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River basin closure: Processes, implications and responses

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ABSTRACT

Increasing water withdrawals for urban, industrial, and agricultural use have profoundly altered the hydrology of many major rivers worldwide. Coupled with degradation of water quality, low flows have induced severe environmental degradation and water has been rendered unusable by downstream users. When supply of water falls short of commitments to fulfil demand in terms of water quality and quantity within the basin and at the river mouth, for part or all of the year, basins are said to be closing. Basin closure is an anthropogenic process and manifested at societal as well as ecosystem levels, and both its causes and consequences are analyzed. Implications in terms of increased interconnectedness between categories of users and between societal processes and ecosystems in different parts of river basins are emphasized. Finally, several possible responses to the challenges posed by the over-exploitation of water resources are reviewed.

1. Introduction

Increasing water withdrawals for urban, industrial, and agricultural use have profoundly altered the hydrology of many major rivers worldwide. Coupled with degradation of water quality, low flows have induced severe environmental degradation and water has been rendered unusable by downstream users. Against this worrying evolution, it is expected that both urban needs (because of urbanization) and agricultural needs (because an increasing population that will have to be fed) will continue to increase, with less scope for reversing basin closure. The current challenge for water management in agriculture is thus to do more with less water in river basins that are already stressed, while in relatively open river basins much stricter scrutiny of new infrastructure development is needed from decision-makes and civil society to avoid overcommitment of water resources.

With basin closure the interconnectedness of the water cycle, aquatic ecosystems, and water users increases greatly. Local interventions such as tapping more groundwater, lining canals, or using micro-irrigation often have third-party impacts and unexpected consequences elsewhere in the basin. The population groups that manage water, make or influence decisions, receive benefits, or bear costs and risk have different levels of access to resources, knowledge, political representation, or courts. Consequently growing pressure over resources also means that more attention and regulation are needed to manage water equitably while minimizing impacts and risks.

This paper therefore first looks at how basins close and how overcommitment of resources tends to occur. It then analyses the manifold implications and impacts of basin closure before reflecting on what are appropriate and possible societal responses to water crises and environmental degradation at a basin level.

2. The process of river basin closure

With population and economic growth, abstraction of water by individual users, industries and state-initiated projects has approached or even exceeded the threshold of renewable water resources in a number of river basins. Water flowing out of sub-basins is often committed to other downstream uses, and outflow to the sea has several often overlooked functions: flushing out sediments, diluting polluted water, controlling salinity intrusion and sustaining estuarine and coastal ecosystems. When river discharges fall short of meeting such commitments (shaded area in Fig. 1) during part of or all of the year, basins (or sub-basins) are said to be closing or closed (as shown in Fig. 1 the fraction of the runoff that is depleted through human use increases). Basin closure is also often accompanied by severe pollution, as increasing effluent and declining flows outstrip the dilution capacity of many rivers and lead to wider ecosystem degradation.

Many closing basins are typically under stress for 1–6 months a year. The Yellow, the Colorado, the Indus, and the Murray-Darling rivers, as well as most rivers in the Middle-East and Central Asia are

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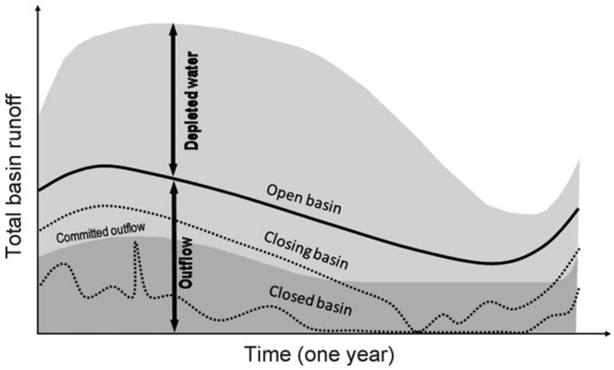

Fig. 1. Illustration of typical basin closure.

severely overcommitted. Even basins in monsoon regions (e.g. southern India) experience months of closure, when salinity creeps inland or outflows are reduced to zero as a result of upstream diversions. Closure and scarcity can also occur in sub-basins or small catchments, while the wider basin remains open. The Greater Ruaha Basin in Tanzania is an example of a sub-basin under stress that contributes to a river (the Rufiji) that is fed by many other tributaries with still abundant flow.

Basin closure is thus by definition a human-induced or anthropogenic process, and it is also manifested through societal as well as physical impacts. Overdevelopment of river basins is a common phenomenon that goes beyond the mere continuation of supply-oriented strategies accompanied by a disregard for demand-management strategies and for the environment. It almost invariably includes the development of infrastructure with a potential demand for water that outstrips basin resources and ecosystem resilience. Because of its dramatic impact on water management and allocation and on the environment, unpacking the logic that drives the overbuilding of basins is essential (Molle, 2008).

Post-WWII development of river basins unfolded under the banner of integrated, or unified, river basin management, out of enthusiasm for large-scale undertakings, as epitomized by the creation of the Tennessee Valley Authority (TVA) in 1933, after the Great Depression (Molle, 2006). The vision of integrated development was mainly confined to the necessity/opportunity to design infrastructure that would serve multiple purposes, in general hydropower generation, flood control and navigation, irrigation or urban water supply. The concept of multiple uses was also useful in maximizing the economic benefits expected from investments and thus helped to facilitate state funding. The large investments in water development projects between the 1950s and 1980s were fuelled by an optimistic belief in the potential of technological transfer for triggering development in the Third World, the conception of development projects as strategic assets in the Cold War (Ekbladh, 2002; Barker and Molle, 2004), strong financial interests from the development industry (western consultancy and construction firms, their local associates, and key persons in government administrations), and the specter of hunger in a world undergoing spectacular population growth (Molden et al., 2007).

These factors, however, explain massive initial structural development but not necessarily why they were furthered to the point of provoking basin closure. The first investments in a river basin are generally made in areas with a favorable combination of soils and water resources. Typically large alluvial plains and deltas are developed first, thus accentuating their natural comparative advantage for crop production. But state investment at a national level is a highly politicized process. Regions with little infrastructure generally lag behind, exhibit higher rates of poverty, fuel migration to cities, and build up their claim for a share of investment, arguing that they have been disadvantaged and that the river that traverses their land is also "theirs". Their claims may gain additional political relevance if and when regional or provincial political leaders are aligned with the ruling party, since their support is implicitly conditional upon effective state support to local development. This leads to further development plans in sub-regions with sometimes only marginal land and to tapping resources that are partly appropriated by downstream users.

Several factors make this possible: the fuzziness or lack of definition of water rights, the supply-driven logic of development banks, the malleability and project-specific nature of cost–benefit analyses and the lack of scrutiny on the assumptions made, and the overriding political nature of decisions that are taken before feasibility studies start. The complexity of river basins as ecosystems has also made it difficult to identify, quantify or value externalities, and projects are allowed to go ahead because these externalities are not factored into decision-making. In some cases, competition between regions, state or countries within the same basin generates a race for water appropriation that results in uncoordinated investments and over-developed infrastructure, as can be seen in the Cauvery or Krishna river basins in India (see Box 1). Equity in terms of spreading benefits is promoted at the cost of basic economic principles, but the necessity to share the induced scarcity creates great management and governance challenges.

3. The implications of river basin closure

During the second half of the 20th century multipurpose development of river basins focused primarily on the construction of large dams (whose numbers increased globally from 5000 in 1950 to 45,000 in 2000, an average of two new large dams each day; WCD, 2000) for hydropower generation, flood control, and water storage for irrigation. During the same period, irrigated areas doubled from 140 million hectares (ha) to 280 million ha (Molden et al., 2007).

Large-scale development of river basins yielded unexpected results, however. River systems turned out to be interconnected transfer and transport systems (Newson, 1997) carrying not only water, but also sediment, nutrients, contaminants, and biota across space and time. Control of water, estimation of extreme events, and management of annual variability posed many problems unanticipated by engineers. The intricacies of surface and groundwater interactions led to unexpected impacts and conflicts, while drastic alterations of the natural water regime provoked severe ecological degradation.

3.1. Social and environmental impacts

The alteration of river flows—droughts and floods of frequencies, intensities and durations beyond natural events, and pollution induced by human activity, tend to provoke adverse impacts on riverine populations and ecosystems. These impacts travel across space and time and frequently materialize somewhere else in the basin, with a certain time lag. While the consequences of these activities are often imperceptible when water is abundant, they become increasingly visible and damage-prone as a basin closes.

With substantial changes in river hydrology, the sensitivity of aquatic ecosystems has become more obvious. The more straightforward – and publicized – impact of river diversion is the drying up of some deltas and lakes. The drying up of the Aral Sea stands out as the epitome of such transformations. Diversion of the Jordan river by Israel and of the Yarmouk river (its main tributary) by Syria and Jordan have reduced the yearly natural flow to the Dead Sea from 1370 to 300 million m^3 (Courcier et al., 2006). As a result the Dead Sea has seen its level decline by 25 m since

Box 1. The closure of the Krishna river basin, India (adapted from Venot et al., 2007)

A typical spatial pattern of basin development is a gradual spread of irrigated areas from downstream to upstream. The Krishna river basin, in Southern India, is shared by the states of Maharashtra, Karnataka and, downstream, Andhra Pradesh (AP). As the most favorable region for irrigation development, the British first developed 250,000 ha in the delta and in suitable valleys on the Deccan plateau upper states (e.g. the Tungabhadra project).

After Independence the irrigated area in the delta was doubled and several hydropower and irrigation projects implemented, among which the Nagarjuna Sagar dam in AP (1967), with its attendant irrigation area of 900,000 ha. In parallel small tributaries in the Deccan plateau were also exploited through water harvesting structures, small tanks and shallow wells that tapped sub-superficial flows, lessening their contribution to the Krishna river. Increased urban needs have also been met by groundwater abstraction, medium dams and transfers from the Krishna (470 million m^3 planned) and other basins.

As a result, the Krishna river discharge to the ocean gradually decreased: this is the first indicator of river basin closure. Fig. 2 shows the river discharge measured at the head of the delta, after diversions to the Krishna delta project. Before 1960, river discharge into the ocean averaged 57 km^3 per year. Since 1965, it steadily decreased at an average of 0.8 km^3 per year to reach 10.8 km^3 in 2000 (less than 15% of its historical runoff) and almost nil in 2004 (0.4 km^3) (Fig. 3).

More development of water resources are planned in upstream states (as well as in AP), whose needs also increase. This 'shift-to-upstream' process reflects a tendency to capture water before other users, especially in a context where the agreement (the ''Krishna tribunal'') that established the theoretical shares of the three states is being renegotiated.

WWII. This has impacted tourism (water retreated from hotel beaches) and resulted in land subsidence and the formation of sinkholes. In Mexico, Lake Chapala, one of the world's largest shallow lakes, lost 90% of its volume in two decades (1982–2002), due to excessive surface water use upstream in the Lerma-Chapala Basin (Wester et al., 2008). Similar effects occur with groundwater use. The exploitation of aquifers typically lowers the water table, reducing the baseflow to rivers and discharge of springs. Groundwater abstraction in Azraq, eastern Jordan, for example has undermined springs that were sustaining the Oasis and Ramsar wetland of Azraq. Induced changes in quality are also frequent either because of groundwater hydrodynamics (mingling with saline aquifers) or because of sea water intrusions (in coastal areas) (Molle and Berkoff, 2006): overdraft of coastal aquifers has rendered aquifers increasingly unfit for both domestic and agricultural use in cities such as Tel Aviv, Lima, Jakarta, Manila or Dakar.

Overexploitation also causes land subsidence in cities like Mexico City (10 m during the last century: WRI, 1996), Manila, Jakarta, Cangzhou and Beijing. Subsidence in some parts of Bangkok has reached up to 20 cm a year and one-third of the city is now below sea level. Costs in terms of flood protection or damage and damage to infrastructure are high. Overabstraction also generates a cone of depression that may deprive water users with more shallow wells. Ta'iz, Yemen, is a case in point. In the early 1980s, new wells to supply Ta'iz were dug in the prime agricultural zone of Wadi Al-Haima, which is 20 km away from the city. Most of the agricultural wells went dry, incurring drastic declines in farm incomes and deep resentment among the local population. By the late 1980s, the situation had degenerated to such an extent that troops had to be sent to quell the strife and restore law and order. Continued abstraction and further drilling were secured through direct negotiations between community leaders and the president of the country (Riaz, 2002).

This serves to illustrate that while externalities induced by basin closure travel across the basin, these tend to concentrate on weaker population groups and on the environment. Urban areas raising flood protection dikes will tend to deflect and concentrate flood damage on unprotected areas. Those with insufficient capital to deepen their well or change their pump will be pumped-out by those who can afford more efficient technology. Dams will generate energy for use concentrated in industries in large cities but will displace local populations and – frequently – impact on fisheries. The Pak Mun dam in Northeast Thailand illustrates how this run-of-the-river dam ridden by faulty EIA, costs overruns and producing less than 0.3% of Thailand's energy has closed off the mouth of the Mun river, near the confluence with the Mekong, disrupting the fisheries of the whole Mun-Chi basin. Years of conflicts included halting of construction, post-construction negotiation of compensation packages, and acceptance by the government of the necessity to leave the gates of the dam open during 4 months each year (Foran, 2006).

In some places these developments have undermined or destroyed elaborate human uses of ecosystems, at the cost of overall economic losses, declining food security, environmental degradation, and loss of ecosystem services. Barbier (2003) describes the case of the Hadejia' Jama'a River in Nigeria, where the natural flood regime used to deposit fertile alluvial deposits taken advantage of by the practice of flood recession agriculture. These wetlands are the source of multiple livelihoods including agriculture, fisheries, animal grazing, harvesting of wood and non-wood products in riparian forests. They have positive impact on groundwater recharge (domestic water use and dry season irrigation) and are hotspots of biodiversity as well as habitats for migratory birds. Economic analysis showed that expansion of irrigation in the basin is uneconomic in view of the benefits foregone downstream. Similar situations can be found in the Kafue flats in Zambia, in the Senegal river valley (Adams, 2000).

3.2. Hydrological interconnectedness

Interactions across a river basin are best exemplified by the ubiquitous upstream–downstream impacts. Yet, as a basin closes hydrologic interconnectedness rises. Diversions amount to an increasing percentage of total runoff; changes in land use modify the share of rainfall that evapotranspires and thus reduces the remaining water potentially available; return flows from one user (e.g. an irrigation scheme) tend to be tapped again, making downstream users sensitive to upstream changes in efficiency; and surface water/groundwater interactions are also more marked. In other words, in closing basins any modification of flow paths tends to have greater repercussion on other users somewhere else in the basin than in open basins. There is little slack left to absorb variations in supply and demand and the occurrence of third-party impacts increases, distributing new costs and risks. Identification of these third-party impacts and understanding of their causes becomes paramount; and their regulation more and more complex. We expand here on some of these points:

Double-accounting. Efficiency in water use is most generally understood at the user or canal level. Return flows are often considered as 'losses' although they are often reused downstream. Reducing losses may merely reduce water availability to these downstream users. Canal lining projects frequently reduce groundwater stock and flows and impact on those who use these sources. Millions of dollars have been invested in recent years to line canals in China's northern Plains: benefits accrue to local canal users but at a wider scale – the scale of the Yellow river basin,

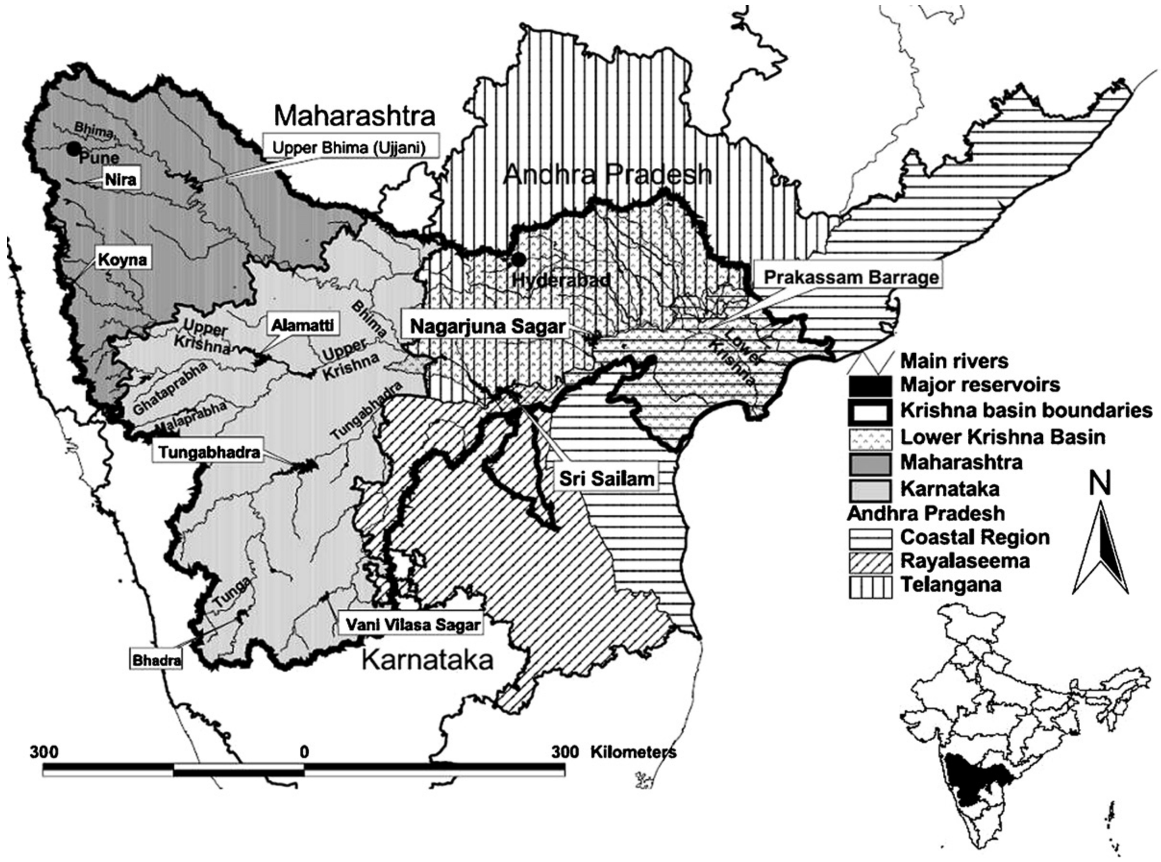

Fig. 2. Layout of the Krishna river basin.

where hardly any water reaches the sea – these interventions on flow paths appear as a redistribution of a fixed amount of water.

The lining of the Upper Ganga (India) and All-American Canals (USA) (Cortez-Lara and García-Acevedo, 2000), which were designed to achieve water savings and redistribute them to urban use, are good examples of 'paper savings', which amount to a mere reallocation of water across space and users rather than reducing usage. Delhi draws its water supply mainly from the Yamuna river. The new Sonia Vihar water treatment plant is to treat 635 million liters of water (232 Mm^3/year) from the Ganges river daily. Water is taken off the Upper Ganga canal, which serves large irrigation schemes north of Delhi, stored in a tank, treated and conveyed to Delhi through a giant 3.25 m-diameter pipeline. In order not to impact on irrigation supply, the canal has been lined to avoid seepage and make use of the "losses". It was soon realized, however, that this seepage was the direct source of supply of hundreds of wells used by farmers further downstream (Shiva and Jalees, 2003). This situation can be found in most of India, where conjunctive use of surface and groundwater has developed to the point that the latter has now surpassed the former (Shah et al., 2003).

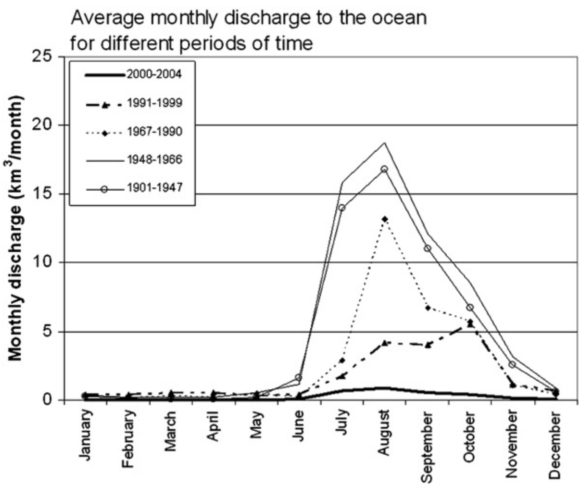

Fig. 3. Evolution of Krishna river's discharge to the ocean (Venot et al., 2007).

Impact of irrigation technology. Governments of water scarce countries at some point promote – and often subsidize – the use of micro-irrigation technologies as a means to reduce water diversions. The rationale is straightforward: if an irrigation system uses 100 units of water with and efficiency of 40%, raising its efficiency to, say, 80% will allow diversions to be reduced by 50 units. Two issues, however, are often overlooked. First micro-irrigation technologies are generally pressurized and allow a better control of irrigation doses in terms of timing, quantity and uniformity. This results in an increase in yields but also in the amount of water depleted by the plants through transpiration (Burt et al., 2001). More frequent irrigation also increases the average moisture of superficial soil layers and, depending on the type of soil, may also raise the proportion of water evaporated from the soil. Overall, micro-irrigation technologies may not always reduce the amount of water depleted (effectively consumed) and may even increase it.

Second, in countries where land is not the limiting factor, it is also very common to see farmers using the water saved through reduced application to increase their irrigated area (see Feuillette, 2001 for Tunisia, García-Mollá, 2000 for Spain, and Moench et al., 2003 for India). Local water depletion is increased and return flows available to downstream users are reduced. To follow our example, the farmer now still uses 100 units of water (with 80% efficiency) but doubled the cultivated area, returning 20 units instead of 60 to the basin hydrologic cycle. If this is the case the chief result of the introduction of micro-irrigation technology is a reallocation of water from return flow appropriators to the farmers or other users.

This reallocation may be desirable or not. What is important is that an intervention designed as efficiency enhancing eventually amounts to a modification of flow paths and to a spatial reallocation of water within the basin. Complicating factors of flow path modification include possible degradation of water quality, time lags, or change in elevation (needs for pumping) which may alter the conditions of access to water. Consideration of all these factors, particularly in contexts with many users and a poorly known hydrology, poses a challenge to the effective regulation of a basin water regime and to the establishment of attendant governance structures.

ET management. The share of rainfall that is consumed by evapotranspiration (ET) is generally the largest one (60% for a country with a temperate climate like France but up to 80–90% in arid areas). The available runoff collected by rivers and water infiltrated to aquifers is thus, by and large, the leftover from the rain after evapotranspiration of cultivated crops, natural vegetation and water bodies. The smaller this closing term is the more sensitive it will be to a change in basin ET. But ET is not fixed and much depends on the type of land cover.

Common wisdom frequently sees forests as sponges that absorb excess water during wet seasons and release it in the dry season. Despite contrary evidence in many regions, particularly in wet areas, and the critical negative impacts of species like pines or eucalyptus on water resources, the "sponge" myth drives multi-billion dollar investments based on uncritical examination of local conditions (CLUFR, 2005; Calder and Aylward, 2006; Forsyth, 1996). Trees do not produce water but consume it and therefore often diminish streamflows. Deforestation in a dry basin such as the Awash basin, Ethiopia, has increased total runoff but also accentuated excess and low flows (Taddese et al., 2003). Because of their recognized impact on basin runoff, plantations of fast-growing trees in South Africa are taxed as water users (Dye and Versfeld, 2007). The impact of particular types of land use on how much water (and sediments) is generated and on how this water is distributed during the year depends on many factors (soil type and slope, type of rainfall, etc.). The significant and complex link between land use and available river runoff shows that river basin management is also about managing ET (Bossio et al., 2007).

Surface water/groundwater interactions. Hydrological interconnectedness is often hard to grasp: contamination is invisible, solid transport cumulative and groundwater flows hidden. Aquifers are sometimes mistakenly considered as "additional" resources. In most hydrogeological situations aquifers act as temporary storage and buffer zones that receive infiltration water and, after some time lag, release it back to springs, river beds or directly to the sea. If the groundwater abstraction exceeds the recharge of the aquifer over a certain time period the return flows to the surface (and the sea) may decline.

These largely hidden interactions are often unexpected. A spring will dry in one place because of the drilling of deep wells many kilometers away (the example of the Azraq oasis in Jordan was noted earlier). Whether a river replenishes an aquifer or the other way around is not easy to observe and determine. In many instances both occur, depending on the season of the year. Yet, in cases – especially in arid countries – where intensive development of wells has occurred, groundwater abstraction tends to "pull" water from the river, thus reappropriating water that would have been used downstream; this is observed in many countries such as India, Iran, or the US (Webb and Leake, 2006).

Dams, diversions, navigation and fisheries. Dams add to the storage capacity of a basin. Inter-basin transfers can enhance the absolute water supply to the river basin, but at the expense of other basins. For example the Thai Water Grid or China's south to north diversion schemes are justified by taking water from "surplus" to "deficit" basins (Berkoff, 2003). However, in a world of rapid basin closure, it is increasingly rare that existing flows are surplus to the full range of ecological as well as human requirements at the full basin level.

In monsoonal basins storage dams are seen to augment supply by storing flood water during the wet season for use in the dry season. But this may have unforeseen impacts as the natural and human ecology of river basins is often finely adapted to existing flow regimes. The Mekong River Basin is a case in point. The Mekong is relatively "underdeveloped" in terms of storage infrastructure. Some see this as a lost opportunity for energy generation, dry season irrigation and flood control (Molle et al., 2009). Yet the Mekong Basin is also the world's largest freshwater fishery, producing 17% of the world total; with some 1700 species of fish, the Mekong is the second most ichtyofaunally biodiverse river basin in the world, and most of these species (70%) are migratory and hence vulnerable to the blocking effect of dams (Coates et al., 2003). Attenuation of the flood pulse by upstream reservoirs also upsets the cues that trigger fish migration that is necessary to maintain feeding, spawning and dispersal. Above all, loss of connectivity between the flood plain and the river reduces the source of nutrients on which the fishery depends (Welcomme, 2003). Other impacts include cold water pollution and reduced dissolved oxygen as releases are made from the bottom of deep reservoirs. Those most affected are the subsistence farmers and fishers directly dependent on the river.

In sum, the closure of river basins comes alongside an increase in interactions between upstream and downstream areas, surface water and groundwater, freshwater and estuaries/coastal areas; and the manipulation of the hydrological cycle in terms of quantity, quality, timing or sediment load increasingly generates third-party impacts. Local efficiency concerns eventually translate into macro-level allocation and equity concerns.

4. The responses to river basin closure

4.1. Trends in river basin governance

The growing pressure on water resources has led to a renewed emphasis on river basin management. River basin development, defined as the unified planning and full development of water resources on a river basin scale in order to achieve regional development (Lilienthal, 1944; White, 1957), started to lose momentum in industrialized countries in the early 1970s, with the growing recognition of associated social and environmental costs, but also with the decreasing availability of suitable dam sites. Priority shifted to the management of water quality and environmental sustainability. In the early 1990s these concerns were reflected in the Dublin Principles (ACC/ISGWR, 1992) and the formulation of integrated water resources management and ecosystem approaches (see Box 2), and later formalized by the European Union in its Water Framework Directive (EU, 2000).

The decision to manage water on the basis of river basins is a political choice, and river basins thus become a scale of governance in which tensions arise between effectiveness, participation, and legitimacy (Barham, 2001; Blomquist and Schlager, 2005; Wester and Warner, 2002). As river basins close, river basin management has to come to grips with a much more complex set of issues, such as population growth, urbanization, and the diversity of competing values, livelihoods, and economic interests, all depending on the same hydrological cycle. This means that river basin management

Box 2. Ecosystem approach

An ecosystem approach, defined by the Convention on Biological Diversity (CBD, 2000) as a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way, provides an analytical framework to examine tradeoffs between water development and ecological integrity. It conceives of a river basin as a continuum of nested ecosystems and provides the foundation for new approaches to river basin management, such as:

- *Economic valuation*: methodologies have been developed to value ecosystem services to make the full costs of interventions explicit and to influence cost–benefit analysis in favor of environmental preservation, and to also facilitate the payment for environmental services.
- *Critical assessment of dams*: some dam projects have been shelved because of more critical assessments and heightened opposition from civil society, while the removal of dams has started in some rivers, to restore fisheries and ecosystems.
- *Environmental flows*: the notion of environmental flow, defined as the flow regime required to ensure the maintenance of particular environmental functions in a river ecosystem, is an attempt to find a compromise with productive uses, while establishing a protection threshold. The scientific determination of these environmental flows is problematic and the flows achieved in practice are frequently the outcome of negotiated tradeoffs.

is currently about mediating conflicts and allocating water in contexts of skewed distribution of wealth and power, critical environmental changes, and increasing variability in water supplies due to climate change.

Much attention has been given to the ideal organizational model for river basin management, while much less emphasis has been placed on the process of developing, managing, and maintaining collaborative relationships for river basin governance. In many people's minds, river basin management requires a unitary basin management organization. However, river basin organizations (RBOs) cover a wide gamut of organizations with quite varied roles and structures. At first sight this seems a source of confusion, but this also reflects both the nature of the problems faced (for example, development or management) and the particular history and context of each basin reflect on each river basin organization (see Box 3).

At one end of the spectrum, there are highly centralized organizations that are (or were) responsible for most water-related development and management functions in the basin. Examples include: the USA's Tennessee Valley Authority, India's Damodar Valley Corporation, Sri Lanka's Mahaweli Authority, and Spain's *Confederaciones Hidrográficas*. Newson (1997) describes the generally poor responsiveness of authorities to local demands and shows how they are often undermined by bureaucratic conflict because they infringe on the competence of other government agencies and line ministries.

At the other end of the spectrum, there are more loosely constituted bodies that bring together stakeholders from various agencies and water use sectors. Their role is generally coordination, conflict resolution, and review of water resources allocation or management. Examples include: Mexico's river basin councils (Wester et al., 2003), South Africa's catchment management agencies (Waalewijn et al., 2005), Brazil's river basin committees (Lemos and Oliveira, 2004), and most international river commissions.

In between, there are organizations that handle tasks such as policy setting, basin-wide planning, water allocation, and information management, with varying degrees of stakeholder participation. Examples include: the USA's Delaware Commission, Australia's Murray-Darling Commission, and France's *agences de l'eau*. Of course, the organizations given here as examples are not static—in some cases, roles and functions have changed over time and the position of the organization along the spectrum has shifted.

Box 3. A River Basin Organization for the Red River, Vietnam: a solution looking for a problem? (Molle and Hoanh, 2007)

Although the 1997 Vietnamese Law on Water Resources mentioned the possibility of establishing management units at the river basin level, the first three ''river basin management agencies'' were not set up until 2001, largely at the instigation of the Asian Development Bank's regional water policy. Somewhat inconsistently, and in contradiction with their mandate and with the idea of intersectoral and integrated development, these agencies – including the Red River Basin Organization (RRBO) – were set up under the Ministry of Agriculture and Rural Development (MARD). They had few staff and small budgets, and for 3 years they existed without internal official regulations. ADB's technical assistance undertook to convene authorities and technical officials from relevant ministries and from the 25 provinces intersecting the basin to identify priority issues; it found basin-wide participation ''both difficult and unnecessary''. At some point it was not clear what the real IWRM issues were and whether a RRBO would be needed or would fare better than earlier coordination mechanisms established for dam management or flood control issues, making the RRBO appear to be a solution looking for a problem. Emphasis was shifted to concrete issues of water allocation and pollution identified in some sub-basins, leaving the RRBO with little role other than overseeing its forthcoming 'offsprings' at the sub-basin level.

MARD's control, however, was unexpectedly challenged by the emergence of the Ministry of Natural Resources and Environment, which saw the intermediate scale of the river basin as its legitimate level of action, as well as a window of opportunity for establishing its power and role within the pre-existing administrative structure. The concepts of integrated river basin management and RBOs were thus first introduced as 'best practices', then faced inadequacies in terms of scale and political/bureaucratic context, and then became sites and objects of struggle within wider institutional change. This example illustrates both the unsoundness of applying policy blueprints without sufficient attention to local context, and the linkages between the introduction of basin management and bureaucratic reforms and realignments.

When the priority shifts from water development to water management, centralized, state-driven institutions are generally less well-situated than a more dispersed set of organizations to address the multiplicity of interactions, interests, and societal values that influence basin water use. Several types of governance configurations are possible (see Fig. 4). Integrated management at the basin level tends toward the unicentric model, as it implies a degree of centralization of data, water allocation decisions, and decision-making power in order to address interactions between users across the basin. This reinforces state control and may militate against the integration of the values and interests of all stakeholders.

In more "polycentric" or "coordination-based" approaches to basin governance – common in Australia or the Western USA, but also emerging in countries such as Mexico or South Africa – user and community organizations, government organizations, and stakeholder initiatives develop coordination mechanisms at the river basin or sub-basin level. Polycentric and multilevel governance seeks to reconcile stakeholder values and objectives by ensuring that information becomes available to all stakeholders

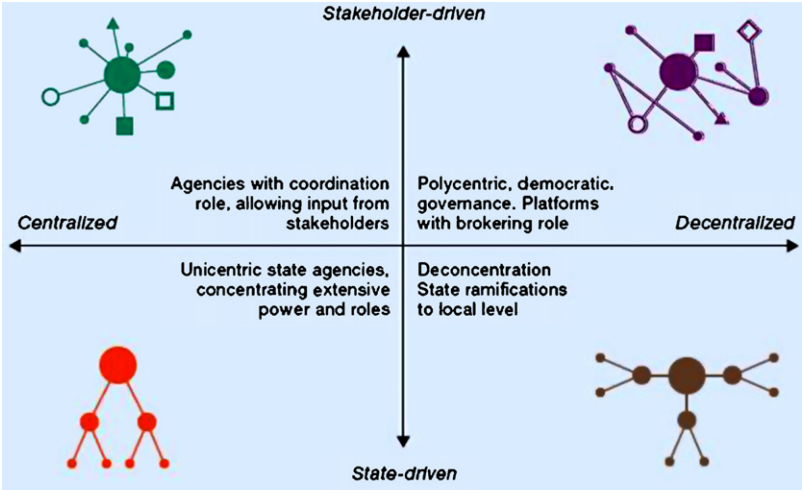

Fig. 4. Typology of river basin governance (Molle et al., 2007).

and that conflicting actions are flagged in advance and duly debated (Svendsen et al., 2005; Blomquist and Schlager, 2005). However, this requires suitable processes, rules and other institutions. It also works best when there is a culture of democratic debate and not too severe imbalances of power. Also, if the goal is equity, just focusing on improving participation and coordination is rarely enough; there is a need to redistribute resources, entitlements and opportunities.

4.2. Developing and conserving water resources

A common response to water scarcity and growing competition in closing basins is to capture more water, even though this is an expensive and frequently unsustainable way to respond to water stress. This includes boosting supplies by capturing more river water (by building new dams) and more groundwater (by sinking more tubewells), and by diverting water from neighbouring basins. However, in closing basins, such efforts only intensify the pressure on water and speed up the closing process. They also often result in people tapping into the water that sustains ecosystems. This causes loss of valuable wetland resources and far-reaching and often unexpected environmental problems. For example, inter-basin transfers can improve the balance between supply and demand in the receiving basin, but it usually implies large losses in terms of direct impact and long-term forgone opportunities for the donor basin, may foster water use in low-return activities, and may have substantial ecological impacts in the receiving and donor basins (Davies et al., 1992).

To varying degrees, all impoundment or diversion projects, whether in open or closed basins, face the same challenges. They must be based on a thorough understanding of their hydrological and ecological impacts and ramifications for water management and water entitlements, and choices must be informed by a review of alternatives, as set out in the rights and risks approach developed by the World Commission on Dams (WCD, 2000). At present, many new dams and inter-basin transfer schemes would benefit from more public consultation. These projects increasingly create economic distortions and incentives for uses of water that do not reflect the financial cost of providing water, let alone the social or environmental costs (Repetto, 1986). Public scrutiny of the cost–benefit analyses and environmental impact assessments commonly used to evaluate such schemes should increase, for example by making them systematically available on the web. The costs of water resource development should be fully accounted for, and full compensation given to people who suffer losses.

The main alternative responses to water overexploitation in closed basins revolve around water demand management. While the scope for real water savings diminishes as basins close, this should not deter efforts to identify situations where real gains are possible and others where reallocations associated with conservation are desirable. City distribution networks often have losses as high as 40%. And even though these losses may return to the aquifer and be reused, this costly treated water should be conserved as much as possible. Outdoor domestic use and industrial use are also amenable to substantial water savings (Gleick, 2000). Slack irrigation management may increase nonproductive losses, and the quality of drainage water may become degraded or even flow to sinks and become unrecoverable. Each situation must therefore be analyzed individually, through a thorough quantitative description of water fluxes and paths.

Because basin management increasingly resembles a zero-sum game as the basin closes, understanding hydrological and ecological interconnections is crucial to identify implicit spatial reappropriation caused by interventions. Demand management and conservation options are important responses in closing basins, but their pervasive third-party impacts at the basin level must be fully examined.

4.3. Water allocation: sharing costs and benefits

How to best share scarce water supplies between competing users – and between users and the environment – is the core issue in closing basins. Allocation arrangements need to take into account that water availability varies between areas and years and need to clearly spell out how to 'share scarcity' in times of shortages. For example, mechanisms to compensate farmers should be planned in advance so that during severe droughts they can release water for other uses. As allocation arrangements may be affected by changes in land use, runoff patterns, or societal values, they need to be adaptable, making it possible to re-allocate water between users and sectors to raise water productivity, or to enhance food security, redress inequities, or restore natural river flows.

Three modes of allocation are commonly recognized (Dinar et al., 1997). First, the state allocates water administratively according to rules that may, or may not, be very transparent or explicit. Second, allocation can be ensured by a group of users among themselves. This case is more common in smaller systems, but users may also manage large schemes. Third, water may be allocated through water markets, as in Australia or Chile. Underlying all three modes of water allocation are water rights, either de facto or usufruct rights, or more legally defined ownership rights. In terms of equity, economic efficiency and environmental sustainability, each allocation method has certain requirements, advantages and drawbacks. Water markets, for example, only work equitably in countries with strong hydrological knowledge, fair political systems and strong law enforcement. Without these things, markets can allow the strong to capture more than their fair share of water.

Currently, the main trend in water allocation is the transfer of water out of nature to agriculture and out of agriculture to urban uses (Meinzen-Dick and Rosegrant, 1997; Molle and Berkoff, 2006). The first transfer needs to be reversed, while the second is going to continue and its consequences must be addressed. As the environment tends to be the ultimate loser, the definition of environmental flows is a good starting point for negotiations (Smakhtin et al., 2004). An effective alternative would be a three-tier system to allocate water: a reserve for basic human needs and the environment (as in South Africa), a reserve for productive water for the poor, and a reserve for productive use, including water for urban areas and agriculture. For this system to be socially acceptable, stakeholders must be given a voice and encouraged to participate in determining water entitlements.

5. Conclusions

River basin management in the future will seek varying expressions within a spectrum bounded by two water paradigms: the water development approach and the ecosystem approach. The development approach focuses on harnessing nature and controlling water for human benefit through infrastructure development, while the ecosystem approach promotes restoring and maintaining the integrity of the water cycle and aquatic ecosystems. Political choices need to be made to initiate a transition toward more balanced practices, with more attention for ecosystems and for the tradeoffs in the development and management of water resources. In closing river basins continuing the emphasis on supply-side approaches will only intensify the pressure on water. Doing better with what we have has profound implications for the choice of responses to basin closure; the allocation of scarce water resources, with a view to sustaining ecosystems and ensuring equity; the emergence of patterns of governance that will ensure these goals; and the need to manage water resources in a context of growing complexity and multiple worldviews.

Reflecting on the challenges facing basin governance, it is clear that where poverty is widespread, river basin management needs a strong developmental dimension. At a minimum, strategies for river basin management should detail mechanisms for addressing imbalances in access to water and establishing recognized and secure water entitlements for the poor. While much can be learned from institutional arrangements for river basin management in affluent countries, these arrangements do not operate in the same way in the conditions of low-income countries: dominance of smallholder agriculture, weak institutions, insufficient financial and human resources, marked social inequity, and extreme poverty. Water management can only partly address these issues, which must explicitly form the points of departure in the reform of institutional arrangements for river basin management in developing countries.

References

ACC/ISGWR (United Nations Administrative Coordination Council Inter-Secretariat Group on Water Resources), 1992. The Dublin Statement and Report of the Conference. Prepared for the International Conference on Water and the Environment: Development Issues for the 21st Century, 26–31 January, Dublin.

Adams, W., 2000. Downstream impacts of dams. Prepared for Thematic Review I.1: Social Impacts of Large Dams Equity and Distributional Issues. World Commission on Dams.

Barbier, E.B., 2003. Upstream dams and downstream water allocation. The case of the Hadejia Jama'are floodplain, Northern Nigeria. Water Resources Research 39 (11).

Barham, E., 2001. Ecological boundaries as community boundaries: the politics of watersheds. Society & Natural Resources 14 (3), 181–191.

Barker, R., Molle, F., 2004. Evolution of irrigation in South and Southeast Asia. Comprehensive Assessment of Water Management in Agriculture Research Report 5. International Water Management Institute, Colombo, Sri Lanka. www.iwmi.cgiar.org/assessment/files/pdf/publications/ResearchReports/CARR5.pdf.

Berkoff, J., 2003. China: the south–north water transfer project—is it justified? Water Policy 5 (1), 1–28.

Blomquist, W., Schlager, E., 2005. Political pitfalls of integrated watershed management. Society and Natural Resources 18 (2), 101–117.

Bossio, D., Critchley, W., Geheb, K., van Lynden, G., Mati, B., 2007. River basin development and management. In: Molden, D. (Ed.), Water for Food-Water for Life. Comprehensive Assessment of Water Management in Agriculture. EarthScan, London, (Chapter 15), pp. 551–585.

Burt, C.M., Howes, D.J., Mutziger, A., 2001. Evaporation estimates for irrigated agriculture in California. ITRC Paper No. P 01-002. Irrigation Training and Research Center, San Luis Obispo, CA.

Calder, I.R., Aylward, B., 2006. Forest and floods: moving to an evidence-based approach to watershed and integrated flood management. Water International 31 (1), 87–99.

CBD (Convention on Biological Diversity), 2000. Conference of the Parties to the Convention on Biological Diversity. www.biodiv.org/programmes/cross-cutting/ecosystem/default.asp.

CLUFR (Center for Land Use and Forestry Research, University of Newcastle), 2005. From the Mountain to the Tap: How Land Use and Water Management can Work for the Rural Poor. UK Department for International Development, London.

Coates, D., Ouch, P., Ubolratana, S., Thanh Tung, N., Sinthavong, V., 2003. Biodiversity and fisheries in the Lower Mekong Basin. Mekong Development Series No. 2. Mekong River Commission, Phnom Penh.

Cortez-Lara, A.A., García-Acevedo, M.R., 2000. The lining of the All-American Canal: the forgotten voices. Natural Resources Journal 40 (2), 261–279.

Courcier, R., Venot, J.-P., Molle, F., 2006. Historical transformations of the Lower Jordan river basin: Changes in water use and projections (1950–2025). Comprehensive Assessment of Water Management in Agriculture Research Report 9. International Water Management Institute, Colombo, Sri Lanka. www.iwmi.cgiar.org/assessment/files/pdf/publications/ResearchReports/CARR9.pdf.

Davies, B., Thoms, M., Meador, M., 1992. An assessment of the ecological impacts of inter-basin water transfers, and their threats to river basin integrity and conservation. Aquatic Conservation: Marine and Freshwater Ecosystems 2 (4), 325–349.

Dinar, A., Rosegrant, M.W., Meinzen-Dick, R., 1997. Water allocation mechanisms: principles and examples. Policy Research Working Paper 1779. World Bank, Washington, D.C.

Dye, P., Versfeld, D., 2007. Managing the hydrological impacts of South African plantation forests: an overview. Forest Ecology and Management 251 (1–2), 121–128.

Ekbladh, D., 2002. 'Mr. TVA': Grass-Root development, David Lilienthal, and the rise and fall of the Tennessee Valley Authority as a symbol for U. S. overseas development, 1933–1973. Diplomatic History 26 (3), 335–374.

EU (European Union), 2000. Directive 2000/60/ec of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. Official Journal of the European Communities 43 (L327), 1–72.

Feuillette, S., 2001. Vers une gestion de la demande sur une nappe en accès libre: exploration des interactions ressources usages par les systèmes multi-agents; application à la nappe de Kairouan, Tunisie Centrale. Ph.D. thesis. Université Montpellier II, Montpellier, France.

Foran, T., 2006. Rivers of contention: Pak Mun Dam, electricity planning, and state–society relations in Thailand, 1932–2004. Unpublished PhD Thesis, University of Sydney.

Forsyth, T., 1996. Science, myth, and knowledge: testing Himalayan environmental degradation northern Thailand. Geoforum 27 (3), 375–392.

García-Mollá, M., 2000. Análisis de la influencia de los costes en el consumo de agua en la agricultura valenciana: Caracterización de las entidades asociativas para riego. Ph.D. thesis. Universidad Politecnica de Valencia, Department of Economics and Social Sciences, Valencia, Spain.

Gleick, P.H., 2000. The changing water paradigm: a look at twenty-first century water resources development. Water International 25 (1), 127–138.

Lemos, M.C., Oliveira, J.L.F., 2004. Can water reform survive politics? Institutional change and river basin management in Ceará, Northeast Brazil. World Development 32 (12), 2121–2137.

Lilienthal, D.E., 1944. TVA: Democracy on the March. Harper and Brothers Publishers, New York and London.

Meinzen-Dick, R.S., Rosegrant, M.W., 1997. Alternative allocation mechanisms for intersectoral water management. In: Richter, J., Wolff, P., Franzen, H., Heim, F. (Eds.), Strategies for Intersectoral Water Management in Developing Countries—Challenges and Consequences for Agriculture. Deutsche Stiftung für internationale Entwicklung, Zentralstelle für Ernährung und Landwirtschaft, Feldafing, Germany, pp. 256–273.

Moench, M., Dixit, A., Janakarajan, M., Rathore, S., Mudrakartha, S., 2003. The Fluid Mosaic: Water Governance in the Context of Variability, Uncertainty, and Change. Nepal Water Conservation Foundation, Katmandu.

Molden, M., Frenken, K., Barker, R., de Fraiture, C., Mati, B., Svendsen, M., Sadoff, C., Finlayson, M., 2007. Trends in water and agricultural development. In: Molden, D. (Ed.), Water for Food-Water for Life. Comprehensive Assessment of Water Management in Agriculture. EarthScan, London, (Chapter 2), pp. 57–90.

Molle, F., 2006. Planning and managing water resources at the river basin level: emergence and evolution of a concept. Comprehensive Assessment of Water Management in Agriculture. Research Report. International Water Management Institute, Colombo.

Molle, F., 2008. Why enough is never enough: the societal determinants of river basin closure. International Journal of Water Resource Development 24 (2), 217–226.

Molle, F., Berkoff, J., 2006. Cities versus Agriculture: Revisiting intersectoral water transfers, potential gains, and conflicts. Comprehensive Assessment Research Report 10. International Water Management Institute, Colombo.

Molle, F., Hoanh, C.T., 2007. Implementing integrated river basin management: lessons from the Red River Basin, Vietnam. Working Paper. Mekong Program on Water, Environment and Resilience, IRD/IWMI.

Molle, F., Wester, P., Hirsch, P., 2007. River basin development and management. In: Molden, D. (Ed.), Water for Food-Water for Life. Comprehensive Assessment of Water Management in Agriculture. EarthScan, London, (Chapter 16), pp. 585–624.

Molle, F., Foran, T., Käkönen, M. (Eds.), 2009. Contested Waterscapes in the Mekong Region. Hydropower, Livelihoods and Governance. Earthscan, London.

Newson, M., 1997. Land, Water, and Development: Sustainable Management of River Basin Systems, 2nd ed. Routledge, London.

Repetto, R., 1986. Skimming the water: rent seeking and the performance of public irrigation systems. Research Report 4. World Resources Institute, Washington, DC.

Riaz, K., 2002. Tackling the issue of rural–urban water transfers in the Ta'iz region, Yemen. Natural Resources Forum 26 (2002), 89–100.

Shah, T., Deb Roy, A., Qureshi, A.S., Wang, Z., 2003. Sustaining Asia's groundwater boom: an overview of issues and evidence. Natural Resources Forum 27, 130–141.

Shiva, V., Jalees, K., 2003. Ganga: Common Heritage or Corporate Commodity? Navdanya, New Delhi.

Smakhtin, V., Revenga, C., Döll, P., 2004. A pilot global assessment of environmental water requirements and scarcity. Water International 29 (3), 307–317.

Svendsen, M., Wester, P., Molle, F., 2005. Managing river basins: an institutional perspective. In: Svendsen, M. (Ed.), Irrigation and River Basin Management: Options for Governance and Institutions. CABI Publishing, Wallingford, UK.

Taddese, G., Sonder, K., Peden, D., 2003. The Water of the Awash River Basin a Future Challenge to Ethiopia. International Livestock Research Institute, Addis Ababa.

Venot, J.-P., Turral, H., Samad, M., Molle, F., 2007. Shifting waterscapes: explaining river basin closure in the lower Krishna Basin, South India. Research Report. IWMI, Colombo, Sri Lanka.

Waalewijn, P., Wester, P., van Straaten, K., 2005. Transforming river basin management in South Africa: lessons from the Lower Komati river. Water International 30 (2), 184–196.

WCD (World Commission on Dams), 2000. Dams and Development: A New Framework for Decision-Making. Earthscan, London.

Webb, R.H., Leake, S.A., 2006. Ground-water surface-water interactions and long-term change in riverine riparian vegetation in the southwestern United States. Journal of Hydrology 320 (3–4), 302–323.

Welcomme, R., 2003, Dependence of tropical river fisheries on flow. In: Proceedings, Large Rivers Symposium, Phnom Penh 11–14 February 2003, pp. 267–283. www.lars2.org.

Wester, P., Merrey, D.J., de Lange, M., 2003. Boundaries of consent: stakeholder representation in river basin management in Mexico and South Africa. World Development 31 (5), 797–812.

Wester, P., Vargas-Velázquez, S., Mollard, E., Silva-Ochoa, P., 2008. Negotiating surface water allocations to achieve a soft landing in the closed Lerma-Chapala Basin, Mexico. International Journal of Water Resources Development 24 (2), 275–288.

Wester, P., Warner, J., 2002. River basin management reconsidered. In: Turton, A., Henwood, R. (Eds.), Hydropolitics in the Developing World: A Southern African Perspective. African Water Issues Research Unit, Pretoria, pp. 61–71.

White, G.F., 1957. A perspective of river basin development. Law and Contemporary Problems 22 (2), 156–187.

WRI (World Resource Institute), 1996. A Guide to the Global Environment: The Urban Environment. Washington, D.C. www.wri.org/wri/wr-96-97/ee_b1.html.