Drawing Water for Thirsty Lands

Stories of the Closing Krishna River Basin in South India

Jean-Philippe Venot

PhD Scholar, International Water Management Institute (IWMI, Hyderabad-India) and GECKO Laboratory, University of Paris X-Nanterre, France. Mailto: j.venot@cgiar.org

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Abstract

Since the 1850s, progressive agricultural and water development in the Krishna basin in South India has led to rising over-commitment of water resources. This over-commitment and signs of basin closure are apparent during dry periods: surface water resources are almost entirely committed to human consumptive uses; increasing groundwater abstraction negatively affects the surface water balance by decreasing base flows; and the discharge to the ocean continues to decrease. The observed runoff to the ocean fell from a pre-irrigation development average of 57 Billion cubic meters a year (Bcm/yr) in 1901-1960, to less than 21 Bcm/yr in 1990-2000 and even more strikingly to 0.75 Bcm in 2001-2004 during an extended period of low rainfall. Based on basin-wide historical water accounting, this paper quantitatively describes the process of closure of the Krishna basin over the last fifty years. In the early 2000s, and without accounting for any environmental flows, total committed volumes accounted for more than 99% of the renewable blue water of the basin. The paper attempts to unpack the forces that drove the overbuilding and closure of the Krishna basin and highlights that current social, economic and political forces have greatly contributed to the mostly ad-hoc reconfiguration of the Krishna basin waterscape. Capturing the process of basin closure requires understanding the political dimension of access to water and the scope for change. Despite rising inter-sectoral and inter-regional tension and reduced investments in rural development, the three states that share the Krishna waters continue to promote their agriculture and irrigation sectors but when a river basin closes, adjustments and management decisions tantamount a spatial re-distribution of water among sectors and regions. This development path can no longer be sustained without impinging on existing water use; leading to further water shortage downstream; severely degrading the resource base; further damaging the environment and creating conflicts. To overcome the difficulties that such adaptive mechanisms may create, there is a clear need for a basin-wide strategy for water management and development that would start with the definition and the implementation of water allocation mechanisms to ensure a balance between equity, sustainability and efficient uses of scarce water resources for both human benefit and environment preservation.

Introduction

Water use for urban, industrial and agricultural growth is approaching and, in some cases, even exceeding the availability of renewable water resources. The Krishna River basin in South India is a good example: it has witnessed intense water development since India gained independence, resulting in over-commitment of water and river basin closure.

A generally accepted definition of a closed river basin is one where all available water is committed (Molden, 1997), resulting in little or no discharge to the ocean during years with average precipitation. The process of basin closure intensifies the interconnectedness of ecosystems and water users: when river basins close, supply development projects lead to regional or sectoral re-distribution of water on the basis of current economic, political, and social forces. Early warnings of such an evolution are emerging in the Krishna basin. During the recent three-year drought (2001-2004), surface water resources were almost entirely committed to human consumptive uses, groundwater was over-abstracted and the discharge to the ocean almost nil. The absence of any basin-wide strategy for water management led to uncoordinated expansion of surface water infrastructure and groundwater abstraction. As the Krishna basin closes, recurring accounts of water conflicts suggest that there is not enough water for all current users and the environment: overdevelopment of infrastructure creates unsatisfied needs and fuels a feeling of scarcity, particularly for irrigation projects located in the lower reaches of a river basin (Molle *et al.*, 2007).

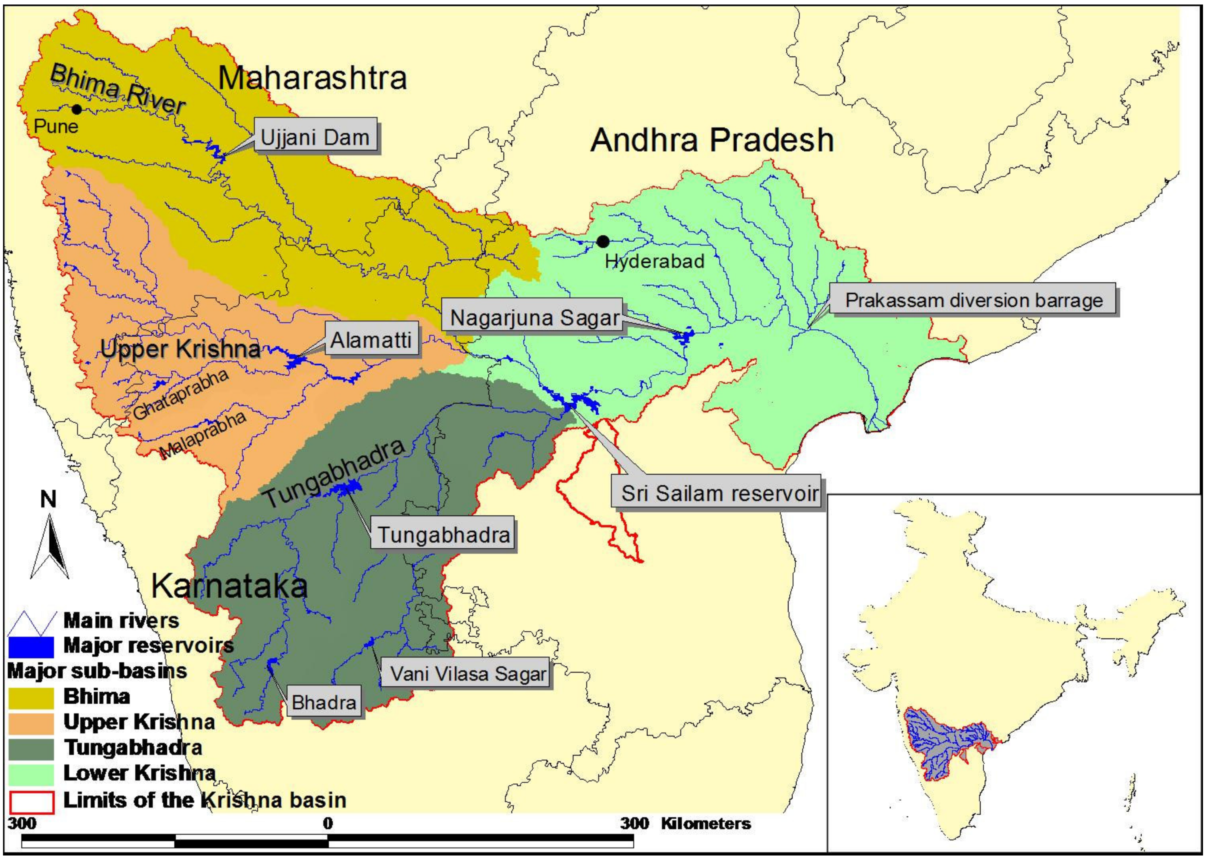
This paper attempts to unpack the forces that drove the closure of the Krisha Basin. The first section presents the main features of the Krishna basin. Section two recounts the history of water development in the basin. The third section provides a water account to quantify past and current water use in the Krishna basin. The final part provides some conclusions.

Human and physical setting of the Krishna River Basin

The Krishna River Basin of South India is the fifth largest river system in India in terms of annual discharge and drainage area (after the Brahmaputra, Ganges, Godavary and Indus river systems) (Biggs *et al.*, 2007). The Krishna River originates in the Western Ghats of Maharashtra and Karnataka, drains the dry areas of the Deccan Plateau, and forms a delta before discharging into the Bay of Bengal. The main stem of the Krishna River has two major tributaries, the Bhima River in the north and the Tungabhadra River from the south (Figure 1).

The Krishna basin drains an area of 258,514 km^2 (that can be extended to 277,768 km^2 if large command areas located outside the hydrological boundaries of the Krishna basin, but receiving water from the Krishna River system, are accounted for). Most of the basin lies on crystalline and basaltic rocks that create hard rock aquifers with low groundwater potential. The Krishna basin is subject to both the southwest and the northeast monsoon: rainfall decrease with distance inland from both coasts. This is particularly striking east of the Western Ghats where rainfall decreases from over 3,000 mm to 500 mm over less than hundred kilometres. Precipitation decreases more gradually from 850-1,000 mm in the Krishna delta in the east to 500-600 mm in the north-western part of the basin. The average rainfall in the basin is 840 mm, approximately 90% of which occurs during the monsoon from May to October. The climate of the Krishna basin is predominantly semi-arid to arid with potential evaporation (1,457 mm a year on average) exceeding rainfall in all but three months of the year during the peak of the monsoon. Irrigation is needed for agricultural development (see Biggs *et al.*, 2007 for further description of the physical setting of the Krishna basin).

Figure 1. The Krishna River Basin, South India



In 2007, the basin contained a total of about 80 million people (estimates based on GoI [2001] and assuming a demographic growth rate of 3% per annum) with 54 in rural areas. The rural population is highest in the Krishna delta and the central west of the basin, and lowest in the centre and southwest. The main city is Hyderabad, the capital of Andhra Pradesh, and accommodates about 8 million inhabitants.

Water resources development and rural changes in the Krishna Basin

For centuries, water has been managed in the Lower Krishna Basin. Originally, small-scale structures allowed diversion of runoff from small streams and storage in small and locally managed tanks (Wallach, 1985). The first major water diversions took place in the Krishna Delta from 1852 onwards in a project designed to irrigate 240,000 hectares of paddy. Between the 1850s and 1947, most efforts to promote irrigation focused on the dry areas of the Deccan Plateau in the Upper Krishna Basin, to provide protection against droughts and famines that regularly struck the region (1876-1880; 1896-1900). During the same period (1850-1947), the lower Krishna basin did not experience large scale expansion of agriculture: irrigation continued to be sustained through local tanks (Venot *et al.*, 2007).

The pace of irrigation development accelerated after India gained Independence with the modernization of the Krishna delta project (1954-1957; irrigating 540,000 ha) and the emergence of a large class of “farmer-capitalists” who accumulated profits and reinvested them, first into land and money lending and then, in agricultural commodities' trade and agro-processing industries. They started to migrate to cities, invested in urban businesses and child education and rose to political prominence (Upadhya, 1988). Irrigation and hydropower production developed further in the 1970s and 1980s with the construction of several multi-purpose reservoirs: Nagarjuna Sagar (1967) and Sri-Sailam (1983) in Andhra Pradesh; Bhadra (1953), Malaprabha (1973); Ghataprabha (1977) and Alamatti (1990) in Karnataka; Koyna (1964) and Ujjani (1981) in Maharashtra for the major ones (Figure 1).

At the end of the 1980s and in the early 1990s, improving the management and performance of existing irrigation systems was given further attention in South and Southeast Asia and the pace of large-scale infrastructure development was slowed down a little (this is visible in Figure 2). With the liberalization of the economy in the early 1990s, the strong state-driven institutional building in agriculture slowed down (Suri, 2006). However, local private or community initiatives (rainfall harvesting structures: tanks, contour ditches, check dams) continued to be heavily promoted all over South Asia (Barker and Molle, 2005) and the Krishna Basin makes no exception. Simultaneously, scattered irrigated plots multiplied due to the availability of private pumps and shallow tube wells. This constituted a silent revolution (Molle *et al.*, 2004), sustained by subsidized electricity as part of populist policies.[1] The dramatic situation of groundwater has raised far less public concern than disappearing river flows but raises equally important issues in terms of management: Mukherji and Shah (2002) described this process as a "colossal anarchy" that could bring "welfare" or "ill-fare" and negatively affect the environment in terms of aquifer depletion and surface runoff reduction (see the section on water accounting below).

Since India gained Independence, total storage capacity in large reservoirs of the Krishna Basin has multiplied eightfold to reach about 54 Bcm i.e., 95% of the pre-1965 river discharge. In the meantime, small scale irrigation projects and groundwater irrigation have also boomed though their total impact on the basin water balance is not well known. The volume of regulated water is higher than the 75%-dependeable flow. While this may not generate significant cuts in water supply in surplus years, it leads to significant shortages and competition in downstream projects during years at, or below, the 75%-dependable flow (Biggs *et al.*, 2007). Finally, these figures underestimate the over-commitment of water resources since they do not account for groundwater exploitation that has skyrocketed over the last 20 years. As a result of infrastructure development, the net irrigated area in the Krishna basin has more than doubled over 1955-2000 from about 2.2 to 4.8 million of hectares (Mha) and the average cropping intensity rose from 107 to 118 percent.[2] Cultivating during the dry season became more common as irrigation expanded. The cropping pattern of the Krishna basin dramatically changed as rainfed corse grains (sorghum and millets) were progressively replaced by rice and cash crops (pulses, oilseeds, chillies, cotton). In the early years of the twenty-first century, about 50% of the irrigated area was irrigated by groundwater

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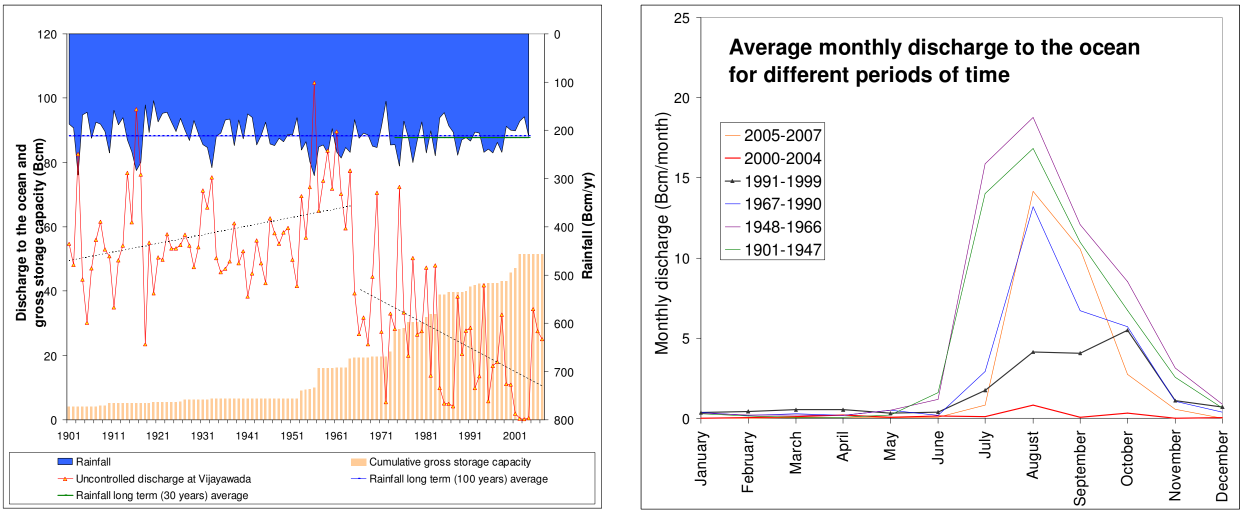
[1] According to the Minor Irrigation Censuses of 1994 and 2001, the number of shallow tube wells in the Krishna basin increased from 35,000 to 515,000 between 1987 and 2001 while the number of deep tube wells increased from 14,000 to 82,000 during the same period. 1.1 million dug wells were registered in 2001 (515,000 in 1987).

[2] All estimates based on district-wise land use data presented in GoAP (2006); GoK (2006); GoM (2005); EPW (2005) and available online, with a subscription at www.indiaagristat.com

(e.g. 1.9 Mha) versus 36% in 1955-1965: the Krishna Basin waterscape is under transition with groundwater becoming one of the main sources of water supply for farmers. In a context of basin closure, this shift towards more local water control is not neutral: it affects existing patterns of water use, spatially re-allocates water from downstream areas to upstream regions, might induce conflicts and raises water management issues.

The Krishna river discharge to the ocean gradually decreased, providing the first indication of river basin closure (Figure 2). Before 1960, river discharge into the ocean averaged 57 Billion cubic meters a year (Bcm/yr). Since 1965, it steadily decreased at an average of 0.8 Bcm per year, falling to 10.8 Bcm in 2000, or less than 15% of its historical value and falling further, close to nil in 2004 (0.4 Bcm). The right panel shows that only monsoon flows (July-October) reached the ocean and that the peak outflow was delayed by about two months: this had dramatic impacts on the coastal ecosystems of the basin. The high discharges observed in 2005-2007 (29 Bcm/yr on average) illustrate that the Krishna River basin is under transition: droughts intensify the interconnectedness of water users and leads to shortage of water downstream. As this might be a harbinger of the future, defining management intervention for sustainable water use at the basin level is increasingly needed. This requires identifying the spatial and historical dynamics of water use and understanding the drivers of the closure of the Krishna basin.

Figure 2. The closure of the Krishna basin: A declining discharge to the ocean

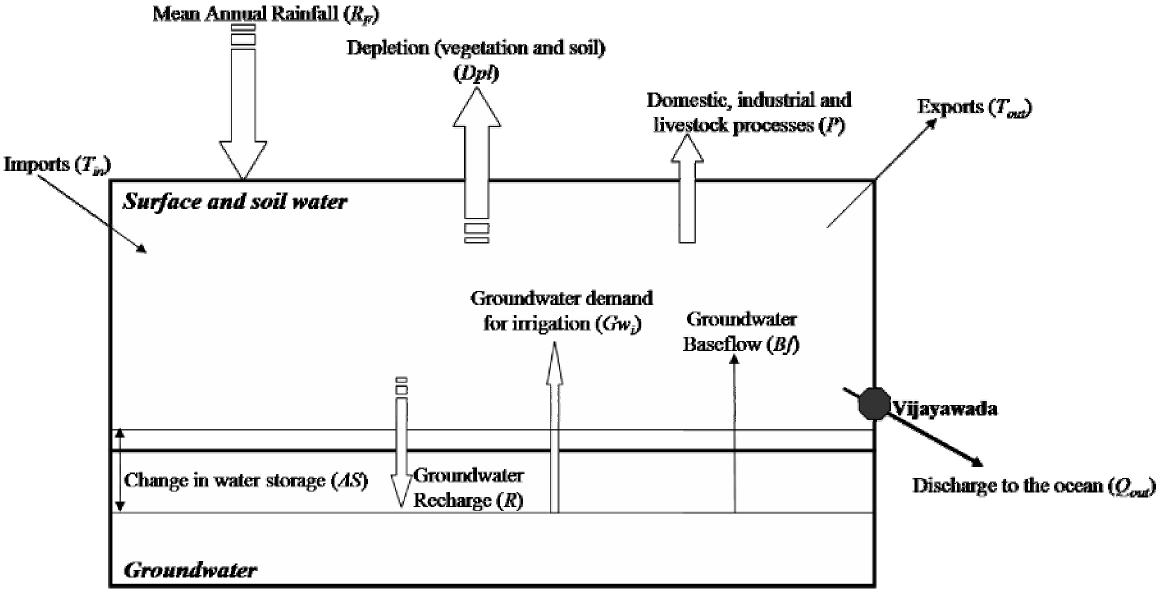


Assessing waterscape dynamics and basin closure: A methodology

The water accounting presented here uses the water balance methodology proposed by Molden (1997) and is presented graphically in Figure 3. The water balance is based on estimates of water depletion (defined as the use or removal of water from a river basin that renders it unavailable for further use downstream) and respects the principle of conservation of mass where total input equals the total of outflows and change in storage.

Total inflows comprised of mean annual rainfall and inter-basins imports must equal to the total depletion from vegetation and bare soil, plus other consumptive uses plus inter-basins exports plus discharge to the ocean plus the net change in water storage in ground- and surface water reservoirs (Figure 3).

Figure 3. Water flows and uses in the Krishna Basin



This is represented by equation 1:

$$R_F + T_{in} = Dpl + P + T_{out} + Q_{out} + \Delta S \tag{1}$$

Where:

***R_F* is the mean annual rainfall** measured from the CRU dataset (CRU, 2007) and district statistical handbooks (GoAP, 2006; GoK, 2006 and GoM, 2005)

T_{in}* are water transfers entering the Krishna basin (Imports)**, estimated from government statistics and data from water supply projects. In what follows, ***R_F* and *T_{in} are pooled together and designated as the gross inflow in the Krishna basin.

***Dpl* is the depletion from any kind of land cover**, and is estimated, as a first approximation, as the evapotranspiration (ET) of a given land cover. Evapotranspiration in irrigated fields and evaporation from reservoirs is derived from climate data and a Penman-Monteith equation (Allen *et al.*, 1998); evapotranspiration by rainfed agriculture and rainfed vegetation is estimated after Ahmad *et al.* (2006); Biggs (in review), Bouwer *et al.* (2007) and Immerzeel *et al.* (2007). Land cover is estimated on the basis of land-use statistics at the district level.

***P* are human and livestock consumptive uses or processes**. Domestic and industrial uses are computed according to Van Rooijen *et al.* (unpublished), assuming water use efficiency of 70% in both sectors. Livestock consumption is computed according to Peden *et al.* (2007).

***T_{out}* are water transfers out of the Krishna basin (Exports)**, estimated from government statistics and salient features of water supply projects.

***Q_{out}* is the discharge to the ocean**, measured at the head of the delta.

***ΔS* is the net change in water storage**, including groundwater and surface water storage.

Except when new reservoirs are built, interannual variability in surface water storage is minimal so, after discounting the volumes trapped in new reservoirs, the variation of water storage can be approximated to changes in groundwater storage; ΔS can be therefore estimated through the groundwater balance, equal to the aquifer recharge minus groundwater irrigation demand and groundwater baseflows to streams. This is represented by equation 2:

$$\Delta S = R - Gw_i - Bf \quad (2)$$

***R* is the aquifer recharge**, e.g. rainwater that infiltrates to the groundwater. It is calculated as a constant fraction of precipitation, depending on the region considered, on the basis of estimates of the NWDA for each sub-basin of the Krishna.

***Gw_i* is the groundwater demand by groundwater irrigated areas**, and is estimated as 70% of all depletion in groundwater irrigated areas (rainfall covers the remaining 30%).

***Bf* is the groundwater baseflow to streams**. We assumed that in pre-groundwater irrigation times, **ΔS** was nil and **R** equals to **Bf** (as **Gw_i** was also nil).

In what follows, the term gross inflow designates the sum of mean annual rainfall and imports to the Krishna basin ($R_F + T_{in}$). The net inflow is the gross inflow minus the net variation of the groundwater stock ($R_F + T_{in} - \Delta S$). Average annual estimates for periods of 5 to 10 years are used. Although interannual variability is important in terms of management, this paper focuses on long-term trends revealed by average balances.

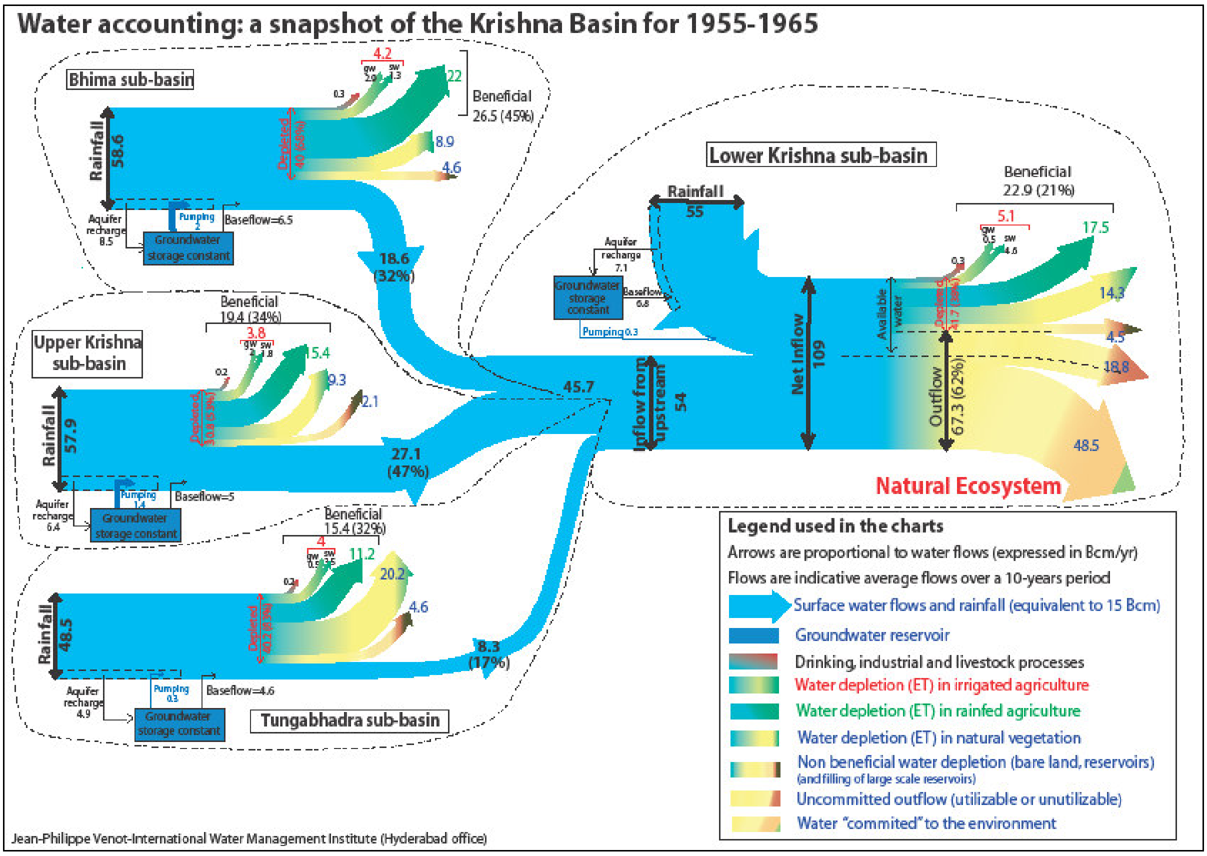
A Land-and-water-scape dominated by rural changes

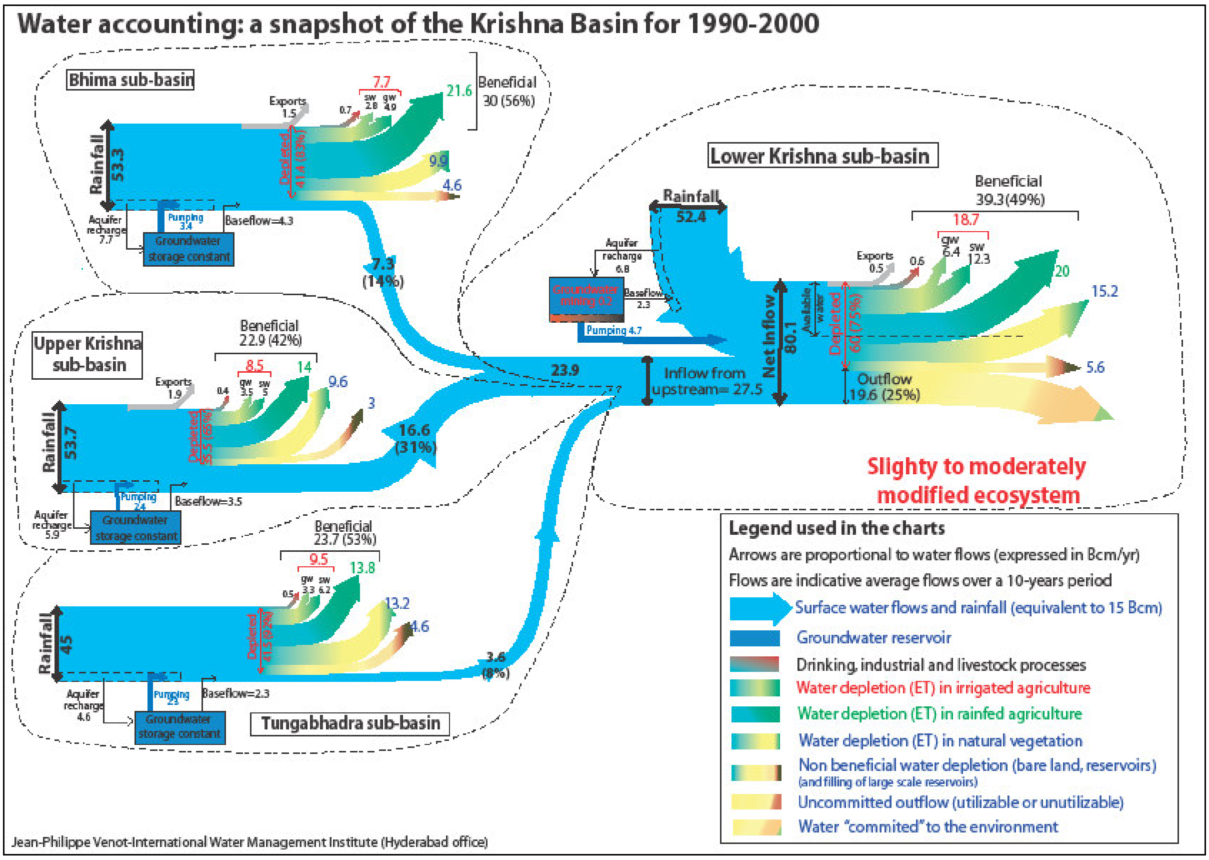
Figure 4 maps the evolution of the Krishna basin water balance since the mid 1950s. Four main regions have been delineated: the Bhima sub-basin in the northwest (located in Maharashtra, Karnataka and Andhra Pradesh); the Upper Krishna sub-basin (Maharashtra and Karnataka); the Tungabhadra sub-basin (Karnataka and Andhra Pradesh) and the lower Krishna basin (Andhra Pradesh) (Figure 1). Figure 4 illustrates that rural changes have dominated the evolution of the Krishna basin waterscape for the past five decades. Notably, the main trend is a dramatic increase of irrigation depletion that has more than doubled from 17.1 Bcm/year during 1955-1965 to 44.3 Bcm/year during 1990-2000. This implied a 19%-rise of the total depletion over the period 1955-2000. The total depletion amounted to 180 Bcm during 1990-2000, i.e., 88% of the net inflow to the Krishna basin. Consequently, the discharge to the ocean dramatically decreased and amounted only to 10% of the net inflow during 1990-2000 (2% of the net inflow was exported to other basins).

Soil moisture and prospects for increased basin efficiency

The relatively high depletion, mainly originating as rainfall, as early as 1955-1965 (69% of the net inflow) highlights the importance of both rainfed agriculture and natural vegetation in depleting soil moisture stored from rainfall and in explaining river basin accounting. Depletion in rainfed agriculture has always been the main user of water, due to the large area coverage of rainfed crops, notably in the dry areas of the Deccan Plateau. Despite decreasing areas, depletion in rainfed agriculture slightly increased over the last fifty years: this reveals that supplemental irrigation of formerly rainfed crops has become widespread.

Figure 4. Water accounting of the Krishna Basin: An evolution for 1955-2000





Supplemental irrigation takes place through groundwater abstraction or diversion of small streams in secondary upstream basins. These findings are consistent with findings from other studies (Biggs *et al.*, 2006; Biggs *et al.*, 2007) that highlight that small irrigated patches in rainfed areas are widely spread. Natural vegetation is the second largest water user.

In 1990-2000, beneficial depletion from rainfed agriculture and low beneficial depletion from natural vegetation accounted, together, for 57% of the total rainfall in the Krishna basin, (evaporation from bare land accounted for an extra 8%). These figures clearly illustrate that sustainable and equitable water management (rainfed agriculture is the main livelihood for the poorest communities) can only be achieved through an increase in the productivity of agriculture in semi-arid rainfed areas. Small scale supplemental irrigation from rainfall is promising to increase both social and economic efficiency of basin water management but this has to be cautiously planned and downstream impacts carefully assessed (see below).

Surface water development: A state wise approach

The planning and development of large irrigation projects in the three states that share the Krishna waters has always led to acute conflicts, highlighting the need for formal interstate allocation rules, because each state has never considered the potential third party impacts of its own development and has engaged in an 'harnessing' approach to water resources development to lay 'prior appropriation' claims on as much water as possible. Major interstates disagreements led to the setting up of the Krishna Water Disputes Tribunal (KWDT) in 1969 and to the enactment, in 1976, of formal allocation procedures that apportioned the 75% dependable flow of the Krishna River (58.3 Bcm/yr, exceeded in 75% of the years) as follow: 15.8; 19.8 and 22.6 Bcm/yr to Maharashtra, Karnataka and Andhra Pradesh, respectively. Any surplus water could then be used by Andhra Pradesh with the caveat that it shall not acquire any right on this "surplus water" (GoI-KWDT, 1976).

Despite this formal process of water apportionment, agriculture and irrigation have been promoted regardless of the availability and variability of resources and few (if any) projects have been stopped (as water use in large and medium surface irrigation projects of all three states never exceeded the state-wise allocations of the KWDT). Between 1955 and 2000, depletion in surface irrigation projects increased from 10.4 to 28.4 Bcm/yr (irrigation development was at its highest in the lower and upper Krishna basin; Figure 4). New projects and modernization/extension of old projects continue to be contentious issues: the KWDT award expired in May 2000 and a new tribunal has been constituted in 2004. It is expected that a decision for allocating water between the three states will be reached between 2008 and 2010. It is crucial that this new tribunal acknowledges and quantifies surface water/groundwater interactions, and accounts for small scale surface water use (minor irrigation; rainwater harvesting and watershed programs) and groundwater abstraction that have both skyrocketed during the last five decades and dramatically impact surface water availability downstream when allocating water (see below). This is not an easy task.

Uncoordinated groundwater abstraction and small scale irrigation

All over India, one of the most striking features of irrigation development during the past five decades has been the rapid growth in the use of groundwater (Vaidyanathan, 2006). This trend was directly and indirectly supported by the government notably through (i) rural development projects that targeted rural areas earlier neglected by the 'Green revolution' (due to the relatively poor conditions for agriculture that prevail there) and (ii) populist policies subsidizing electricity for agricultural uses. According to remote sensing and census data, groundwater and minor irrigated areas cover today more land than large and medium irrigation projects. This raises many management issues notably because groundwater use has not been acknowledge by the first KWDT. Though the nature and extent of surface water/groundwater interactions are not well know, the water balance presented in this paper highlights that increasing groundwater abstraction (from 5.9 to 18.1 Bcm/yr between 1955 and 2000) led to decreasing base flows (-9.4 Bcm between 1955 and 2000)[3] and aquifer overdraft (-0.25 Bcm/yr). Diffuse irrigation development significantly impact on downstream water users. Linkages between agricultural development in upper secondary catchments and large downstream projects are not yet public knowledge and have been neglected by recent agricultural development policies. However, in a context of basin closure, this shift towards more local water control is not neutral: it is tantamount to a re-appropriation of water and might raise tensions as supporting minor or large scale irrigation, which do not have the same social and economic implications, has become highly political (Dhawan, 2006)

Hydroelectricity generation

Increasing electricity needs have led to the completion of several hydropower projects and hydroelectricity acquired a crucial importance in managing peak-hours demand. Major inter-basin transfers take place in the Western Ghats of Maharashtra (~3.5 Bcm are transferred each year to the Western Coast because of a much higher head). Hydroelectricity generation is a major concern for the government of Maharashtra which is contemplating increasing the capacity of these transfers. Those plans are strongly opposed by downstream states (Karnataka and Andhra Pradesh), arguing that hydroelectricity generation is not recognized as a priority water use by the National Water Policy of 2002 (electricity production arrives third in the order of priority after domestic and agricultural water use), because they entail declining water availability further down the river system. In other parts of the basin (and notably in the lower Krishna basin, hydro-power project do not deplete water. They have slightly delayed the timing of river runoff, although balancing reservoirs have minimized impacts on existing agricultural uses further downstream (Venot *et al.*, 2007). In some dams, water discharged to produce hydroelectricity to meet peak-hours demand is pumped back in the reservoir to be further reused. Impacts of growing electricity needs on existing water uses and the environment need to be further studied.

Domestic and industrial uses

Industrialization and urbanization are fast developing in the Krishna Basin (Van Rooijen et al. Unpublished document). The demand for domestic and industrial water keeps growing, notably around the megalopolis of Hyderabad (8 million inhabitants) and Pune (3 millions), which are increasingly supplied from distant sources, by shifting water out of agriculture (see Van Rooijen *et al.*, 2005 on the Hyderabad case).

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[3] Declining base flows from groundwater mean that the 75% dependable flow of the Krishna River considered by the first KWDT (58.3 Bcm/year) is today only exceeded less than every other year. This means that downstream irrigation uses have been planned on water resources that do not exist anymore: supply security is affected and crisis situation more likely.

At the basin level, domestic and industrial water uses have trebled during the last fifty years but still only represent less than 1% of all water uses in the Krishna Basin. These figures highlight that inter-sectoral re-allocation of water from agriculture to more productive uses is unlikely to shape the future waterscape of the Krishna basin in average years. However, urban and industrial uses will be preferentially met (Molle and Berkoff, 2006): intra and inter-basin transfers could, in case of a drought, deprive water users in rural areas and sharpen conflicts at the local level (see Celio (2008) for a case study of water transfers, and related conflicts, around Hyderabad). Finally, groundwater overexploitation and degradation is problematic for meeting the domestic water needs of the large rural population depending on hand pumps.

The environment: A new large scale water user

Water and infrastructural development to meet growing human consumptive uses has taken place with little regard to the limits of availability and sustainability of renewable resources. This has resulted in significant degradation of various ecosystems. Although the impacts of reduced flows on ecosystems are not well quantified, there is well documented evidence of downstream environmental degradation in the lower Krishna basin, manifesting itself by soil and groundwater salinization, increasing pollution, disappearing mangroves and wetland desiccation (Venot *et al.*, 2008). With increasing evidence of the adverse impacts of water and land degradation on people's livelihoods, environmental concerns have started to gain strength and the notion of environmental flows is establishing itself firmly and challenge the very notion of "surplus water" commonly called upon to justify new infrastructure. According to a simple desktop assessment method proposed by Smakhtin and Anputhas (2006) to quantify environmental water needs in data scarce river basins, preserving the ecosystems of the Krishna basin in their current status would require an environmental flow allocation of about 6.5 to 14.2 Bcm/yr. This will point to a rate of water resources commitment of 95 to 99% showing that resources will be fully committed under average conditions.

Interlinking the rivers

In addition to the water transfers from the Godavari basin to Hyderabad, which were implemented in the early 1990s, several projects withdraw water from the Lower Krishna and transfer it southwest to irrigate some dry areas of Andhra Pradesh (see Figure 1). Some of this water is also supplied to the water scarce megalopolis of Chennai in Tamil Nadu. These projects have performed well below expectations even at times of abundant water availability and their full implementation would further increase the pressure on the Krishna waters.

The long mooted project of interlinking the Indian rivers may further affect water availability in the Krishna basin. Despite strong opposition by NGOs, this project has recently been given further impetus. Most links will concern the lower Krishna basin where water availability is to increase by 11.6 Bcm/yr (e.g. about 15% of the net inflow to the lower Krishna basin in 1990-2000, a fifth of which being "reserved" for the Krishna delta to support agriculture, counterbalance the observed decline in discharge of the Krishna river and limit environmental degradation [NWDA, 2007]). These transfers could redress over-use of water resources in the lower Krishna basin through a significant increase of surface water availability, and alleviate crisis situations likely to recur in the near future, but plans to extend irrigation with this transferred water defeat these objectives. The construction of a diversion from the Godavari basin began in 2006 and demonstrates the continued commitment of the Andhra Pradesh government to the interlinking project. A transfer from the Alamatti dam to the Pennar River basin, south-east, is also contemplated but plans to develop en-route irrigation make unlikely that any water will ever cross the hydrological boundaries of the Krishna basin. Finally, internal transfers to the Krishna basin take place in the Western Ghats of Maharashtra.

Forecasting the future: The drought of 2001-2004

Between 2001 and 2004, rainfall was 12% below the long-term average in the Krishna basin. This situation is not particularly unusual: in the Krishna Basin, such level of rainfall has been recorded with a probability of occurrence of 0.3 over the last 100 years and seven droughts of 3 years or more have been recorded over the last century (CRU, 2007). Despite this relatively low rainfall deficit, the basin water balance has been dramatically affected.

Evaporation in surface irrigated areas shrank by 37% due to the fallowing of a large area of irrigated lands (see for example Gaur *et al.*, 2008 and Venot *et al.*, 2008 for the dynamics of irrigation in the Nagarjuna Sagar irrigation project); groundwater based irrigation also decreased but to a lesser extent (-15%); groundwater base flows further declined and aquifer overdraft intensified. Another striking change is the 38% decline of the depletion from rainfed agriculture and the corresponding increase of the depletion from natural vegetation. The lower Krishna basin which bears the brunt of any intervention upstream was the region the most affected by the drought: its net inflow fell dramatically to 57.2 Bcm/yr (with surface water inflows from the upper basin as low as 10 Bcm/yr e.g. less than one fifth of their value in 1955-1965) (see Venot *et al.*, 2007). During this period almost no water reached the ocean as the basin consumed or stored 99.5% of its net inflow (the deficit in the discharge to the ocean was sharpened by the filling up of the Alamatti reservoir in Karnataka with nearly 3 Bcm, following a raise in the level of the dam). Any further development of water use in the basin will impinge on existing uses and the consequent re-allocation is likely to exacerbate competition and conflicts and is certain to reduce the security of supply to most existing users. This will happen while water depleted in surface irrigation projects always remained, for all three states and for the past five decades, within the limits of the KWDT award: this observation calls for the design and effective implementation of new allocations within the framework of the present Krishna Water Disputes Tribunal.

Conclusion

Over-commitment of water resources and signs of basin closure are apparent during dry periods in the Krishna Basin. However, despite rising inter-sectoral, inter-regional and inter state tension and reduced investment in rural development, the three states that share the Krishna waters continue to expand their agriculture and irrigation sectors. This development path can no longer be sustained without leading to a *de-facto* re-distribution of water among sectors and regions and further damage the environment. The paper highlights that it is not only water availability that is crucial in explaining the evolution of water use: with increasing pressure on water resources, water users generally develop informal adjustments, adapting to water scarcity and its socio-ecological ill-effects, on the basis of political, institutional and economic forces. But, basin closure intensifies the interconnectedness between water users and their environment: localised interventions tend to have unexpected consequences elsewhere in the basin. To overcome the difficulties that uncoordinated adaptive mechanisms may create (rent seeking, competition among users, increasing inequalities) and to avoid conflict, there is a clear need to articulate options that preserve a balance between equity, sustainability and efficient use of scarce water resources for both human benefit and preservation of the environment (Molle *et al.*, 2007).

Following the example of Australian water allocation procedures, it is crucial that the current Krishna Water Disputes Tribunal ensures a fair degree of stakeholder participation across the board from the local users to the administrations of the different states involved to design formal effective and adaptive allocation mechanisms that would (i) be defined at the basin level; (ii) be based on a comprehensive and transparent understanding of the hydrology; (iii) recognise the interactions between surface and groundwater; (iv) estimate long-term reliable supplies in any part of the basin in light of actual and projected use; and (v) recognise customary rights, local strategies and local adjustments (Scott *et al.*, 2001; Venot, 2008). Water development in the Krishna Basin has happened with little regard to the formal allocation mechanisms defined in the mid-1970s: this illustrates the need for a clear governance system with legally empowered actors who could act to stop any project contradicting the award of the tribunal.

Moreover, river basin closure means that overall basin efficiency is close to maximum: the scope for effective water savings remains limited and all options of water management must be pursued together. State governments are calling for the implementation of demand management options (participatory irrigation management, modernisation and rehabilitation of existing projects, water pricing strategies, technical on-farm improvements, conservation methods, etc) but supply augmentation projects (such as the Godavari-Krishna link) also enjoy a strong commitment from local governments. These supply augmentation projects will certainly re-open the basin but their social, ecological and economic consequences need to be carefully evaluated: mega-scale projects should not be used as justifications to disregard highly needed water-sharing procedures. Finally, sustainable management of water resources cannot be achieved with policies limited to the water sector only: interactions between state-driven surface water irrigation, state supported watershed development and farmers' private initiatives of groundwater abstraction in secondary upstream basins highlighted the need to resort to integrated rural development policies that would ensure the rural population alternatives within or outside the agricultural sector

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