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Explaining Basin Closure in the Lower Krishna Basin, South India

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Cover photograph by Jean-Philippe Venot shows paddy fields in the Krishna Delta.

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Contents

Acronyms and Abbreviations

AP	Andhra Pradesh
BCM	Billion cubic meters
CADA	Command Area Development Authority
ET	Evapotranspiration
gw	Groundwater
HMWSSB	Hyderabad Metropolitan Water Supply and Sewerage Board
KD	Krishna Delta
lpcd	Liters per capita per day
Mha	Million hectares
Mm^3	Million cubic meters
M&I	Municipal and Industrial
NJS	Nagarjuna Sagar
NWDA	National Water Development Agency
sw	Surface water

Summary

The Krishna River Basin in South India crosses the semi-arid Deccan Plateau from west to east. Since the 1850s, the Krishna Basin has seen an increasing mobilization of its water resources and a dramatic development of irrigation, with little regard to the limits of available water resources. This progressively led to closure of the basin (zero or minimal discharge to the ocean): by 2001-2004, surface water resources were almost entirely committed to human consumptive uses, increasing groundwater abstraction contributed to the decrease in surface water baseflows and the discharge to the ocean was almost zero. Despite evidence of basin closure, the three states that share the Krishna waters continue to strongly promote their agriculture and irrigation sectors. This development path can no longer be sustained without impinging on existing water use and affecting the security of supply for existing users.

The downstream areas of the Krishna Basin largely depend on the actions of upstream water users. The Lower Krishna Basin is one of the first regions to be adversely affected by any hydrological changes that take place elsewhere in the basin and to witness both severe water shortages and a spatial redistribution or re-appropriation of water during times of drought. Taking place on the basis of current political, institutional and geographical forces, this re-appropriation of water raises sociopolitical questions of sectoral and regional water apportionment within the Lower Krishna Basin, and may be at the origin of conflicts between water users.

This paper identifies the main changes that have affected the waterscape of the Lower Krishna Basin during the last fifty years: (i) a decrease by more than half of the surface water inflow into the lower basin (~25.8 billion cubic meters (BCM) a year in 1996-2000) due to water development in the upper basin; and (ii) an uncontrolled irrigation development in excess of existing formal allocation procedures in the Lower Krishna Basin itself. Irrigation depletion has increased almost four fold in 50 years and accounted for a fourth of all water depleted in the Lower Krishna Basin in 1996-2000. This local overcommitment of water resources in the Lower Krishna Basin is due to the uncontrolled development of private groundwater abstraction and the introduction of several biases, both at the farmer and command area levels, in the way *protective irrigation* has been practiced in that region. At the local scale, farmers take some liberties vis-à-vis a highly controlled management of water: they generally want to intensify their production and therefore require an optimal and flexible water supply, which they often obtain at the expense of their less well-placed peers and by always increasing the amount of water they use compared to what they are entitled to. At the irrigation project level (notably in Nagarjuna Sagar), governmental decisions and recommendations of the World Bank have led to changes in the design and practices of *protective irrigation* that have resulted in increased water use. By 1996-2000, 77% of the Lower Krishna Basin net inflow was depleted and discharge to the ocean amounted to 17.9 BCM/yr, defining a moderately modified ecosystem. During the drought of 2001-2004, likely to forecast the future waterscape of the Lower Krishna Basin, all indicators pointed to a fully committed situation, with depletion amounting to 98.8% of the net inflow, a lack of discharge to the ocean, a dramatic overdraft of the aquifers and the shrinkage of surface irrigated agriculture.

This paper shows that, while total water available in the Lower Krishna Basin is decreasing, changes in the waterscape of the basin are being shaped, to a large extent, by local users. This study underlines that it is not only the availability of the physical resource that is crucial in explaining the evolution of water use but, as water has become a disputed and highly politicized object, waterscapes are also strongly shaped by the social and political conditions of a region (a state for example), the boundaries of which often exceed the area where water is effectively used. In the Lower

Krishna Basin, both the intra-agriculture and the intersectoral distribution of water are being reshaped. In the agriculture sector, the strong political divide among the three regions of Andhra Pradesh and the need to balance rural development among those regions are two of the main driving forces of this shifting agricultural water use. Two paradoxical, yet complementary, observations can be made: (i) surface water distribution among large irrigation projects tends to be to the advantage of the politically influential coastal region, but (ii) uncontrolled groundwater development mainly benefits the dry upland regions of Telangana and Rayalaseema and is tantamount to a spatial and social redistribution of water, affecting surface water use in the lower reaches of the basin. These phenomena are not common public knowledge but will likely lead to conflicts as water scarcity is likely to become a recurrent feature of the Lower Krishna Basin waterscape. The intersectoral distribution of water is also being modified. First, increasing electricity needs have led to the completion of hydropower projects. However, while the hydropower projects can delay river runoff, they do not deplete water and balancing reservoirs have minimized the impacts on existing agricultural uses downstream. Second, domestic and industrial needs of urban areas are increasing and are preferentially met. Currently, this is not affecting existing water uses much as volumes considered remain marginal at the basin scale. But, in case of drought, it could further deprive agricultural uses in the large irrigation projects located downstream. Third, environmental degradation, notably in the delta area, has led to increasing awareness of the need to recognize the environment as a water user in its own right. This has yet to be translated into formal allocation mechanisms and will point towards further water commitment, leaving very little room for further water resources development.

This study, among others, shows that as a basin closes, water users, sectors and regions are increasingly interconnected. Local interventions have third party impacts and unexpected consequences elsewhere in the basin. Informal adjustments and uncoordinated, short-term management decisions, generally lead to an overcommitment that may severely degrade the resource base. To overcome the difficulties that such adaptive mechanisms may create (rent seeking, competition among users, increasing inequalities, etc.) and to avoid conflict, there is a clear need to articulate a specific course of action among the available options to keep a balance between equity, sustainability and efficient uses of scarce water resources for both human benefit and preservation of the environment. This could be done at the basin level through the definition and implementation of formal effective and adaptive water allocation mechanisms, both in time and space, to allow transparent and sustainable use of available water resources. At present, calls for demand management measures by both the Andhra Pradesh Government and international donors are strong, but the consideration and implementation of large interbasin water transfers from the Godavari Basin and the promotion of small-scale water structures in secondary upstream basins perpetuate an unsustainable rush towards further resource development. Alternatives are difficult to find, but supply augmentation options should not be taken as a justification for disregarding other management options as formal allocation procedures that will regulate water use, notably in the agriculture sector.

Shifting Waterscapes: Explaining Basin Closure in the Lower Krishna Basin, South India

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Introduction

The Krishna Basin lies in southern peninsular India and crosses the Deccan Plateau from its sources in the Western Ghats to its estuary, where the Krishna forms a delta before flowing into the Bay of Bengal. It has witnessed intensifying development of agriculture and water abstraction, with little regard to resource limitations. This has led to the progressive overcommitment of water resources (or closure) of the basin. By 2001-2004, there were no uncommitted outflows reaching the ocean, surface water resources were committed for human consumptive uses and groundwater was being abstracted at an unsustainable rate. The observed runoff to the ocean fell from a pre-irrigation development average of 57 BCM/year in 1901-1960 to less than 21 BCM/yr in 1990-2000, and even more strikingly, to 0.75 BCM/yr in 2001-2004, during an extended period of low rainfall. This decreasing outflow to the ocean highlights the modified status of the basin from an environmental point of view and clearly shows that there is only little scope for further water supply development.

However, the three states sharing the Krishna Basin continue to follow a path of agricultural development that strongly relies on both large and small-scale water abstraction. This development path will lead to further overcommitment of water resources and to regional de facto ‘re-appropriation’, will impinge on existing water uses, and will affect the security of supply for existing users that are increasingly interconnected in hydrological, social and political terms. Although all sub-basins of the Krishna are under threat of closure, this paper focuses on the Lower Krishna Basin which is the first to feel the adverse consequences of any hydrological changes in the basin. The scope of these changes (increasing variability and uncertainty, decreasing quantity, and declining quality) is likely to be at its highest in this region. The present study analyzes the long-term trends in agriculture and water resources development in the Lower Krishna Basin and examines past and current contextual factors impinging on water availability and uses in the basin. It aims to identify the principal drivers behind the current closure of the basin and understand how contemporary formal and informal institutional arrangements shape the geography of water use. This study is seen as a means to identify potential interventions in water management (notably irrigation) that can define new allocation procedures between regions and sectors in a context of growing scarcity.

The section, *Human and Physical Setting of the Lower Krishna Basin* sets the context by presenting the main human and physical features of the Lower Krishna Basin. The section, *How Does a River Basin Close? The Case of the Lower Krishna Basin* identifies the main driving forces behind water resources overcommitment in the Lower Krishna Basin. The section, *Expressing River Basin Closure in Figures: An Historical Water Account of the Lower Krishna Basin* provides a water account to assess past and current water uses and quantify the changes in the waterscape of the Lower Krishna Basin. The section, *Beyond the Description of Basin Closure: A Shifting Waterscape in the Lower Krishna Basin* investigates how different institutions and stakeholders have participated in this shifting waterscape with increasing interconnections and trade-offs among irrigation projects, as well as between domestic, industrial and agriculture sectors. The section, *Discussion and Conclusions* provides some conclusions.

Human and Physical Setting of the Lower Krishna Basin

The Krishna River Basin covers part of three Indian states: Maharashtra, Karnataka and Andhra Pradesh (Figure 1). The Lower Krishna Basin contains the sub-basins of the Lower Krishna, Musi, Palleru and Muneru rivers as well as the Krishna Delta and a poorly delineated area in the east of the delta: the Kolleru Wetland. Most of the lower basin (98.5%) belongs to Andhra Pradesh, with the remaining area lying in two districts of Karnataka (Figure 1).[1]

The Lower Krishna Basin has an area of 80,742 square kilometers (km²) and is the most densely populated part of the Krishna Basin (447 persons per km²). In 2006, the lower basin accommodated 36.1 million inhabitants, that is, 48% of the total basin population on an area representing just 30% of the whole basin. The population is mainly rural (65%) and half the urban population is concentrated in Hyderabad (7.9 million inhabitants).[2]

The downstream reaches of the basin accommodate more than 500 inhabitants (inh) per km² in large irrigation project areas, while the northeastern and central parts of the basin are less densely populated (100 to 200 inh/km²; cf. Appendix 1). Appendix 2 provides a map of average rainfall based on mandal level statistics: precipitation decreases from the northeast (above 1,000 millimeters (mm) per year in forested areas) to the semi-arid southwest (400 to 600 mm/yr).

FIGURE 1. The Krishna Basin, South India.

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[1] The part of the Basin remains negligible in terms of water use and is not considered in the water accounting presented in this paper. The boundaries of Andhra Pradesh and the Lower Krishna Basin do not coincide (the Tungabhadra and Bhima sub-basins cover part of Andhra Pradesh).

[2] Evaluations based on the 2001 All-India Census and assuming a growth rate of 3% per annum.

The Lower Krishna Basin can be divided into six main regions according to land-use and the extent of irrigation development.[3] Figure 2 identifies the following:

The Eastern Ghats where forest dominates: precipitation is high (>1,000 mm/yr) and provides runoff and groundwater recharge for downstream use. Supplementary irrigation by small-scale water harvesting structures remains limited.

A deciduous forest in the southwest. This region has little impact on the water balance of the basin due to high evaporation rates, though there are no stream gauges to establish a water balance (Biggs et al. 2007).

A large rainfed area divided into two subregions: 1) a rainfed ecosystem, and 2) an area where there is some diffuse irrigation based on groundwater or surface water use along valley bottoms; the metropolis of Hyderabad and the wastewater use area located downstream of the city.

The large irrigation project of Nagarjuna Sagar covers an area of about 900,000 hectares (ha) irrigated thanks to two main canals: the left bank canal (415,000 ha) and the right bank canal (485,000 ha).

The Krishna Delta project covers an area of about 540,000 ha.

An environmentally sensitive zone consisting of the coastal area (with some mangroves) and the adjacent Kolleru Lake, which is a wetland of international importance under the Ramsar Convention.

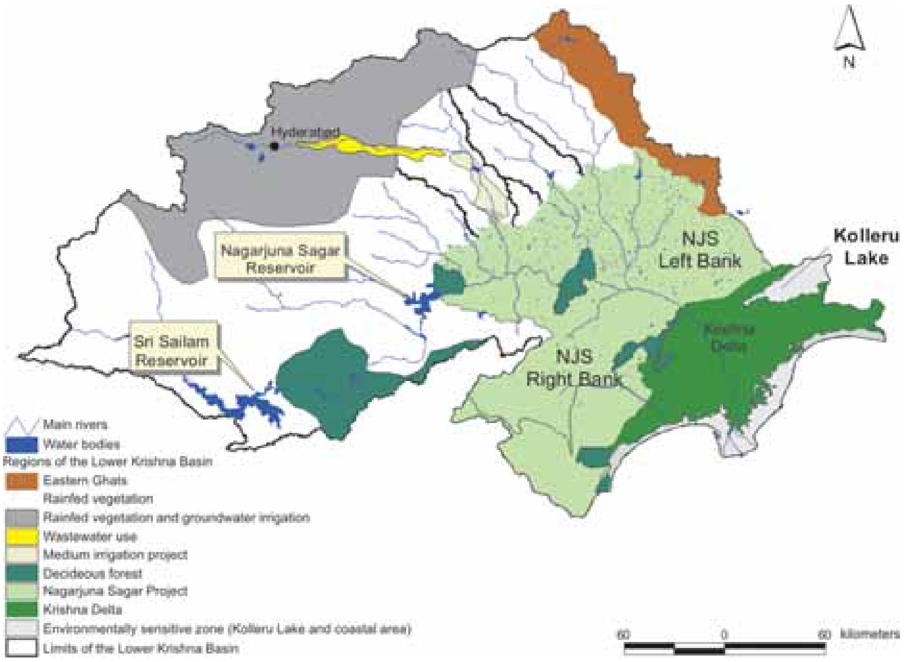

FIGURE 2. Regions of the Lower Krishna Basin. *Source:* adapted from Biggs et al. (2007)

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[3] Three large irrigation projects drawing water from the Krishna and located in Andhra Pradesh are not considered here as they are not located within the hydrological boundaries of the Lower Krishna Basin. They are: The Tungabhadra Left Bank Canal, the Rajolibunda Diversion Scheme and the Kurnool-Cuddapah Canal.

How Does a River Basin Close? The Case of the Lower Krishna Basin

This section argues that two main forces led to the changes in the Lower Krishna Basin waterscape during the last fifty years. The first reason is exogenous: a decreasing inflow in the lower basin due to upstream water development. The second is endogenous: the Lower Krishna Basin has seen an un-coordinated development of its own water resources with little regard to the initial plans of *protective irrigation*.

Upstream Developments and their Impacts on the Lower Krishna Basin

Since India gained Independence, many large dams have been built in the Upper Krishna Basin (the Tungabhadra, Malaprabha, Ujjani, Koyna and Alamatti dams are the largest among these dams): the storage capacity of large reservoirs in the upper basin increased from 3 to 27 BCM over the period 1947-2004 and, by 2004, was equivalent to a third of the historical mean annual runoff of the river as evaluated by the Central Water Commission at the head of the delta (77.6 BCM/yr [CWC 2002]).

Large irrigation projects, small-scale interventions (tanks and river diversions) and increasing access to groundwater led to a rapid expansion of the irrigated areas. Between 1970 and 2000, surface irrigated areas in the upper basin increased by more than half to cover some 1.14 million hectares (Mha) by 1996-2002. The bulk of this area was brought under paddy - the staple food crop. The groundwater irrigated area almost doubled in thirty years reaching about 1 Mha in 1996-2002.[4] This expansion occurred mainly in Maharashtra primarily for the promotion of sugarcane cultivation by private investors.

As irrigation expands, natural vegetation and rainfed crop areas slowly decrease (even if they are still dominant in the basin); local evapotranspiration increases and groundwater baseflows diminish. As a result, runoff declines. The Krishna Basin is no exception: the rainfall/runoff coefficient in the upper basin decreased from 0.22 to 0.15 between 1971-1974 and 1996-2000 translating larger water diversion and higher evapotranspiration in the upstream catchments. Between 1966-1975 and 1996-2000, the total inflow into the Srisailam Reservoir (which is a good proxy for surface water inflows to the Lower Krishna Basin) decreased by about one third (from 38.4 to 25.8 BCM/yr). During the dry period 2001-2004, this inflow decreased further to 10 BCM/yr (Appendix 3).

Un-coordinated Water Development in the Lower 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; Shiva 1991). 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. For a short period of time after the first anicut (diversion weir) was built (1855-1875), irrigation did not develop much in the Krishna Delta as cultivators faced burdensome taxation (some were still subjected to the *Zamindari system*), adverse climatic events (cyclone of 1864), poor management practices (both at the canal and farm level) and were used to crops that were not suitable for irrigation (Rao 1985; Ramana Rao 2004). The removal of the *zamindari system* and its replacement by the *ryotwari system*, the confirmation of ownership rights in land, the famine of 1876-1880 and the development of the road infrastructure in the delta region made irrigation more attractive and led to the expansion of rice cultivation (Rao 1985; Upadhya 1988).

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[4] Estimates based on district-wise land use data presented in GoAP (2006); GoKT (2006); GoMH (2005) and available online, with a subscription at http://www.indiaagristat.com

Between the 1850s and 1947, and except in the Krishna Delta, the Lower Krishna Basin did not experience any large-scale expansion in agriculture: irrigation continued to be sustained through local tanks. In the 1920s, two reservoirs were established near Hyderabad, the regional capital, for flood control and urban water supply (Biggs et al. 2007). During the same period (1850-1947), 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). British engineers promoted large *protective irrigation* schemes that met with varied success. The key projects included the Kurnool-Cuddapah Canal in present-day Andhra Pradesh (1860s); the Nira canals in present-day Maharashtra (1880s); the Gokak canals (1890s) and the Vani Vilasa Sagar project (1910s) in present-day Karnataka and finally the Tungabhadra project, which was designed in the 1930s, with a dam located in Karnataka and a large command area in Andhra Pradesh. After 1947, and despite a troubled post-independence period, irrigation development policy showed a strong continuity with the colonial era and had similar proclaimed goals, complementarities and contradictions: (i) agricultural growth and increased productivity, (ii) self-sufficiency in food and fiber requirements, (iii) agricultural modernization, (iv) protection of areas vulnerable to drought, (v) social welfare, (vi) regional equity, and (vii) long-run economic viability. This continuity also expressed itself through: (i) a strong governmental involvement in irrigation development (through successive five-year plans); (ii) the persistence of British administrative structures within a newly created Irrigation Department; and (iii) the similarity of technical designs of large-scale systems (Mollinga 1992, 2001). Finally, irrigation and water management became increasingly politicized.

Extensive irrigation development in the Lower Krishna Basin began with the modernization of the Krishna Delta project in 1954, when the first anicut that was built a century before collapsed. The present-day anicut irrigates about 540,000 ha. After independence, a greater part of the agricultural profit accrued to the cultivators and the increasing commercialization of agriculture led to the emergence of prosperous peasants or owner-cultivators who constituted a large class of “farmer-capitalists” (Upadhya 1988). These farmers, from agricultural casts, accumulated profits and reinvested them, first into land and money lending and then, in agricultural commodities, trade and agro-processing industries (rice mills, sugarcane factories, etc.). They started to migrate to cities, invested in urban businesses and child education and rose to political prominence. This led to a close integration of towns and countryside on one hand and agricultural production and urban market centers on the other, which makes the Krishna Delta one of the most dynamic and influential rural areas of Andhra Pradesh. The changes in the agrarian structures and the intensification of agriculture in the Krishna Delta are some of the reasons for the high historical usage of water in the Lower Krishna Basin. Irrigation and hydropower production developed further in the 1970s and 1980s with the construction of several large multi-purpose reservoirs: the Nagarjuna Sagar project (constructed from 1967 onwards) was designed to irrigate about 900,000 ha and accommodates a large number of migrants who left the Krishna Delta due to high land pressure [Jayashankar 2007]; and the Srisailam hydropower project (1983).

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. Local initiatives were heavily promoted (tanks, contour ditches, check dams) (Barker and Molle 2005). The Krishna Basin is no exception. Simultaneously, scattered irrigated plots multiplied due to the availability of private pumps and shallow tube wells (Deb Roy and Shah 2002). This constituted a silent revolution (Molle et al. 2004a), sustained by subsidized electricity as part of populist policies. The groundwater situation 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”[5] and negatively affect the environment in terms of aquifer depletion and surface runoff reduction.

Consequently, between 1955 and 2005, the net irrigated area in the Lower Krishna Basin increased more than twofold from about 0.52 to 1.3 Mha and the average cropping intensity rose from 108 to 120%. Cultivating during the dry season became more common as irrigation expanded. The cropping pattern dramatically changed as rainfed coarse grains were progressively replaced by rice and cash crops (pulses, oilseeds, chillies and cotton) benefiting from greater market integration. In the early years of the twenty-first century, about 39% of the cropped area in the Lower Krishna Basin was irrigated, compared to 13% in 1955. Groundwater irrigated areas have increased fourteenfold over the last 50 years, amounting to about 596,000 ha in 2001/2004 (i.e., 45% of all irrigated area in the Lower Krishna Basin compared to 8% in 1955).[6] Over the last decade, the Lower Krishna Basin waterscape has been completely modified with groundwater becoming one of the main sources of water supply for farmers. As surface water will be increasingly scarce and less reliable, this change may indicate the future of water use in the Lower Krishna Basin. In a context of basin closure, this shift towards more local water control is not neutral: it affects existing patterns of water use and spatially re-allocates water from downstream areas to upstream regions and might raise political tensions. The scope of these changes depends on the social and political context of the basin and on the institutional arrangements that stakeholders develop in the face of decreasing water availability. Nonetheless, they will have crucial impacts on the basin water balance and raises water management issues.

History of Formal Allocation Procedures in the Krishna Basin

The planning and development of large irrigation projects in the three states that share the Krishna waters (Andhra Pradesh, Maharashtra and Karnataka) 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 (Gulhati Commission 1962).[7] While major interstate disagreements brewed during the 1950s, the National Planning Commission of the

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[5] Private groundwater abstraction as well as lift irrigation from canals and rivers superimposed a logic of individual, un-coordinated, flexible and on-demand access to water. This has important implications for the regulation and management of water resources and may undermine attempts for collective action in water management (Molle et al. 2004a).

[6] All estimates are based on statistical data presented in GoAP (2006). According to the Minor Irrigation Censuses of 1994 and 2001, the number of shallow tube wells in the Lower Krishna Basin increased from 26,000 to 236,000 between 1987 and 2001 while the number of deep tube wells increased from 1,300 to 10,500 during the same period. Finally, 378,000 dug wells were registered in 2001 (261,000 in 1987). Among those about 100,000 dug wells, 9,000 shallow tube wells and 250 deep tube wells are not in use due to high water salinity or drying up. Statistical data on irrigated areas have to be cautiously considered: in addition to data quality issues, a lot of farmers conjunctively use groundwater and surface water and it is not clear how these large areas are accounted for. Nevertheless, the importance of groundwater exploitation remains unquestionable.

[7] The first disputes developed about the sharing of the Tungabhadra waters (a tributary of the Krishna, flowing in Karnataka). Until 1947, disputes involved the Madras and Bombay Presidencies and the independent states of Mysore and Hyderabad and were conditioned by the political and administrative context of the British Colony. In most of the cases, the Madras Presidency, located downstream and under direct British rule, exerted paramount power over the independent states. Madras prevented the construction of most projects planned in the Deccan Plateau (mostly located in the Hyderabad state, upstream) using the justification of ‘prior-appropriation right’, and objecting that these projects would threaten the established water uses in the irrigated areas of the Krishna Delta located in the presidency. For further description of the legal aspects of water sharing and water allocations in Colonial India and their consequences on present water allocation procedures and water uses, refer to D’Souza (2006).

central government defined the first formal allocation rules in 1951.[8] Several interstate conferences were held (notably in 1963 and 1969) under its auspices to negotiate these rules, which were slightly modified according to the state reorganization of 1956. The three states never reached an amicable agreement. Finally, at their request, the Government of India put an end to the negotiations and constituted the Krishna Water Disputes Tribunal (or Bachawat Tribunal) on April 10, 1969.

Based on an evaluation of the status of water resources and uses at that time, as well as on expected future use (mainly though irrigation project development), the tribunal announced its final award in 1976. This decision was legally equivalent to an order of the Supreme Court of India and set definitive water allocation rules between the three states.[9] The tribunal allocated the 75%-dependable annual flow (58.3 BCM/yr, exceeded in 75% of the years) as follows: 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 whatsoever to use any water nor be deemed to have been allocated, in any water year, water of the River Krishna in excess of* [its formal allocation]” (GoI-KWDT 1973, 1976: 94 Clause V).[10] Box 1 presents some of the limitations of the water allocation procedures as set out in the Krishna Water Disputes Tribunal award of 1976 and identifies some new features that should be included in any new formal allocation mechanism.

The Bachawat Award expired on May 31, 2000. As no amicable agreement to apportion water between the three states had been reached thereafter, a new Krishna Water Disputes Tribunal was constituted on April 4, 2004 and is expected to reach a decision in the course of 2008. An interim verdict has been delivered to the states by the new Tribunal on June 9, 2006 (The Hindu 2006e). In the meantime, water uses are based on de facto water diversions and ad hoc arrangements made between governors and chief ministers of Andhra Pradesh, Karnataka and Maharashtra. Andhra Pradesh, for example, regularly seeks more water to be released from upstream states, claiming that its irrigation projects face low water availability. These arrangements are highly publicized (The Times of India 2002; The Hindu 2003a), disputed and politicized and center heavily on local politics in the three states.

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[8] These first allocation rules evaluated the dependable flow at about 48.5 BCM/yr. Existing uses (20.2 BCM/yr) were preserved and the remaining 28.3 BCM were allocated as follows: 13.3, 7.9, 6.8 and 0.3 BCM for the Madras Presidency, the Hyderabad State, the Bombay Presidency and Mysore State, respectively. Surplus water, if any, was to be proportionally apportioned at a ratio of 39:30:30:1 (Shiva 1991).

[9] The tribunal based its award mainly on competitive reports prepared by the different states. Each of these state reports presented: (i) an evaluation of the water resources, the present and the expected water uses of the state, (ii) the claims of the state (in terms of water quantity to be allocated to each of the projects it considered in its evaluation), and finally, (iii) the rules of apportionment that the state wanted to be considered in the final allocation granted by the tribunal (See GoI-KWDT 1973, 1976; Bhongle 2004).

[10] This volumetric and fixed apportionment of water between the three states is known as the “Scheme A” and constitutes the default scheme to be implemented as per the tribunal award. Another scheme (Scheme B) considered a proportional apportionment of water between the three states. Following Scheme B, allocations would depend on water availability and either scarcity or surplus water would be proportionally shared by the three states. “Scheme B“ was supported by upstream states and opposed by Andhra Pradesh and thus never implemented (Sajjan 2005).

Box 1. Limitations of the Bachawat Tribunal Award and features that are required in a new allocation system.

First, as in many other river basins notably in Western United States, the Bachawat Tribunal neglected the relationships between surface water and groundwater systems as the three states *"will be free to make use of underground water within their respective territories in the Krishna River Basin [and] use of underground water shall not be reckoned as use of the water of the River Krishna"* (GoI-KWDT 1973, 1976: 72).

In the meantime, groundwater use has steadily increased in the Krishna Basin (45% of all irrigated areas are groundwater irrigated). The situation is particularly critical in the upper basin, where groundwater use has boomed mainly along river valleys. In these regions, where shallow alluvial aquifers and river systems are highly connected, heavy groundwater exploitation may have decreased or even cutoff baseflow (Hanumantha Rao 2006). Consequently, the 75%-dependable flow may, in fact, be lower than the flow considered by the tribunal during the 1970s. This is of crucial importance for downstream regions: if groundwater exploitation can temporarily buffer the 'loss' of surface water supplies, its current overexploitation greatly contributes to the magnitude and extent of overcommitment of water resources and poses further difficulties for resolution in the future. Understanding the interactions between groundwater and surface water in the Krishna Basin is critical in order to reach a better understanding of the basin hydrology and to define adapted allocation rules that would consider both surface water and groundwater resources and cap their respective use.

Second, return flows from large irrigation projects need to be further investigated as they may significantly fluctuate according to the volumes of water diverted into the canals (Gaur et al. 2007) and thus affect water availability further downstream (see Box 2). They should be accounted for establishing a sustainable allocation framework.

Third, while the Bachawat Tribunal mentioned that "*beneficial use shall include uses […] for domestic, municipal, irrigation, industrial, production of power, navigation, aquaculture, wildlife protection and recreation purposes*" (GoI-KWDT 1973, 1976: 95, clause 6), its award does not mention the relative shares allocated for these consumptive and non-consumptive uses. As domestic and industrial demands steadily increase and potentially conflict with other uses, there is a clear need to formally quantify the water entitlement for cities and industries. Finally, environmental needs have to be recognized and formally quantified as well.

Ignoring Water Availability: Over-Exploitation of Water Resources in the Lower Krishna Basin

Despite the formal process of water apportionment between the three states in 1976, agriculture and irrigation have been promoted regardless of the availability of resources. While implementing their own projects, the three states raised objections to the various projects promoted by other states, claiming that these were illegal, in the sense that they contradicted the order of the Bachawat Tribunal. Finally, few (if any) projects have been stopped in accordance with central government recommendations, highlighting the paramount power of states over the federal government in the matter. As early as 1991, Shiva (1991) pointed out that the ratio of demand to formal allocation in the Lower Krishna Basin was about 2.5:1. This is due to the fact that the Bachawat Tribunal only partially recognized and sanctioned the high historical usage of water in the lower basin while it continued to expand.[11] The Lower Krishna Basin is a ‘deficit’ basin where local uses considerably exceed local runoff. Biggs et al. (2007) showed that the Lower Krishna Basin had an aggregate deficit (allocation versus local runoff) of 11.1 BCM/yr over the period 1994-2002, highlighting its dependency on inflows from the upper basin that are continually decreasing and becoming more unreliable. The discrepancy between water allocation and water use is even more striking at the irrigation system level. While the tribunal ‘protected’ water uses of 7.9 and 5.1 BCM/yr in the Nagarjuna Sagar and the Krishna Delta projects, respectively, these systems used 10.5 and 6.5 BCM (i.e., 133 and 128% of this protected use), respectively, throughout most of their recent history (cf. section *Nagarjuna Sagar versus Krishna Delta*).

Practices of Protective Irrigation: A Driver of the Current Water Resources Over-Exploitation in the Lower Krishna Basin

The Concepts of Protective Irrigation[12]

Canal irrigation in India was always an important instrument of colonial rule (Stone 1984). Irrigation developments that were attempted were burdened with contradictory goals highlighting the conundrum of colonial policy. Irrigation projects were indeed intended to stabilize food crop production, increase the cultivated area and provide relief work, but they were also meant to maximize revenue and extend cash crop cultivation. While the first dimensions of this policy contributed to drought relief and famine prevention, the last objectives worked against it and could cause social unrest (Mollinga 1992; Ramamurthy 1995). Irrigation was meant to ‘protect’ crops from failure by supplementing water to a region as large as possible (IIC 1903; quoted in Mollinga 2003): this constitutes the first and most general usage of the term *protective irrigation*. In the last quarter of the nineteenth century, the term acquired another signification: it was used to designate irrigation projects that yielded low financial results and were mainly constructed for famine prevention. This administrative-financial meaning of protective irrigation is no longer part of the irrigation planning discourse (Mollinga 2003). Finally, the term *protective irrigation* designates a specific type of irrigation: protective irrigation systems are large-scale canal systems found in semi-arid drought-prone regions and aimed at spreading available water resources thinly over a large area and to a large number of farmers: supplementary irrigation is implied (Mollinga 2003). These schemes need low intensity management as the design of the system is supply oriented with a continuous flow safeguarding the crop (Bolding et al. 1995; Jurriëns and Mollinga 1996). Water rationing in the protective irrigation systems of the Lower Krishna Basin (and of semi-arid South India more generally) was introduced through a form of agricultural land use planning: the *localization*. The government regulates the cultivation of particular crops on selected pieces of land and water distribution is meant to be indirectly regulated through controlling the cropping pattern (see Mollinga [2003] for further discussion on the history, implementation and monitoring of the localization).

At first, protective irrigation emphasized supplementary irrigation of coarse grains (traditional food crops: sorghum and millet). Increasing the production and productivity of food and commercial crops (rice, sugarcane, cotton and chillies) quickly became the main objective of an irrigation sector pursuing economic objectives. However, the form of production implicit in the concept of protective irrigation remains one characterized by relatively extensive farming. This contradicts the individual production and income maximization strategies of

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[11] While the tribunal assumed that 4.8 BCM/yr were used in the Andhra Pradesh part of the Krishna Basin in 1968/1969 (volumes diverted to projects using more than 85 million cubic meters [Mm^3]/yr [GoI-KWDT 1973, 1976: 94]), a total of 5.9 and 7.8 BCM/yr were already diverted to the Nagarjuna Sagar and the Krishna Delta canals, respectively (cf. section Nagarjuna Sager versus Krishna Delta).

[12] This section heavily draws on Peter Mollinga’s work “On the Waterfront” (Mollinga 2003).

most farmers who therefore do not adhere to protective cropping patterns and plant rice and sugarcane that need more water but enjoy high returns (Mollinga 2003). Denying the natural tendency towards intensification (as population increases and landholdings shrink), protective irrigation is hardly viable in the long run. The impossibility of enforcing strong land-use planning through localization led to the concentration of irrigation water on wet crops, mainly located at the head-end of the canals, and to the unequal distribution of economic benefits of irrigation (Mollinga 2003). In certain cases, it also led to an overcommitment of water at the command area level.

The Politics of Protective Irrigation: Is it really Protective?

We argue here that the gap between the theory and the practices of protective irrigation is one of the reasons for the overcommitment of water resources in the Lower Krishna Basin. Paradoxically, and despite the acknowledgement of its failure, this model of irrigation development remains central in the irrigation policy of Andhra Pradesh today: it provides convenient legitimacy for the State for infrastructure development and may have introduced and cemented a social justification, called upon by local politicians, for overbuilding. The continued existence of protective irrigation lies in the populism characterizing Indian politics (Ramamurthy 1995; Suri 2002; Mooij 2003): as political representatives have to secure resources for their constituencies, there is actually a pressure to spread public resources thinly over /to a large number of people (Mollinga 2003). Protective irrigation fits well in this context:

> *"In the contemporary context, while the policy is still justified using the rhetoric of 'protection' and socialist planning (sharing benefits as widely as possible), longer canals also provide an opportunity to maximize the number of constituencies that [politicians] have favored (Ramamurthy 1988, quoted in Mollinga 1992)"*

While this populist political agenda sustains the existence of protective irrigation at the policy level (for poverty and inequity alleviation), it also defeats its implementation as rich peasants who appropriate more than their relative share of irrigation water also constitute the main political support base of the local politicians (Mollinga 2003). The latter are thus likely to condone the non-achievement of protective objectives: the unequal distribution of water within an irrigation project is thus socially and politically shaped.

The politics of protective irrigation, the undermining of the *spreading scarcity* approach and the sharpening of existing inequalities do not always lead to overcommitment of water resources if the irrigation project is considered as a whole. In the Tungabhadra project, for example, the design of the canal network limited water supply, with the result that deliveries to the main canals were less than the allocation awarded by the Bachawat Tribunal. Further, even when water was plentiful, the canals could not meet the actual demand of the command area, where wet crops were more common than had been planned. In this case, the relative lack of canal water led to both increasing conjunctive use (lift irrigation from canals and small rivulets; groundwater pumping) and to tailender problems, as upstream farmers used more than their formal entitlement to irrigate higher value and more water-intensive crops (Mollinga 2003).

The situation in the Lower Krishna Basin is different. The Nagarjuna Sagar project, for example, was designed along protective lines to irrigate large areas of both paddy and field crops during the rainy season (IRDAS 1996; GoAP 2001a). The allocation of the Bachawat Tribunal was calculated according to the "protective localization" envisioned in 1969, "*however, the design features of the project and the areas proposed to be irrigated were changed during its actual execution while there was no alteration in the quantum of proposed utilisation [of water]"* (GoI-KWDT 1973, 1976: 107). These changes are also mentioned by Hashim Ali (1982) in the Report of the Commission for Irrigation Utilisation in Andhra Pradesh and have mainly consisted in extending the area to be irrigated in the dry season as proposed by the World Bank (World Bank 1976; Hashim Ali 1982). Thus, the intended 'protection' was defeated by: the impossibility of enforcing the localization, which denies the natural tendency towards intensification; the unplanned extension of water-intensive crops and the modification of the project design during its implementation through the slackening of land use planning. As a consequence, water uses exceeded the formal allocation of the Bachawat Tribunal (World Bank 1976; Hashim Ali 1982; cf section *Reshaping the Agricultural Waterscape of the Lower Krishna Basin*). This loose implementation of a strong technical and managerial concept has been driven by economic, social and political factors. This formal institutionalization of high water use in the Nagarjuna Sagar project induced lower flows downstream and the overcommitment of water resources in the Lower Krishna Basin that is observed today.

Expressing River Basin Closure in Figures: An Historical Water Account of the Lower Krishna Basin

An Indicator: The Decreasing Discharge to the Ocean

The first striking indicator of river basin closure is the decreasing discharge to the ocean. Figure 3 shows the pattern of discharge from the Krishna River measured at the head of the delta, after diversions to the Krishna Delta project (the last point of measurement). Before 1960, river discharge into the ocean averaged 57 BCM per year. Since 1965, it has steadily decreased at an average of 0.8 BCM per year to reach 10.8 BCM in 2000, which is less than 15% of its historical runoff, while it was almost nil in 2004 (0.4 BCM). Figure 3(b) illustrates that only little utilizable monsoonal flows (July-October) reach the ocean and that the peak outflow has been delayed by about two months due to an ever-increasing upstream regulation.

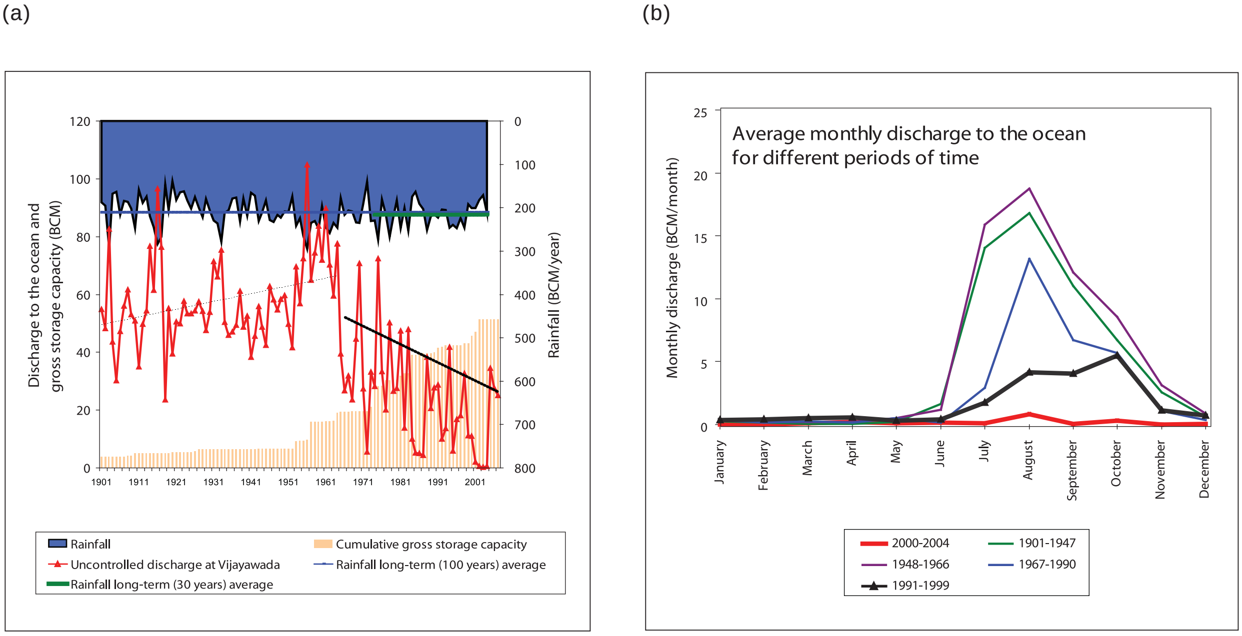

FIGURE 3. The closure of the Krishna Basin: A decreasing discharge to the ocean. *Sources:* (a) adapted from Biggs et al. (2007); (b) Andhra Pradesh State Water Data Centre.

Since independence total storage capacity in large reservoirs of the Krishna Basin has been multiplied eightfold to reach about 54 BCM, i.e., 95% of the pre-1965 river discharge (half of this infrastructure development took place in the Lower Krishna Basin). In the meantime, small-scale irrigation projects have also boomed. Though their total volume is not well known, the Bachawat Tribunal estimated that 6.5 BCM/yr were committed to such projects in the 1970s (Shiva 1991). In these conditions, the volume of regulated water is higher than the 75%-dependeable annual 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 annual flow (Biggs et al. 2007). Moreover, these figures underestimate the overcommitment of water resources since they do not account for groundwater abstraction that has skyrocketed over the last 20 years.

Spatial Distribution of Water Uses in the Lower Krishna Basin

The water accounting presented in Figure 4 and Appendix 3 draws on the categories of water balance proposed by Molden (1997). It estimates water depletion, defined as the use or removal of water from a river basin that renders it unavailable for further use. It identifies eight categories of depleted water: beneficial depletion from 1) surface irrigation, 2) groundwater irrigation, 3) rainfed agriculture, 4) domestic processes, 5) industries, 6) livestock, 7) low-benefit depletion from natural vegetation (forest, shrublands, fallows, etc.), and 8) non-beneficial depletion from bare land and reservoirs. As a first approximation, the depletion from any kind of land cover is estimated as its evapotranspiration (ET). Evapotranspiration in irrigated fields and evaporation from reservoirs is derived from climate data and a Penman-Monteith equation (Allen et al. 1998).

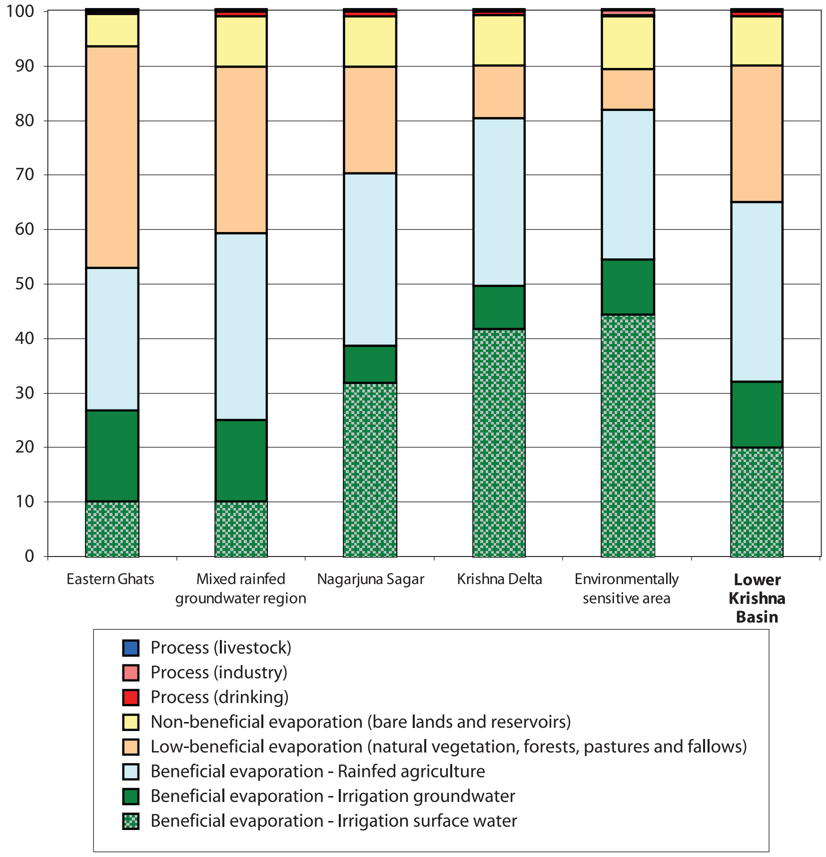

FIGURE 4. Total depletion (relative value), broken down into eight categories for each region of the Lower Krishna Basin (base period 1996-2000).

Evapotranspiration by rainfed agriculture and rainfed vegetation is estimated after Biggs (in review) and Bouwer et al. (2007) on the basis of P-ET (Precipitation-Evapotranspiration) curves and assumes minimal soil moisture limitation. Land cover is estimated on the basis of land use statistics at the district level (GoAP 2006). Domestic and industrial uses have been computed according to Van Rooijen et al. (Unpublished document). Livestock process is computed according to Peden et al. (2007). We used average figures referring to periods of 5 to 10 years, expressed in Mm^3/yr. With this method, we do not consider the year-to-year variability that can affect the water balance. Although this variability is important in terms of management, we focus here on long-term trends characterized by average balances.

Overall, total depletion in the Lower Krishna Basin amounted to 77% of the net inflow (rainfall + inflow from the upper basin + aquifer overdraft) in 1996-2000. Rainfed agriculture was the main user of water, most of which originated as rainfall: depletion in rainfed agriculture accounted for 25% of the net inflow in 1996-2000; natural vegetation depleted 19% of the net inflow. Irrigation depletion amounted to 25% of the net inflow (9% of the inflow is evaporated through groundwater irrigation); and the share of M&I uses was negligible and represented less than 1% of the total depleted fraction in the Lower Krishna Basin. Finally, 7% of the net inflow was evaporated in bare lands and open water bodies. The discharge to the ocean amounted to about 23% of the net inflow (1% of the total available water was exported to other basins) and there is a clear need to protect it from further human consumptive use to avoid further degradation of an already environmentally impacted basin.

Beneficial depletion (ET irrigation, ET rainfed, drinking, industry and livestock depletion) was at its highest in the Krishna Delta and in the environmentally sensitive zone where it reached 80% of the total depleted water. The rainfed region is characterized by low beneficial depletion (59% of the depleted water) and high ‘low-benefit’ depletion (30% of the depleted water). This is linked to the large areas of natural vegetation characterizing this region. The Eastern Ghats have the highest, low-benefit depletion (41% of all water depleted in the region) due to large areas of forest. Irrigation depletion increases downstream and is particularly high in the Krishna Delta and in the environmentally sensitive zone (coastal area and Kolleru Lake region) where it accounts for 49 and 54%, respectively, of total beneficial depletion. Non-beneficial depletion varies between 6 and 10% of the total depleted volumes depending on the region.

Historical Trends in Water Use in the Lower Krishna Basin

This section aims at identifying the main long-term changes of the Lower Krishna Basin waterscape. It describes the process of closure in further detail by mapping the regional and sectoral evolution of water uses since 1955. First, historical water accounting highlights that the gross inflows (rainfall + inflow from the upper basin) in the Lower Krishna Basin have fallen from 109 BCM/yr between 1955-1965 to 79 BCM/yr between 1996-2000, as a consequence of increasing water control in the upper reaches of the Krishna Basin. Surface water inflows from the upper basin have indeed decreased by about 52%, down to 25.8 BCM/yr over the period 1955-2000 (cf. Figure 5 and Appendix 3). This is still higher than the protected volumes to be used by Andhra Pradesh and mentioned in the Bachawat Tribunal Award of 1976.[13]

Another striking element is the decreasing groundwater baseflow contribution to the surface water balance (minus 5 BCM/yr on average ~ 6% of the net inflow) and the over-exploitation of aquifers by about 0.5 BCM/yr during the same period (cf. Appendix 3). The extent of groundwater depletion is better illustrated when compared to the ET of irrigated areas: aquifer mining represented 3% of the

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[13] Moreover, Andhra Pradesh also enjoys water in the Tungabhadra and Bhima sub-basins, which cover part of the state. This available water is not accounted for here.

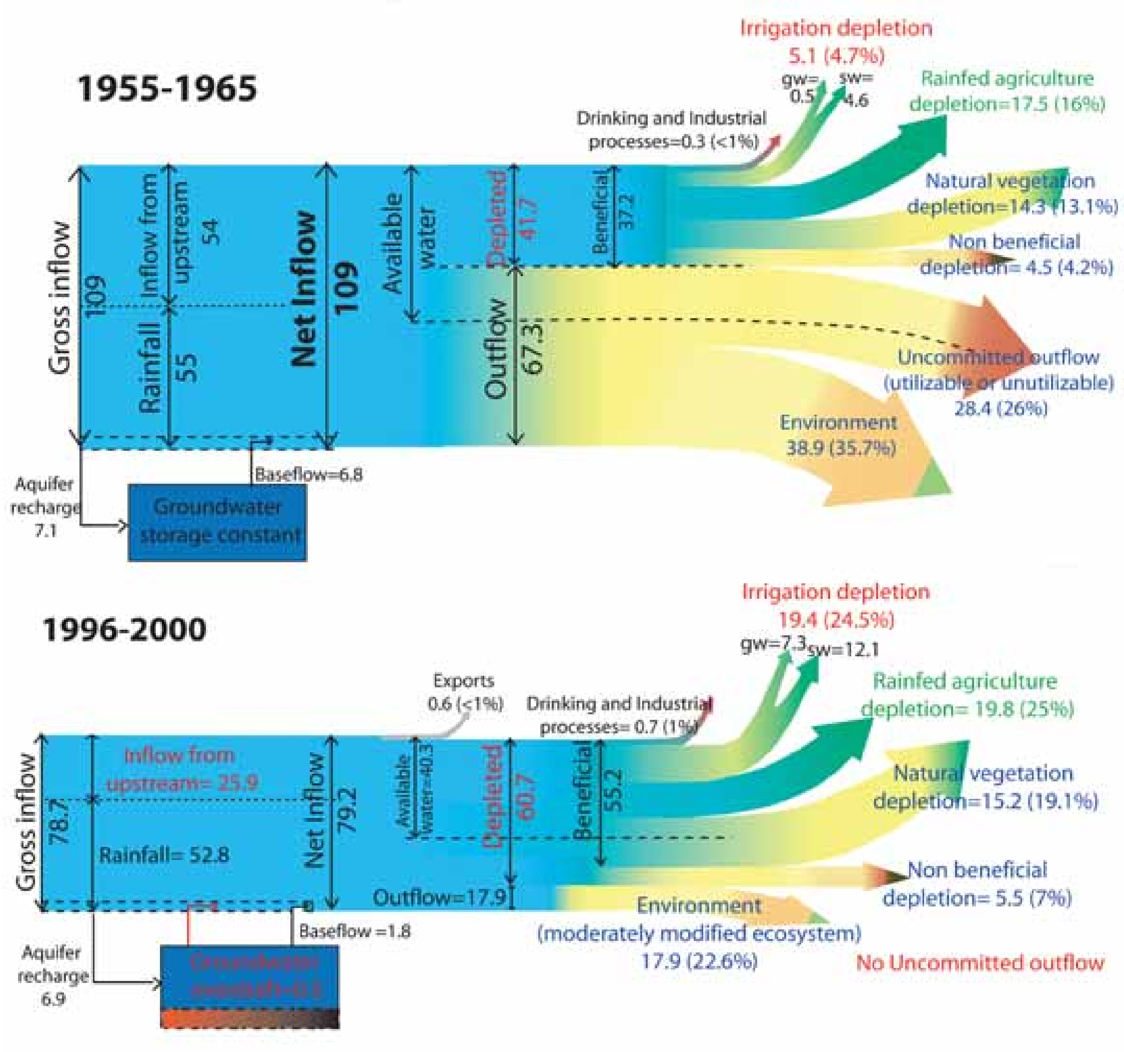

FIGURE 5. Water depletion in the Lower Krishna Basin: Trends since 1955.[14]

total water evaporated in irrigated areas in 1996-2000. These figures should be treated with caution; nevertheless, they may constitute a good proxy of the unsustainable status of groundwater in the Lower Krishna Basin.[15]

Figure 5 and Appendix 3 give further information on the changing components of the water balance in the Lower Krishna Basin since the mid-1950s. All indicators have registered their highest increase during the 1970s and 1980s. The main trend is a strong increase in irrigation depletion that, overall, has almost increased fourfold from about 5 BCM a year in 1955-1965 to 19.4 BCM a year in 1996-2000. In line with the development of the Nagarjuna Sagar project and a groundswell of private small-capacity irrigation pumps, irrigation depletion increased from 5 to 25% of the net inflow (rainfall plus inflow from the upper basin and aquifer

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[14] All figures are in BCM/yr; the size of the arrows is proportional to water flows. Environmental flows have been computed according to Smakhtin and Anputhas (2006) to maintain a slightly modified ecosystem: environmental requirements have been evaluated at 35.7% of the historical annual runoff observed during the period 1955-1965.

[15] These estimates depend heavily on the estimation of the actual evapotranspiration of crops and natural vegetation for which several uncertainties remain, as well as on the interactions between groundwater and surface water systems which need to be studied further. The Andhra Pradesh Groundwater Department has estimated that 38% of its watersheds have unsustainable groundwater abstraction, including more than 15% that are over-exploited (Biggs et al. 2007).

overdraft) and from 22 to 48% of the beneficial depletion. This implied a 31% rise in the total depletion, amounting to 60.7 BCM/yr in 1996-2000, i.e., 77% of the net inflow into the Lower Krishna Basin.

Low benefit depletion remained constant in absolute values but its share increased slightly. Rainfed agriculture remained of major importance until the mid-1980s when rainfed crops constituted a major component of the local diets. Then, depletion from rainfed agriculture slightly decreased as it has been replaced, little by little, by groundwater supported cultivation (cf. Appendix 3). The relatively high depletion, mainly originating from rainfall, as early as 1955-1965 (38% of the net inflow) highlights the importance of both rainfed agriculture and natural vegetation depletions, which highly depend on soil moisture or ‘green water’. Finally, municipal and industrial processes increased dramatically but still represent a minimal share of the total depletion (about 1% in an average year). This illustrates that conflicts over intersectoral allocations are not likely to happen in an average year despite the growing needs of cities. The situation may change during dry years with potentially more acute competition (Van Rooijen et al. Unpublished document).

Comparing the volumes of water depleted in irrigated fields with observed streamflow gives further information on the extent of closure of the Krishna Basin. In 1996-2000, evapotranspiration from irrigated fields consumed 19.4 BCM/yr, i.e., 75% of the surface inflow coming from the upper basin. The remaining volume was discharged to the ocean (17.9 BCM). Further, surface irrigation in the Lower Krishna Basin accounts for more than 100% of the local runoff and aquifers are critically over-exploited.[16] This makes further mobilization highly uncertain as water supply to these newly irrigated areas would have to depend entirely on an increasingly unreliable inflow from upstream.

Finally, an analysis of the spatial evolution of the water balance of the Lower Krishna Basin shows only small changes in the regional distribution of the depleted volumes (not shown). Due to its large area and drier climate, the rainfed region was and remains the main water consumer of the Lower Krishna Basin (evapotranspiration, mainly fed by rainfall, is at its highest). Its relative importance, however, decreased slightly as irrigation expanded in the Nagarjuna Sagar project.

What’s Next: Can the Drought of 2001-2004 be a Likely Forecast for the Future

Between 2001 and 2004, the entire Krishna Basin witnessed a period of drought: rainfall in its lower reaches was 15% below normal (10% below normal in the Krishna Basin as a whole [cf. Appendix 3]). Despite this relatively low rainfall deficit, the basin water balance has been dramatically affected as the total net inflow in the Lower Krishna Basin decreased to 57.2 BCM/yr, i.e., about half of its value in 1955-1965.

Inflow from the upper basin was as low as 10 BCM/yr (2001-2004) and, if we consider the local runoff, total available streamflow was about 20.6 BCM a year, similar to the 22.6 BCM/yr allocated to Andhra Pradesh by the Bachawat Tribunal. This situation is not particularly exceptional: rainfall that is 10% below average has been recorded with an occurrence of 30% during the last 103 years (CRU 2007; GoMH 2005; GoAP 2006; GoKT 2006). The drought of 2001-2004 may predict how the Lower Krishna Basin waterscape will look in the near future. Almost no water reached the ocean: this illustrates the impossibility to further develop water resources without impinging on actual uses and exacerbating competition and conflicts among users as well as trade-offs between regions and sectors of water use. Figure 6 illustrates that new changes as well as the sharpening of long-term trends have affected the Lower Krishna Basin waterscape during the last few years.

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[16] The local rainfall/runoff coefficient has been evaluated at 23% based on the calculation presented in Table 3 of the report by Biggs et al. (2007) for the different regions of the Krishna Basin.

Evaporation in surface irrigated areas shrank by 37% due to the fallowing of a large area of irrigated lands in the Nagarjuna Sagar and Krishna Delta projects (Gaur et al. In press; Venot et al. 2007). Groundwater irrigation increased and accounted for 51% of the total volume evaporated in irrigated areas. Finally, depletion from rainfed agriculture declined by more than 25%.

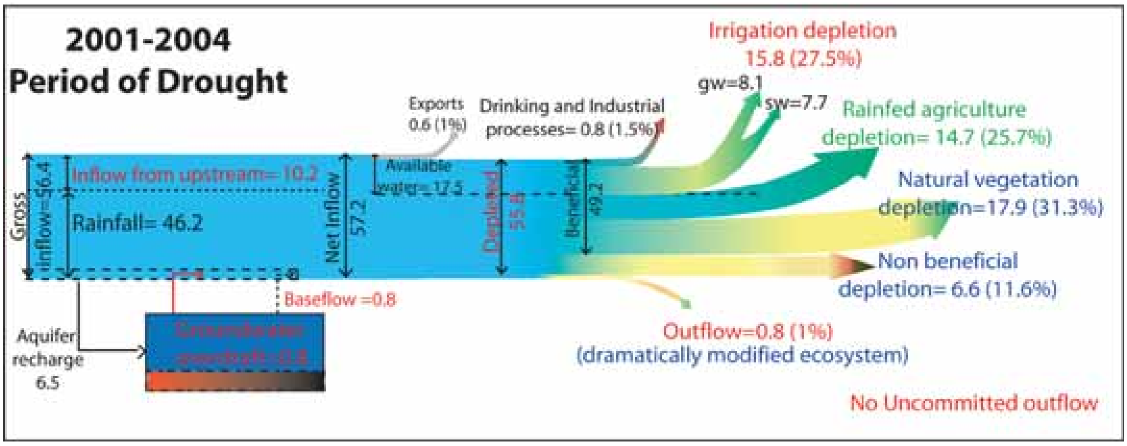

FIGURE 6. Water depletion in the Lower Krishna Basin between 2001 and 2004.

Beyond the Description of Basin Closure: A Shifting Waterscape in the Lower Krishna Basin

This section argues that the shifting waterscape described above has been paralleled by an ad hoc redefinition of water use patterns in the Lower Krishna Basin. It also investigates how different institutions and stakeholders have participated in shaping this waterscape and how they have created new relationships between water use sectors and regions. The first section, *Increasing Interdependence between Regions and Sectors of Water Use* will present the different linkages that have developed in the Lower Krishna Basin during the last fifty years. The second section, *Reshaping the Agricultural Waterscape of the Lower Krishna Basin* focuses on the regional redistribution of water within the agriculture sector in the Lower Krishna Basin. The third section, *Reconsidering the Intersectoral Distribution of Water* addresses how the intersectoral distribution of water use in the Lower Krishna Basin has been reshaped; and, finally, the fourth section, *Water Transfers In and Out of the Lower Krishna Basin* identifies how increasing water transfers in and out of the Lower Krishna Basin may affect local water users.

Increasing Interdependence between Regions and Sectors of Water Use

As the Krishna basin closes, water users are increasingly interdependent on each other and various linkages develop: such interactions are typical of a region facing changes in water availability and unreliable supplies. Linkages may be: 1) regional - between lower and upper reaches of the basin; 2) internal to agriculture - between different large irrigation projects and diffuse water developments; but 3) may also take place between different sectors of water use, either geographically close or distant. Domestic and industrial water uses, for example, claim a growing part of the resources used for electricity generation, agriculture or that needed for environmental preservation.

Figure 7 identifies the main interconnections and the main water conflict prone areas in the Lower Krishna Basin. Table 1 summarizes the

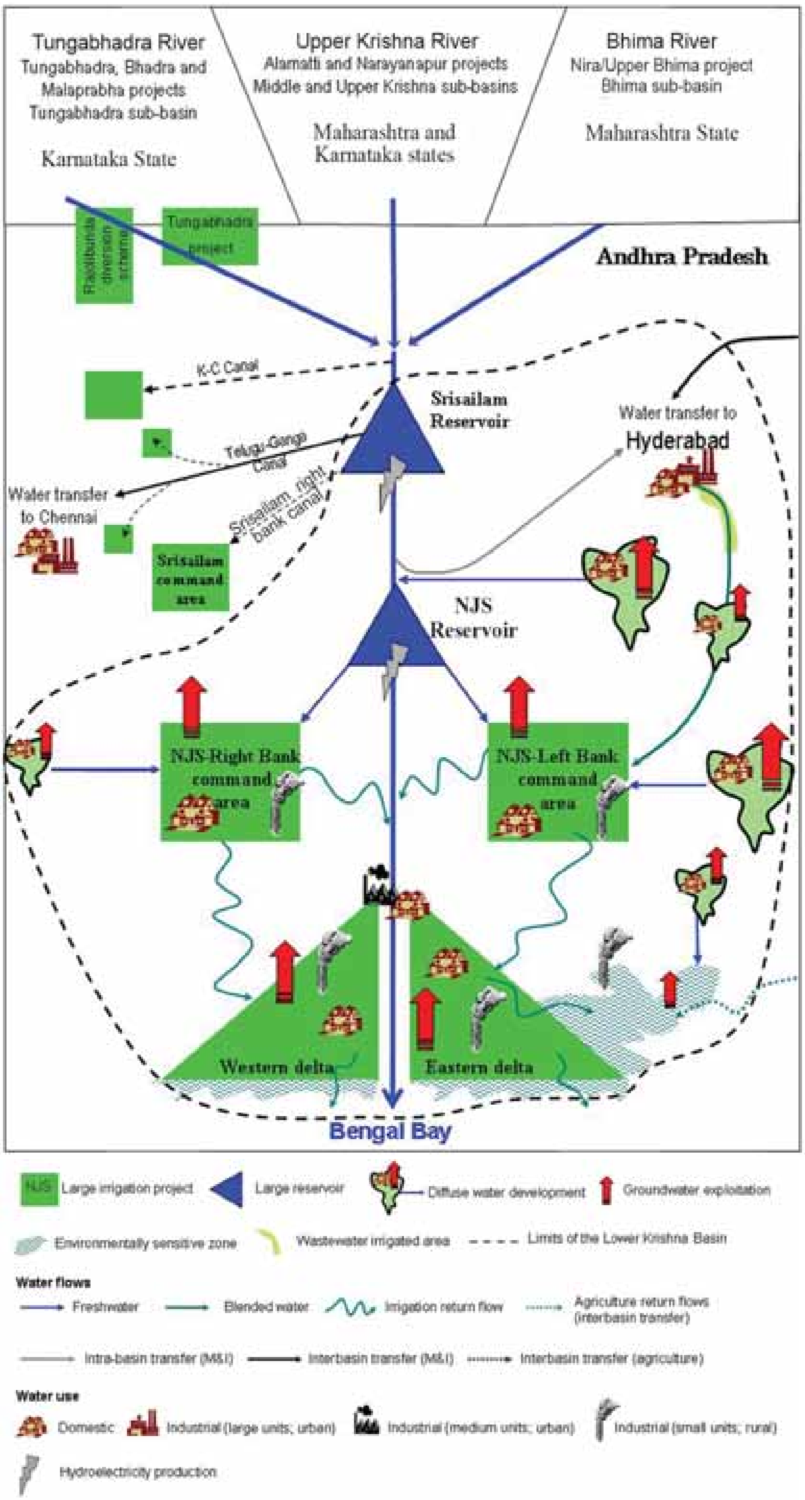

FIGURE 7. Schematic representation of the Lower Krishna Basin. Size of arrows and other shapes are not proportional to water flows, water users of irrigated areas.

TABLE 1. Different levels of interconnection between water uses and users in the Lower Krishna Basin.

Geographic linkages	Technical characteristics of linkages	Key features of linkages
A. Between the Lower Krishna Basin and other basins	Linkages between domestic and agricultural water use in the Pennar Basin and water uses in the Lower Krishna Basin.	• Dependability, timing and quantity of water releases through the Kurnool-Cudappah, the Srisailam Right Bank and the Telugu Ganga canals
	Linkages between water use in the Godavari Basin (domestic and agricultural); domestic and industrial water needs of Hyderabad and environmental needs of the Kolleru Lake.	• Dependability, timing and quantity of water transferred from and to Hyderabad • Status and extent of water to be transferred through the river interlinking project • Return flows from the Godavari Delta Canal and drains to the Krishna Delta system
B. Between Lower Krishna and upstream reaches of Krishna Basin	Links between water development upstream and water use in the Lower Krishna Basin.	• Water use in upper reaches of the Krishna Basin (quality, quantity, dependability and temporality) • Inflow to the Lower Krishna Basin
C. Internal to the Lower Krishna Basin between different regions	Intra-sectoral (agriculture) distribution of water between the Nagarjuna Sagar and Krishna Delta irrigation projects	• Nagarjuna Sagar Dam releases (dependability, timing and quantity) • Nagarjuna Sagar return flows (Nagarjuna Sagar efficiency)
	Connections between diffuse water developments in the rainfed region; groundwater replenishment and water use further downstream in the large irrigation projects of Nagarjuna Sagar and the Krishna Delta	• Scale of watershed, rainwater harvesting and groundwater development programs • Impact of local water development and groundwater replenishment on quality, quantity and dependability of surface water flows (rainfall/runoff patterns) • Water depletion by uses and regions as well as changes over time
	Intersectoral linkages between the domestic and industrial water needs of Hyderabad and water use (agriculture, industrial and domestic) in downstream irrigation projects	• Dependability, timing and quantity of water transferred from the Krishna River to Hyderabad
	Intersectoral issues between agricultural use in the Krishna Delta (and the Godavari Delta) and environmental needs of the Kolleru Lake and the delta's own ecosystem	• Canals and drains flow from the Krishna and Godavari delta systems to the Kolleru Lake and the coastal area (delta systems efficiency) • Groundwater exploitation in the delta systems and related soil/aquifer salinization.
	Intersectoral links between hydroelectricity production at the Srisailam and Nagarjuna Sagar dams and the water needs further downstream	• Electricity needs and demands • Quantity and schedule of dam releases for hydroelectricity generation • Downstream agricultural and environmental needs (quantity and timeliness)
D. Internal to the Lower Krishna Basin within a single region	Intersectoral links between domestic/ industrial needs of the population and high agricultural use in highly densely populated irrigation projects (Nagarjuna Sagar and Krishna Delta)	• Urban and industrial water needs and demands of the population. • Population dependent on project's canal releases (timing and quantity)
	Intra-sectoral issues (agriculture) within an irrigation project between groundwater, canal and lift irrigation	• Groundwater quality and quantity. • Groundwater dependability on rainfall and canal releases
	Intersectoral linkages between domestic and industrial needs of Hyderabad and neighboring agricultural water use	• Urban and industrial water needs and demands of Hyderabad and other local users (quantity, quality) • Quality and quantity of return flows from Hyderabad. • Local agricultural water uses

main linkages from the macro to the micro level (four different levels have been identified). Finally, the following sections examine the drivers of the main interactions that develop in the Lower Krishna Basin for three levels of linkages (A, B and C as summarized in Table 1; linkages at the micro level are not studied here and need to be looked into further).

Reshaping the Agricultural Waterscape of the Lower Krishna Basin

The Regional Divide within Andhra Pradesh: Driving Force of a Shifting Waterscape

The State of Andhra Pradesh was formed in 1956 in two stages. In 1953, the Telugu-speaking areas of the Madras State were separated to create the 'Andhra State' comprising two subregions, namely the Coastal Andhra region, and the south interior dry region, known as Rayalaseema (Suri 2002). The coastal region was economically better off because of the long history of irrigation in the Godavari and Krishna deltas. The formation of this "Andhra State" had been conditioned upon the implementation of the *Sri Bagh Pact* signed between Rayalaseema and Coastal Andhra in 1937, which notably stated that "*to ensure the rapid development of the agricultural and economic interests of Rayalaseema* (…) *to the level of those in the coastal districts, schemes of irrigation [in Rayalaseema] should, for a period of ten years or such longer period (…) be given a preferential claim*" (Rao 1972).

Later in 1956, the Telugu-speaking districts of the old Hyderabad State (referred to as Telangana region) were merged with the Andhra State to form the Andhra Pradesh State: it was the first State in independent India to be formed on linguistic principles.[17] Levels of economic development in the three regions were uneven at that time and the political influence of agricultural castes of the Krishna Delta was already high (Upadhya 1988): the State came into existence after a prolonged struggle and a great deal of bargaining and compromise by the political elites of the different regions ending up in a *Gentlemen's Agreement* meant to safeguard the economic development of Telangana (Forrester 1970).

The lack of confidence regarding the implementation of this *Gentlemen's Agreement* and the respect for constitutional safeguards, reserving public jobs and educational facilities for the Telangana people and ensuring that a third of the development funds would be spent in the Telangana region (Acharya 1979; Seshadri 1970; Vittal 2007), led to recurrent movements marked by violent conflicts for bifurcation of the State and a separate statehood for Telangana as in 1969 or for Andhra as in 1973. "*Some sections of the Telangana population feel that their region remained backward because of the 'raw deal' meted out to the region by the successive governments and disproportional benefits reaped by the people from the coastal region, some sections in coastal Andhra think that they could have developed much faster if they were not encumbered by the Telangana region*" (Suri 2002)[18]: The demand for a separate Telangana State is still strong today, voiced through the Telangana Rashtra Samithi Party and its leader Chandrasekhar Rao (The Hindu 2004c, 2004d, 2006c, 2007a).

From the early years of Andhra Pradesh, access to water and irrigation facilities were among the issues that contributed to the outbreak of unrest (Forrester 1970; Ramamurthy 1995). Recently, the sharing of river waters has also become a contentious issue between the various regions of the State (Suri 2002; The Hindu 2006g; Jayashankar 2007): the Krishna waters are mostly used in the coastal region while they flow through Telangana upstream and are to be increasingly transferred to the Rayalaseema region located outside the Krishna

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[17] In 1955, the State Reorganization Commission made balance statements on whether the creation of Andhra Pradesh was beneficial to all stakeholders involved in the process (GoI 1955; Suri 2002; Jayashankar 2007).

[18] The website, http://www.telangana.org/home.asp, illustrates how non-resident people originating from the Telangana region envision Andhra Pradesh policies (notably about rural development), since the formation of the State in 1956, as having always favored the coastal Andhra region over Telangana.

Basin (cf. section *Water Transfers In and Out of the Lower Krishna Basin*). Allocation of state funds for irrigation among the three regions is a critical matter of concern, regularly exploited by regional leaders for political purposes. Distorted irrigation development has indeed been central to the claims of the recent separatist movement in the state as government funded canal irrigation was and still is predominant in Costal Andhra; whereas Rayalaseema and Telangana mainly rely on groundwater for irrigation (Ratna Reddy and Behera 2002; Ratna Reddy 2006).

As conceptually illustrated by Molle (In press), for water stressed environments, local politics strongly influence water use patterns: the strong regional divide in Andhra Pradesh, the political influence of the rural dominated constituencies of the coastal region and the need for a government to balance rural development among the three regions of the state, as expressed in the Jalayagnam program (Ratna Reddy 2006), are some of the major factors explaining the overbuilding and the changes in the waterscape of the Lower Krishna Basin. Water has indeed been supplied regardless of either resource availability or formal allocation rules, at a time when water was plentiful: agricultural water use in the Lower Krishna Basin has exceeded the allocation awarded by the tribunal over most of its history. This dramatic overcommitment of water resources artificially creates a situation of scarcity, since users have benefited from greater but ultimately less reliable supplies. Users increasingly depend on a hypothetical surplus of water that is evidently decreasing as a result of a rising upstream development. Consequently, if formal allocations were to be respected in the Lower Krishna Basin, the consequences for agriculture and the livelihoods of farmers could be dramatic.

Large Irrigation Projects Downstream versus Upstream Diffuse Irrigation Development

Several hydrological studies have shown that water and land conservation projects (notably watershed programs) increase groundwater recharge and surface storage capacity of watersheds and secondary upstream basins in a significant way. As a result, (groundwater or surface water) irrigated areas and evapotranspiration in the watersheds often expand (Ratna Reddy 2005). Finally, surface runoff and groundwater baseflow to downstream regions decrease (Batchelor et al. 2003; Molle et al. 2004a).

Water accounting shows that total depletion in the mixed rainfed-groundwater irrigated region of the Lower Krishna Basin increased by 44% over the last 50 years and reached about 35.2 BCM (i.e., 58% of the total water depleted in the Lower Krishna Basin) in 1996-2000. Most of this change (63%) is due to the conversion of rainfed lands to irrigated fields and to the related increase in irrigation depletion (from 2 to 8.8 BCM during the same period). This increase in irrigation (both based on surface water and groundwater) in the formally rainfed region represents one-third of all water depleted in irrigated areas in the Lower Krishna Basin in 1996-2000. If we assume a rainfall/runoff coefficient of 18% (Biggs et al. 2007); scattered irrigation development led to a decrease of surface water availability of about 1.2 BCM/yr over the last 50 years. This is 11% of the total decrease the Nagarjuna Sagar inflow registered since the construction of the dam (the inflow in the reservoir decreased by 8.9 BCM/yr between 1967-1970 and 1996-2000) and 6% of all water diverted into the Nagarjuna Sagar and Krishna Delta canals in 1996-2000.

During the drought of 2001-2004, surface water irrigation declined in the Lower Krishna Basin and farmers increasingly resorted to groundwater use (Appendix 3). Our preliminary water balance shows that during this period; 5.2 BCM of groundwater were depleted each year in irrigated fields of the rainfed region (i.e., 33% of all water depleted in irrigated fields in the Lower Krishna Basin). This led to declining groundwater baseflows and dramatic aquifer overdraft negatively affecting the surface water balance further downstream (Appendix 3). This highlights the significant impacts that diffuse irrigation development in dryland areas may have on large irrigation projects further downstream.

Until now these linkages have been neglected by agricultural development policies that find their justification in (i) the implicit primacy of the rights that [local] communities have over precipitation and groundwater rather than over diversions benefiting downstream areas (Shah et al. 2005), and (ii) the announced goal of addressing the problems of dryland agriculture to counterbalance the perceived inequalities of the ‘Green revolution’ that neglected dry regions due to the relatively poor conditions for agriculture that prevail there (Fan et al. 1999; GoAP 2001d; Ratna Reddy 2006). These linkages raise issues in terms of water allocation procedures between different regions of the same state and might become politically disputed. Groundwater-based irrigation and watershed programs are actually tantamount to a redistribution or spatial re-appropriation of water by the Telangana people over the Coastal region. However, this local redistribution of water resources remains small compared to the reduction of 28.2 BCM per year registered in the inflow from the upper basin (1955-2000). This observation calls for extending the present study to the entire Krishna Basin to better understand (i) the social and political dynamics, the spatial distribution, and the local benefits of changing patterns of water use in the upper basin and (ii) the consequences these changes have on the Lower Krishna Basin.

Nagarjuna Sagar versus Krishna Delta

Two large irrigation projects commanded by the same balance reservoir (Nagarjuna Sagar) dominate the lower reaches of the Lower Krishna Basin (cf. Figure 7). The Nagarjuna Sagar project services areas on the left and right banks of the river. The left bank canal should irrigate 415,000 ha with an allocation of 0.9 meters (m) of water; the right bank canal is designed to irrigate 485,000 ha (allocation of 0.8 m of water). The Krishna Delta project is spread over an irrigated area of 540,000 ha (irrigation depth of 0.7 m). Water availability in the Krishna Delta is dependent on releases from the dam and on management practices and water use efficiency within the Nagarjuna Sagar system (NJS). There are thus alternative scenarios between operating a more relaxed upstream-system (NJS) allowing drainage and reuse downstream or having a very tightly controlled operation with little or no excess water and limited opportunity for reuse in the Krishna Delta (Molden et al. 2001).

Recent Water Use in the Two Irrigation Projects

Figure 8 illustrates water use in the Nagarjuna Sagar and Krishna Delta projects, computed from 1965 to 2004. After a period of steadily increasing canal flows in NJS (1967-1985), releases in the left and right bank canals remained constant until 1998 and 1999, respectively. The allotment of about 5.2 BCM/yr for each canal was 37% higher than the tribunal award of 3.8 BCM/yr/canal. Despite

Box 2. Are Nagarjuna Sagar return flows essential to determine water availability in the Krishna Delta?

On average, between 1974 and 2003, lateral rivers and return flows between the Nagarjuna Sagar Dam and the Krishna Delta amounted to 18% of the total water reaching the head of the delta. This proportion fluctuates according to water availability and is at its highest when the Krishna River discharge is low. Between 2000 and 2003, return flows from the Nagarjuna Sagar project represented more than 40% of the total water available at the head of the delta (against 17% between 1974 and 1984, when the Krishna River discharge was high).

Drought conditions (low inflow into the Nagarjuna Sagar Reservoir, low dam releases, low canal flows and high crop water demand) have direct impacts within the Nagarjuna Sagar command area (Gaur et al. In press; Venot et al. 2007) and dramatically highlight the increasing vulnerability of farmers and the declining trend in water resources availability seen over the past 30 years. They also imply a sharp decrease in return flows. This could have adverse impacts on water availability in the Krishna Delta. This is especially true as the ‘macroscale’ efficiency of water use in Nagarjuna Sagar is expected to increase significantly when water availability to the project decreases (Gaur et al. In press). This is due to the increasing use of both drainage and groundwater. The extent of the water shortage faced in the Krishna Delta will depend on the ‘elasticity’ and the trends in efficiency in the Nagarjuna Sagar project. These issues need further study.

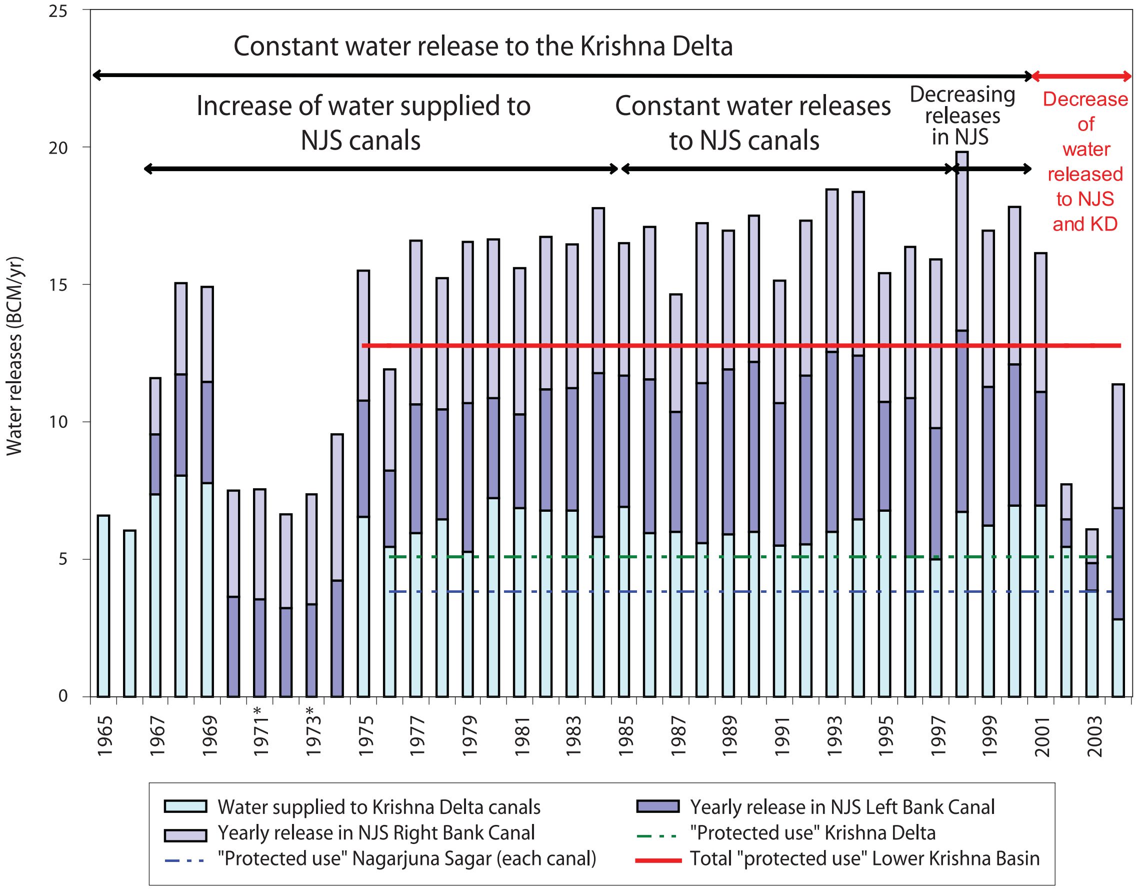

FIGURE 8. Historical evolution of the volumes of water diverted towards the Nagarjuna Sagar and Krishna Delta main canals for the period 1965-2004. *Source:* Nagarjuna Sagar Camp Office (Hyderabad) and Superintending Engineer Krishna Delta project (Vijayawada); data for Krishna Delta canals are missing between 1970 and 1974.

constant water releases, and until 1998, the irrigated area increased in both banks and double cropping extended: this might be due to lower application of water per unit of area, increasing water use efficiency and groundwater tapping. Available figures for the left bank indicate an increase of about 200,000 ha between 1986 and 1998 (of both 'wet' and 'dry' crops[19]). Finally, from 1998/1999 onwards releases to both main canals steadily and dramatically decreased: in 2003/2004 the left and the right bank command areas have been supplied with only 1 and 1.2 BCM of water, respectively.

Quantitative changes have been paralleled by qualitative ones. In the left bank canal and until 1998, 80% of the water was delivered for the Kharif crop season (June-November). By 2001 and 2002, 50% of the releases occurred between December and May to sustain a Rabi crop season (Venot et al. 2007). This was mainly linked to delayed runoff (cf. Figure 3). In the right bank canal, and until 1999, water ran continuously between the end of July and the end of March (with high discharge in November). By 2000-2002 water was mainly supplied during Rabi season (January-April) while 'emergency' releases occured in September and October to avoid crop failure (notably at crucial growth stages: flowering and harvesting) and general farmer unrest. These emergency releases are practical translations of institutional adjustments that take place in the Nagarjuna Sagar command area.

After 1999, the irrigated area decreased on both banks with a clear shift from wet crops (paddy) to

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[19] 'Wet' crops are rice and sugarcane, with high annual crop water requirements. 'Dry' crops include sorghum, millet and pulses.

field crops (chillies, cotton, pulses, etc.) or fallow (Gaur et al. In press; Venot et al. 2007). Changes are particularly striking on the left bank: the total irrigated area decreased by nearly 36% (180,000 ha) between 1998 and 2003 and only field crops (*irrigated dry*) were cultivated in 2003. On the right bank, during the same period, the total irrigated area decreased by 25%. In 2003, all wet crops disappeared, and the area planted with irrigated dry crops increased by 110,000 ha (evaluations based on Nagarjuna Sagar Camp Office data).

Until 2000, a steady average of 6.5 BCM/yr was supplied to the Krishna Delta (i.e., 128% of the tribunal award - 5.1 BCM/yr) to irrigate 543,300 ha in the Kharif season and 183,300 ha in the Rabi season. Diversions were independent of both rainfall and inflow at the head of the delta. From 2000 onwards, water diversion in the Krishna Delta canals steadily decreased to 2.7 BCM in 2003 (i.e., 53% of the allocation). As in Nagarjuna Sagar, the irrigated area decreased after 2000 (minus 20%, i.e., 128,000 ha of wet crops as per 2003). Additionally, water releases have been delayed by about a fortnight from mid-June to end of June. In 2003, the situation was highly critical as canals only opened during the second fortnight of July. This delay in water supply led to lower paddy yields and sometimes crop changes (cf. Box 3). Finally, whereas canals remained open until April prior to 2000, they closed in December/February during 2001-2004: groundwater is increasingly needed to sustain a Rabi crop season.

Drivers of Observed Trends

The recent drought of 2001-2004 may foreshadow the situation that farmers of the Lower Krishna Basin will have to face in the near future with much lower water availability for both Nagarjuna Sagar and the Krishna Delta due to increasing water use upstream. We emphasize that diversions to the Krishna Delta have been preserved as much as possible while diversions to the canals of Nagarjuna Sagar have decreased earlier.[20] Technical reasons and the sociopolitical context of Andhra Pradesh may explain the recent institutional adjustments and trends in water use observed in the lower reaches of the Lower Krishna Basin.

Technical Characteristics of the Two Irrigation Projects

- Irrigation water can be supplied to the Krishna Delta from the Nagarjuna Sagar Reservoir as soon as the Nagarjuna Sagar water level reaches 148 meters (137 meters in case of severe water scarcity [GoAP 2001a]). On the contrary, irrigation water can only be supplied to the Nagarjuna Sagar command area when the reservoir level reaches 155 meters (this level has not been reached from April 2002 to June 2004; cf. Appendix 4).
- Any releases from Nagarjuna Sagar to the Krishna Delta produce a much demanded hydropower.[21] This may constitute a further incentive to divert water to the Krishna Delta

Box 3: Institutional Arrangements at the Irrigation System Level

Among other studies, Gaur et al. (In press) and Venot et al. (2007) have documented adjustments by farmers and engineers in the two large command areas of the Lower Krishna Basin. These adjustments include: (i) the shift from double cropping to single cropping; (ii) the shift from wet crops (rice) to *irrigated dry* crops (pulses); (iii) an increasing use of groundwater (dug or bore wells) or other alternative sources of water (drains, streams, etc.); (iv) an increasing dependency on livestock systems for the poorest stakeholders; (v) higher out-migration patterns; and (vi) the introduction of differential canal supply management based on canal size and corresponding localized cropping pattern.

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[20] In a study focusing on the period 2001-2004, Gaur et al. (In press) have shown that the Krishna Delta received a comparatively higher share of the Nagarjuna Sagar inflow during deficit years. In 2002/2003, for example, the Krishna Delta received 60% of all water diverted for irrigation purposes in the two projects compared to an average of 40% for the period 2001-2004.

[21] Little capacity turbines (90 and 60 megawatt-hours [MWh]) are located on each of the main canal outlets but their production is negligible compared to the production of the main powerhouse located below the dam (815 MWh).

especially in August and September when hydroelectricity production accounts for 15% of the power generated in Andhra Pradesh (cf. the section *Irrigation versus Hydroelectricity Production*).

- Conjunctive use (local streams, tube and bore wells) is more common in Nagarjuna Sagar than in the Krishna Delta (cf. Appendix 5), partly because groundwater quality declines away from the main stem of the river. As conjunctive use acts as a buffer to soften the consequences of a drought, it may also act as an incentive for engineers to decrease canal releases.[22]
- Despite higher rainfall, the Krishna Delta cropping pattern (65% of wet crops) is more sensitive to any changes in water availability than the Nagarjuna Sagar cropping pattern (45% of wet crops), which can better stand deficit irrigation. Farmers have more choices in terms of crop adoption in Nagarjuna Sagar than in the Krishna Delta due to the diversity of the situation regarding topography, crops, water access, etc. Decision makers might be more inclined to decrease canal releases in projects having an 'irrigated-dry' cropping pattern (more resistant to drought) even if it challenges the revered concept of protective irrigation.
- Due to the possibility of saline water intrusion, canal releases in the Krishna Delta are essential to limit both groundwater and soil salinization; they are also a major source of drinking water for the coastal population (GoAP 2003; Venot et al. In review).
- Finally, on the basis of their political clout, farmers' lobbies and representatives in the Krishna Delta emphasize their central role for food surplus production at the state level in order to influence both state and federal policies that have always aimed at food sufficiency and to secure additional water releases (The Hindu 2001a).

The Sociopolitical Context of Andhra Pradesh

In a context of "populist anarchy" where politics and politicians have entered the field of water management (Wade 1982), populist promises to bring irrigation, regardless of resource availability, or to decrease electricity costs, are common to secure the support of rural population on the eve of elections. Farmers press their demands through roadblocks, demonstrations, hunger strikes, blockading the houses of irrigation department officials, marches to dams and sit-ins (Mollinga 2001; The Hindu 2003a; Deccan Herald 2004a, 2004b; see Figure 9). Complaints are voiced through members of parliament (in Delhi) or members of the legislative assembly in Hyderabad, the regional capital. Taking advantage of the historical subdivision characterizing the politics of Andhra Pradesh, voices of the rural political lobbies of the Krishna Delta rise above others and find resonance in the corridors of power. This may explain the recent allocation patterns that favor the delta. One can, for example, read that: "Farmers as well as political parties [in the KD] had risen above party politics and were united in their struggle for their riparian right which is being unjustly denied by the Government, bowing to pressure from Telangana leaders" (The Hindu 2003b) and that "It is not just to starve Krishna Delta for the sake of Nagarjuna Sagar project. Farmers should be allowed to raise crops at least in Krishna Delta so that there would be no shortage of food grains in the State [...] it is ironical that Karnataka is releasing water from Alamatti for the sake of Andhra farmers even though they have no right over them [and that] the Andhra Pradesh Government is

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[22] Conjunctive use (and notably groundwater abstraction), however, depends heavily on canal flows: Chambers (1988) has, for example, shown that canal seepages and losses may account for at least half the water pumped from the ground (shallow aquifers) and used for supplemental irrigation in large surface irrigation systems in India. Decreasing canal releases because of conjunctive use might thus be counterproductive as it will also decrease the scope for using alternative water supplies.

FIGURE 9. Farmers stage a protest at Prakasam Barrage, Vijayawada. *Source:* The Hindu (2003b)

refusing to release water from Nagarjuna Sagar project to Krishna Delta even though it had right over them" (The Hindu 2001b).[23]

Reconsidering the Intersectoral Distribution of Water

Irrigation versus Hydroelectricity Production

The construction of the hydroelectric project of Srisailam in 1983 introduced a new large-scale water user: the volumes used for Hydropower generation have increased and reached a peak during the 1990s. Most hydroelectricity in the Lower Krishna Basin is produced by the Srisailam and Nagarjuna Sagar dams during the months of July to November (cf. Appendix 4).[24] In 2005/2006, for example, total hydroelectricity production in these two dams amounted to 62 and 26%, respectively, of the state hydroelectricity production (and to 11 and 5% of the total power generated in the state). Hydroelectricity is, therefore, of crucial importance to Andhra Pradesh during peak hours.

The Srisailam Dam commands about one-third of the total surface water available in the Lower Krishna Basin and dam releases are thus crucial for the large irrigation projects located further downstream. Adequate management and fine-tuning of Srisailam and Nagarjuna Sagar reservoirs are thus crucial for both the hydropower and irrigation sectors and there is a clear need for integrated management to meet both demands.[25] Appendix 4 illustrates the schedule of releases for both hydropower generation and irrigation at Srisailam and Nagarjuna Sagar reservoirs. Most hydroelectricity is produced thanks to flood management releases, in July and August, just before the high monsoonal inflows reach the reservoirs. Dam releases for hydroelectricity

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[23] At that time, Nagarjuna Sagar storage was sufficient enough to supply the Krishna Delta but the reservoir level was lower than Nagarjuna Sagar canals' intakes. The government argued that water could not be released to the delta in order to preserve the interests of Nagarjuna Sagar, threatened by further low inflows into the dam.

[24] The two dams have respective capacities of 1,670 and 965 MWh. According to the main power generation company of Andhra Pradesh (APGenco), the thermal production of electricity is low during this period of the year and hydropower generation policy is to augment the peak load.

[25] A state-level Committee for Integrated Operation of Krishna and Pennar Basin Projects (CIOKRIP) meets every year before the start of the Kharif season (June) to finalize the release pattern in the Srisailam, Nagarjuna Sagar and Krishna Delta irrigation systems. The decision of the committee is based on a working table presenting the demands of the Nagarjuna Sagar and Krishna Delta irrigation systems and the estimated inflow to the Srisailam Reservoir. In the season, reviews are held by the CIOKRIP to discuss and revise the plan of operation for the remaining part of the season.

production are also high during mid–March, but these releases might also be driven by a high demand for irrigation downstream ('grain fill' irrigation prior to the harvest of the Rabi crop). Two other observations argue that there is little antagonism between the hydropower and the agriculture sectors in the Lower Krishna Basin:

- Before the drought, water has always been carried over from one hydrological year to another to meet the early demand of agriculture for the Kharif crop plantation. Gaur et al. (In press) have estimated that 5 to 19% of the live storage of NJS is carried over from a surplus year to another (Appendix 4 also shows that the water level in the Nagarjuna Sagar Reservoir had never dropped below the live storage level before 2001);
- During the recent drought (2001-2004), hydroelectricity generation by the two dams reached its lowest level in history and releases only took place at times when irrigation demands further downstream could also be met: this shows that water resources are managed in an integrated manner.[26]

We, therefore, argue that hydroelectricity production in the Lower Krishna Basin does not compete with agricultural water uses much. This is mainly due to the fact that irrigation projects are located downstream of hydroelectric dams. In these conditions, adequate planning of dam releases allows meeting the peak hydropower demand in August-November (when thermal power production is low) while it also benefits farmers who particularly need water for the harvest of their Kharif crop ('grain fill' irrigation) and at the start of their Rabi crop in November-January (soil preparation). However, as several irrigation projects that draw water from the Srisailam Reservoir are being extended (The Hindu 2004b, 2007b, 2007c), dam releases in the months of March and April for hydropower production could, in the near future, impede agricultural use, as is currently the case in Nagarjuna Sagar. These possible negative impacts would be attenuated as Srisailam acts as a balance reservoir for Nagarjuna Sagar, which in turn acts as a balance reservoir for the Krishna Delta irrigation project. Rather than redefining an intersectoral apportionment of water, these releases are tantamount to another redistribution of water among different agricultural users.

Irrigation versus Urban 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 (7.9 million inhabitants), which is increasingly supplied from distant sources (cf. Figure 10). In 1950, two nearby reservoirs (Osman Sagar and Himayat Sagar in the Musi sub-catchment of the Krishna Basin) provided the city with 3.5 Mm^3 a month to assure 105 liters per capita per day (lpcd), but over time, water from the Manjira River (a distributary of the Godavari River) (in 1960 and 1991 successively) and then from the Krishna River downstream (in 2002) has been diverted to meet the growing urban demand in Hyderabad.

In 2005, per capita net water availability was about 97 lpcd, of which two-thirds was from local sources. Local surface water supplies (from Osman Sagar and Himayat Sagar) to Hyderabad have been decreasing (both in absolute and relative values) since the 1970s and are now completely committed. There is evidence that agriculture and irrigation development in the upstream catchments of the mid-basin reservoirs (Osman Sagar and Himayat Sagar) led to lower inflows to these reservoirs historically supplying the city. By 1995-2004, local supplies to the megalopolis were 18 Mm^3/yr lower than in 1975-1985 (Biggs 2005; Bouma 2006). To compensate for this loss, the growing demands of the city can only be met through expensive (and politically sensitive) long

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[26] There would only be little room for improvement as the annual storage capacity of the Srisailam and Nagarjuna Sagar reservoirs are about 8 and 7 BCM/yr, respectively (e.g., 20% of their annual inflow during the period 1991-1999).

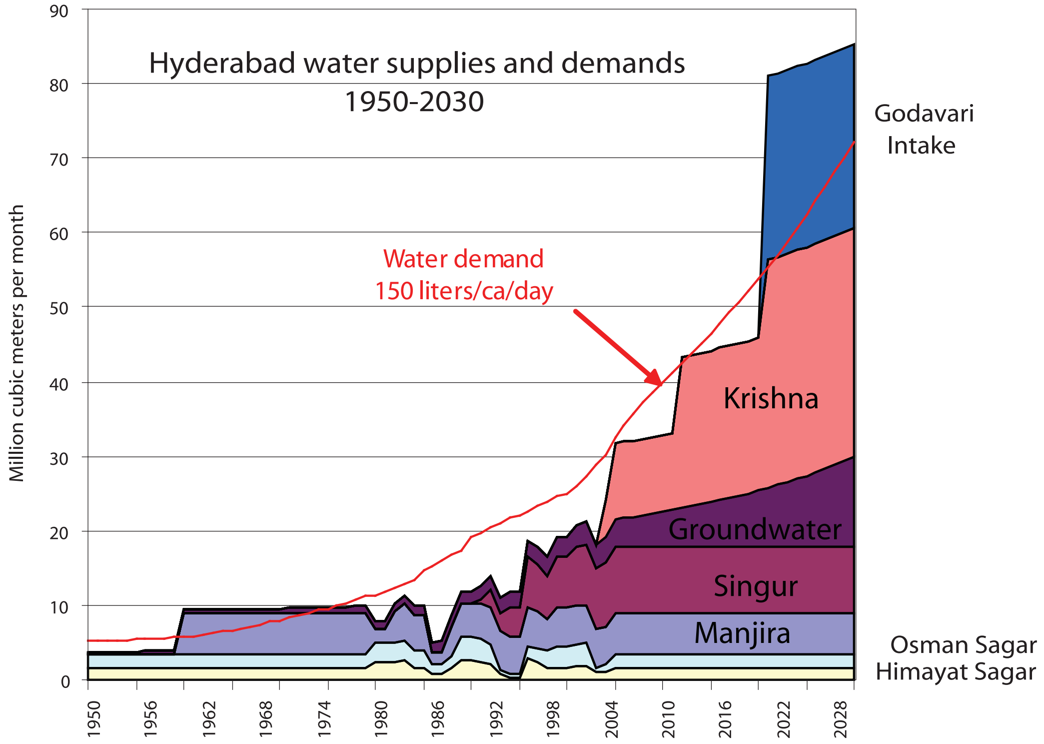

FIGURE 10. Hyderabad water supplies and demands.[27] *Source:* adapted from Van Rooijen et al. 2005

distance transfers (notably from the downstream reaches of the Krishna River through the Krishna Drinking Water Supply Project), by shifting water out of irrigated agriculture.[28] In this case, contrary to the common fact of water being transferred from agriculture to cities, agricultural development in the upstream catchments has not been constrained. The increasing transfer of water from the downstream reaches of the Krishna River (upstream of the Nagarjuna Sagar project, 155 kilometers away from the city) can therefore be considered as a regional redistribution of water from large irrigated areas downstream to small-scale water users in dryland areas upstream, who have further opportunities to reuse wastewater from the cities. So far, the volumes of water transferred to urban uses have been negligible compared to the total water used for irrigation in downstream irrigation projects[29] and no disputes between the city and farmers of the Nagarjuna Sagar project have developed yet. This situation may rapidly change as the releases through the canals of Nagarjuna Sagar are likely to be much lower in the future, as observed in 2001-2004. The planned increase in the transfer (470 Mm^3/yr by 2020) and a lower flexibility of farmers facing lower water supplies make

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[27] Data between 1980 and 2004 are observed water supplies. Before 1980 and after 2004, the figure presents potential or expected water supplies for the different projects considered.

[28] A transfer from the Godavari Basin is also currently contemplated. Biggs (2005) estimated the extra cost that the city incurs by transferring water from the Krishna River to compensate for the decreasing local supplies at US$6 million per year. Bouma (2006) documents the economic consequences of agricultural development in the upstream catchments of the reservoirs, along with the water transfer from the Krishna River that leads to shrinking agriculture in irrigated areas downstream. The main lessons of this study are that (i) the net effect of the re-allocation is rather beneficial in terms of the value of agricultural production due to high value horticulture in the upstream catchments, but (ii) this net effect is more than counterbalanced if increasing water costs are accounted for: overall costs of the re-allocation overtakes the benefits.

[29] Between 2002 and 2006, 156 Mm^3/yr have been transferred, i.e., less than 2% of the water released through the canals of the Nagarjuna Sagar project between 1990-2000 when the irrigation system proved to be highly flexible at such a level of water availability (no significant cropping pattern changes were observed despite changes in inter-annual water availability of ± 20% during this period).

conflicts more likely, especially in drought years. Conflicts may arise if the transfer to Hyderabad (not considered in the present tribunal award) prevents the command area from getting its full allotment as sanctioned by the tribunal.

Water distribution and use in the neighboring areas of Hyderabad are generic examples of interconnections between a powerful urban centre and its surrounding rural areas (Celio 2006; Molle and Berkoff 2006):

- Prior appropriation by local users is generally not recognized. Local users in rural areas receive less than their entitlements and only after water supplies for Hyderabad are secured. This is shown by Celio (2006) in the case of the Singur Reservoir supplying both Hyderabad and the Ghanpur and Nizamsagar irrigation projects located in the Godavari Basin and recurrently running short of water.
- Competition between users of different sectors has not been widely publicized yet but complaints from small neighboring urban areas have been voiced through local leaders and representatives. This has, however, rarely led to the redefinition of the de facto allotments that benefit Hyderabad. Local towns have to rely on alternative sources (private tankers, purchase of water from agricultural wells, etc.) to meet the needs of their constituency (Celio 2006).
- Groundwater is increasingly and unsustainably abstracted and its quality decreases; aquifer levels are falling and little attention is given to these issues (Van Rooijen et al. 2005). Although, restrictions and control over groundwater use may be desirable, such measures are likely to lead to social unrest as the poorest are also the most dependent on groundwater hand pumps. Such restrictions and control measures will also be opposed by private tanker contractors and large commercial or industrial users looking for secure supplies. They will have dramatic consequences on the overall water supply to the millions of users in the city (groundwater accounts for 11% of the water used in the city today [Van Rooijen et al. 2005]).
- The quality and quantity of water supplies are highly variable within the city. Informal housing settlements, as well as ‘official slums’ that are the poorest and most populated areas of the city, are generally characterized by unreliable municipal supply (if any) and often have to rely on expensive private tankers. In 1997, the HMWSSB, in charge of the domestic water supply in Hyderabad, evaluated that non-slum dwellers were supplied with 135 lpcd while slum-dwellers served by public stands could expect 20 lpcd. A poor municipal supply may lead to social unrest and increasing the use of private tankers relying on groundwater pumped from neighboring agricultural land may lead to further groundwater depletion and degradation, to conflicts with farmers and has a negative impact on the already loss-making public budget (Davis n.d.).
- Urban and industrial effluents from Hyderabad are drained into the Musi River, a tributary of the Krishna River flowing through the city (Van Rooijen et al. 2005). The urban wastewater, mostly untreated, is then reused in agriculture further downstream. Linkages between urban and industrial water uses in Hyderabad and wastewater reuse along the Musi River include: (i) the currently limited capacity for wastewater treatment in the city of Hyderabad, its cost and the possible trends in capacity; (ii) the trends in water quality along the river - improving as it moves downstream; (iii) the impacts of water quality on crops, the health and livelihoods of farmers (Buechler et al. 2002; Buechler and Devi 2003; Raschid-Sally et al. 2005); (iv) the importance of the Hyderabad market in driving agricultural practices that are oriented towards fodder (for feeding large numbers of stall-fed livestock within the city), rice, fruit and vegetable production; and (v) the linkages between domestic and industrial sewage systems and effluents.

Finally, despite the fact that rural areas accommodate 65% of the population in the basin, the domestic and industrial water demand in rural areas is, in crude terms, not likely to impact on other water use sectors. However, rural folks face different issues when accessing domestic water: (i) inequalities within a community; (ii) unreliable and sporadic public supply, if any; (iii) drying up of wells due to nearby intensive agricultural abstraction; and (iv) groundwater quality deterioration. These issues need further investigation.

Consumptive Human Uses versus Environmental Needs

Until recently only consumptive human uses were considered in water resources apportionment policies. Environmental water requirements were neglected if not ignored completely as the water flowing to the sea was considered to be lost or wasted. This view is still often expressed by engineers, politicians and researchers all over the world (Molle et al. 2007: see for example, GoAP 2001b; Ratna Reddy 2006; as well as the speeches of the last two Chief Ministers of Andhra Pradesh as transcribed in The Hindu 2003c, 2005b, and 2006f). The Krishna Basin is no exception. The ever increasing regulation and diversion of water resources has led, along with increasing effluent discharges, to a degradation of the basin ecosystems. According to the classification of Smakhtin and Anputhas (2006), the average discharge to the ocean observed since the mid-1980s - 14.6 BCM/yr - defines a moderately to largely modified ecosystem. Though the impacts of reduced water flows on the coastal ecosystem are not well quantified, there are evidences of saline water intrusion in aquifers of the Krishna Delta, soil salinization and mangrove deterioration during low flow years (GoAP 2001e; GoAP 2003; Venot et al. In review). To avoid further deterioration of the Krishna Basin ecosystems, there is a clear need to recognize the environment as a water user in its own right and to set aside a quantum of water for the environment, especially for the fragile coastal ecosystems. Maintaining the Lower Krishna Basin in its present environmental status would require a minimum of 6.5 to 14.2 BCM a year (Smakhtin and Anputhas 2006): this will commit 86 to 95% of the net inflow to the Lower Krishna Basin to designated uses (period 1996-2000).[30] Meeting both human consumptive demands and environmental requirements seems to be possible during a surplus year. However, such figures illustrate that there is only little room for further water use development. Years near or below average precipitation (2001-2004) send some warning signals: the discharge to the ocean is almost zero and water shortage affects both human uses and the environment. Ignoring environmental needs might be socially justifiable in the short-term, yet preserving ecosystems is needed for human benefit, since sustainable agriculture in the coastal areas depend on environmental flows that replenish shallow aquifers and limit saline water intrusion (Dyson et al. 2003; GoAP 2003; Venot et al. In review).

Environmental concerns in the Lower Krishna Basin include:

- Saline groundwater intrusion and nitrate pollution in the Krishna Delta due to decreasing groundwater levels caused by unsustainable groundwater pumping for agricultural purposes, infiltration of highly loaded agricultural return flows and lower recharge from surface water as canal and Krishna River flows decrease (GoAP 2003; Saxena et al. 2002).
- The increase in inland groundwater salinity has turned some productive lands into wasteland, where cultivation is now barely possible. According to the Department of Agriculture, about 2,250 hectares of land have turned saline in the Krishna District (eastern delta) between 1994 and 2003 and salt affected soils covered about 42,250 ha in 2003 (Rao 2006). It also jeopardizes present and future groundwater use for domestic purposes in a region where most of the population rely on hand pumps for their daily consumption (GoAP 2003).

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[30] The recent example of the apportionment of the waters of the Cauvery River is interesting: the Cauvery tribunal award considered the environment as a water user in its own right and set aside a quantum of water for its preservation. Volumes considered remain anecdotal at about 1.9% of the 50%-dependable flow of the Cauvery River (The Hindu 2007d; Menon 2007) far from the 8.4 to 18.3% of the historical runoff of the river mentioned by Smakhtin and Anputhas (2006) to preserve a moderate to largely modified ecosystem.

- Land degradation and contamination through brackish water use for shrimp farming, waterlogging, disruption of mangrove ecosystems (GoAP 2001c).
- Pollution due to urban and industrial effluents resulting in health problems and biodiversity degradation (GoAP 2001e; Ramani and Anjaneyulu 2002).

Finally, the Kolleru Lake provides an example of a critically modified ecosystem within the Lower Krishna Basin. This wetland of international importance under the Ramsar convention connects the Krishna and the Godavari deltas. It has undergone dramatic changes since the late 1970s (cf. Figure 11). Until the end of the 1970s, the local population used to fish (during the rainy season) and take up seasonal cultivation of paddy around the islands dotted over the wetland area and on the edges of the lake (during winter and summer). However, since 1977, the Government of Andhra Pradesh promoted aquaculture as a supplementary source of revenue for fishermen, who were entitled governmental lands in the lake bed and encouraged to form registered cooperative societies. Fish tanks progressively replaced capture fisheries within the wetland area. The construction of fish ponds was also seen as a means to soften the impacts of floods that were common at that time and damaged paddy crops leading to insecure livelihoods for farmers. Cooperatives managed by local fishermen did not survive long and rich local entrepreneurial farmers took over by renting fish ponds from members of the societies, who often became de facto laborers, although they were the official land 'holders' (Rama Rao et al. 2006). Driven by the high demand of urban centers (notably Calcutta), aquaculture has been a real success and was further developed during the 1990s, when outsiders began to invest in the sector. In the 1990s, prawn farming also developed and was accompanied by growing groundwater exploitation. The aquaculture boom in the 1980s and 1990s mainly benefited the rich (local entrepreneurial farmers and outsiders that invested in the region) and led to the progressive drying up of the wetland, illegally encroached by fish tanks reducing inflows from local rivulets and from the two delta systems (Rama Rao et al. 2006). The limits of the wetland are fuzzy: in the early 2000s, the only remains of the once large wetland were just some small areas of open water and some submerged vegetation (Figure 11).

Protecting the lake ecosystem has long been presented as a government priority (The Hindu 2006a). However, removing illegal fishponds is a highly sensitive question and is opposed by a powerful lobby. While the Andhra Pradesh High Court of Justice passed an order to remove illegal fish tanks, the measure has been delayed several times. Further, an attempt has been made to set right land records and identify the persons responsible for lake encroachment, but this ended prematurely with the death of the assigned official before he could put forward his findings (Rama Rao et al. 2006). Finally in February 2006, the Supreme Court of India passed an order to remove illegal encroachment in the lake (The Hindu 2006a). In May 2007, most fishponds encroaching the Ramsar Reserve had been destroyed, but this had required the involvement of police forces to maintain public order (The Hindu 2006b, 2006d) and the situation remains highly sensitive as illustrated by the transfer of the governmental official in charge of the preservation of the Kolleru Lake (Newsind.com 2007).

Little is done to limit pollution and the lake receives discharges from: fishponds; return flows from agriculture loaded with manure and chemical fertilizer residues; effluents from neighboring agro-industries (paper and rice mills, jute and sugarcane factories [Ramani and Anjaneyulu 2002]); and largely untreated sewage from the many urban centers located in the Krishna Delta. As a result, water-related diseases develop due to the decreasing availability of good quality water for domestic purposes. Thirty years ago, villagers were able to drink water from the lake, but now they increasingly rely on expensive private tankers and the Krishna canals for potable supply (Rama Rao et al. 2006). Water flows in the latter are likely to decrease in the near future as illustrated during the

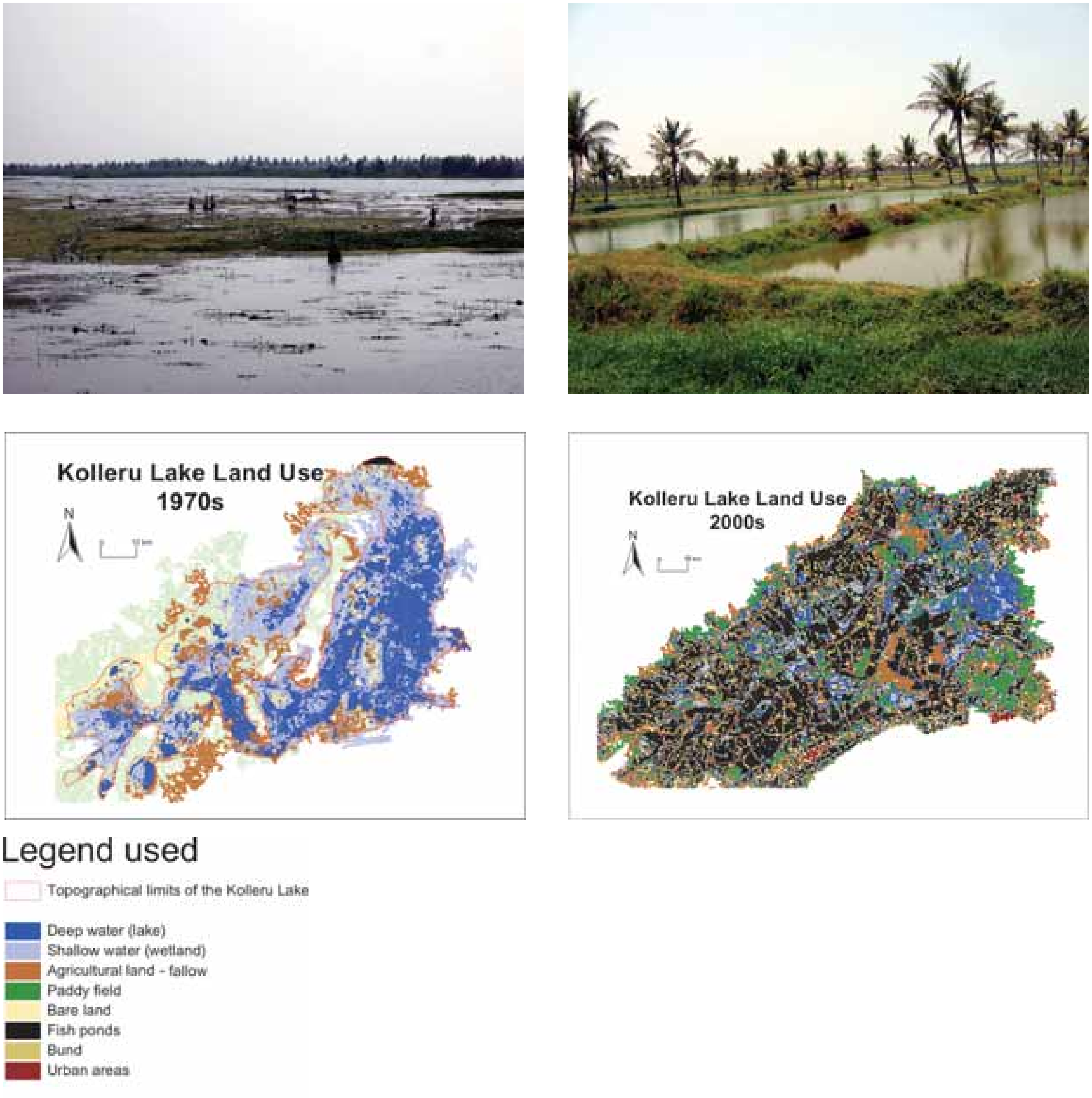

FIGURE 11. Changing landscape of the Kolleru Lake: From capture fishing in a wetland to fish tanks in a dried region. Landuse (unsupervised) classification in the 1970s and 2000s has been made based on landsat images dated June 1, 1977 and October 28, 2000, respectively, and are available online at: http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

recent drought. The domestic needs of the population, the agricultural water use within the Krishna Delta and the environmental needs of the lake itself are closely interconnected and there is competition for the same water resources. This is likely to increase further with the decreasing water availability at the head of the delta and calls for effective allocation procedures that consider both the domestic needs of the population as well as the environmental needs of the lake.

Water Transfers In and Out of the Lower Krishna Basin

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 Krishna and transfer it to the Pennar Basin in the southwest of Andhra Pradesh. The Kurnool-Cuddapah Canal (commissioned in 1866) and the Rajolibunda diversion scheme (dating back to the 1960s) draw water upstream of the Srisailam Reservoir and irrigate some dry areas of Andhra Pradesh (cf. Figure 7). The Telugu-Ganga Canal is used to irrigate the Rayalaseema region of Andhra Pradesh and to partly meet the urban needs of Chennai in Tamil Nadu (Nikku 2004). It is planned that the Srisailam Right Bank Canal will bring irrigation to the dry areas of Rayalaseema.

These latter two projects divert water from the Srisailam Reservoir (Appendix 6) and were planned during the 1980s on the expectation of surplus water from the Krishna. They were promoted by the then Chief Minister to bolster political support in the Rayalaseema region, which was the less sympathetic region during his landslide victory in the 1983 elections (Suri 2002). All of these projects functioned well below their design expectation, even at times of abundant water availability.[31] This underlines the fact that it is not only the availability of the physical resource that is crucial to explaining the evolution of water use, but as water has become a disputed and highly politicized object, water use is shaped by the social and political conditions of a region that is not always hydrologically bound: here, internal dynamics of the Andhra Pradesh State are some of the main drivers that explain why and where the Krishna waters are used.

Given the backdrop of continued upstream development of irrigation infrastructure and the decrease in water availability in the Srisailam Reservoir, these water transfers (and notably the irrigation projects to be developed outside the Krishna Basin) are strongly opposed by upstream states that consider them as an attempt by Andhra Pradesh to lay claim to water beyond its formal allocation. However, they enjoy strong social and local political support (The Hindu 2001b; Deccan Herald 2005). Sanctioning and implementing these projects would lead to a new diversion of about 1.8 BCM per year (cf. Appendix 6). This will deprive water users further downstream from the same quantity and is likely to lead to regional water conflicts, internal to Andhra Pradesh, as the new diversions will partly benefit the Rayalaseema region at the expense of the Telangana and the coastal areas (The Hindu 2004a; The Hindu 2005a). The present Chief Minister of Andhra Pradesh is a native of the Rayalaseema region and this acts as a further impetus for promises of irrigation development in this dry area (The Hindu 2007b, 2007c): government plans to develop irrigation are packaged in the *Jalayagnam* program and aim to decrease future inter-regional disparities around 2020 but, once again, without regard for water availability.

On the other hand, the long held dream of interlinking the Indian rivers in a ‘national water grid’ may further affect water availability in the Lower Krishna Basin. The National River Linking Project was envisioned as early as the 1970s (based on an idea conceived by Sir Arthur Cotton in the mid-nineteenth century). It has been given further impetus with the formation of the National Water Development Agency (NWDA, created in 1982) to carry out the corresponding studies, and more recently: (i) a Supreme Court suggestion to consider this plan (October 2002); (ii) the formation of a National Task Force by the Ministry of Water Resources (GoI 2002); (iii) the publication of several pre-feasibility studies by the NWDA in 2004; and (iv) several official declarations by senior politicians (Abdul Kalam 2003; Vajpayee 2003). This plan is, however, strongly opposed by NGO activists on several grounds: its ecological (soil salinity, waterlogging, river water pollution) and human consequences (large-scale displacements of population without proper resettlement plans); the disputable cost-benefit analysis and the lack of effort to identify any alternatives; the quality of data on which feasibility studies are based; the likely evaporation and channel seepage losses (Allen 2004). Moreover, it is not clear if ‘the national water grid’ has achieved consensus among national politicians and decision makers (see Krishna (2004)

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[31] For example, the Telugu-Ganga project, which saw the light of day thanks to favorable political conditions in the early 1980s, did transfer water to Chennai but only from 1996 onwards. The average volume of water transferred was 75 Mm^3/yr instead of the 340 Mm^3/yr as mentioned in the agreement between the two states of Andhra Pradesh and Tamil Nadu. Moreover, farmers along the canals do not receive their water allotment and irrigation did not spread as much as planned (Nikku 2004).

mentioning the position of the Supreme Court [Supreme Court of India (2002)] and Prime Minister Manmohan Singh [Singh 2004]).

Andhra Pradesh opposed large-scale diversions of water from the Godavari to the Lower Krishna during the 1970s as both Karnataka and Maharashtra claimed a share of these waters to the Bachawat Tribunal (GoI-KWDT 1973, 1976; Vittal 2007). The situation has changed and the leaders of Andhra Pradesh, regardless of their political affiliation, presently support these projects (The Hindu 2003c, 2004b, 2006f). Three links would affect the Lower Krishna Basin waterscape: one is already in progress and canal construction began in 2005 (the Polavaram-Krishna link); the two others (the Inchampalli-Nagarjuna Sagar and the Inchampalli-Pulichintala links) are contemplated. The three transfers would draw about 26.1 BCM of water a year (e.g., about 33% of the net inflow to the Lower Krishna Basin in 1996-2000) from the Godavari Basin for multi-purpose projects producing hydropower, supplying dry areas with domestic and industrial water, irrigating an extra 1.5 Mha and diverting 14.5 BCM/yr further south. Finally, total water availability in the Lower Krishna Basin would thus increase by 11.6 BCM/yr (e.g., 15% of the 1996-2000 net inflow to the Lower Krishna Basin). Among those, 2.25 BCM/yr (9% of the total transfer) would be “reserved” for the Krishna Delta to support agriculture, counterbalance the observed decline in discharge of the Krishna River and limit environmental degradation (NWDA 2007). This ‘environmental allotment’ remains low and it is not clear yet if the water will discharge to the ocean or be diverted to the Krishna Delta canals.

The National River Linking Project illustrates the lasting dominance of the engineering-based approach to water resources development and management. This could redress over-use of water resources in the basin through a significant increase in net inflow, and alleviate crisis situations likely to recur in the near future. But plans to extend irrigation with this transferred water defeat these objectives as such projects are designed regardless of resource availability both in the Krishna and Godavari basins. Moreover, because of its very size, the river interlinking project is presented by its supporters as the miracle solution to all torments: this might be counterproductive as it often leads to a disregard for other alternative management solutions which could yield cumulative benefits by regulating water use, notably in the agriculture sector.

Discussion and Conclusions

Progressive agricultural and water development, coupled with uncoordinated short-term management decisions within the water sector but generally beyond it (at the basin, state or irrigated command area level) and unregulated private investments in groundwater exploitation have ignored resource limitations. This led to a progressive overcommitment of water resources of the Krishna Basin. Early warning signs of shortage and basin closure emerge 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 baseflows, and the discharge to the ocean decreases. However, despite evidence of basin closure leading to sectoral and regional interdependence, the three states that share the Krishna waters continue to strongly promote their agriculture and irrigation sectors as the basis for their broader economic development. It is important to realize that this development path, relying on both large and small-scale water control facilities, can no longer be sustained without impinging on existing water use and affecting the security of supply for existing users. The Lower Krishna is a deficit basin where irrigation has a long history. It depends heavily on inflow from the upper basin and on upstream water users. It is also one of the first regions to face the adverse consequences of hydrological changes in the basin. In times of drought, it is the first region to face severe water shortages and to witness a spatial redistribution or re-appropriation of water. Driven by current political, institutional and economic forces, this re-appropriation of water raises questions of sectoral and regional water apportionment within the Lower Krishna Basin and may be the origin of conflicts between water users.

As the Krishna Basin is closing, this paper identifies the main drivers of the changes that have affected the Lower Krishna Basin waterscape during the last 50 years. First, the surface water inflow into the Lower Krishna Basin decreased by more than half during the last 50 years and amounted to about 25.8 BCM a year in 1996-2000 due to increasing irrigation development in the upper basin. Second, irrigation in the Lower Krishna Basin registered a tremendous hike, as evapotranspiration from irrigated areas has increased almost fourfold to 19.4 BCM in 1996-2000. Increasing water use for agriculture has been linked to both the promotion of large protective irrigation schemes and a groundswell of pumps allowing lift irrigation (from canals and rivers) as well as groundwater use. This paper highlights how two biases, associated with the implementation of protective irrigation in the Lower Krishna Basin, have contributed to an overcommitment of the water resources. First, on a local scale, farmers generally unilaterally intensified production, which required a more generous and flexible water supply, which has been obtained by various means, often at the expense of their less well-placed peers. Typically, excessive diversion in the head reaches of the main canals has caused shortages further down the irrigation system. This internal “mismanagement” of water has been paralleled by governmental decisions and recommendations of the World Bank to extend double cropping: this implied increased water use while the formal allocation remained stable (Hashim Ali 1982; World Bank 1976). By 1996-2000, 77% of the net inflow to the Lower Krishna Basin was depleted (the total depletion being only 38% of net inflow in the period 1955-1965) and discharge to the ocean fell to 17.9 BCM/yr, defining an environmentally moderately modified ecosystem. During the drought of 2001-2004, likely to foreshadow the future waterscape of the Lower Krishna Basin, all indicators pointed to further commitment of water resources with total depletion amounting to 98.8% of the net inflow, a lack of discharge to the ocean and the shrinking of surface irrigated agriculture.

Total water available in the Lower Krishna Basin is decreasing and publicized interstate water conflicts are generally presented as the main reason for water shortages downstream and closure of the basin. However, this paper shows that the re-configuration of a large river basin is also due, to a large extent, to local users’ responses and local historical dynamics in the downstream riparian. Water users and managers change their recurrent patterns of behavior and their everyday interactions in adapting to, and coping with, water scarcity and its socio-ecological and economic ill-effects (Shah et al. 2005). Without denying the importance of interstate water sharing issues, this study clearly illustrates that ad hoc water use distribution among sectors and regions within one state also raises many social and political questions. This underlines the fact that it is not only the availability of the physical resource that is crucial in explaining the evolution of water use. As water becomes a disputed and highly politicized object, waterscapes are strongly shaped by the social and political conditions of a region, not always hydrologically bound and often spreading beyond the area where water is effectively used.

In the Lower Krishna Basin, both the intra-agricultural and the intersectoral distribution of water are being reshaped. In the agriculture sector, the strong political divide among the three regions of Andhra Pradesh and the need to balance rural development among them are two of the main driving forces of this shifting agricultural water use. Two paradoxical yet complementary observations can be made about trends in the spatial pattern of agricultural water allocation in the Lower Krishna Basin: (i) surface water distribution among large irrigation projects tends to benefit the politically influential coastal region, but (ii) uncontrolled groundwater development mainly benefits the dry upland regions of Telangana and Rayalaseema. As groundwater baseflow decreases, this is tantamount to a spatial and social redistribution of water impacting surface water use in the lower reaches of the basin. These phenomena are not public knowledge yet, but are likely to lead to conflicts as water scarcity becomes a recurrent feature of the Lower Krishna Basin.

The intersectoral distribution of water is also being modified. First, increasing electricity needs have led to the completion of hydropower projects in the upper reaches of the Lower Krishna Basin. These projects do not deplete water but they have slightly delayed the timing of river runoff, although balancing reservoirs have minimized impacts on existing agricultural uses further downstream. Second, the domestic and industrial needs of urban areas are increasing and are preferentially met as illustrated by the large transfers of water that have been made to supply the state capital, Hyderabad. Currently, this does not affect existing water uses much as the volumes involved remain marginal. But, in case of a drought, it could further deprive agricultural users in the large irrigation projects of Nagarjuna Sagar and the Krishna Delta. Third, environmental degradation, notably in the Krishna Delta, is leading to increasing awareness of the environment as a water user in its own right. This awareness is not translated into formal allocation mechanisms yet. The definition and quantification of environmental requirements are indeed controversial, challenge the idea that any water in excess of human requirements is “lost” and affect both the extent of basin closure and the room for further water development: environmental needs often constitute the closing term of the basin water balance (Molle et al. 2007). ‘Preserving’ a quantum of water (6.4 to 14.2 BCM/yr) to protect the environment of the Lower Krishna Basin from further degradation will commit 86 to 95% of the net inflow to the basin to designated uses.

Basin closure generally leads to an overcommitment that may severely degrade the resource base, both in quantity and quality (Scott et al. 2001). As a basin closes, water users, sectors and regions are increasingly interconnected on social, political, institutional, economic and physical grounds and local interventions have third party impacts and unexpected consequences elsewhere in the basin (Molle et al. 2004b). Water ‘losses’ are typically reused and the scope for effective water savings remains limited while water resources might, in effect, be spatially and temporally ‘redistributed’. Overcommitment of water resources increases the unreliability of water supplies upon which users depend. Problems may not arise during surplus years but in case of a drought, an ‘artificial scarcity’ or crisis is created as users cannot obtain customary volumes which they have come to rely on. Consequently, water users and managers generally develop informal adjustments to accommodate scarcity and overcome formal institutional constraints and the lack of flexibility that increase under conditions of water scarcity (Fontenelle 2001; Svendsen 2005; Wester et al. 2005). But, the extent of participation by stakeholders in the shaping of a particular waterscape is highly variable as people who use or manage water have differing levels of access to natural resources, knowledge, political representation or to the courts (Molle et al. 2007). To overcome the difficulties that such adaptive mechanisms may create (rent seeking, competition among users, increasing inequalities, etc.) and to avoid conflict, there is a clear need to articulate a specific course among different available options, to strike a balance between equity, sustainability and efficient uses of scarce water resources.

The definition and implementation of formal effective and adaptive water allocation mechanisms, both in time and place, is fundamental within the framework of the present Krishna Water Disputes Tribunal to allow transparent and sustainable uses of available water resources (Fontenelle 2001; Turral 2006). Water allocation should be considered as the clear and stable apportionment of a specified quantity and quality of water, for given purposes, to a user or group of users, with a specified reliability and supply security that accounts for spatial and temporal variation in water resources availability, and contains provisions for changing the allocation during times of low water availability (Turral 2006). Allocation mechanisms should (i) be defined at the basin level and ensure a fair degree of stakeholder participation (from the local users to the administrations of the different states involved); (ii) be based on a comprehensive understanding of the hydrology; (iii) recognize the finite and variable character of the physical resources and the interactions between surface water and groundwater; (iv) estimate long-term reliable supplies in any part of the basin in light of actual and projected use; and (v) create a formal room for water management flexibility by recognizing customary rights, local strategies and local adjustments (Scott et al. 2001). These mechanisms should account for (i) a reserve for basic human needs and the environment, (ii) a reserve for productive water for the poor, and (iii) a third tier for other productive uses (Molle et al. 2007). Moreover, the example of the Krishna Basin, where water development occurred with little regard to the formal allocation mechanisms enacted in the mid-1970s, illustrates the need for a clear governance system with an identified river basin organization that will be responsible for the coordination and efficient implementation of such mechanisms. There is a need to extend this study to the entire Krishna Basin and to complement it by describing inter-annual variability and temporal peaks of water use in relation to both dry areas and periods where conflicts are more likely to develop. When these dynamics are better understood, a more integrated regulation of water use and reuse could contribute to a more sustainable future for water management in the basin.

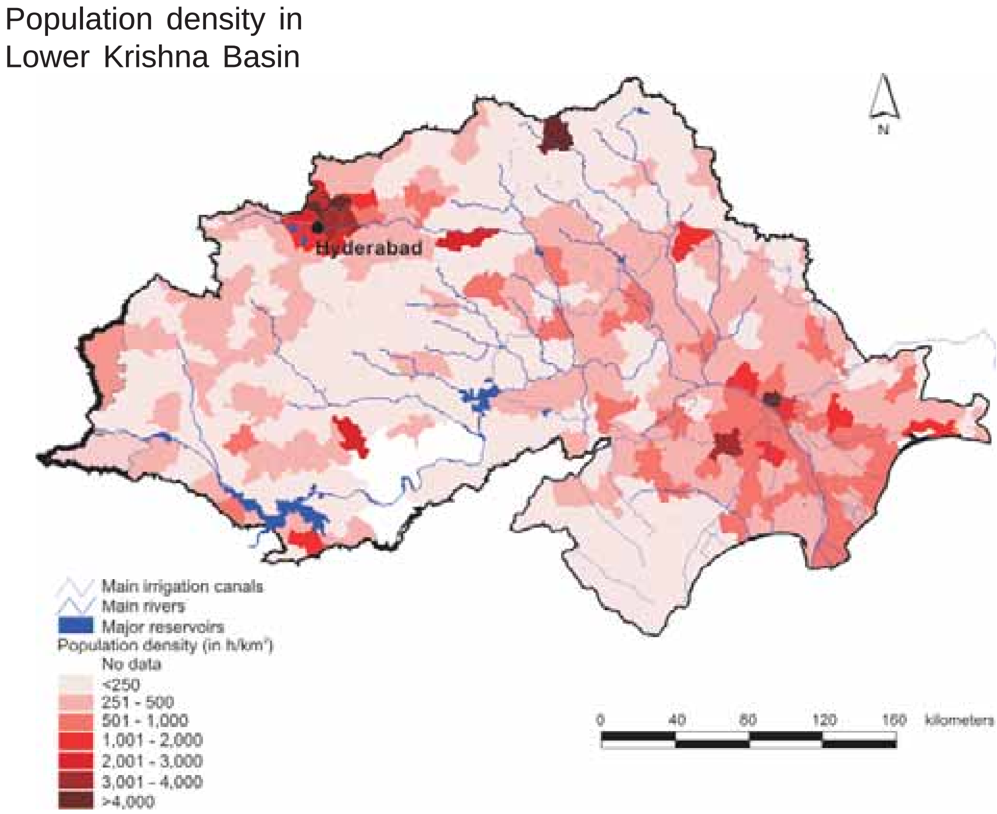
The Government of Andhra Pradesh, supported by the World Bank, has already called for the implementation of water demand management options (participatory irrigation management, modernization and rehabilitation of existing projects, water pricing strategies, technical on-farm improvements, conservation methods, etc. [GoAP 2001b; World Bank 1991, 1997, 1998]). With water becoming scarcer, river basins closing from a hydrological point of view, and the investments needed to control water always being higher, decision makers call upon another water management paradigm and generally curtail their investments in the irrigation sector. To take up the hydrological terminology of basin closure, this shift could be designated as the *institutional and financial closure* of the Lower Krishna Basin.

Nevertheless, this study clearly highlights that successive governments of Andhra Pradesh have continuously invested in supply augmentation options. The most recent examples include increasing water transfers out of the Lower Krishna Basin to the Rayalaseema region and the plans to link the Godavari and the Krishna rivers to benefit the lower reaches of the Krishna Basin. If the latter partly addresses the issue of decreasing water availability in the Lower Krishna Basin, it can also be seen as the continuing dominance of a politically driven engineering-based approach to water resources development in a favorable Indian populist context where bringing irrigation to dry regions is one of the most effective means to secure votes (Ramamurthy 1995). It also raises questions about the continued headlong rush towards more water-consuming investments (might they be large or small-scale infrastructures), more water for more irrigation and more people regardless of resource availability and sustainability. But alternatives are difficult to find and generally entail engineering: this underlines the limitations of formal allocation procedures and, more generally, demand management options. However desirable these might be, they may only alleviate the actual situation without providing long-term solutions. Just as in other water-stressed environments, basin closure means that overall basin efficiency is close to the maximum and all options (conservation, recycling, re-allocation and interbasin transfers) must generally be pursued together: transfers may well be needed in the future but need to be carefully envisaged and should not be taken as a justification for disregarding short-term demand management options and long-term water-sharing procedures (Venot et al. In press). Alternatively, a re-allocation of water at the basin level could become the dominant mode of management and satisfaction of competing demands (Turral 2006). But, as re-allocation is likely to take place mainly on economic (increasing water productivity) and political grounds, primary attention is to be given to equity and environmental preservation principles in the implementation of formal water allocation mechanisms.

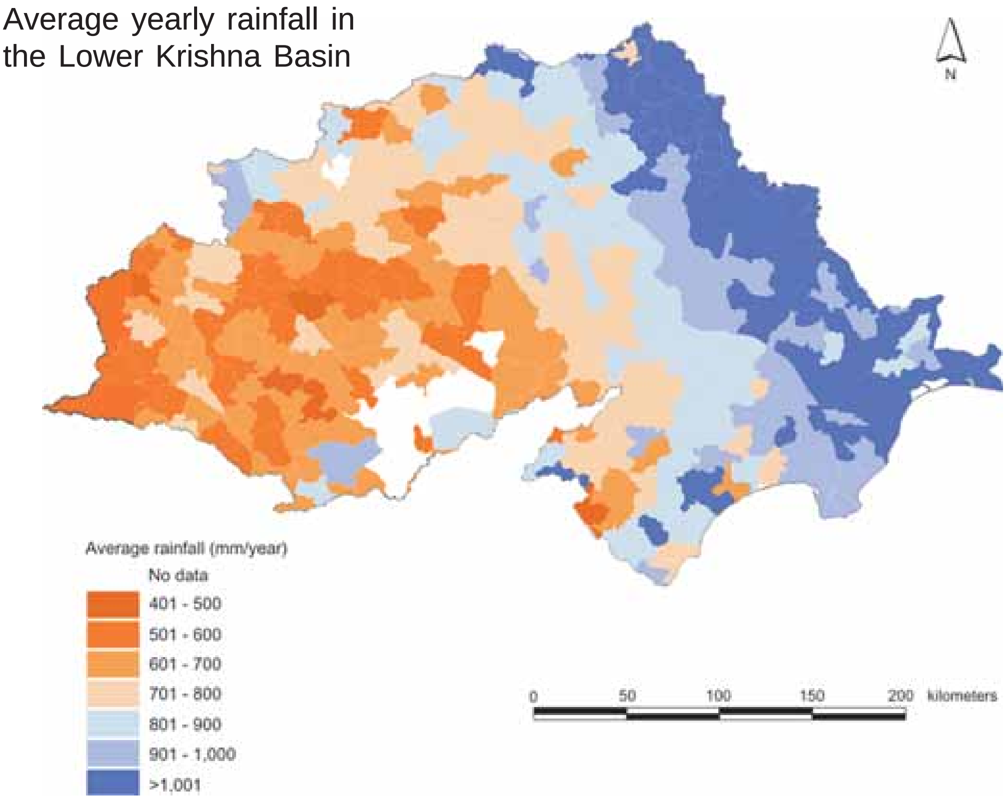
Finally, policies limited to the water sector are unlikely to ease the pressure on water resources alone: the demand for water, notably in agriculture, would actually be difficult to cap in order to match a sustainable and reliable regime. There is a clear need for strategies and policies that would assure the rural population a successful transition beyond agriculture (Moench 2002). National and international policies that facilitate access to credit, communication and road development and which create a propitious context for migration and urbanization are sorely needed. This transition will be difficult to implement as illustrated by the well-known public face of urban India characterized by mushrooming slums mainly inhabited by rural dwellers for whom migration does not mean improved livelihoods.

Appendix 1

Population density map of the Lower Krishna Basin.



Appendix 2
Rainfall map of the Lower Krishna Basin.



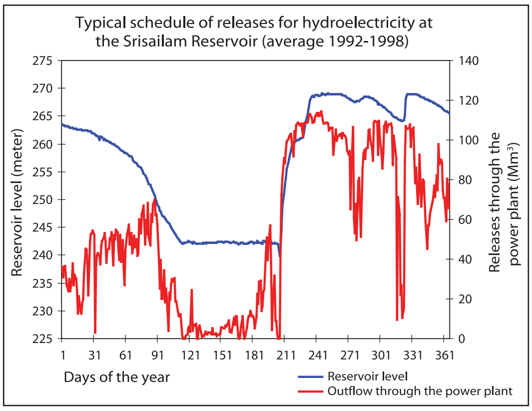
Source: Appendix 1 and 2 are based on *Mandal* statistics as presented in the district statistical handbooks of Guntur, Khammam, Krishna, Kurnol, Mahoobnagar, Nalgonda, Prakasam, Rangareddy, Warangal and West Godavari for the year 2002/2003.

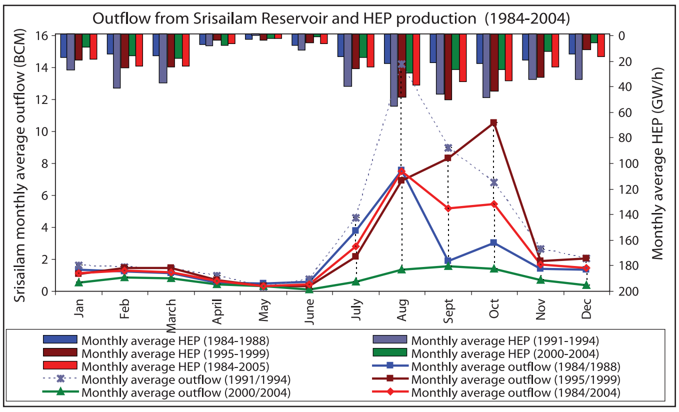
Appendix 3

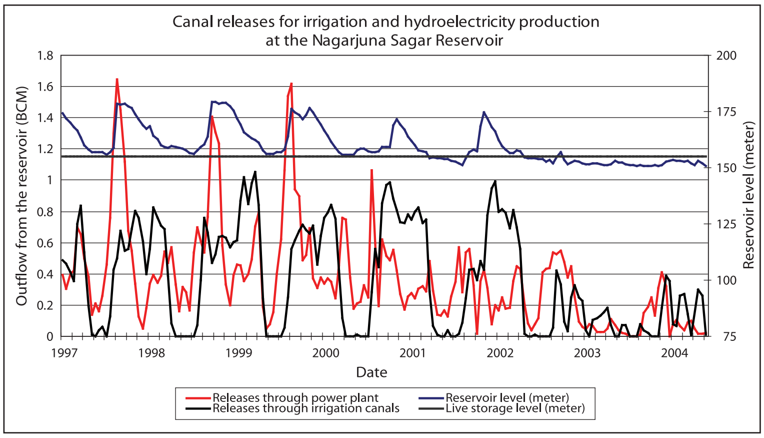
Details of Water Accounting for the Lower Krishna Basin for some Specified Periods between 1955 and 2004.

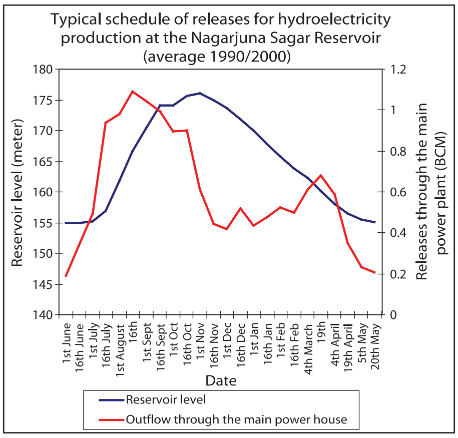
Unit of measure is the Mm^3/yr	1955-1965	1966-1975	1976-1985	1986-1995	1996-2000	2001-2004
1. Direct rainfall	54,960	52,157	54,521	53,538	52,826	46,235
2. Surface water inflow from upper basin	53,971	38,429	29,089	29,481	25,776	10,053
3. Imports to Hyderabad (from Godavari Basin)	32	65	52	53	124	149
4. Net depletion of groundwater stock (aquifer overdraft)	0	0	0	0	-504	-753
Net inflow (1+2+3-4)	108,963	90,650	83,661	83,072	79,229	57,190
Beneficial ET - Irrigation surface water	4,632	10,241	11,180	12,600	12,123	7,673
Beneficial ET - Irrigation groundwater	463	1,548	2,306	4,749	7,290	8,071
Beneficial ET - Rainfed agriculture + supplemental irrigation	17,446	20,193	21,608	20,162	19,851	14,674
Process (industry)	26	31	40	53	102	105
Process (drinking)	138	170	214	287	500	561
Process (livestock)	127	141	155	150	150	140
Low beneficial ET - Natural vegetation	14,268	14,194	14,584	15,136	15,167	17,931
Non-beneficial ET - bare lands and reservoirs	4,509	4,475	4,523	5,316	5,532	6,646
Total depleted	41,607	50,994	54,609	58,453	60,715	55,801
Runoff	67,258	36,343	28,139	20,295	17,900	752
Export to other basins	0	0	0	540	615	615
Filling of large-scale reservoirs	98	3,313	1,159	3,839	0	0
Total outflows	108,963	90,650	83,661	83,072	79,229	57,190
Recharge to aquifer	7,145	6,780	7,088	6,960	6,867	6,473
Baseflow from groundwater	6,821	5,696	5,473	3,635	1,764	823
Total depletion (percentage of net inflow)	38	56	65	70	77	98
Beneficial depletion (percentage of net inflow)	44	49	54	52	53	42
Beneficial depletion (percentage of net inflow)	21	36	42	46	51	55
Low beneficial depletion (percentage of depleted water)	34	28	27	26	25	32
Low beneficial depletion (percentage of net inflow)	13	16	17	18	19	31
Irrigation depletion (percentage of beneficial depletion)	22	36	38	46	49	50
Irrigation depletion (percentage of depleted water)	12	23	26	30	32	28
Irrigation depletion (percentage of net inflow)	5	13	16	21	25	28
Surface water irrigated areas	4,803	9,542	9,967	10,477	9,592	7,286
Groundwater irrigated areas	418	1,180	2,188	4,075	6,666	5,961
Rainfed agriculture areas	34,751	35,195	32,558	27,296	25,767	22,132
Natural vegetation areas	29,990	25,630	26,741	28,243	28,235	32,935
Bare land areas	10,780	9,195	9,288	10,651	10,482	12,428

Appendix 4
Hydroelectricity Production in the Lower Krishna Basin.


Typical schedule of releases for hydroelectricity at the Srisailam Reservoir (average 1992-1998)


Outflow from Srisailam Reservoir and HEP production (1984-2004)

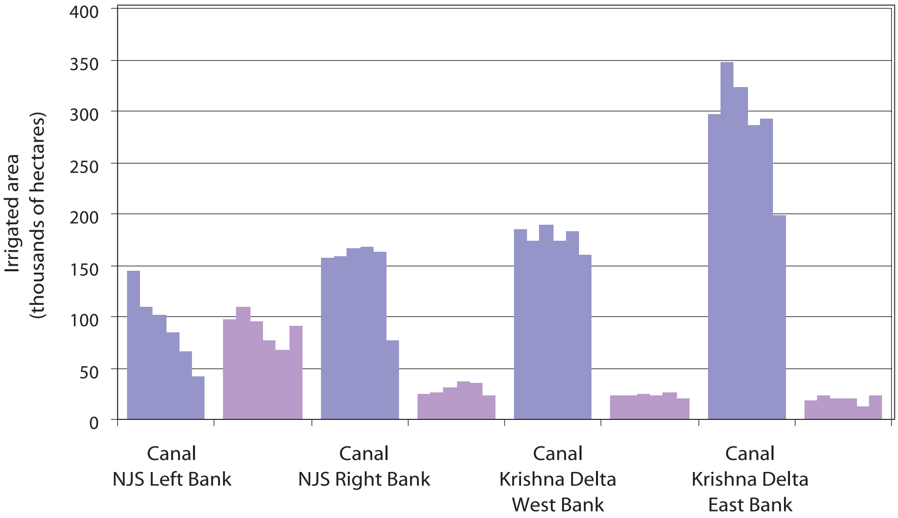

Canal releases for irrigation and hydroelectricity production at the Nagarjuna Sagar Reservoir


Typical schedule of releases for hydroelectricity production at the Nagarjuna Sagar Reservoir (average 1990/2000)

Source: Nagarjuna Sagar Camp Office (Hyderabad) and Executive Engineer, Srisailam Project.

Appendix 5

Importance of Conjunctive Use in the Large Irrigation Projects of the Lower Krishna Basin (1997-2003).



Source: Mandal-wise land-use statistics as presented in the District Statistical Handbooks of Nalgonda, Khammam, Krishna and Guntur districts for the period 1997-2003.

Appendix 6

Status of the Projects Withdrawing Water Out of the Lower Krishna Basin.

		Yearly water allocation (Mm^3)	Project design (ha)	Status
K-C canal		450	118,000	Ongoing modernization work (Andhra Pradesh Irrigation Department and Japan International Cooperation Agency)
Rajolibunda Diversion Scheme		1,130	35,000	The project receives less water than its entitlement as per the Krishna Water Disputes Tribunal due to upstream water use: irrigated area is smaller than envisaged
Srisailam Right Bank Canal (SRBC)		540	65,000	Ongoing modernization work (Andhra Pradesh Irrigation Department and Japan International Cooperation Agency) (an extra 23,500 ha is contemplated)
Telugu Ganga Project - refer to Nikku (2004) for a comprehensive study		425 (85 Mm^3 as evaporation losses and 340 Mm^3 reaching the Poondi Reservoir in Tamil Nadu from which Chennai withdraws the water)		The project has been completed, but the supply to Chennai is lower than what has been allocated
Srisailam Left Bank Canal (SLBC)	Irrigation development along the Telugu Ganga Project (TGP)	820; flood flow during the monsoon	117,000	Ongoing project: 52,200 ha have been achieved, but the system is functioning well below its design capacity
	Chennai Water Supply	850	120,000 in the Krishna Basin + hydroelectricity production	Command area development is contemplated; hydroelectricity is effectively produced

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