RESEARCH
REPORT

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The Lower Krishna Basin Trajectory: Relationships between Basin Development and Downstream Environmental Degradation

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International Water Management Institute

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International Water Management Institute
P O Box 2075, Colombo, Sri Lanka

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The authors: Jean-Philippe Venot is a PhD scholar with the International Water Management Institute, Hyderabad, India, and at the GECKO Laboratory of the University of Paris X-Nanterre. He is also affiliated to the Centre for the Study of Regional Development at the Jawaharlal Nehru University, New Delhi, as a casual student (e-mail: j.venot@cgiar.org). Bharat Sharma is Senior Researcher-I (Water Management) and Head of the International Water Management Institute, New Delhi office, India (e-mail: b.sharma@cgiar.org). Kamineni V. G. K. Rao is an independent consultant and Head, Consultancy Services of Indwa Technologies Pvt. Ltd., 506, Topaz Building, Panjagutta, Hyderabad 500 082, Andhra Pradesh, India (e-mail: kvgkrao@hotmail.com).

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Cover Photograph by Jean-Philippe Venot shows aquaculture ponds along the Krishna River, in the estuary region. Otherwise stated, all pictures are from Jean-Philippe Venot.

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Contents

Acronyms and Abbreviations

BCM	Billion cubic meters
CRZ	Coastal Regulation Zone
ET	Evapotranspiration
EWR	Environmental Water Requirements
ha	hectare
MAR	Mean Annual Runoff
Mha	Million hectares
Mm^3	Million cubic meters
MPEDA	Marine Products Export Development Authority
SADA	Shore Area Development Authority

Summary

Since the 1850s, the Krishna Basin in South India has seen a dramatic development of irrigation and water demand. In 1990-2000, consumptive water use accounted for 90.5% of the basin net inflow: warnings of basin closure (zero or minimal flow to the ocean) emerge during dry periods. This paper links basin water development and downstream environmental degradation. It shows that decreasing water availability due to upstream water regulation; recent trends of increasing groundwater abstraction and aquaculture development in the Lower Krishna Basin; and a fragmented institutional landscape have led to environmental degradation manifesting itself by soil and groundwater salinization, increasing pollution, disappearing mangroves and wetland desiccation. The paper further illustrates that natural resources management is often determined by political and economic interests with lesser emphasis on equitable use of the resources or environmental sustainability of the ecosystem. The formal recognition of the environment as a water user in its own right would be a first step towards improving the de-facto water allocation procedures that prevail today. The paper calls for the definition and implementation of an environmental water provision based on a two-tier allocation system with assured discharges in the irrigation canals of the delta and to the ocean. Other measures facilitating integrated natural resources management from the local level (regulating practices, drought-mitigation mechanisms) to the state level (integrated coastal management, institutional support, devolution process) and the basin level (integrated basin management and water-allocation procedures) are needed too. In the Krishna Basin, nearly all water resources are committed to existing uses: allocating water to the environment will increase the pressure over water resources but this is the price to pay to reconcile the social, economic and environmental objectives of a sustainable development. When a river basin is closing, any supply augmentation projects would lead to a re-appropriation of water rather than to an increase of the total water availability. As this reallocation is likely to mainly take place on economic grounds, high attention is indeed to be given to equity and environmental preservation principles when implementing water allocation mechanisms for the satisfaction of competing demands.

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Introduction

Water and infrastructural development to meet growing human consumptive uses has taken place with little regard to the limits of availability of renewable resources. The result is significant degradation of various ecosystems (Falkenmark et al. 2007). In the Krishna Basin, warnings of environmental degradation due to long- and short-term rural dynamics have emerged in the lower basin which bears the brunt of any intervention further upstream. As upstream water use is not adjusted to reflect changes in water availability, environmental threats are likely to be further sharpened.

There is increasing evidence of the adverse impacts of water and land degradation on the livelihoods of people (MEA 2005; Falkenmark et al. 2007). Therefore, environmental concerns have started to gain strength and the notion of environmental flows is establishing itself firmly. It is an attempt to find a compromise between productive uses and some protection threshold. But achieving this balance represents a considerable challenge in many of the world's river basins, especially in arid and semiarid areas of the developing world, as population and associated water demands increase to sustain a broader economic development (ACC/ISGWR 1992; NCIWRDP 1999; WWAP 2003).

The United States of America, South Africa and Australia are countries where environmental water requirements have been mainstreamed in water resources policies. This mainstreaming led to the recognition of formal water allocation procedures as the most adapted tools to reconcile the social, environmental and economic objectives of sustainable development and integrated water resources management. However, to date, most developing countries do not have well-defined procedures for effective water allocation and water policies generally only list "allocation priorities." The Indian National Water Policy of 2002 provides guidelines for prioritizing water allocation to different competing sectors, giving precedence to drinking water over irrigation, hydropower generation, industrial and navigation needs. Environmental concerns mentioned under the heading "ecology" are given fourth priority but nothing is said on how this should be implemented (MoWR 2002).

This report is a case study on the Krishna River Basin in South India. The basin has witnessed intense water development resulting in downstream environmental degradation. The observed decline in discharge to the ocean sends a strong signal: there is only little scope for further water supply development, and further taming the Krishna waters will exacerbate environmental degradation. This report investigates the linkages between rural development dynamics and the downstream environment of the Krishna Basin in order to understand when and how rural development and environmental preservation come or do not come into conflict and identify potential areas of intervention to limit the degradation of the downstream ecosystems of the Krishna Basin.

The section, *Human and Physical Setting of the Lower Krishna Basin*, presents the main features of the Lower Krishna Basin. The section, *Basin Water Allocation in the Framework of Environmental Flows*, describes a methodology for water allocation in the framework of environmental flows in a data-scarce context and applies this methodology to the Krishna Basin. It is mainly based on literature review and secondary data collection. The section, *The Drivers of Environmental Change in the Lower Krishna Basin*, provides a historical assessment of water availability and uses in the Krishna Basin. It depicts the rural dynamics and the institutional context of the Lower Krishna Basin as some of the main driving forces of downstream environmental degradation. Based on field interviews and on a comprehensive review of the literature on the region, the section, *Linkages between Rural Development and Environmental Degradation*, describes the linkages between agriculture, aquaculture and the environment in the Lower Krishna Basin. The final section, *Discussions and Conclusions*, provides a set of conclusions applicable to the Krishna Basin and other similar basins facing water scarcity.

Human and Physical Setting of the Lower Krishna Basin

The Krishna Basin lies in southern peninsular India. The Krishna River originates in the Western Ghats, drains the dry areas of the Deccan Plateau, and forms a delta before discharging into the Bay of Bengal. The Krishna Basin drains an area of 258,948 square kilometres (km^2) (in three Indian States: Andhra Pradesh, Karnataka and Maharashtra) and its climate is predominantly semiarid. This report focuses on the impacts that rural development dynamics witnessed in the Krishna Basin over the last 50 years have had on the Lower Krishna basin, located in Andhra Pradesh (South India; Figure 1). The Lower Krishna Basin has an area of 8,746 km^2, a population density higher than 250 inhabitants per km^2 (Appendix 1) and annual rainfall is in the range of 650 to 1,150 millimeters (mm) (Appendix 2). There are three main agro-ecosystems (Figure 1):

1. The Krishna Delta, where a large irrigation project irrigates 540,000 hectares (ha) thanks to gravity canals drawing water from a barrage on the Krishna River at *Vijayawada*. The delta accommodates about 4 million inhabitants depending mainly on agriculture and aquaculture. Aquaculture is concentrated in the east of the delta between the Kolleru Lake region and the coastal fringe (Figure 1). The urban network is dense with many medium size cities of 0.5 to 1 million inhabitants (Machilipatnam, Gudivada, Tenali, Vijayawada, etc.).
2. The Kolleru Lake, which is a freshwater inland lake designated as a wetland of international importance under the Ramsar convention in 2002. It is located between the Krishna and Godavari river deltas. Limits shown in Figure 1 are indicative: they do not correspond to the boundaries of the Ramsar site itself but correspond to a larger lowlying region designated as the Kolleru Lake region. Aquaculture ponds are widespread in this region where half a million people live.
3. The coastal zone where mangroves and natural vegetation have been progressively cut and replaced by aquaculture ponds.

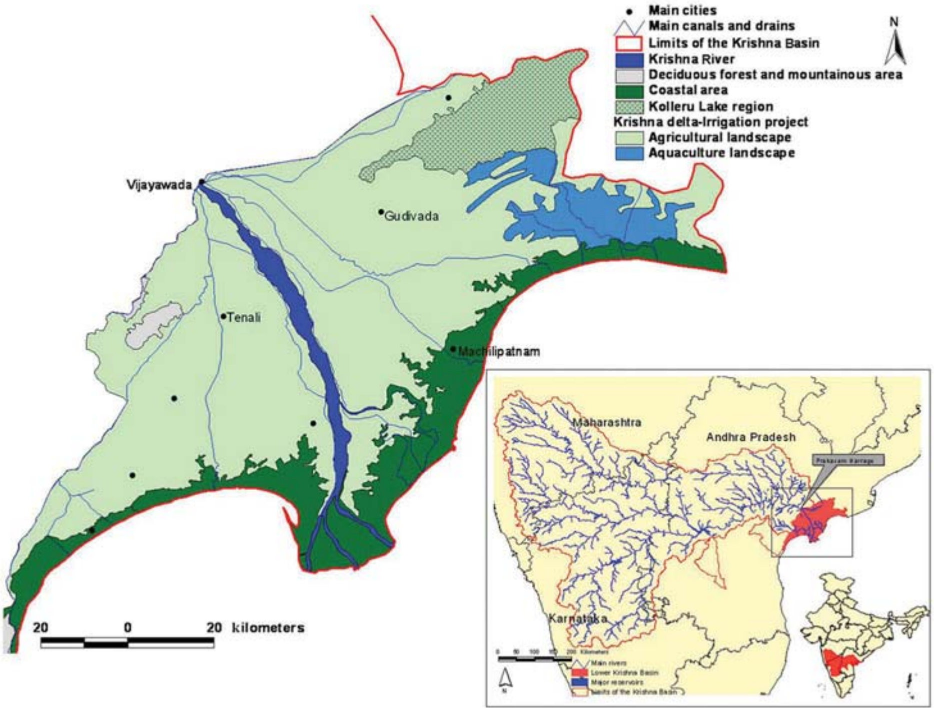


FIGURE 1. The Lower Krishna Basin in South India.

Basin Water Allocation in the Framework of Environmental Flows

Defining Environmental Water Allocation in a Data Scarce Context

The lack of understanding of, and commitment to, the notion of environmental flows in the developing world arises from two main questions: a) how to define environmental water needs, and b) how to quantify them? While many of the world's river basins are closing,[1] the question of recognizing and quantifying environmental flows holds a crucial importance. In closed or closing river basins, water resources cannot be further extended without impinging on actual uses: estimate of environmental flows will determine to what extent a river basin is closed and whether new water resources can be developed. Understanding the environmental dynamics at stake and the interconnectedness between the environment and rural development is crucial.

At a first approximation, environmental water requirements (EWR) of a river basin can be defined as *an ecologically acceptable flow regime*. It is designed to maintain or upgrade a river in a desired, agreed or pre-determined status referred to as an *environmental management class* ranging from the natural (pristine) environment to a critically modified ecosystem. A detailed discussion of these notions can be found in Smakhtin and Anputhas (2006) and Tharme (2003).

[1]Murray Darling, Yellow River, Indus and Jordan River basins. A generally accepted definition of a closed river basin is one where all available water is committed [Molden 1997], resulting in little or no discharge to the ocean during years with average precipitation.

Defining an annual volume of water to be set aside for the environment (bulk allocation), according to arbitrarily predefined preservation objectives, appears a futile exercise without sound ecological meaning. Yet, such a desktop assessment method constitutes the first step towards the recognition of the environment as a water user in its own right (Smakhtin et al. 2004). This basin-wide reconnaissance assessment is based on a single arbitrary hydrological index (the discharge to the ocean) and is considered to be most appropriate at the planning level of water resources development, notably in developing countries where water governance structure is weak and hydrological and ecological data scarce (Tharme 2003; Smakhtin et al. 2007a). Based on a work by Smakhtin and Anputhas (2006), Table 1 presents what would be the environmental annual water requirements of the Krishna Basin, measured at the head of the Krishna Delta in Vijayawada (the last point of measure of the Krishna flow; Figure 1), according to different objectives of downstream ecosystem preservation.

In arid and semi-arid regions affected by the monsoon, the seasonality and inter-annual variability of water flows are crucial for the functioning of water dependent ecosystems. It is generally recognized that environmental flows should be defined against this backdrop of natural variability of flow regime (Dyson et al. 2003; Tharme 2003). Figure 2 shows recommended monthly flow regimes to preserve the Krishna Basin in a moderately to largely modified environmental status (the two lowest acceptable statuses as per the DWAF guidelines in South Africa [DWAF 1999]). These monthly flow regimes are obtained by scaling down the regime observed between 1901 and 1947 (when little impoundment and land use changes had affected the functioning of the Krishna Basin drainage network) by 81.7% (for a moderately modified system) and 91.6% (for a largely modified status) to match the thresholds presented in Table 1.

Water Availability and Environmental Status of the Krishna Basin

Figure 2 gives the first indication of river basin closure and downstream environmental degradation. It shows the decline of the Krishna River's discharge, measured at the head of the delta, in Vijayawada. Before 1960, river discharge into the ocean averaged 57 BCM per year and the threshold of 48.5 BCM a year, defining a "*natural ecosystem*" (Table 1), was reached with 76% reliability. Since 1965, the river discharge has steadily decreased to reach 10.8 BCM in 2000 while it was almost nil in 2004. The lower panel in Figure 2 illustrates that taming the Krishna waters also affected the flow regime of the river with a two-month delay in the peak outflow and slightly increased runoff during the dry season (due to irrigation return flows). In standard conditions, the average discharge to the ocean observed between 1988 and 2000 (between the last two major droughts) was 21.2 BCM/yr but the threshold of 14.2 BCM/yr defining a moderately modified ecosystem was only reached with 60% reliability. Similarly, historical monthly flow regimes show that the Krishna Basin is a moderately to largely modified ecosystem.

Table 1. Annual Environmental Water Requirements (EWR) for the Krishna Basin (flow measured at Vijayawada) for different "protection thresholds".

Environmental Status	Natural ecosystem	Slightly modified	Moderately modified	Largely modified	Seriously modified	Critically modified
EWR (% historical MAR)*	62.5	35.7	18.3	8.4	3.5	1.5
EWR (BCM/yr)	48.5	27.7	14.2	6.5	2.7	1.2

* The historical Mean Annual Runoff (MAR) has been evaluated at 77.6 Billion cubic meters (BCM) a year (CWC 2002)
Source: Smakhtin and Anputhas (2006).

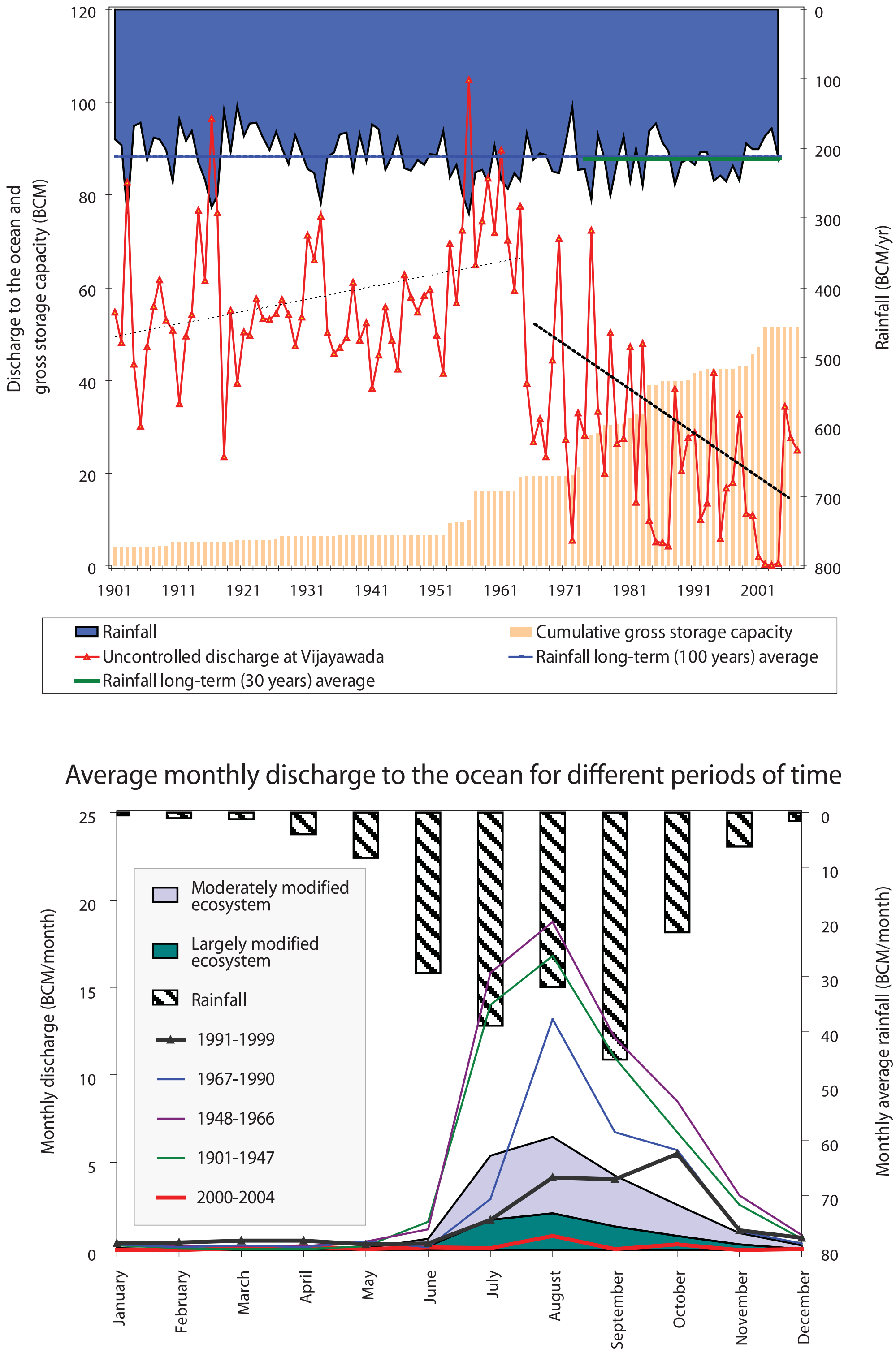


FIGURE 2. The closure of the Krishna Basin: A declining discharge to the ocean. *Source* : Adapted from Venot et al. (2007).

The top panel in Figure 2 illustrates the recurrence of low-discharge events (1971-1972; 1984-1988; 2001-2004) that resulted from a rainfall deficit at the basin level. In the Krishna Basin, rainfall 10% below average [as in 2001-2004] has been recorded with a probability of occurrence of 0.3 over the last 100 years and seven droughts of more than 3 years have been recorded over the last century (CRU 2007). By 2001-2004, the discharge to the ocean fell below 1.2 BCM/yr; a level that had never been recorded before but the drought itself was not particularly unusual. Given continued upstream development of irrigation infrastructure; this may predict future water availability in the Lower Krishna Basin. Long-term trends of environmental degradation are likely to be sharpened during low rainfall periods.[2]

The Drivers of Environmental Change in the Lower Krishna Basin

Coastal ecosystems are sensitive to changes in water availability and use (Ramsar Convention Secretariat 2006) and the degradation of estuarine resources, due to a variety of human activities within and outside the estuaries, has become a major environmental concern in India (Bhatta and Bhat 1998). This section argues that three main forces led to environmental degradation in the Lower Krishna Basin: (i) a continuous development of the Krishna Basin water resources and a decrease in water availability in the lower basin; (ii) the rural dynamics of the Lower Krishna Basin; and finally (iii) the institutional context of natural resources management in the Lower Krishna Basin.

Shifting Land and Waterscape in the Krishna Basin

History of Water Development in the Krishna Basin

Water has been managed for centuries in the Krishna Basin. Originally, small-scale structures allowed diversion of runoff from small streams and storage in small tanks (Wallach 1985). The first major water diversions took place in the Krishna Delta from 1852 onwards, with a project designed to irrigate 240,000 ha. Between the 1850s and 1947, most efforts to promote irrigation focused on the dry areas of the Deccan Plateau in the Upper Krishna Basin where British engineers built large gravity irrigation systems (refer to Mollinga (2003) for further description of the functioning and the problems faced by these irrigation systems).

The pace of irrigation development in the Krishna Basin accelerated after independence with the modernization of the Krishna Delta project (1954-1957) which, at present, irrigates 540,000 ha. Irrigation also expanded with the establishment of several irrigation and hydropower projects: Nagarjuna Sagar (1967) and Srisailam (1983) in Andhra Pradesh; Bhadra (1953), Malaprabha (1973); Ghataprabha (1977) and Alamatti (1990) in Karnataka; Koyna (1964) and Ujjani (1981) in Maharashtra were the major ones.

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 slightly slowed down (Barker and Molle 2005) (this is visible in Figure 2 for the Krishna Basin). With the liberalization of the Indian economy in the early 1990s, state investment in agriculture weakened (Landy 2006). However, local private and community initiatives continued in the dry areas of the basin and scattered groundwater-irrigated plots multiplied, sustained by subsidized electricity.

[2]The high discharge observed in 2005-2007 (29 BCM/yr) illustrates that the Krishna River Basin is under transition.

Since independence, total storage capacity (in large and medium reservoirs of the Krishna Basin) has been multiplied eightfold to reach about 54 BCM in the early years of the 21st century. In the meantime, small-scale irrigation projects have also boomed and existing infrastructures regulate more than the 75%-dependable flow (Biggs et al. 2007). Along with infrastructure development, surface irrigated areas nearly doubled from 1995-2000: they covered about 2.8 million hectares (Mha) in 1996-2000. Groundwater irrigated areas have also doubled during the same period and covered about 2 Mha in 1996-2000.[3]

Basin-wide Water Accounting

The water accounting presented in Figure 3 and Appendix 3 draws on the categories of water balance proposed by Molden (1997) and use the same methodology as presented in Venot et al. (forthcoming). It evaluates water depletion, defined as the use or removal of water from a river basin that renders it unavailable for further use, according to five categories: beneficial evapotranspiration (ET) from 1) irrigation, 2) rainfed agriculture, 3) domestic, industrial and livestock processes, 4) low benefit ET from natural vegetation, and 5) non-beneficial ET from bare land and reservoirs. Rainfall estimates are based on CRU dataset (CRU 2007); land-use statistics are collected at the district level (GoAP 2006; GoK 2006; GoM 2005). The depletion from any kind of land cover is estimated as its evapotranspiration (ET), evaluated according to the Penman-Monteith methodology (Allen et al. 1998) for irrigated crops and based on Biggs (in review), Bouwer et al. (2007) and Immerzeel et al. (2007) for other land covers. Urban and industrial uses have been computed according to Van Rooijen et al. (forthcoming), assuming water use efficiency of 70% in each sector. Livestock process is computed according to Peden et al. (2007). We used average figures referring to periods of 10 years.

Figure 3 confirms that the main trend is a strong increase of irrigation depletion that has more than doubled from 17.1 BCM/year during 1955-1965 to 44.3 BCM/year during 1990-2000 (see also Appendix 3). This implied a 19%-rise of the total depletion over

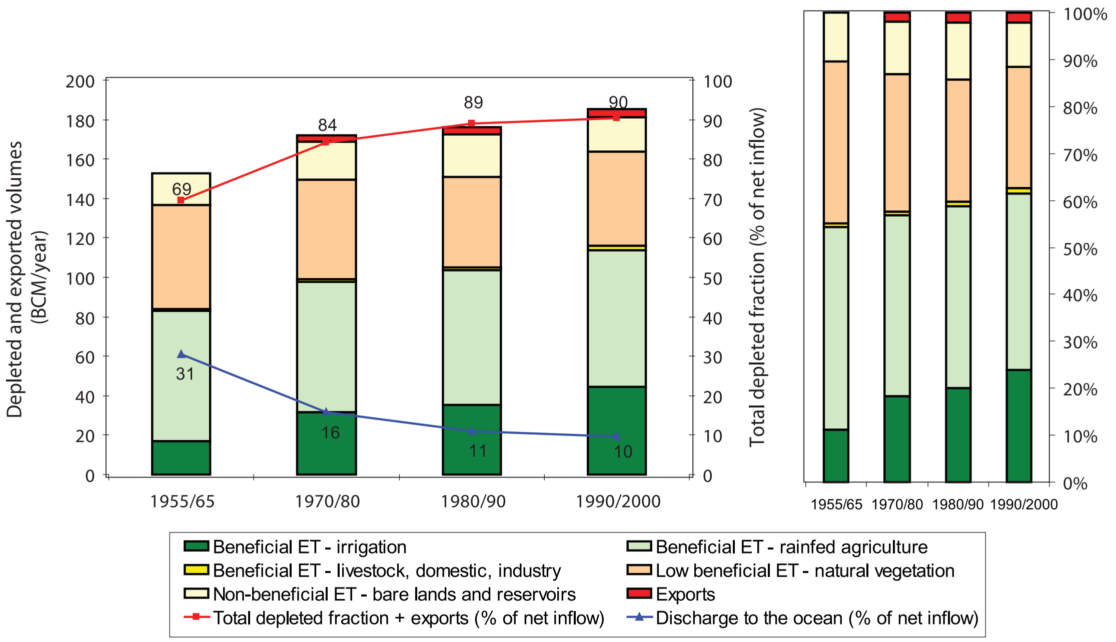


FIGURE 3. Historical water account of the Krishna Basin (1955-2000).

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

the period 1955-2000. The total depletion amounted to 181 BCM during 1990-2000, i.e., 88.5% of the net inflow to the Krishna Basin. Consequently, the discharge to the ocean dramatically decreased and amounted only to 9.5% of the net inflow during 1990-2000 (2% of the net inflow was exported to other basins). This led to dramatic environmental changes in the Lower Krishna Basin. According to Smakhtin and Anputhas (2006), preserving the moderately to largely modified ecosystem of the Krishna Basin would require an environmental flow allocation of about 6.5 to 14.2 BCM/yr (Table 1). This will point to a rate of water resources commitment of 92 to 96%.

Agrarian Dynamics in the Lower Krishna Basin

The Making of the 'Farmer-Capitalists' of the Krishna Delta

Large-scale irrigation in the Lower Krishna Basin dates back to the 1850s with the construction of a diversion weir at Vijayawada, at the head of the delta. Irrigation development, notably from the turn of the twentieth century onwards, led to agricultural surplus production and commercialization and set the stage for agricultural growth (Rao 1985). This went together with the emergence of a large class of prosperous peasants or owner-cultivators who can best be termed "farmer-capitalists" (Upadhya 1988). These farmers rapidly re-invested their agricultural surplus in grain trade and small-scale agro-processing industries (mainly rice mills) and migrated to cities in pursuit of economic prosperity, higher education (for the youngsters) and political influence. In the post-Independence rural economy characterized by a strong involvement of the State (Landy 2006); the Green Revolution (1965-1985) and the subsequent agricultural productivity boom highly benefited the Lower Krishna Basin and strengthened the "*capitalist tendencies in the agrarian economy [of coastal Andhra Pradesh …]"*(Upadhya 1988: 1379). Large landowners were the main beneficiaries of this evolution and invested heavily in urban manufacturing activities; agro-industries (inputs and agricultural machinery dealers, fertilizer plants); industries (cement factories) or speculated in urban real estates. Small landowning families benefited from a trickle down effect and began to diversify their activities too. Nevertheless, economic disparities between landed and landless, relying on wage labor, increased. Economic diversification, integration of agriculture to market, links between rural and urban activities are some of the main reasons for the prominent role played by the coastal region in Andhra Pradesh politics. This historically prominent position notably translates itself into higher and more reliable access to water resources (Venot et al. 2007).

The Indian Agrarian Crisis

In the mid 1980s, and further with the liberalization of the Indian economy in the early 1990s, State investments in rural development policies slowed down and the importance of the corporate sector in Indian agriculture increased (Landy 2006). This is said to have pushed rural India into an *agrarian distress* (Suri 2006). The farmers of the Lower Krishna Basin faced problems of heavy dependence on high-cost inputs; volatility of crop output; market fluctuations; lack of remunerative prices; indebtedness, etc. These problems worsened as agriculture got embedded in a broader liberalized economy. The "farmer-capitalists" of the Lower Krishna Basin looked for other economic opportunities: aquaculture was one of them and its development had significant impacts on the rural landscape of the Lower Krishna Basin.

The Blue Revolution: Landscape Changes in the Lower Krishna Basin

In Andhra Pradesh, aquaculture development was a State policy as far back as the mid-1970s and enjoyed strong support from the central government as well: the aim was to promote a *Blue Revolution* (Naganathan et al. 1995) to enhance local livelihoods. Farmers and fishermen were entitled governmental land[4] and encouraged to form registered cooperative societies for fish and shrimp farming. Simultaneously, small "farmer-entrepreneurs" invested private funds on small areas of un-appropriated governmental land to benefit from a booming aquaculture sector. Aquaculture development reached its peak in the 1990s. The extension of the governmental and institutional support for both financial and technical aspects of aquaculture (Anonymous 2005), the liberalization of the Indian economy, and the decreasing profitability of agriculture and capture fisheries triggered a change in the social structure of the Lower Krishna Basin aquaculture. Cooperatives managed by local people did not survive as land speculation became common and land-prices rose rapidly. Attracted by the prospect of high revenues and being under economic and political pressure, small farmers and fishermen sold or leased out their land entitlements to rich local entrepreneurs and outsider investors and often became daily or monthly contracted laborers (Rama Rao et al. 2006). Villages and local administrations easily delivered further land entitlements to entrepreneurs to develop aquaculture on un-appropriated governmental lands and mangrove areas. This increased the pressure on the natural resources of the Lower Krishna Basin. Social movements backed up by the mobilization of the local elites (the "farmer-capitalists") emerged. They aimed at limiting in-migration of outsider investors who could have cornered the sector. This pushed the government to legislate on shrimp farming in 1996 (Supreme Court of India 1996) and to control aquaculture development more carefully.

The strong commitment of the "farmer-capitalists" of the Lower Krishna Basin limited the phenomenon of land concentration contrary to what happened in the Godavari Delta where large-scale industrial shrimp production is common (Grandcolas 2006). In the Lower Krishna Basin, the average size of aquaculture farms is about 0.75 hectares and 95% of the farmers cultivate less than 2 hectares (Fisheries Department [Unpublished documentation]). These official figures, however, do not account for the informal land concentration that has taken place through large-scale, yet illegal, leasing of land entitlements (field visits in April 2006 and 2007 highlighted the existence of large ponds of more than 50 hectares managed by entrepreneurial farmers). There are large differences in revenue among the population: local fishermen, who were involved in capture fisheries, have generally been driven out of business and many small farmers have seen their paddy field and grazing areas encroached by aquaculture ponds. Pushed into poverty, many migrated towards cities seeking various ancillary job-opportunities related to shrimp cultivation.

At the end of the 1990s, the development of aquaculture had come out of the control of the concerned governmental departments (Anonymous 2005). In the Lower Krishna Basin, poor management practices resulted in the outbreak of diseases, and in soil and groundwater salinization. Despite increasing inputs, yield decreased (Anonymous 2005; MPEDA 2006). A Supreme Court order of 1996 (Supreme Court of India 1996) banishing anything but traditional shrimp farming from the Coastal Regulation Zone (Box 1) illustrates the will to slow down environmental degradation. But, implementing this order is a difficult task as it goes against the objective of the Andhra Pradesh Government to revive an aquaculture sector that has a crucial economic importance for the State (GoAP 2001c; Anonymous 2007; GoAP 2007a).[5]

Aquaculture has beneficial impacts in the Lower Krishna Basin: it sustains many livelihoods, triggered the construction of road infrastructure to transport the production and opened up the costal zone. However, as observed in Karnataka, *"the emergence of commercial aquaculture in estuaries […] has resulted in the breakdown of traditional*

[4]Transaction of these land entitlements (purchase, selling, leasing) is not allowed.

[5]Aquaculture in Andhra Pradesh accounts for 10% of the total fish and shrimp production in India (GoAP 2007a) and 45% of all ponds in Andhra Pradesh are located in the Lower Krishna Basin (Fisheries Department unpublished documentation).

methods of resource management and adverse impacts on the coastal environment (Bhatta and Bhat 1998).*"* The problem is to find a balance between aquaculture, agriculture and environmental preservation in the Lower Krishna Basin. Within the aquaculture sector itself, fish and shrimp farming have to be considered differently as they do not have the same impacts on population and environment.

Institutional Context

Brugere (2006) shows that conflicts over coastal resources and subsequent environmental degradation are predominantly the outcome of institutional failures. Mapping the institutions involved in the use, control and preservation of natural resources in regard to the Lower Krishna Basin is thus central to the understanding of the drivers of environmental degradation. It reveals a fragmented institutional framework (GoAP 2001c) with:

- Federal institutions enacting rules and regulations to be implemented in the different Indian states: the Ministries of Water Resources, of Environment and Forests, of Agriculture, and of Rural Development; the Marine Products Export Development Authority, etc.
- State agencies: the Fisheries; Agriculture; Irrigation; Revenue; Environment, Forests, Science and Technology Departments of the State of Andhra Pradesh; the Andhra Pradesh Pollution Control Board; the Shore Area Development Authority; the Aquaculture Authority, etc. The roles and objectives of these governmental bodies are often overlapping but conflicting on the long run (GoAP 2001c). The Fisheries Department, for example, promotes aquaculture but does not cover the environmental degradation resulting from shrimp farming in the coastal area or in protected reserves under the jurisdiction and the protection of the Forest Department. Agriculture is promoted by the related department but faces acute competition from aquaculture as land pressure is high throughout the Lower Krishna Basin. The Groundwater Department should preserve water quality while aquifers are over-used for both agriculture and aquaculture, etc.
- Judiciary bodies, such as the Supreme Court of India and the High Court of Andhra Pradesh. They have to ensure that existing legislations are effectively implemented. The absence of proactive governmental role in mitigating the environmental impacts of rural development often led to actions being imposed by the Judiciary as a result of public interest litigation (GoAP 2001c; see, for example, the Supreme Court order of 1996 on shrimp farming in the coastal regulation zone).
- The Krishna Water Disputes Tribunal has allocated water to the three states sharing the Krishna waters (GoI-KWDT 1973, 1976). This did not hinder irrigation development: infrastructures have been built with little regard to the limits of availability and sustainability of water resources (Venot et al. 2007).
- International, federal, state-wise conventions, regulations or legislations: the Ramsar Convention; the Indian Forest Act (1972); the Wildlife Protection Act (1972); the Water Prevention and Control of Pollution Act (1974); the Environment Protection Act (1986); the Coastal Regulation Zone Notification (1991); the Indian Fisheries Act (1997); the Coastal Aquaculture Authority Act (2005), etc. Most of these acts and regulations are about *preserving* the environment. Few are effectively implemented.
- Local institutions: *Panchayats*, farmers and fishermen's associations, etc. *Panchayats* are responsible for protection and sustainable use of resources while local associations press for the demands of the users they represent and lobby to ensure their access over natural resources for their direct economic benefits.

Local rural dynamics and new economic opportunities (e.g., aquaculture) have led to changes in the institutional context in which resource extraction takes place in the Lower Krishna Basin. The legal and institutional framework of natural resource management broadened in line with the recognition of the importance of environmental preservation for sustainable development. Federal and state-level actors emerged and impinged on what was previously the remit of local institutions. This institutional formalization aimed at better preserving ecosystems but also led to a fragmentation of the institutional setting. This hindered effective implementation and often led to further degradation of the environment. To offset this evolution, recent moves encourage devolution processes (Brugere 2006). Interventions that put users at the center of management policies are promoted (e.g., *Integrated Resources and Participatory Management* (GoAP 2001a and 2001c)). But lack of technical and financial support and rent seeking behaviour of the local rural elites often thwart their effective implementation (see Mollinga et al. (2001) on the case of Water User Associations). What is required is further integration and coordination among the different institutions involved in resource management. Making the existing legal provisions context-specific and their implementation effective could be achieved by making these regulations more easily available; building up enforcement mechanisms; training officials in the use and implementation of laws; and improving the still low awareness of these policies among stakeholders, etc. (GoAP 2001c). New institutional arrangements have to be devised: users should be at the center of managerial decisions (GoAP 2001a) but centralized interventions such as integrated coastal management, the regulation of on-farm practices (Gowing et al. 2006), and the implementation of formal environmental water allocation are needed. This will impinge on existing water use and come up against existing politico-economic powers but is needed to ensure sustainable and equitable development in the Lower Krishna Basin.

Box 1. The Coastal Regulation Zone notification of 1991 (GoI 1991).

This notification aims at protecting the near-coastal environment. The area under tidal influence all along the coast, up to 500 meters inland, has been subdivided into three zones with different levels of protection according to their proximity to the coast. Within the Coastal Regulation Zone (CRZ), activities such as building, industries, waste dumping, groundwater use, land reclamation, and resource extraction have been banned or restricted if they already existed at the time of the notification.

However, fragmented institutional framework, lack of interaction among existing agencies involved in the management of natural resources and understaffing act as impediments for the implementation of the CRZ notification. In Andhra Pradesh, for example, the CRZ regulation is overseen by the Shore Area Development Authority (SADA) under the Environment, Forests, Science and Technology Department. It has limited staff and few senior officials at the State level, in Hyderabad, to monitor development activities in respect of the notification. Local level regulation and enforcement have been delegated to the District Collector office that is in charge of the overall economic development of the district. As a result, the CRZ notification gets the last priority compared with many other pressing responsibilities (GoAP 2001c).

In this context, the problems that had motivated the CRZ notification are still common: groundwater is unsustainably abstracted for coastal aquaculture; seawater progresses further inland; mangrove covers disappear; pollution is increasing due to aquaculture effluents; and there are major problems of drinking water supply (GoAP 2001c).

Linkages between Rural Development and Environmental Degradation

This section investigates the linkages between rural development and environmental degradation in the Lower Krishna Basin. First, we highlight the strong connections between irrigation development patterns and environmental change. Second, we investigate the nature of the connections between coastal resources extraction and environmental degradation. Finally, a case study on the Kolleru Lake, where acute conflicts between short-term financial gains and long-term environmental sustainability exist, is presented. This section highlights that all environmental threats cannot be solved by environmental water allocation: other measures are needed.

Surface Water and Groundwater Irrigation: Impacts on the Aquifers

The Aquifer System of the Lower Krishna Basin

The Lower Krishna Basin has a multilayered aquifer system, and hydrological studies have shown that groundwater levels are shallow due to the influence of the canal network (GoAP 2003). Seepage from unlined canals and return flows from irrigation are the main sources of recharge for the fresh shallow aquifer (0 to 30 meters) used for agricultural and drinking purposes. The Krishna River is the main source of recharge for plains along the river channel. Deeper aquifers are generally brackish to saline and mainly recharged by slow seepage from upper levels and the Krishna River itself during the monsoonal period (DRDA 1999). Figure 4 illustrates that the closure of the irrigation canals (and the subsequent decrease in surface irrigation) leads to an average decline of the water table by one to two meters in a month's time. A 50%-decrease of the yield of the wells tapping the shallow aquifer has also been observed (GoAP 2003).

Long-term Trends: When Agriculture Development Causes Groundwater Degradation

As observed in the entire Krishna Basin, farmers in the lower basin have increasingly tapped the

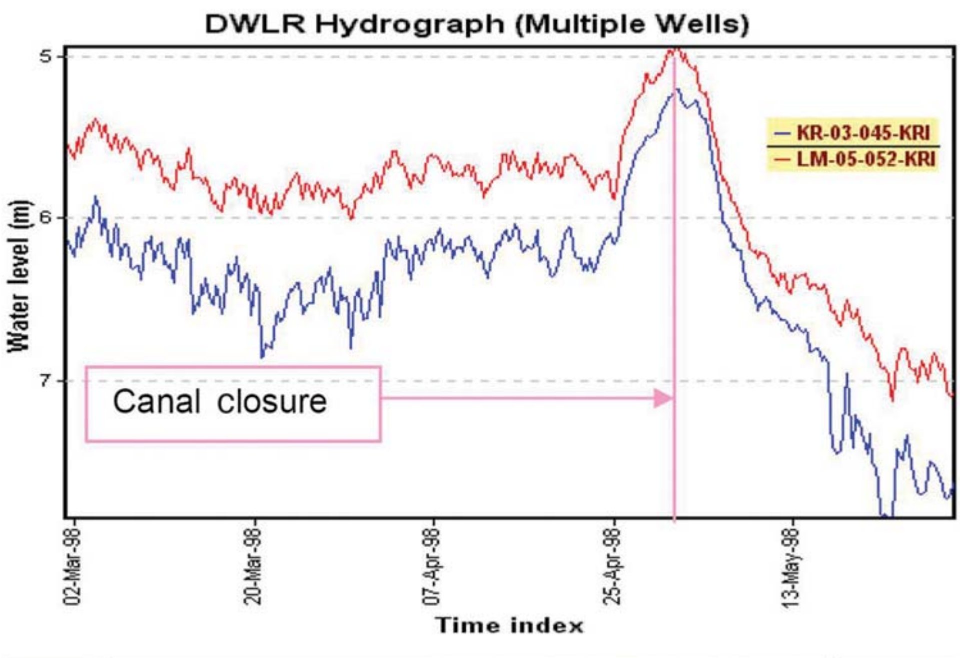


FIGURE 4. Decline of the water table in relation to canal closure. *Source:* GoAP (2003).

local aquifers for both agriculture and aquaculture.[6] This long-term increase in groundwater abstraction has caused a lasting decline of the water table by one to two meters over the last decade and a progressive salinization of the aquifers (GoAP 2003; Saxena et al. 2002; cf. figures 5 and 6). These trends go beyond the seasonal variations in salinity and groundwater levels that characterize coastal and deltaic regions. The decline in the water table has been more pronounced in the upper delta and close to the Krishna River where the good-quality groundwater is extensively used for paddy and sugarcane production.

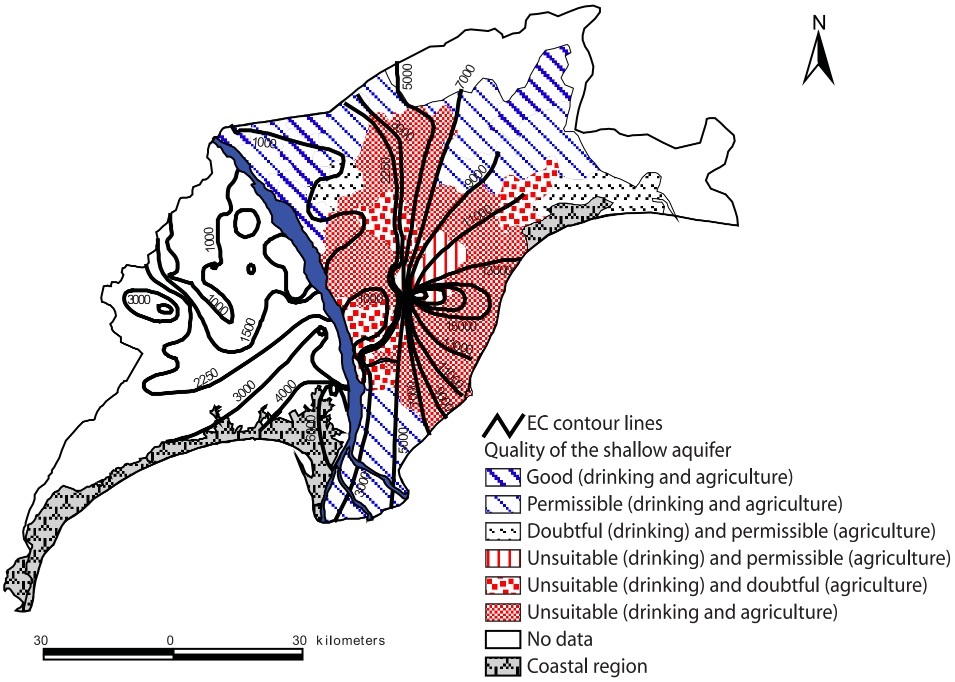


FIGURE 5. Groundwater quality in the Lower Krishna Basin. *Source:* after GoAP (2003).

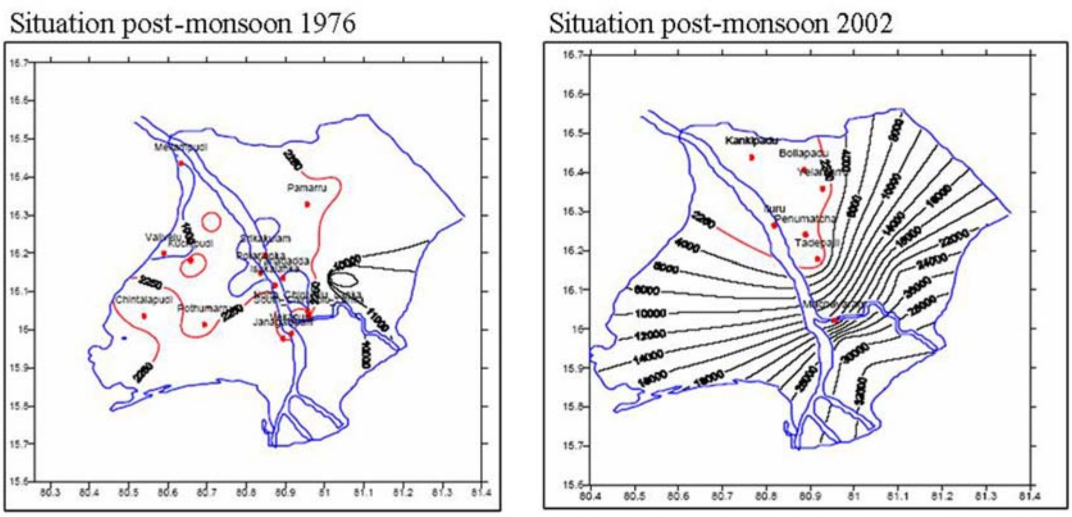


Figure 6. Evolution of the salinity of the second aquifer (30 to 60 meters) in the Krishna Delta. *Source:* GoAP (2007c).

[6]In 2001, the Minor Irrigation Census and district statistical handbooks indicated that 19,000 wells were used in the Lower Krishna Basin (this is more than twice the amount in 1987).

The salinization of the Lower Krishna Basin aquifers is due to two different processes. First, in the inland region where groundwater use is intensive, the shallow freshwater aquifer has been dramatically depleted and fossil saline water, trapped during the deltaic formation in deeper aquifers, has reached the upper horizons (GoAP 2003). Second, in the coastal zone and in the tail-end region of the Krishna Delta irrigation project, the decline in the water table led to seawater intrusion likely to leave a permanent imprint on groundwater quality. GoAP (2007c) describes a landward intrusion of the saltwater/freshwater interface of the second aquifer (30 to 60 meters deep) by 10 to 20 kilometers inland over the last two decades (Figure 6).

Finally, highly loaded return flows from agriculture and aquaculture have also been identified as a main cause of pollution of surface water and groundwater in the delta. Agrochemical residues accumulate in the aquifers and nitrate pollution can be observed in some pockets of the delta (GoAP 2001b). These are major concerns in a region where most of the population, notably in the coastal area, depend highly on fresh groundwater lenses tapped by hand pumps for domestic purposes and by electric motors for agricultural activities (GoAP 2003).

Short-term Changes: Impacts of Low Irrigation Canal Flows

The long-term trend of groundwater salinization has been further sharpened during the recent spell of drought as lower flows in irrigation canals (Table 2) and in the Krishna River itself (Figure 2) caused lower seepages, lower recharge of the upper aquifer and further landward saline water intrusion.

In 2004, total surface water available in the Krishna Delta canals amounted to 45% of the long-term average observed between 1975 and 2000 (Table 2). Soil and water salinity in a delta are natural phenomena and local agricultural practices have long been adapted to these conditions (Gowing et al. 2006). However, lower and delayed canal flows[7] compelled farmers to change their land use and cropping techniques (GoAP 2003). They left some areas fallow, continued tapping groundwater to irrigate the remaining cropped areas while return flows concomitantly decreased. In spite of such adaptive strategies, paddy yields have been strongly affected by water scarcity and hence livelihoods. Figure 7 shows that in *Kharif* 2003, yields 50 to 70% below average were recorded in the tail-end regions of the Krishna Delta irrigation project and in the coastal area, respectively. Farmers in other regions of the Lower

TABLE 2. Evolution of canal flows in the Krishna Delta project.

Period of time	1975-2000	2001	2002	2003	2004*
Average rainfall (mm) in the Krishna Basin	844	776	702	661	819
Canal discharge (BCM/yr)	6.15	6.96	5.46	3.88	2.81

* Despite average rainfall, canal discharges in 2004 have been low as most runoff had been committed upstream both to fill-up emptied reservoirs after a three-year drought and to supply large irrigation projects. *Source:* Superintending Engineer Krishna Delta project (Vijayawada) and CRU (2007).

[7]In 2003, for example, the east and west main canals of the Krishna Delta opened on July 17 and August 1, respectively. Until 2002, they usually opened during the second fortnight of June (Venot et al. 2007).

Krishna Basin have been less affected by decreasing yields: the delay in canal water supply was shorter and the scope for fresh groundwater use higher (Figure 5).

where brackish groundwater cannot be used for domestic purposes (GoAP 2001b).

There is a clear need for measures of drought mitigation and regulation of on-farm practices to lessen the environmental consequences of a dry period. Maintaining a minimal flow in the irrigation canals of the Krishna Delta could be a first step. It is needed to sustain the local agriculture but it could also indirectly contribute in the preservation of the Lower Krishna Basin environment. It would recharge the local aquifers through seepages. Interestingly, as early as 1976, the first Krishna Water Disputes Tribunal mentioned the role of irrigation canal flows to limit salinization in the Lower Krishna Basin and designed its allocation accordingly (GoI-KWDT, 1973, 1976). This allocation could be a good basis for further refinement of the Krishna Delta allotment given the backdrop of increased cropping intensity and groundwater abstraction.

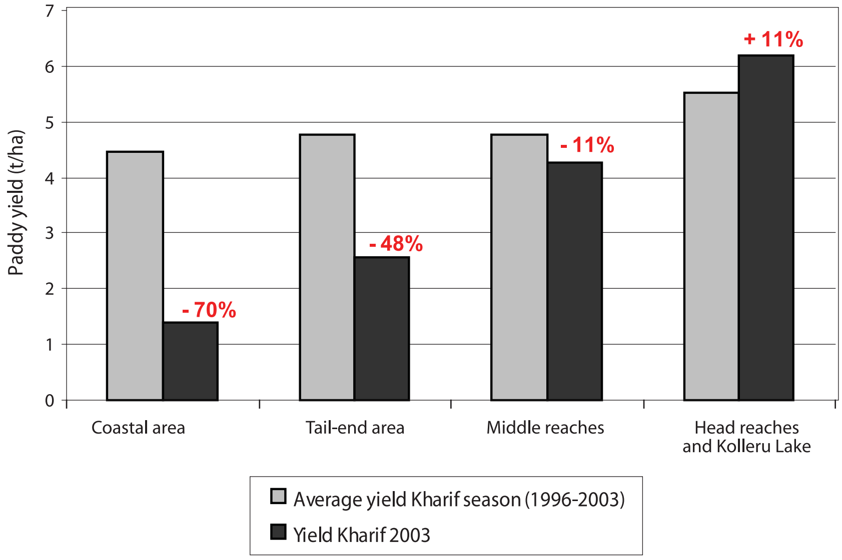


Figure 7. Impacts of water scarcity on paddy yields in the Eastern Lower Krishna Basin *Source:* Adapted from *mandal* wise statistics

For many farmers, delayed water supplies meant a shift from a long duration paddy to a short duration cultivar and higher input costs rarely offset by better prices or yields. Delayed sowing of the second crop (generally black gram, raised on residual moisture) also led to yield losses up to 50% (APWAM 2005). Many freshwater ponds located in the south and east of the Lower Krishna Basin and historically supplied through the Krishna Delta irrigation canals have also not been supplied all yearlong. This has negatively affected fish production in the region, and low water availability further jeopardizes the sustainability of aquaculture (GoAP 1998, 2002; Box 2). Finally, lower flows in the canals have led to domestic water shortage in the coastal zone

Box 2. Is there enough water to supply a booming aquaculture?

In 2003/2004; the Fisheries Department evaluated that 30,500 ha were under brackish shrimp farming in the Lower Krishna Basin (two thirds of which were double cropped). Freshwater shrimp farming was taken up, twice a year, on 2,000 hectares. Fish ponds covered 41,000 hectares. Evaporation in open water bodies of the Lower Krishna Basin has been evaluated at 1,150 mm/year: ponds in the region deplete about 845 Mm^3/yr (of which 494 Mm^3/yr is freshwater, e.g., 13% of all water diverted in the Krishna Delta canals in 2003/2004). Aquaculture freshwater demand is higher than evaporative losses. GoAP (2001c) estimates that total water requirements in freshwater shrimp and fish farming are twice and three times higher than evaporative losses, respectively. In these conditions, the "aquaculture freshwater demand" in the Lower Krishna Basin would reach 1.5 BCM/yr, most of which returning to the aquifers or draining to neighboring fields.

Aquaculture ponds require reliable supplies: the aquaculture boom in the 1980s and 1990s has been sustained thanks to unconstrained water availability. Aquaculture farmers are likely to face lower freshwater supplies (as observed during the 2001-2004 drought). Return flows from agricultural areas that have been long used for brackish aquaculture downstream will also decrease. Water shortages are likely to become recurrent concerns for culture fishermen.

Allocating water to aquaculture is an economically sound policy: water productivity (defined as the ratio of gross output to evapotranspiration) of fish and shrimp ponds is about US$0.38 and 1 per cubic meter, respectively (US$0.18/$m^3$ in paddy fields)[8]. However, this would raise equity issues as (i) large farmers are the main beneficiaries of the aquaculture sector, and (ii) this allocation would deprive agriculturalists in the Krishna Delta irrigation project. The objective of further expanding aquaculture in the state (GoAP 2001c) despite environmental issues does not seem sustainable on the long-term. The observed tendency to decreasing profitability (even if still higher than paddy cultivation) due to lower yields and market fluctuations (MPEDA 2006) also raises some questions.

Uses of Coastal Resources and Environmental Degradation

Reshaping the Coastal Landscape: Disappearing Mangroves

Relationships that communities nurture with their environment progressively evolve with the identification of new economic opportunities. The area of mangroves in the Lower Krishna Basin declined as (i) they have long been used for multiple purposes (see MEA (2005) for different possible uses of mangroves) by a population of about 30,000 people increasingly attracted by a profitable brackish aquaculture sector; (ii) more recently, their land status partially changed when exploitation licenses for agriculture and brackish aquaculture were delivered by the local authorities (before 1997); and (iii) their management, long devolved to the local *Panchayats* has been entrusted to State level agencies such as the departments of forest and fisheries.

Between the mid-1970s and the early 2000s, mangrove covers had decreased by about 2,200 hectares in the Lower Krishna Basin. In 2001, mangroves covered about 8,000 hectares (GoAP

[8]We considered average yields of 775, 4,000 and 5,000 kg/ha/crop for shrimp, fish and paddy farming, respectively. There are two cropping seasons for shrimp and paddy cultivation. Farm gate prices have been taken at US$7.5; 1.1 and 0.15 per kilogram of shrimp, fish and paddy, respectively. Ponds and paddy fields evaporate 1,150 and 850 mm/year, respectively.

2001c; FAO 2002). Mangrove areas are now protected and the creation of Coastal Regulation Zones, in 1991, is a first step towards integrated coastal management to regulate the exploitation of this fragile ecosystem (Box 1). However, implementation difficulties remain and mangroves are still under the threat of several interconnected processes: (i) overgrazing due to the reduction of the grazing areas and the increase in the population for which livestock is a primary source of revenue (Grandcolas 2006), (ii) overexploitation of timber products (GoAP 2001c), (iii) conversion to shrimp ponds: FAO (2002) evaluated that 3 to 5% of all shrimp ponds in Andhra Pradesh had been dug in mangrove areas, this being about 1,200 hectares in the Lower Krishna Basin (e.g., more than half the mangrove areas that disappeared during the last three decades), (iv) alteration of tidal flows in and out of the mangroves and biota changes due to lower river flows and the formation of a sand bar in the mouth of the delta (Selvam 2003), and (v) increasing pollution due to agriculture and aquaculture return flows (notably from shrimp hatcheries; Ronnback et al. 2003), etc.

Land Degradation and Salinization

Salinity problems are common features of coastal areas and deltaic environments (Gowing et al. 2006). But aquifer salinization and aquaculture development observed during the last decade and a relative lack of drainage are likely to have sharpened the problem of soil salinization. APWAM (2005) evaluated that strongly saline and alkaline soils covered 25,000 hectares in the Lower Krishna Basin while an extra 45,000 hectares had lower but significant salinity levels. Decreasing irrigation canal flows and low rainfall further sharpen this problem: adequate supplies are indeed increasingly needed for flushing and leaching affected soils in the tail-end areas of the canals during dry periods but they are not available. This leads to further land salinization which requires high investments to be controlled (notably through re-configuration of the soil surface; and sub-surface drainage [APWAM 2005]).

Another source of land degradation is brackish aquaculture. First, soils are generally not adequately flushed and when done it is often with brackish groundwater: they become highly saline and improper to other kinds of reclamation (GoAP 2001b). Second, contamination of bacteria, fungi and viruses can lead to large-scale land degradation as observed during 1994-1996 even if shrimp farming remains mainly extensive (Ronnback et al. 2003). Third, saline percolation from ponds contaminates neighboring fields which become unsuitable for paddy cultivation. Delineating different areas for aquaculture and agriculture could be a solution to some of these problems (Gowing et al. 2006).

Direct Impacts of Lower River Flows: Salinization and Erosion

There is evidence of increasing salinity in the river channels. The saline/freshwater interface in river water is progressively moving inland due to lower freshwater flows in the river (Saxena et al. 2003). This affects the small plains located along the river. Finally, Smakhtin et al. (2007b) show that there is a tendency towards land losses to the sea as less water with lower sediment load reaches the ocean. Maintaining a given discharge to the ocean could allow limiting these losses that have remained restricted to small areas in the mouth of the Krishna River until now.

The Kolleru Lake: Acute Conflicts in an Endangered Wetland

The Kolleru Lake is a freshwater lake, located 35 km inland, fed by several rivulets, and is connected to the Krishna and Godavari irrigation systems through several canals and drains supplying water for drinking and agricultural purposes to the population. The wetland has undergone dramatic changes during the last three decades. Until the end of the 1970s, the local population used to fish in the open freshwater body and take up seasonal cultivation of paddy around the islands dotted over the wetland area and on the edges of the lake (Rama Rao et al. 2006). Agriculture was permitted in the lake bed area through occasional annual permits delivered by the government (GoAP 2007b). From 1977 onwards, land entitlements in the lake bed were granted to local farmers and fishermen. Culture fisheries quickly replaced the traditional capture fisheries. As generally observed in the Lower Krishna Basin, the role of local entrepreneurs has been tremendous in explaining the success of aquaculture development: they heavily invested in the sector by renting fishponds from local farmers and fishermen who were holding land entitlements (Rama Rao et al. [2006]; in the late 1990s almost all ponds in the Kolleru region were leased out [GoAP 2001c]).

Aware of the dramatic environmental changes affecting the Kolleru Lake, the Government of Andhra Pradesh took strong symbolic decisions to protect the region. In 1999, the wetland was declared a wildlife sanctuary under India's Wildlife (Protection) Act of 1972. This decision was strongly opposed by fishermen and farmers lobbies who filed several Writ Petitions in the High Court of Andhra Pradesh, on the grounds that this decision was threatening their livelihoods. However, in November 2002, the Kolleru Lake was designated a wetland of international importance under the International Ramsar Convention (GoAP 2007c). The protected area covers 308 km^2 lying below the five feet above sea level contour line. Despite the official recognition of the remarkable character of the Kolleru Lake ecosystem, environmental degradation and lake encroachment continued in the early 2000s. In 2006, aquaculture ponds covered between 10,300 (Nageswara Rao et al. 2004) and 12,200 hectares (Anonymous 2007) of the protected area while agriculture covered an additional 5,000 to 6,000 hectares: about half the protected Ramsar area was without encumbrance. Venot et al. (2007) illustrate the major changes of the landscape of the Kolleru Lake through a comparison of two satellite images taken in 1977 and 2000, respectively. In the early 2000s, the only remains of the once large wetland were some small areas of open water and some submerged vegetation.

Other environmental problems include: (i) increasing pollution due to aquaculture and agriculture return flows, effluents from neighboring agro-industries, and largely untreated sewage from nearby urban centres; (ii) lack of drainage and subsequent eutrophication of the lake, increasingly covered with waterweed; (iii) decrease in, and contamination of, the fish population of the lake; and (iv) increased siltation leading to floods (GoAP 2001c; Anjaneyulu and Durga Prasad 2003; GoAP 2007b). This also raises human health issues as water related diseases develop (GoAP 2001c).

Protecting the lake ecosystem has long been presented as a government priority (GoAP 2001c). However, removing illegal fishponds from the protected area has always been a sensitive question, opposed by a powerful lobby. While the Andhra Pradesh High Court of Justice passed an order to remove illegal fish tanks in 2001 (The Hindu 2001), the measure has been delayed several times. Finally in February 2006, the Supreme Court of India passed an order to remove illegal encroachments in the lake (The Hindu 2006a). Once again, this decision was strongly opposed by fishermen and farmers lobbies. Landless farmers benefiting from land entitlements mobilized too as they would be denied lease income if ponds were to be demolished. Eventually, land entitlements in the Ramsar area have been cancelled and it is estimated that about 19,500 hectares of aquaculture ponds were demolished by June 15, 2006 (GoAP 2007b). This required the involvement of police forces (The Hindu 2006b; Figure 8). Field visits in May 2007 confirm that most of the ponds located in the protected area have been demolished: open water areas have extended and more birds have been observed lately.

FIGURE 8. Andhra Pradesh police forces mobilized for blasting fish ponds in the Kolleru Lake. *Source:* The Hindu (2006b).

Some ponds still remain and the transfer, of the Conservator of Forests in charge of the protection of the Ramsar site highlights the sensitivity of a measure affecting both large investors and landless farmers pushed into poverty. Other measures to rejuvenate the lake are being taken and the organization *Wetlands International* is entrusted with the writing of a *multidisciplinary integrated management plan* for the restoration of the Kolleru Lake.

Discussion and Conclusions

Since India gained independence, the Krishna Basin has witnessed a dramatic development of irrigation with little regard to the limits of availability and sustainability. This led to a rising overcommitment of water resources, and signs of basin closure are apparent during dry periods. During the last decade (1990-2000), the Krishna Basin consumed 90.5% of its net inflow. This becomes 92 to 96% if environmental water requirements are set aside to preserve ecosystems from further degradation. These percentages highlight that water resources are fully committed under average conditions: water users and managers have only little room for maneuver to cope with a drought and limit its socio-ecological and economic ill effects. Eventually, short-term adaptations and informal adjustments to accommodate scarcity may lead to a degradation of the resource base (Scott et al. 2001) and thus affect the environment. This has been tragically illustrated during the dry years of 2001 to 2004 when the discharge to the ocean was almost zero; the rate of water commitment hiked to 99.6% without accounting for any *environmental flows*; and water shortage affected livelihoods, notably in the Krishna Delta irrigation project and in the coastal region. This is a likely harbinger of the future.

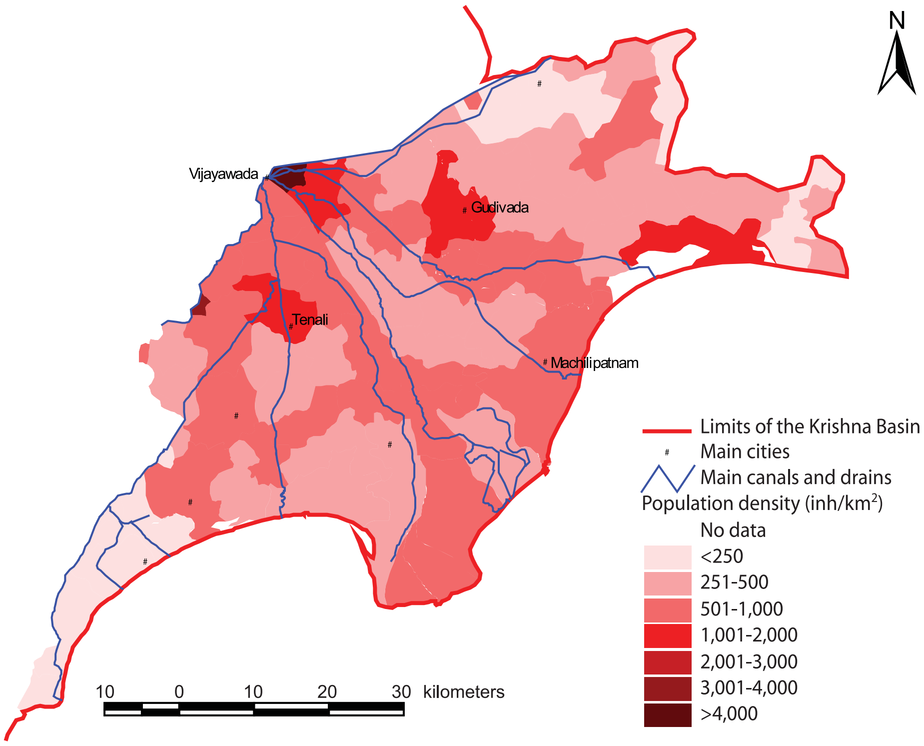
This report highlighted that river basin closure comes with downstream environmental degradation that manifests itself by increasing soil and groundwater salinity, aquifers and surface water pollution, shrinkage of mangrove covers and coastal wetland desiccation. Environmental degradation in the Lower Krishna Basin has three main drivers: (i) the long-term tendency to decreasing water availability linked to ever-increasing agricultural development and upstream water regulation; (ii) the rural dynamics of the Lower Krishna Basin where short-term financial gains conflict with the long-term objective of sustainable development; and (iii) finally, the fragmented institutional landscape of natural resources management in Andhra Pradesh. As basin closure intensifies the interconnectedness between water users and their environment (Molle et al. 2007), further water resources development will tantamount to sectoral and regional reappropriation of water. There is a need to find compromises to meet competing and increasing water demands. Supply augmentation projects to increase water availability in the Lower Krishna Basin through the transfer of water from the Godavari Basin are a partial response and hold short-term promises. But, the transfer of 2.25 BCM/yr through the Polavaram project (NWDA 2007) to support agriculture, counterbalance the observed decline in the discharge of the Krishna River and limit environmental degradation does not seem to bring long-term solutions to the pending problems the region is facing. This volume is similar to the recent deficit observed between surface water availability in the Krishna Delta canals and their allotment according to the Bachawat tribunal award, and short of the 6.5 to 14.2 BCM/year recommended by Smakhtin and Anputhas (2006) to protect local ecosystems from further degradation. Moreover, it is not specified if this volume is to be discharged to the ocean or diverted to the irrigation canals and the social, economic and ecological impacts of the project have been largely overlooked (Biksham et al. 2007).

Mitigating the detrimental impacts of rural development on downstream ecosystems will only been achieved through an integrated management of land, water and ecosystems at the basin scale (Falkenmark et al. 2007). The current Krishna Water Disputes Tribunal is expected to reach a decision concerning the apportionment of the Krishna water among the three states of Andhra Pradesh, Karnataka and Maharashtra. In this context, this paper calls for a formal allocation of water to be set aside for the purpose of environmental preservation. At first, an environmental provision could be defined on the basis of a two-tier allocation. First, a given discharge in the irrigation canals of the Krishna Delta to meet the agriculture and domestic demand of the local population and also the environmental requirements of groundwater recharge and salt leaching from the soil. The award of the first Krishna Water Disputes Tribunal could be used as a first basis for further refinement given the backdrop of increased cropping intensity and groundwater abstraction. Second, a fixed annual discharge to the ocean, maintained by the Irrigation Department (as recommended in GoAP 2001c), to limit seawater intrusion in the river branches and preserve the functioning of coastal ecosystems. This environmental provision would have to be calculated on the basis of a pre-defined compromise between the condition of the ecosystems and the level of human uses for competing demands. Average allocations still leave problems of management during dry years. Once this basin-wide planning or reconnaissance-level assessment is generally recognized as necessary and benefit from a strong commitment of the different users and managers; environmental provisions could evolve into a more complex set of environmental flow rules defined in a polycentric governance setup allowing participation of all for an integrated management of natural resources (for more precision on the rules, concepts and methodologies that could be considered, see Tharme [2003]). This is notably observed in the United States of America, South Africa and Australia.

Other measures facilitating an integration of the management of natural resources, notably water, from the local to the basin level are needed. Strengthening the institutional context is crucial as governance systems that are required to support the institutional and managerial arrangements for the allocation of water resources in the framework of environmental flows seem difficult to achieve (Falkenmark et al. 2007; Molle et al. 2007). Promoting integrated coastal management with, for example, the delineation and effective implementation of zones with different development and environmental objectives (cf. the CRZ regulation); regulating on-farm practices; creating additional non-farm livelihood options; implementing drought mitigation measures; facilitating the coordination between departments; maintaining database on wetlands, mangroves, soil and water salinization; and promoting the role of the resource users in the decision-making process are some of the most commonly advocated measures (Brugere 2006; Gowing et al. 2006). These measures will be effective only if managers and decision makers are strongly committed towards environmental preservation objectives (GoAP 2001c; Falkenmark et al. 2007). To what extent this will happen depends on the political ecology of the resources that are considered. The socioeconomic context in which resource extraction takes place, the political and social weight of the different stakeholders involved in the use and control of natural resources and their ability to mobilize to press their demands is central to foresee the environmental impacts of a development path chosen among several options. There is a need to convince decision makers that providing environmental flows can produce long-term environmental, social and economic benefits. This will be achieved only if the links between altered flow regimes and losses in bio-systems and dependent livelihoods are highlighted and more accurately quantified (Bunn and Arthington 2002). The recent work of Smakhtin et al. (2007a) to assess the ecological status of Indian river basins is a step forward in the data scarce environment of India and need to be revisited on the basis of scientific, experts, managers and local knowledge. Finally, there is a risk that preserving ecosystems will be used as a justification for building new dams or new water transfers heightening the process of overbuilding (see, for example, Blanchon (2006) on the South African case). The multiplication of small-scale water infrastructures for irrigation and groundwater recharge in the dry areas of South India already finds an environmental justification as these structures are said to create local wetlands (GoAP 2001c). However, they have a dramatic impact on surface water availability and downstream ecosystems that are overlooked (Venot et al. 2007). As water allocation is likely to be driven by economic motives, high attention is to be given to equity and environmental preservation principles when designing water allocation mechanisms for the satisfaction of competing demands.

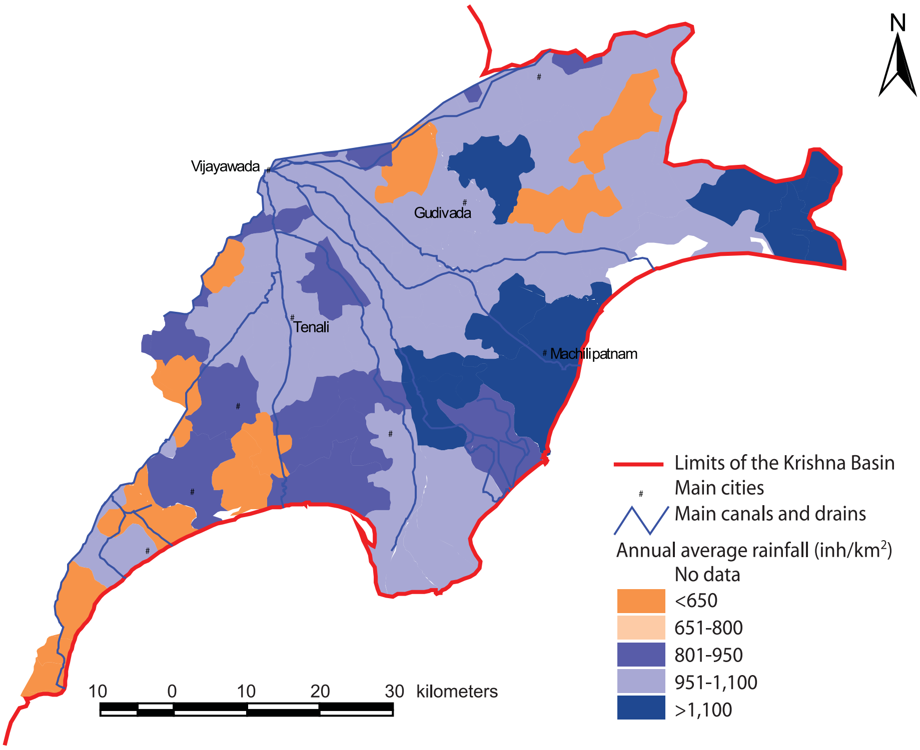
Appendix 1

Population density map of the Lower Krishna Basin.



Source: Maps are based on GoI (2001) data.

Appendix 2
Average rainfall map of the Lower Krishna Basin.



Source: GoAP (2004a, 2004b).

Appendix 3

Details of water accounting for the Krishna Basin for special periods between 1955 and 2000.

Unit of measure (BCM/yr)	1955/65	1970/80	1980/90	1990/2000
Direct rainfall	219,953	204,171	198,287	204,523
Surface water imports	0	0	0	0
Groundwater depletion	0	0	0	-252
Net inflow	219,953	204,171	198,287	204,775
Beneficial ET - irrigation	17,133	31,430	35,384	44,353
Beneficial ET - rainfed agriculture	65,982	66,305	68,217	69,402
Process (industry)	70	97	131	244
Process (drinking)	477	650	870	1,183
Process (livestock)	495	551	605	682
Low beneficial ET - natural vegetation	52,721	50,501	45,924	47,847
Non-beneficial ET - bare lands and reservoirs	15,849	19,094	21,479	17,550
Total depleted	152,727	168,628	172,610	181,261
Runoff	67,258	32,147	22,005	19,570
Export to other basins	-32	3,396	3,672	3,944
Total outflow	219,953	204,171	198,287	204,775
Recharge to aquifer	29,303	26,546	25,926	26,950
Baseflow from groundwater	22,018	14,182	13,259	9,493
Depleted fraction percentage of net inflow	69	84	89	90
Beneficial depleted fraction percentage of depleted water	55	59	61	64
Beneficial depleted fraction percentage of net inflow	38	49	53	57
Low beneficial depletion percentage of depleted water	35	30	27	26
Low beneficial depletion percentage of net inflow	24	25	23	23
Irrigation depletion percentage of depleted water	11	19	20	24
Irrigation depletion percentage of beneficial depletion	20	32	34	38
Irrigation depletion percentage of net inflow	8	15	18	22

References

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

Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Rome: FAO.

Anjaneyulu, Y.; Durga Prasad, M. K. (Eds). 2003. Kolleru-Environmental status (Past and Present. Sultan Bazaar: Hyderabad: B. S. Publications.

Anonymous. 2005. Concept paper on revival of shrimp aquaculture in Krishna District. Project document for a follow up of the FAO assisted project TCP/IND/2902(A) on Health Management of shrimp aquaculture in Andhra Pradesh.

Anonymous. 2007. Kolleru Lake profile. Available online at http://westgodavari.org/DRDA%20WEBSITE/KOLLERU%20WEBSITE/KOLLERUPROFILE.htm (accessed April 25, 2007).

APWAM (Andhra Pradesh Water Management Project). 2005. Proceedings of the First Annual Workshop held at RARS, Tirupati. March 1-12, 2005. Hyderabad: Acharya N.G. Ranga Agricultural University.

Barker, R.; Molle, F. 2005. *Evolution of irrigation in South and Southeast Asia*. Comprehensive Assessment Research Report 5. Colombo, Sri Lanka: International Water Management Institute.

Bhatta, M.; Bhat, M. 1998. Impacts of aquaculture on the management of estuaries in India. *Environmental Conservation* 25(2): 109-121.

Biggs, T. W. Simplified models of evapo-transpiration from rainfed crops in Southern India. Agricultural and Forest Meteorology. In Review.

Biggs, T. W.; Gaur, A.; Scott, C. A.; Thenkabail, P.; Rao, P. G.; Krishna, G. M.; Acharya, S.; Turral, H. 2007. *Closing of the Krishna Basin: Irrigation, Streamflow Depletion and Macroscale Hydrology*. IWMI Research Report 111. Colombo, Sri Lanka: International Water Management Institute.

Biksham, G.; Goud, V.; Ramakrishna, S. 2007. Perspectives on Polavaram: A Major Irrigation Project on Godavari. India: Independent Pub Group.

Blanchon, D. 2006. La politique de l'eau en Afrique du Sud: le difficile équilibre entre développement durable et valorisation optimale de la ressource. Revue Développement Durable et Territoires. Available online at http://developpementdurable.revues.org/document1735.html (accessed July 10, 2007)

Bouwer, L. M.; Biggs, T. W.; Aarts, J. C. J. H. 2007. Estimates of spatial variation in evaporation using satellite-derived surface temperature and a water balance model. *Hydrological Processes* 22(5): 670-682.

Brugere, C. 2006. Can Integrated Coastal Management Solve Agriculture-Fisheries-Aquaculture Conflicts at the Land-Water Interface? A Perspective from New Institutional Economics. *In* Tuong, T. P.; Hoanh, C. T.; Gowing, J. W.; Hardy, B. (Eds), *Environment and livelihoods in tropical coastal zones: managing agriculture-fishery-aquaculture conflicts.* Oxford: CABI.

Bunn, S. E.; Arthington, A. H. 2002. Basic principles and ecological consequences of altered flow regime for aquatic biodiversity. *Environmental Management* 30(4): 492–507.

CRU (Climatic Research Unit, University of East Anglia). 2007. Monthly precipitation data. Information available online at http://www.cru.uea.ac.uk/~mikeh/datasets/global/ (accessed May 11, 2007).

CWC (Central Water Commission). 2002. *Water and related Statistics.* Water Planning and Projects Wing. New Delhi, India: Central Water Commission.

DRDA (District Rural Development Agency). 1999. Groundwater resources and prospects-Krishna District. Hyderabad: GoAP.

Dyson, M.; Bergkamp, G.; Scanlon, J. (eds) 2003. Flow. The Essentials of Environmental Flows. Gland, Switzerland and Cambridge, UK: IUCN.

DWAF (Department of Water Affairs and Forestry. 1999. Resource directed measures for protection of water resources. Volume 3: River ecosystems. Version 1.0. Institute of Water Quality Studies, Department of Water Affairs and Forestry. Pretoria, South Africa: DWAF.

Falkenmark, M.; Finlayson, M. C; Gordon, L. J 2007. Agriculture, Water, and Ecosystems: Avoiding the costs of going too far. In Molden, D. (Ed), *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London: Earthscan and Colombo, Sri Lanka: International Water Management Institute.

FAO (Food and Agriculture Organization of the United Nations). 2002. FAO Aqua-book 2002. Available online at http://aquaculture.tn.nic.in/pdf/FAO%20Aqua41-79.pdf (accessed April 25, 2007).

Fisheries Department. Statistical data on the extent of shrimp farming in Andhra Pradesh. Hyderabad: GoAP (unpublished documentation).

GoAP (Government of Andhra Pradesh). 1998. Handbook of Statistics - Krishna district. Machilipatnam, India: Chief Planning Officer, Krishna District.

GoAP. 2001a. Andhra Pradesh Vision 2020. Vol. I: Sectoral overview of water and water management. Hyderabad: GoAP.

GoAP. 2001b. Andhra Pradesh water vision 2020. Vol. II: Methods, Position paper and districts reports. Hyderabad: GoAP.

GoAP. 2001c. Andhra Pradesh Water Vision. Position paper No.3 - Strategic Overview of the aquatic ecology. Hyderabad: GoAP.

GoAP. 2002. Handbook of Statistics - Krishna district. Machilipatnam, India: Chief Planning Officer, Krishna District.

GoAP. 2003. Freshwater-saline water interrelationhip in the multi-aquifer system of the Krishna delta. R&D project Abridged version. Hyderabad: GoAP.

GoAP. 2004a. Handbook of Statistics - Guntur district. Guntur, India: Chief Planning Officer, Guntur District.

GoAP 2004b. Handbook of Statistics - Krishna district. Machilipatnam, India: Chief Planning Officer, Krishna District.

GoAP. 2006. Statistical Abstract of Andhra Pradesh 1955-56 to 2004-2005. Hyderabad, Andhra Pradesh: Ministry of Agriculture.

GoAP. 2007a. Fisheries Department Presentation on the Commissionerate of Fisheries. Available online at http://www.aponline.gov.in/apportal/departments/departments.asp?dep=02&org=20 (accessed April 24, 2007).

GoAP. 2007b. Notes on agriculture and related activities. Available online at www.aponline.gov.in/Apportal/SocioSurvery0607/Chapters/5.%20Agriculture.doc (accessed April 24, 2007).

GoAP. 2007c. Presentation on the nature of coastal alluvial aquifer in the Krishna delta. Presentation held by the Department of Groundwater at International Water Management Institute Workshop on Groundwater Externalities. 5 September, 2006, Hyderabad.

GoI (Government of India). 1991. Notification under section 31 and section 32(v) of the Environment (Protection) Act, 1986 and Rule 5(3)(d) of the Environment (Protection) Rules, 1986 declaring coastal stretches as Coastal Regulation Zone (CRZ) and regulating activities in the CRZ. New Delhi: Ministry of Environment and Forests, GoI.

GoI. 2001. All India Census. New Delhi: GoI.

GoI-KWDT (Government of India-Krishna Water Disputes Tribunal). 1973, 1976. The report and the further report of the Krishna Water Disputes Tribunal with the decision. New Delhi.

GoK (Government of Karnataka). 2006. Statistical Abstract of Karnataka 2000-2001. Bangalore: Directorate of Economics and Statistics, GoK.

GoM (Government of Maharashtra). 2005. Statistical Abstract of Maharashtra State 1997-98 and 1998-99. Mumbai: Directorate of Economic and Statistics, GoM.

Gowing, J. W.; Tuong, T. P.; Hoanh, C. T. 2006. Land and water Management in Coastal Zones: Dealing with Agriculture-Aquaculture-Fishery Conflicts. *In* Tuong, T. P.; Hoanh, C. T.; Gowing, J. W.; Hardy, B. (Eds), *Environment and livelihoods in tropical coastal zones: managing agriculture-fishery-aquaculture conflicts.* Oxford: CABI.

Grandcolas, D. 2006. Pêcheurs, Etat et Mondialisation, Stratégies des populations locales et gestion des ressources naturelles : le cas du delta de la Godavari, inde du Sud. PhD thesis, University of Paris X-Nanterre (In French).

Immerzeel, W. W.; Gaur, A.; Droogers, P. 2007. *Remote sensing and hydrological modeling of the Upper Bhima Catchment*. Research Paper 3. The Netherlands: Future Water.

Landy, F. 2006. Un milliard à nourrir- Grain, Territoire et Politiques en Inde. Paris, France : Belin (In French).

MEA (Millennium Ecosystem Assessment). 2005. Ecosystems and Human Well-Being: Synthesis. Washington DC: Island press.

Molden, D. 1997. Accounting for water use and productivity. SWIM Paper 1. Colombo, Sri Lanka: International Water Management Institute.

Molle, F.; Wester, P.; Hirsh, P. 2007. River Basin Development and Management. In Molden, D. (Ed), *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture.* London: Earthscan and Colombo, Sri Lanka: International Water Management Institute.

Mollinga, P. P.; Doraiswamy, R.; Engbersen, K. 2001. The implementation of participatory irrigation management in Andhra Pradesh, India. *International Journal of Water* 1(3/4).

Mollinga, P. P. 2003. On the waterfront-water distribution, technology and agrarian change in a south Indian canal irrigation system. New Delhi, India: Orient Longman.

MoWR (Ministry of Water Resources). 2002. National Water Policy. New Delhi, India: Ministry of Water Resources, GoI.

MPEDA (Marine Products Export Development Authority). 2006. Statistical data on the extent of shrimp and fish farming in Andhra Pradesh. New Delhi: MPEDA. Unpublished documentation.

Naganathan, M.; Sivagnanam, K. J.; Rajendran, C. 1995. Blue revolution in a green belt. *Economic and Political Weekly* 30(12):607-608.

Nageswara Rao, K.; Murali Krishna, G.; Hema Malini, B. 2004. Kolleru lake is vanishing-a revelation through digital processing of IRS-1D LISS-III sensor data. *Current Science* 86(9).

NWDA (National Water Development Agency). 2007. Information available at http://nwda.gov.in/indexmain.asp?linkid=84&langid=1 (accessed May 5, 2007).

NCIWRDP (National Commission for Integrated Water Resource Development Plan) 1999. Integrated water resource development: a plan for action. Delhi: Ministry of Water Resources, GoI.

Peden, D.; Tadesse, G.; Misra, A. K. 2007. Water and Livestock for Human Development. In Molden, D. (Ed.), *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture.* London: Earthscan and Colombo, Sri Lanka: International Water Management Institute.

Rama Rao, J.; Jairath, J.; Umesh, P. 2006. Pollution through Aquaculture: Kolleru Wildlife Sanctuary. *Economic and Political Weekly* 41(7): 585-587.

Ramsar Convention Secretariat. 2006. Coastal management: Wetland issues in Integrated Coastal Zone Management. Ramsar handbooks for the wise use of wetlands, 3rd edition, Vol. 10. Gland, Switzerland: Ramsar Convention Secretariat.

Rao, G. N. 1985. Transition from subsistence to commercialised agriculture: a study of Krishna District of Andhra 1850-1900. *Economic and Political Weekly* XX(25-26): A60-A69.

Ronnback, P.; Troell, M.; Zetterstrom, T.; Babau, D. E. 2003. Mangrove dependence and socio-economic concerns in shrimp hatcheries of Andhra Pradesh, India. *Environmental Conservation* 30(4): 344-352.

Saxena, V. K.; Radhakrishna, I.; Krishna, K. V. S. S.; Nagini, V. 2002. Nitrate pollution in groundwater, Krishna delta, India. *In* Thangarajan, M.; Rai, S. N.; Singh, V. S. (Eds) *Proceedings of the International Conference IGC-2002*. Oxford: Dindigul & New Delhi: IBH.

Saxena, V. K.; Singh, V. S.; Mondal, N. C.; Jain, S. C. 2003. Use of chemical parameters to delineation fresh groundwater resources in Potharlanka Island, India. *Environmental Geoology* 44: 516–521.

Scott, C. A.; Silva-Ochoa, P.; Florencio-Cruz, V.; Wester, P. 2001. Competition for water in the Lerma-Champala basin - Economic and Policy implications of water transfers from agricultural to urban uses. *In* Hansen, A.; Van Afferden, M. (Eds), *The Lerma-Champala watershed: Evaluation and Management*. New York: Kluwer Academic/Plenum publisher.

Selvam, V. 2003. Environmental classification of mangrove wetlands of India. *Current Science* 84: 757-765.

Smakhtin, V.; Revenga, C.; Doll, P. 2004. *Taking into account environmental water requirements in global-scale water resources assessments*. Comprehensive Assessment Research Report 2. Colombo, Sri Lanka: Comprehensive Assessment Secretariat.

Smakhtin, V.; Anputhas, M. 2006. *An assessment of environmental flow requirements of Indian river basins*. IWMI Research Report 107. Colombo, Sri Lanka: International Water Management Institute.

Smakhtin, V.; Arunachalam, N.; Behera, S.; Chatterjee, A.; Das, S.; Gautam, P.; Joshi, G. D.; Sivaramakrishana, K. G.; Unni, K. S. 2007a. *Developing procedures for assessment of ecological status of Indian river basins in the context of environmental water requirements*. IWMI Research report 114. Colombo, Sri Lanka: International Water Management Institute. 40p.

Smakhtin, V.; Gamage, N.; Bharati, L. 2007b. *Hydrological and environmental issues of interbasin water transfers in India: A case of Krishna River Basin*. IWMI Research Report 120. Colombo, Sri Lanka: International Water Management Institute.

Supreme Court of India. 1996. Judgment on Coastal Shrimp Aquaculture: S. Jaganath Vs. Union of India. Judgment of Kuldip Singh and Sagir Ahmed on December 11, 1996.

Suri, K. C. 2006. Political Economy of Agrarian Distress. *Economic and Political Weekly* 41(16): 1523-1529.

Tharme R. E. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications* 19: 397-441.

The Hindu. 2001. Kolleru Lake, a sanctuary: court. Article published in the July 31, 2001 edition.

The Hindu. 2006a. Panel wants Kolleru Lake cleared of encroachments. Article published in the February 15, 2006 edition.

The Hindu. 2006b. Operation Kolleru resumes amid heavy security. Article published in the April 21, 2006 edition.

Upadhya, C. B. 1988. The Farmer-Capitalists of Coastal Andhra Pradesh. *Economic and Political Weekly* 23(27& 28): 1376-82, 1433-42.

Van Rooijen, D. J.; Turral, H.; Biggs, T. W. Urban and industrial water use in the Krishna Basin. *Irrigation and Drainage*. Forthcoming.

Venot, J. P.; Turral, H.; Samad, M.; Molle, F. 2007. *Shifting Waterscapes: Explaining Basin Closure in the Lower Krishna Basin, South India*. IWMI Research Report 121. Colombo, Sri Lanka: International Water Management Institute.

Venot, J. P.; Sharma, B. R.; Rao, K. V. G. K. Krishna Basin development: Interventions to Limit Downstream Environmental Degradation. *Journal of Environment and Development*. Forthcoming.

Wallach, B. 1985. British irrigation works in India's Krishna Basin. *Journal of Historical Geography* 112: 155-173.

WWAP (World Water Assessment Program). 2003. Water for People - Water for Life, The United Nations World Water Development Report. Paris: UNESCO Publishing/Berghahn Books.

Research Reports

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Postal Address
P O Box 2075
Colombo
Sri Lanka

Location
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Telephone
+94-11-2880000

Fax
+94-11-2786854

E-mail
iwmi@cgiar.org

Website
http://www.iwmi.org

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