This framework is also based implicitly on a linear vision of development towards a “mature” situation where uses are attuned to the renewable supply, while water quality is maintained and environmental-flow requirements are ensured. The evolution is depicted as a “*natural* progression of water development in river basin” (emphasis added).

These stages are broadly consistent with a vision of development described in economic terms by Hayami et al. (1976) and Kikuchi et al. (2002). Development starts with the expansion of rain-fed agricultural land. A point is reached where the marginal cost of opening up new lands exceeds the cost of developing irrigation and the *construction* phase begins. The cost of surface irrigation systems rises as irrigation expands into increasingly marginal areas but the marginal cost is shifted downward by technological innovation (e.g. the Green Revolution). Eventually, a point is reached where the cost of new irrigation exceeds the cost of investment in effective *utilization*. Depending on the situation, more effective utilization and better performance will be sought through better control and management of surface-water flows, recycling water by pumping from drainage ditches, and development of groundwater resources. This economic view focuses on technology and on the costs of development and management. It neglects transaction and political costs of institutional reforms.

Another conceptual framework for water-resources development has been developed by Turton and Ohlsson (1999). They also distinguish between three phases, in which water scarcity is answered by different strategies. During the first phase (*supply*), "the individuals surrender their responsibility for providing water for themselves to a central authority," which embraces a hydraulic mission devoted to large-scale hydraulic infrastructure. Later, water deficits arise and demand management (*demand phase*) first consists of raising the efficiency of use, and then of operating intra- and inter-sectoral reallocation of water resources. In a third phase (*adaptive*), the society has to cope with absolute water scarcity and must bring water demand in line with a sustainability level defined by annual renewable resources. This description is similar to the preceding ones[2] but Turton and Ohlsson's (*ibid.*) analysis goes beyond the quantitative analysis of imbalances in supply and demand, and discusses the societal responses induced. They are interested in the links between the nature and legitimacy of the "coping strategies" devised by decision-making elites and social stability. In particular, they see the emergence of water deficit conditions (demand phase) as a crucial period where environmentalism is likely to gain momentum and where the adaptive capacity of the social entities concerned is put on trial.

Ohlsson and Turton (*ibid.*) distinguish between a "first-order scarcity" of natural resources (water), and a "second-order scarcity" of the social resources required to adapt to the former. They have reformulated their framework as the "turning of the water screw," where engineering development, improvements in end-use efficiency, and allocative reforms, are seen as the three successive responses that are needed to address a persistent water scarcity. Although they claim to go beyond the kind of linear vision described above, this reformulation does not really provide a conceptual alternative, although it adds a more intuitive visualization of the fact that every turn of the water screw is "tighter." That is, the social resources needed to achieve it are increasingly high.

In addition, Ohlsson and Turton (*ibid.*) are also concerned with distinguishing between situations in which social resources enable society to adapt, and others where conflicts and social unrest are likely to be the outcome. In particular, they do not necessarily posit that crises generated by water scarcity will be eventually solved, especially with regard to ecological impacts, rightly shifting the attention on the adaptive capacity or social capital of societies.

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[2] Although the demand management phase includes both conservation and allocation strategies, while the adaptive phase is construed as an additional phase where social stability is at risk and major societal adjustments are needed.

3 The Demand-Supply Equation and Adaptation to Scarcity

The conceptual frameworks reviewed above hypothesize about the nature and chronology of the challenges and responses that society faces, with respect to water resources. The underlying assumption is that population growth puts pressure on water resources and that this, in turn, creates challenges for the society and leads to a gradual closure of the basin. The focus is here on basins with significant and growing anthropogenic pressure and it is reasonable to retain both the gradual closure and consequent adjustments/conflicts as general phenomena. What is debatable, however (and questioned in this section), is whether the sequences described in these frameworks are found in all basins, and whether responses are similar, or if a more inclusive framework can be designed.

It is hypothesized here that societal responses to water scarcity comprise a set of several strategies defined both at the individual/community and state levels, and elaborated or induced, based on several location-specific factors, without any other assumption about a possible "natural" order or sequencing.

3.1 Range of Responses

While Turton and Ohlsson (1999) emphasize the way "technocratic elites" devise "coping strategies" to respond to water scarcity, they tend to overlook the multileveled adjustment of society to basin closure. In particular, they do not account for local adjustments made by individual users, or groups of individuals, and by local managers/officials in addition to the state. This constrains the analysis of processes and lead to envisioning future changes as governed by the decisions of the state and its elites. Broadening the scope for analyzing actors' responses provides a richer understanding of the processes at work. We will distinguish herein between micro/local and macro/global adjustments. These two types of adjustments can be further broken down into three categories. (These are similar to the three consecutive steps mentioned by Ohlsson and Turton [*ibid.*], but, at this stage, no hypotheses are made on the order in which they materialize).

1. Supply responses: These consist of solving water scarcity by augmenting the supply from existing sources (foremost, increasing the quantity of controlled water), as well as tapping additional sources. Typically, this is done not only by constructing new reservoirs or digging more tube wells but also by diverting water from neighboring basins, desalinizing seawater (which is tantamount to importing and treating water from a sink), by artificial groundwater recharge or by cloud seeding.

At the local level, farmers may tap shallow or deep aquifers and also invest in local storage facilities (most commonly farm ponds, which are used to store excess irrigation flows or rainfall). They also develop conjunctive use of water, by using water from drains, rivers, ponds and even by pumping from irrigation canals when the water level does not allow for gravity inflow to their plot. Thus they broaden their access to a variety of sources and augment their individual potential supply.

It is already apparent here that the relationship between local dynamics and the basin (macro level) must be considered. For example, pumping water from drains increases supply locally but not necessarily at the macro scale, if the pumped water was to be reused downstream.

Techniques and interventions aimed at capturing more rainwater, for example, water-harvesting techniques aimed at increasing groundwater recharge, can also be considered as means to augmenting one's effective supply.

At a more global level, the import of food stuff is also an indirect way to increase water supply, or at least water supply as a necessary factor of food production and security. This transaction is often referred to as *virtual water* because of the water used by the crops that comes embedded in food stuff.

2. Conservation responses: The key phrase here is "efficiency in use." Conservation refers to making a better use of existing resources, without increasing supply or the sources of water. Line agencies may not only implement structural measures, such as lining canals, controlling leakage in pipe systems, or treating and allowing the reuse of wastewater, but also resort to nonstructural measures, such as improving dam or canal management (so that unproductive or nonbeneficial releases are not lost[3] to the sea) and establishing rotations or other arrangements for a better scheduling. The state is also instrumental in devising and enforcing policies that may elicit water savings, such as water pricing, rationing and quotas. In these two latter cases, conservation aims at "doing as well as before with less supply," rather than "doing more with the same amount."[4] The state may also supply innovations derived from research (plot-level water management, improved varieties, and cultivation techniques).

Improved coordination between users and innovative organizational patterns may also contribute to water savings and can be mentioned here, particularly in the setting of water-user groups or river-basin organizations. Subsumed in the "conservation strategy" are, more generally, better management practices that not only tend to conserve water but may also increase equity or reliability in water supply.

At the local level, farmers and groups of farmers are not passive. Saving water may, for example, come from shifting calendars or raising bunds around rice fields (to make a better use of direct rainfall), adopting adequate cultivation techniques (such as mulching, the alternate wet/dry water regime in rice farming, shortening of furrows, etc.), or choosing crop varieties with a shorter cycle. These farmers or groups of farmers may also invest in water-saving technologies, such as micro-irrigation. However, such technologies may sometimes result in better control of irrigation doses and in an increase in the amount of water depleted by evapotranspiration (see an example for Chile in Cai et al. 2001). The water saved thereby may also be used to increase the farmers' irrigated area (see Feuillette 2001, for an example in Tunisia), further reducing the return flow available to downstream users. Therefore, expected water savings at the basin level may or may not occur and may also have an adverse impact on other users. Here, too, a case-by-case cautious analysis must be carried out to fully understand the relationships between the local level and the macro level.

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[3] Again, this does not mean that all water reaching the sea is lost, since minimum flows are essential to maintain ecosystems and control salinity intrusion in lower reaches of the rivers. These losses must be understood as the extra water that reaches the sea after abstraction by all other users, including environmental services.

[4] These two situations are rarely distinguished, although they differ fundamentally. In the latter case, the incentive to conserve water is strong, and users' adjustment forced by circumstances and generally effective. In the former case, users may or may not be willing to take necessary steps to conserve water.

3. Allocation responses: A third type of strategy consists of reallocating water from one user to another, either within the same sector (e.g., within or between irrigation schemes) or across sectors. This reallocation may be justified by a concern to raise water productivity, but the objective may also be to ease tension by favoring uses which enhance land productivity, food security or equity, or reduce conflicts and protests. This broadens the principle that water should be moved to uses that are economically more beneficial, to which reallocation is usually attached, towards an approach whereby reallocation is a means to reduce and better spread out the overall pressure on water resources.

Reallocation can occur within the farm, when a farmer chooses to direct his/her limited water resources to the crops that give him/her a higher return per m^3 (assuming that risks and marketing conditions are similar for all crops).[5] At the irrigation-system level, managers allocate water, based on a set of factors. This allocation can be more or less even in terms of water duty per hectare, but it can also be driven by other considerations: for example, areas that are too distant or endowed with sandy soils may be excluded because they incur too high losses. On the other hand, reducing canal head-end/tail-end differences is conducive to higher equity and, often, to increased economic efficiency (Hussain et al. 2003).

At the basin level, managers also have the possibility to reallocate water according to a given priority system. Within the agriculture sector, water can be shifted from one area to another with comparative advantages regarding water productivity (typically, areas with orchards or aquaculture). The rationale for inter-sectoral transfers is generally economic: water is channeled to cities for domestic uses and industries before agriculture, where the economic return of one cubic meter of water is much lower. Such allocation decisions are, of course, not only potential sources of conflicts and tension but also sometimes mediated by market mechanisms or negotiations. Groups of users within an area (e.g., a catchment or an irrigation scheme) may also agree to renegotiate rights in order to ease tension. To some extent, giving up agriculture (or other water-consuming activity) can also be interpreted as a strategy that allows one's water allotment or right to be reallocated to other uses.

At a more global level, water can be reallocated to nonagricultural uses at the cost of lower food production if imports are increased accordingly (see *virtual water* mentioned earlier).

The conservation and allocation responses are often pooled together under the concept of water *demand management*, which can be typified by "doing better with what we have," as opposed to supply augmentation strategies.

Figure 2 synthesizes these different responses and shows how the three categories can be broken down in two sublevels. It must be emphasized that the definition of these categories cannot be totally freed from ambiguity, because of the complex relationships between local and basin-level processes: a farm pond dug out by a farmer can be seen as *conservation* if it captures some canal water that would be further lost (to sinks, to nonbeneficial evaporation or flowing out of the system), but it may also be a *reappropriation* if this water was ultimately to be used by some downstream users. The pond can also be considered as an augmentation of the *supply* to that particular farmer if it captures runoff that was lost earlier. In practice, because it

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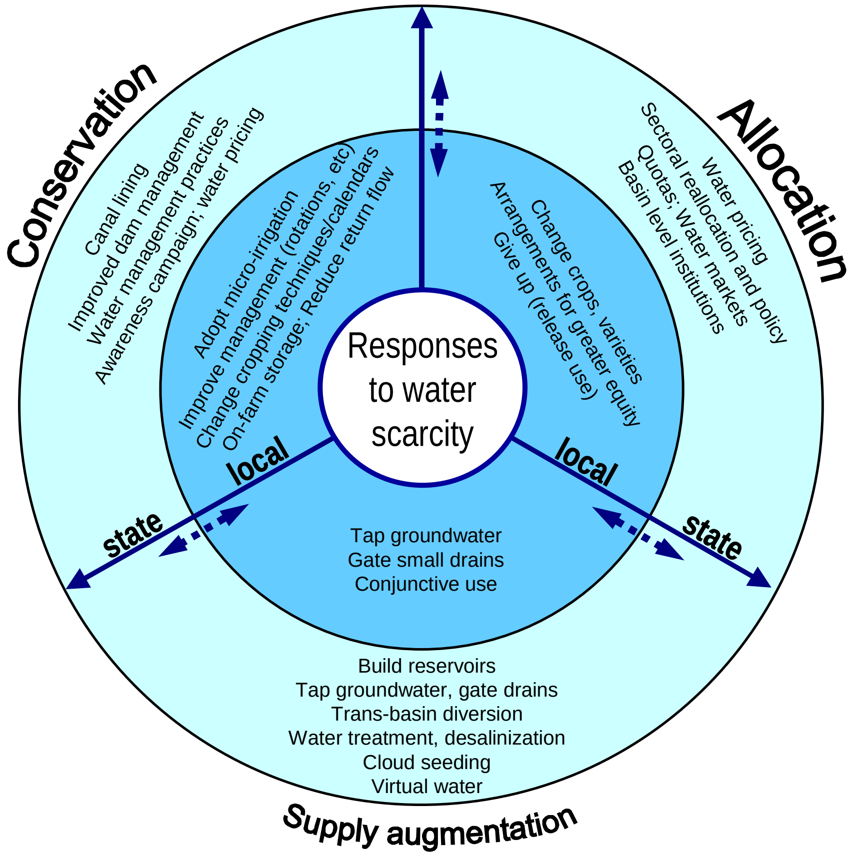
[5] Again, clear-cut definitions are not always possible. A crop shift can be either a conservation measure (less water used), a reallocation to a more productive (crop) activity (more $\$/m^3$), or both.

is not always possible to establish what fraction of a specific return flow is eventually lost or reused, it may not be possible to define a precise terminology.

The same difficulty arises when new tanks are constructed in the catchment area of an existing reservoir. Normally, isolated tanks capture runoff and transform it into controlled water but, in that case, the flow captured by these new tanks was already potentially *controlled* by the reservoir into which it would have flowed, if the new tanks had not been added. Overall, there is no or little increase[6] of controlled water but a mere *spatial redistribution* of the resource. Likewise, trans-basin diversions, and even cloud-seeding, can be considered as supply augmentation from a narrow/local point of view, but they can also be treated as spatial redistribution (or reallocation) when seen at a wider scale.

Figure 2. Types of responses to water scarcity.



These examples show that the measures taken at the two levels (individual and collective) schematized in figure 2 are not purely additive. This fact, however, should not be treated as "noise." The relationship between micro- and macro-processes is, in fact, at the core of the analysis. Because the closure of river basins results in a growing interdependence of the users within the basin, one must carefully analyze how the paths of the different surface and

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[6] An increase occurs if the amount of spill in the reservoir—now reduced—was formerly lost out of the system. This is more or less significant depending upon the dimensions of the reservoir relatively to the hydrologic regime (and, of course, upon what downstream users and ecosystems there are).

underground flows are interrelated and how any local intervention that modifies the quantity, the quality or the timing of one of these flows impacts on the whole system.[7] What is stored, conserved or depleted at point A dictates what is available at point B, further downstream.

Likewise, it is not always possible to separate decisions taken by farmers from the economic environment that is shaped by State policies. The adoption of micro-irrigation, for example, might be an individual decision influenced by the availability of subsidized credit supplied by the state. (This is symbolized in figure 2 by the arrows that link the two layers).

Figure 2 also highlights that actors within the system are not passive and inactive. On the contrary, they respond individually and collectively to the growing water scarcity, just as agrarian systems respond to changes in the relative scarcity of other production factors. This has been shown by case studies, such as by Zilberman et al. (1992) for California and by Molle (forthcoming) for Thailand. State-driven responses are only a part of the transformation, although officials tend to see rural areas as globally static and malleable through public interventions (infrastructures or otherwise), overlooking the constant endogenous adjustment of rural households and communities, as well as of line managers, to changing conditions.

3.2 Context-Specific Responses

The question under consideration here is whether the types of responses categorized above occur sequentially, as suggested by the different linear framework reviewed earlier. Keller et al. (1998) or Kikuchi et al. 2002 place emphasis on the economic logic of the sequence of development. At any point in time, the cheapest solutions are selected, from simple flow diversion through desalinization, or from upland reclamation to demand management. In Ohlsson and Turton’s (1999) approach, the logic of the succession is based on a scale of complexity, the solution of water-scarcity problems demanding ever-increasing levels of social resources. It is thus assumed that hydraulic development is the easiest response, and that its exhaustion leads to conservation efforts, later followed by allocative decisions and adjustments. The latter are regarded as much more sensitive and are prone to generating social conflicts and widespread disruption. These analytical grids probably apply to many cases but may not capture important nuances found in varied situations. The following examples provide instances in which the “natural” sequencing, or part of it, as proposed by the abovementioned frameworks, does not represent satisfactorily the historical transformations observed.

- Sakthivadivel and Molden (2001) have compared five basins said to be at different stages of evolution and have found that the problems faced by these basins were different. However, some of the problems encountered were not those that would be typical of the phase in which each basin was assumed to be. For example, in the Singkarak-Ombilin basin, Sumatra, which is considered to be at the beginning of the utilization/conservation phase, it seems that water allocated to nonagricultural activities and trans-basin diversions threatens to throw the basin directly into the third phase, where water rights and reallocation rules need to be defined. The East Rapti basin in Nepal is an open basin, with only 5 percent of

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[7] See Keller (2000) with regard to water management in California, and Molden et al. (2001a) who developed the concept of hydronomic zones, with a call to reason interventions based on a zoning of river basins. “Hydronomic zones are defined to characterize the combination of hydrologic and water-use settings within a basin. The zones are based primarily on considerations of outflow of water from the particular areas” (Molden et al. 2001a).

water resources used by agriculture. In spite of this, water pollution from industries and competition for river water during the dry season among wildlife sanctuaries, tourist requirements, ecological requirements and human use are apparent problems that are normally associated with later phases of development.

- More generally, most of Africa, with the exception of northern and South Africa, is characterized by a still limited development of infrastructures. The number of large dams in a continent that makes up 20 percent of the world area amounts to only 1,192 out of a total of 24,864 worldwide (IWMI 2002). A conjunction of endogenous and exogenous factors has constrained large-scale development of water resources, while problems related to other phases have emerged.
- In some basins, tapping shallow aquifers occurred in the inception phase of development (Keller et al. 1998) but in many other cases the spread of wells was a late reaction to poor access to surface water (see Thailand, Bangladesh, India, etc.). The availability of technology and the investment capacity of users must also be considered.
- Very often too, large dams were not constructed to increase supply but to control flood and generate electricity. Because their potential has been then—often later—taken advantage of to develop irrigation areas, demand consequently built up *because* of the new supply, rather than demand for water being a driver of supply development. This has often been the case in river basins of the United States (Wengert 1985).
- Problems of pollution are generally associated with late phases in which the scarcity of the resource does not allow adequate mitigation by dilution, but it may also happen very early if there are significant point sources of pollution with little regulated water to ensure dilution (such as with mines in South Africa).
- The need to design more complex and integrated forms of organization at the basin level are associated with an ultimate phase of “allocation” of very scarce water resources but, in some cases, as with the case of France in the 1960s, it was the problem of water quality, not quantity, that was the driving force behind the establishment of the “Basin Agencies” (despite both aspects being interlinked).
- Trans-basin diversion is generally considered as a possibility to “reopen” the basin after it has closed but this option is often taken at much earlier stages of development (at the first stage), especially in small and medium basins. This was commonly achieved in Sri Lanka at least as early as the fifth century (Mendis 1993) and has remained a basic principle of water-resources development ever since. Such transfers are also typical of irrigation in mountain interfluves, where irrigated areas straddle the boundary of two adjacent basins (e.g., in the Andes).
- It seems that, in many cases, the later phases of basin closure employ not only allocation strategies but, more pragmatically, *all* the options that may help relieve pressure. The case of California, as described by Turral (1998), clearly shows not only that efficiency and allocative measures are both sought in parallel but also that the gains they provide are more limited than are commonly believed and need to be accompanied with a substantial amount of supply augmentation. Closure does not end up with allocative strategies but, rather, elicit continuous improvements on the three “fronts” (conservation, allocation, supply).
- In contrast to the impression that the current focus on the economic value of water is characteristic of a late phase of water-resources development, the British period of the

Indian history clearly shows that all the questions currently debated on the economics of irrigation were already prominent ones. The questions of who was to finance infrastructures (local revenue, the Crown, or private interests), whether and how a water fee should be charged and what its impact on different categories of people is, whether it should be increased, whether it could influence crop choice or water-use behaviors, to cite a few examples, were fiercely debated from the beginning of the nineteenth century onwards. Privatization, bulk volumetric pricing and crop-based differential rates were experimented with.

- Not all trajectories are upward. Historical examples of civilizations that have not successfully maintained their resources base and have collapsed can also be easily found. For example, aerial photographs of some basins in Sri Lanka reveal a very high density of small tanks that have been abandoned, silted or destroyed. After Independence (in 1948), new water-resources developments have sometimes been superimposed upon the older systems, and larger dams have been built. Other examples include ancient Mesopotamia in the ninth century (cf. Pointing 1991) and, more generally, all the impacts of climatic change, salinization or tectonic change that are often overlooked in historical studies (Brown 2001).
- The “averaged” vision inherent in the trajectory concept may also obscure the heterogeneity of on-the-ground reality. Subareas in the basin are often at different stages of evolution and the problems they face, as well as the solutions to these, vary significantly. Molden et al. (2001a) have attempted to address this issue by defining “hydronomic zones” within a basin.
- Spatial heterogeneity is paralleled by human heterogeneity. When considering the diversity of farming systems, one finds at the same time different individual responses: water conservation, intensification, diversification, giving up agriculture, etc. Factor endowments, farmers’ agency and market opportunities, among other things, shape individual strategies and, therefore, it is not always possible to describe the resulting aggregated trend at the basin level in a simple way.

3.3 Critical Elements Shaping Basin Development

The above examples suggest that specific historical evolutions and patterns can be easily encountered. Investigating in detail the causal correlations between particular physical/societal contexts and historical transformations of river basins is beyond the scope of this paper, but this section attempts to single out a few elements that appear to be crucial in shaping responses.

- *The Nature of the State and State/Citizenry Relationships*

The state is often described as the main actor that shapes all river-basin evolution by virtue of its investments and policies. Turton and Ohlsson (1999) identified the building up of its power with the beginning of its embracing of the “hydraulic mission.”[8] As mentioned earlier, this emphasis tends to obscure the magnitude and significance of endogenous efforts undertaken by local actors, especially in their development of conjunctive use. It also fails to account for situations in which resources are principally managed by the users themselves, such as in the

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[8] It is not always very clear whether Turton and Ohlsson (1999) refer to river basins or countries.

case of the tank systems of South India or of the mountainous regions of the Andes, Nepal or upland Southeast Asia.

The nature of the center/periphery and state/citizenry relationships defines the scope and the room for maneuver and adjustment allowed to the different actors in the system. Authoritarian or despotic states may be more often associated with large-scale development and centralized management (regardless of how the causality is theorized), while weak states may leave more scope for local initiatives. The degree of decentralization and democratization also obviously influences how negative impacts (particularly on health or the environment) are both perceived and addressed.

The role of the state often changes over time. Ruf's (2001) description of the Prades Valley in the south of France shows that, during its five centuries of existence, the irrigation system has been managed, in turn, by the state, communal associations and private entrepreneurs, and that these changes could be traced to the prevailing nature of the center/periphery relationships defined within the wider political and historical context. Theories of induced institutional change tend to see changes as occurring by necessity, in response to a mismatch between demand and supply, and do not account for the (numerous) cases where the power and political structure eventually dictates and supplies new institutions and forms of organizations (see below).

Potkanski and Adams (1998) describe the response of the Sonjo, in Tanzania, to water scarcity and show the interrelationship between agricultural commercialization, property rights and water scarcity, on the one hand, and the complex and tightly interactive relations between local institutions and the state on the other.

Economic power and political will are often associated, and small communal schemes may be captured and enlarged when new actors, such as local lords or colonial estates, come into play. Larger-scale interventions that are beyond the scope of local actors may be later undertaken by the state or by some capitalistic private entity.[9] When basins are developed in stages, defined by successive historical, economic and political contexts, then several phases of supply augmentation followed by growing water scarcity and resulting conservation/allocation measures are likely to take place. This scenario differs from that of the above frameworks, which tend to hypothesize one single compact phase of state intervention and "heroic engineering" that exhausts (or nearly exhausts) the physical opportunities for such interventions.

Turton (1999) posits that a popularly supported legitimate government will be able to introduce measures that an unpopular government will not be able to escalate. This is consistent with the hypothesis that reallocative strategies are likely to be unpopular, but the link with the dichotomy of democratic versus authoritarian regimes is not developed. In fact, it is evident that the latter may sometimes reallocate water with more facility, irrespective of whether this is done in a sound manner or not.

- *The Political Economy of Water Resource Development*

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[9] Ruf's (2001) paper also provides such an example in the Ecuadorian Andes.

Clearly, the economic rationality described by Keller et al. (1998) has a strong impact on the choices that are made. However, it is necessary to go beyond a formal model of rationality towards a political-economy approach, where decisions are understood not only on the basis of their actual financial costs but also on the benefits and increased power that accrue to the different categories of actors within the society, and sometimes beyond.[10] Costly (and even absurdly costly) solutions such as groundwater recharge by injection or trans-basin diversion are sometimes justified and implemented in lieu of demand-management options because they fit the logic of pork-barrel politics and serve as substitutes of other more politically risky options. The conflicts between politicians, construction firms, consultants, local population and environmentalists, provides the best example of how the decision about building a dam is eventually debated in a political arena, where financial or political interests coexist with environmentalism, communitarianism and concerns for local livelihoods.

Another way to look at these societal debates is to weigh the monetary costs of infrastructural development (and their financial benefits) against the transaction and political costs of more demand-management-oriented options. The difficulty of reforming management, including efficiency and/or equity aspects, varies depending on many cultural, social and political factors. But it is recognized that "regional politicians have a powerful intuition that economic principles and the allocative measures, which follow logically from them, must be avoided at all costs" (Allan 1999). This largely explains the persistent gap between consultant's and expert's rationality and the actual adoption of policy measures in the real world. It also provides hints on why strict economic logic is not always the best criteria to understand the succession of state investments and responses. Resource capture can occur at any time, depending on the power balance within the society and is perhaps more frequent than rational allocation. More generally, the responses given to water shortages depend on which constituency succeeds in making its discourse legitimized and accepted (Ingram 1971). The example of water conservation in the Imperial Valley Irrigation Scheme, southern California, given by Waller (1994) neatly shows how local influential farming elites associated with irrigation managers could legitimize policies which shifted the cost of conservation onto other parties. Rather than accepting on-farm conservation systems, which would have raised the amount of time and effort needed in farming, as well as the reliance on hired labor, these elites successfully pushed for temporary measures of land fallowing for which they would be compensated.

This leads Wester and Warner (2003) to call for a vision of water as a politically contested resource and the closure of river basins as a political process where the overexploitation of resources is accompanied by changing patterns of access to water, and by the legitimization of certain forms of basin management by the production of dominant water discourses.

It is interesting to note that the financial costs of the three main responses (supply augmentation, conservation, allocation) options are generally in a decreasing order.[11] The lesson that can be drawn from this is that decision makers in most societies have an inverted

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[10] Barker and Molle (2003) stress how investments in large-scale infrastructure during the cold war can be partly ascribed to geopolitical considerations. The "lending culture" of development banks has also been criticized as reflecting either the interest of western construction firms or that of the banks in increasing the scale of their interventions.

[11] Except for the case of water treatment, it can be posited that investments in urban water supply and sanitation create the potential for a "new construction bonanza" (Turral 1998), similar to that of the earlier "hydraulic mission."

perception of what the costs to the society are, or more to the point, of how the political and financial "benefits" accruing to them and to their supporters compare with the political costs and the risk of societal discontent incurred.

- *Shock Events*

The responses and behavior of water users and of the society at large regarding water use and water-related problems depend on their perception of the magnitude and seriousness of these problems. This perception, in turn, is often sharply influenced by extreme natural events, such as typhoons, droughts and floods, which are generally accompanied by food shortage, disasters, and the disruption of livelihoods. Waves of dam construction are often launched after severe droughts or famines, such as in Burkina Faso or Northeast Brazil (see Molle 1991). The drought periods of 1987-1991 in California (Zilberman et al. 1992; Keller 2000), of 1992 in Turkey (GDRS and IWMI 2000), of 1982-83 in Australia (Turral 1998), of 1986 in Israel (Allan 1999), and of 1991-94 in Thailand (Molle et al. 2001), to mention a few examples, have catalyzed a series of significant local and global responses. Dams are also designed in response to floods, as the case of the Tennessee Valley Authority well exemplifies.

The most significant example of a crisis, however, remains the El-Niño-related climatic perturbation of 1972, which severely affected grain production and sent prices rocketing up. The psychological impact of this event on both national decision makers and western countries (engaged in the Cold War and bent on investing in countries potentially threatened by the spread of communism) was so high that much of the huge investments in dams and irrigation infrastructures that were to follow can be ascribed to the threat of food shortage in the particular geopolitical context of the time (Barker and Molle 2003).

Shock events often allow politicians to impose policies that would have been otherwise unpopular and opposed. Allan (1999) has remarked that politicians are more likely to wait for the exhaustion of resources and the surge of crises before embarking on draconian reforms.

Other shock events with a dramatic impact on agricultural development in general and water resource use and development in particular, are political events, such as wars, revolutions, agrarian reforms, etc. The periodization of water-infrastructure development in Vietnam (Tessier and Fontenelle 2000) or in China (Lohmar et al. 2002), for example, neatly dovetails with that of political upheavals and reforms. Likewise, the collapse of the Mesopotamia irrigation in the early Middle-Age owes a lot to the impacts of wars and epidemics (plague) (Christensen 1998).

- *"Spatial Equity" and Regional Politics*

Another important point drives the choice of supply augmentation as a response. The economic rationality at the basin or country level has to be combined with a notion of "equity" that pervades regional politics and, more often than not, conflicts with economic criteria. The regions with lower comparative advantages stand to lag behind other regions and often display higher levels of poverty. These "problem" regions, therefore, turn out to be the target of special investments, which generally have a low return. Political and socioeconomic concerns dictate such investments.

An example in point is that of "overbuilt basins," where regulated water resources are insufficient to serve the existing irrigated areas, but where more irrigation schemes are built based on the claim that the regions not benefited hitherto also have a right to receive investments. This, Ingram (1971) noted, is supported by the strong local sentiment that water is always locally thought of as “our” water. Local sociopolitical dynamics and strategies conflict with macro considerations and logic, a typical example of basin-level issue. When decentralization means that local regions or provinces have the mandate to design local strategies without considering their impact at a wider level, these situations are often very salient. The Mekong delta offers a good example of how provincial plans are based on the same freshwater resource, and how their combined impact on the whole delta hydrology might have catastrophic consequences on salinity intrusion in dry years (Can Tho University and IRD 2001). In other words, the micro/macro dialectic of water use within the basin is paralleled by a similar spatial interconnectedness with regard to economic planning. The result is often “artificial” scarcity created by overcommitment of resources, fostered by flimsy knowledge or consideration of hydrology, and promoted by developmentalism. In Algeria, for example, the World Bank supported both irrigation projects and urban water supply networks in competition for the same scarce resource (Winpenny 1994).

A particular form of the impact of regional politics on water resource development is well exemplified by the case of the U.S.A. The states wishing to see their local projects funded by federal agencies need to muster support from other states in order to obtain congressional acceptance. This “pork barrel” politics leads to the spread of projects with very low return and, often, environmental impacts. The case of the Central Arizona Project (CAP) discussed by Welsh (1985) shows how Colorado garnered projects for its vote authorizing the CAP and how other states like New Mexico, Utah, and California could take advantage of the CAP to claim for their own projects (Welsh 1985).

- *Agrarian Pressure and Agrarian Transition*

Individual and societal responses are also strongly governed by the alternatives of livelihoods offered to people and to what can be termed “agrarian pressure.” If strong population growth occurs in a context where nonagriculture sectors are unable to absorb the excess rural labor, then the pressure upon land and water resources is likely to increase. This translates not only into greater agricultural intensification and water conservation but also into water-quality degradation and conflicts. If water supply to agriculture is squeezed, then the social consequences on the rural world (and also the possible political clout of the farming sector) are likely to trigger state responses (as exemplified by the subsidizing of western agriculture). On the other hand, if favorable alternatives are supplied within the wider economy, water users with deficient supply will be encouraged to diversify their activities or to simply give up farming, thus easing the tension on resources.

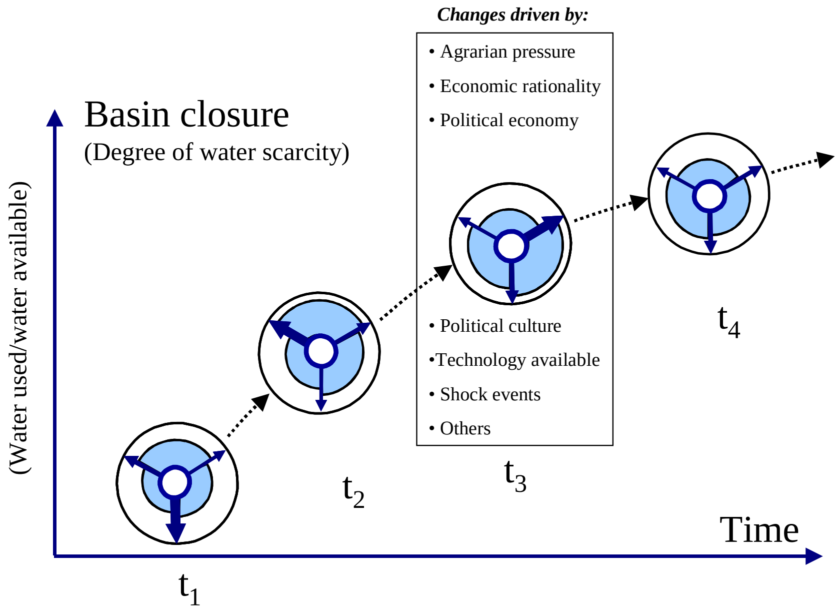
Agrarian pressure is also directly linked to household incomes and, therefore, at least for those products with a degree of import/export, to the price of commodities in the world markets. This price, in its turn, depends on a more complex and global equation that includes food production, population growth, productivity, as well as all other variables that impact on or distort markets. The Middle East provides a good example of a region where water policy is “subordinate to the political economy of global trade in staple food” (Allan 1996).

The intensity of societal demand for change, the individual responses to the deterioration of access to water, the relative growth of the different economic sectors and the impact on water use are all interrelated with macro-economic settings.

4 Basin Trajectories

Acknowledging the variety of societal responses to water scarcity and the complexity of the determination of which particular response appears at a certain point in time, we may represent a river-basin development trajectory by the graph shown in figure 3. The schematization retains the general evolution towards basin closure, although it is also recognized that a basin can be "reopened" (see below). The succession of circles (corresponding to that of figure 2) represents successive adjustments to water scarcity, which are made by the implementation or the inducement of a range of individual, collective, and state responses that come under three categories (supply expansion, conservation, allocation). (The varying respective shares of the inner circle [local] and the outer circle [global], as well as the varying sizes of the arrows, symbolize that the relative importance of each response varies depending on the point in time).[12]

Figure 3. Basin trajectories (1).



Which strategies have been implemented at a given point in time, and similarly what options are more suitable for the current situation, can only be determined based on a sound analysis of all relevant physical, economic and societal factors. The preceding section provided examples of issues situated at the convergence or interface of several of these important factors.

Figure 4 proposes a variant of figure 3 and introduces two visual modifications. The first one represents a possible (albeit transient) breakdown of the system, while the second indicates successive potential ceilings towards "resource closure." This accounts for the fact that if total renewable basin resources can be hydrologically defined, the share that is available at one point in time often depends on the existing technological level. In other words societies are faced

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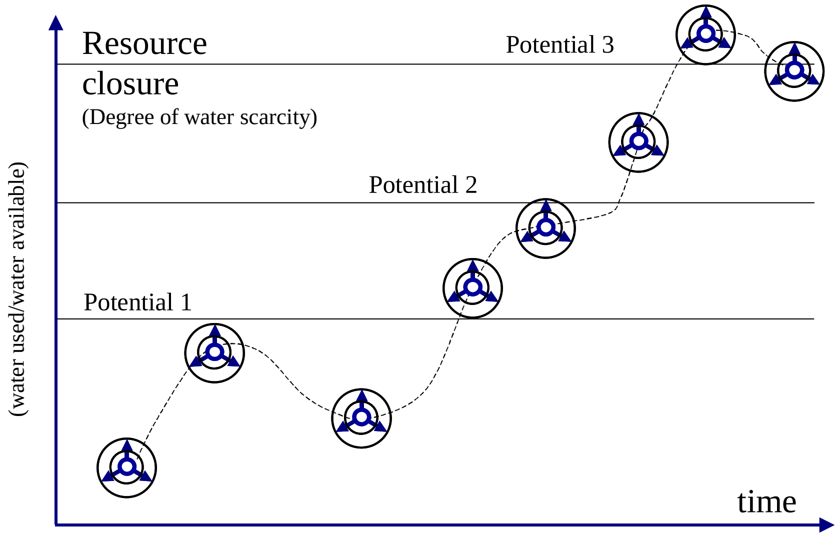
[12] The sizes and shares indicated here are arbitrary. This graph should be taken as a conceptual representation rather than a concrete visualization of a particular change.

with different ceilings that may shift with time but that are sensed as absolute ceilings for a certain period. Basins can be reopened, and often are, by achieving a new increment in supply through a costly investment that was formerly thought not technically or financially feasible. This, in particular, includes trans-basin diversions, which are much more common than is usually believed. Only 20 percent of the water used by South California, for example, is generated locally, as the region is mostly supplied by water from the Colorado river (57%) and from the north of the State.

The figure also reminds us that unsustainable management may lead to using resources beyond the potential threshold. This means that aquifers may be "mined" (or depleted faster than they are replenished), and reservoir security stocks tapped during a few consecutive seasons. It is not sure, either, that unsustainable management will always be tackled in an appropriate manner, since many aquifers are probably doomed to be mined until exhaustion (or, in practical terms, until abstraction becomes economically unviable).

Figure 4. Basin trajectories (2)



4.1 Demand-/Supply-Driven Innovations

Beyond the identification of driving forces of change, remains the question of a more general theorization of technical, institutional, and societal change in relation to resource bases. Molden et al. (2001b) argue that as basins develop, new forms of organization and rules are required but they take the view that new "institutions [inevitably] evolve to fulfill management requirements," and they do not address the issue of whether and how these institutions emerge.

The evidence that some societies seem to avert crises (as well as to "reconstruct" resources after their degradation) through the mobilization of appropriate innovations and new institutions, while others do not, has led Ohlsson (1999) to posit that some societies were endowed with "adaptive capacity". However, he does not provide many clues on what makes societies endowed or deficient in "adaptive capacity." Therefore, stating that some societies adapt because they have enough "adaptive capacity" might be seen as tautological. Turton (1999) distinguishes a first social component, "existing in the hearts and minds of the governed," which basically defines the willingness and ability of the people to accept the measures to be taken, as well as the ability and legitimacy of the regime to generate the needed strategies. The second component can be engineered to some extent and consists in the capacity to mobilize and analyze data and information, and to derive adequate strategies. While stressing the importance of quantitative information and human resources, he does not fathom the societal term, which "is the difficult one to come to terms with."

Much of the theories of institutional changes derived from the works by Hayami and Ruttan (see for example 1985), as well as later New Institutional Economics (NIE) approaches, tend to emphasize the demand side of change, with its links to changes in relative resource endowments and technical change. Individuals, seen as rational entrepreneurs, respond to both "deadlock situations" and opportunities. It would be naive to assume that constraints faced by a society give way, through a perfect, market-like mechanism, to a solution that minimizes transaction costs and improves efficiency (Wegerich 2001). It must be acknowledged that the distribution of the power embodied in the access to (water) resources is a societal, historical construction, where equity and efficiency might not be the chief aspects. As emphasized by North (1995), "institutions are not necessarily or even usually created to be socially efficient; rather they, or at least the formal rules, are created to serve the interests of those with the bargaining power to create new rules." This is also emphasized by Feeny (1988) who sees the benefits and costs to the elite as a main determinant of change. A policy implication of this is that ignoring power structures is likely to doom bottom-up movements or policies to failure (Wegerich 2001; Schlager and Blomquist 2000).

5 Concluding Reflections

Population growth and economic development translate into growing pressure on water resources. In the course of time, the interdependence of users in the basin increases and conflicts arise. Scarcity elicits adjustments in water-supply augmentation, water-use efficiency and in water allocation. Several existing conceptual frameworks that provide a description of basin development have been examined. The great merit of these frameworks is that they offer a simplicity of reading that conveys the notion of basin closure with great strength. They are based on a sequence of phases that is widely relevant to depict the evolutions observed during the twentieth century in many basins or countries. The downside of these approaches, however, is that the simplification of reality does not always allow one to fully capture or understand the geographical and historical diversity of river-basin development.

The different types of responses to scarcity may occur concomitantly or sequentially, not always in the order proposed by existing frameworks. Adjustments in water-supply management, allocation and institutions are made not only by the state but also by individuals and groups, and are characterized by their interrelatedness. Each time a decision, taken either locally or at the global level, impacts on water flow paths in terms of quantity, quality or timing, other users are likely to be affected somewhere else in the basin. The characteristics of each basin command a particular pattern of evolution, which may include gridlocks, collapses and the diversion of water flows across basin boundaries.

Existing linear visions of basin development tend to be based on economic rationality or on concepts of social adaptiveness that are difficult to evaluate. Societal responses to scarcity of resources are driven not only by economic considerations or locally perceived needs. They must be understood in the wider political economy framework where costs and benefits are attributed to different categories of actors who, often, have antagonistic interests that are not even internally homogeneous. The particular blend of responses selected by a society at a particular point in time of its history to address water-resources problems must therefore be understood within a framework that spans not only hydrological, physical or economic constraints but also the distribution of agency and power among actors, and their respective interests and strategies.

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