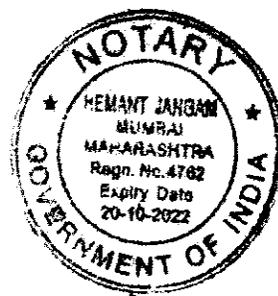


BEFORE THE NATIONAL GREEN TRIBUNAL

SOUTHERN ZONE BENCH AT CHENNAI

APPEAL NO. 15 OF 2020(SZ)



**IN THE MATTER OF:**

The Conservation Action Trust & Anr.

...Appellants

Versus

Union of India & Ors.

...Respondents

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6.

**ANNEXURE-A38:**

Copy of the relevant pages of the study published online in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/ird.439 titled 'Urban and Industrial Water Use in the Krishna Basin, India (2008)'

19-21

THROUGH

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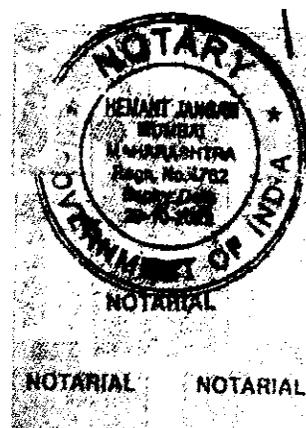
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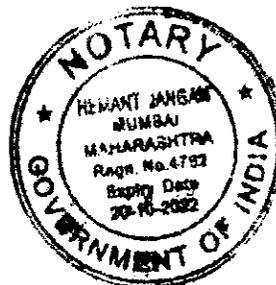


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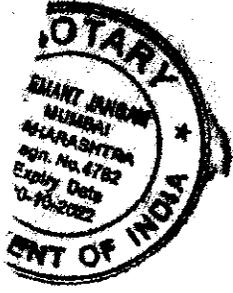
...Appellants

...Respondents

**ADDITIONAL AFFIDAVIT ON BEHALF OF APPELLANTS**

I, Debi Goenka, S/o Shri Nandlal Goenka, aged about 64 years, R/o B-502, Glengate, Hiranandani Gardens, Powai, Mumbai-400076, Executive Trustee and Authorized Representative of Appellant No. 1, do hereby solemnly affirm and state as under:

1. That I am presently the Executive Trustee and Authorized Representative of Appellant No. 1 Organization and am well conversant with the facts and circumstances in the abovementioned Appeal and as such, I am competent to swear this additional affidavit.
2. That according to Respondent No.4 "the minimum flow from upstream reservoir would ensure sustenance of down stream ecology of the River Krishna", which is wrong and denied. It is submitted by the Appellants that it is important to understand that the flow in the River Krishna varies dramatically through the year, and sufficient flow must be maintained year round to sustain aquatic ecosystems. Various studies show that in most years, the Krishna river water has not been joining the sea due to the complete extraction of water, mainly for agriculture. The International Water Management Institute (IWMI), a CGIAR institution, has clearly documented In its 121st Report that the Lower Krishna Basin has become a closed basin, i.e., there is no outflow to the sea in number of years. The Report, J.P. Venot et al, Shifting Waterscapes: Explaining basin closure in the Lower Krishna Basin, South India (IWMI, Colombo, 2007), says:



"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 base flows and the discharge to the ocean was almost zero..."

...

"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."

Copy of the relevant page of the 121st Report of International Water Management Institute (IWMI) is already annexed with the Rejoinder as Annexure-A31.

3. That in the research report No. 111 published by the International Water Management Institute (IWMI) titled '**Closing of the Krishna Basin: Irrigation, Streamflow Depletion and Macroscale Hydrology (2007)**',

[http://www.iwmi.cgiar.org/Publications/IWMI Research Reports/PDF/PUB111/RR111.pdf](http://www.iwmi.cgiar.org/Publications/IWMI%20Research%20Reports/PDF/PUB111/RR111.pdf) it has been reported at page 31 that:-

*"The basin is 80 percent closed due to irrigation development, and streamflow to the ocean from 1995-2005 was only 20 percent of pre-irrigation discharge (1900-1960). Total reservoir capacity is approximately equal to annual average runoff, and total demand exceeds sanctioned allocations by nearly double. Basin closure is happening in tributaries as well as at the outlet to the ocean, resulting in interstate conflicts over scarce water resources."*

Copy of the relevant pages research report No. 111 published by the International Water Management Institute (IWMI) titled '**Closing of the Krishna Basin: Irrigation, Streamflow Depletion and Macroscale Hydrology (2007)**' are annexed herewith as **ANNEXURE-A34**



4. That in the study published in ResearchGate titled '**Krishna River Basin, India - Case Study (2014)**'

<https://www.researchgate.net/publication/321758841> Krishna River Basin

India - Case Study it is has been highlighted at page 4 that:-

*"Due to a long history of unsustainable water allocations, the river has regularly stopped flowing to the sea. The basin is now considered to be almost "closed". In a closed basin, annual rainfall matches the extractions from the basin, and no water flow reaches the ocean. According to Biggs (2007), the cause of the reduction in flow was almost completely from irrigation expansion. Discharge at the Vijayawada gauging station downstream from the diversion to the Krishna Delta had reduced from 56 km<sup>3</sup> in the 1960's, to 13km<sup>3</sup>, despite no significant reduction in rainfall (Biggs, 2007). By the late 1990s the total reservoir capacity in the Krishna River basin approximated the annual run-off volume."*

Copy of the relevant pages of the study published in ResearchGate titled '**Krishna River Basin, India - Case Study (2014)**' are annexed herewith as **ANNEXURE-A35**

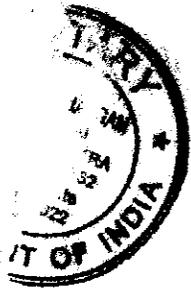
5. That in another study titled, '**Land, Water and Ecosystems Management in the Krishna River Basin (2007)**,

<https://edepot.wur.nl/29999> it is mentioned that at page 35 as follows:-

*"In the Krishna River Basin, the area under irrigation increased about five fold, due to impressive works such as Nagarjunasagar, proudly advertised as 'the world's biggest masonry dam'. Wallach comments: 'The dams and canals are splendid monuments, but as water-distribution systems they are rarely able to deliver water to more than half of their commands, or service areas. The problem is partly an engineering one, with leaky, undersized canals; more fundamentally however, the problem is political, for the government is unable to prevent farmers at the upper or head ends of the distribution system from taking so much water that the tail end runs dry...'"*

At page 37 it is mentioned that:

*"As in the colonial era, the GOAP and the Irrigation Department are eager to expand irrigable area by building new canals, even though irrigation water in the existing systems hardly ever reaches the tail ends."*



4

At pages 57-58 it is further mentioned that:

*"....Rapid urbanization in the basin also makes demands on water supplies, resulting in adverse social, economic and environmental impacts. As the three states share the shrinking water resource, basin closure has resulted in interstate water conflicts."*

*"...Nowadays, the increased fresh water need for mainly drinking water, irrigation and industrial purposes in the upstream areas of the river basin has led to an increased total storage capacity of 34.5 km<sup>3</sup>. This has resulted in a significant decrease of fresh water flow into the Krishna estuary and an increase of saline water intrusion. Bouwer et al (2006) have studied the combination of this increased water use in the upper Krishna river basin in view of the expected climate change. They concluded that the impact of salt water intrusion will increase even more in the next decennia."*

Copy of the relevant pages of the study titled, '**Land, Water and Ecosystems Management in the Krishna River Basin (2007)**', are annexed herewith as **ANNEXURE-A36**.

6. That in another study published in ResearchGate titled, '**Water Scarcity Effects on Equitable Water Distribution and Land Use in a Major Irrigation Project—Case Study in India (2008)**', at page 27 it is observed as follows:-

*"The Nagarjuna Sagar reservoir is one of the largest and most important Irrigation projects in the lower Krishna basin in India. Continued rapid surface and groundwater development throughout the basin resulted in historically low inflows to the Nagarjuna Sagar reservoir during a recent severe drought period 2002–2004. This hydrological drought presented challenges to allocate water equitably among different irrigation zones and water use sectors. Due to continuing upstream development, the frequency of such events will increase in the future Biggs et al. 2007." (Pg 27)*

At pages 33-34 it is further observed in the section on Summary and Conclusions that:-

*"Continued rapid development of surface and groundwater throughout the Krishna Basin in southern India resulted in historically low inflows during a recent drought event, particularly in lower Krishna reservoirs..."*



Copy of the relevant pages of the study published in ResearchGate titled, '**Water Scarcity Effects on Equitable Water Distribution and Land Use in a Major Irrigation Project—Case Study in India (2008)**' are annexed herewith as **ANNEXURE-A37**.

7. That in yet another study titled '**Urban and Industrial Water Use in the Krishna Basin, India (2008)**', it has been highlighted at page 2 that:-

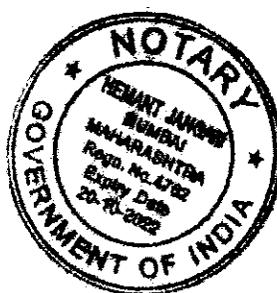
*"The Krishna Basin, in southern India (258 514 km<sup>2</sup>), has experienced increasing water scarcity due to rapid irrigation development (see map, Figure 1). The basin faces strong inter-seasonal and spatial variations in rainfall (Biggs et al., 2007), which can cause acute scarcity and competition during dry years."*

Further at Page 11 it is mentioned that:-

*"As the basin is considered nearly closed, average annual basin water availability can be determined as annual average runoff, which is around 58.3 BCM (Biggs et al., 2007)."*

Copy of the relevant pages of the study published online in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/ird.439 titled '**Urban and Industrial Water Use in the Krishna Basin, India (2008)**', are annexed herewith as **ANNEXURE-A38**.

8. That the contents of this additional affidavit are true and correct and nothing material has been concealed therefrom and no part of it is false.



*Debi Goenka*

**DEPONENT**

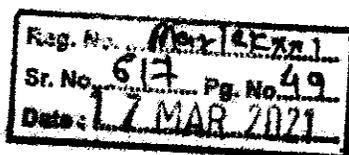
**VERIFICATION:**

I, Debi Goenka, S/o Shri Nandlal Goenka, aged about 64 years, R/o B-502, Glengate, Hiranandani Gardens, Powai, Mumbai-400076 do hereby verify that the contents of the Paras 1 to 8 of the above Affidavit are true to my personal knowledge and that I have not suppressed any material fact.

*Debi Goenka*

**DEPONENT**

**BEFORE ME**  
HEMANT JANGAM  
NOTARY, GOVT. OF INDIA  
MUMBAI, MAHARASHTRA  
17 MAR 2021



RESEARCH  
REPORT

111

## Closing of the Krishna Basin: Irrigation, Streamflow Depletion and Macroscale Hydrology

Trent W. Biggs, Anju Gaur, Christopher A. Scott, Prasad Thenkabail, Parthasaradhi Gangadhara Rao, Murali Krishna Gumma, Sreedhar Acharya and Hugh Turrall



**IWMI**  
International  
Water Management  
Institute

FUTURE<sup>™</sup>  
HARVEST  
IWMI is a Future Harvest Center  
supported by the CGIAR

low risk of contamination, and the background soil stock of lead is high compared with the flux from the wastewater (Gerwe et al. 2004).

Some saline groundwaters occur in the Krishna Delta, likely due to seawater intrusion, which may have been exacerbated by groundwater pumping (Saxena et al. 2004; Saxena et al. 2003). Whether the reduction in flow into the delta at Vijayawada (Figure 17) will increase saltwater intrusion is not known. Pollution of shallow hard-rock aquifers has been documented in areas with sugarcane processing (Pawar et al. 1998), though the extent and impact on water productivity is not known.

### **Mangrove Ecosystems and Fisheries**

Mangroves occur in the Krishna Delta (Selvam 2003). Decreased flow at Vijayawada caused by

irrigation has likely changed the mix of freshwater and saltwater in the mangroves, potentially altering community structure. Very limited information is available on the mangrove systems and their response to the hydrologic changes in the delta.

Extensive aquaculture occurs in the Krishna Delta and its wetlands. The shrimp industry depends on mangrove ecosystem services for hatcheries, and there are signs that current mangrove area is insufficient to maintain the shrimp industry in the neighboring Godavari Delta (Rönnbäck et al. 2003). Kolleru Lake, a RAMSAR wetland, has been significantly impacted by aquaculture and agriculture (Malneedy 2003). Andhra Pradesh also has important fisheries in many of its tanks (Sugunan 1995). The rapidly changing hydrologic regime in the basin will result in a changing mosaic of aquatic environments.

### **Conclusion**

The broad conclusions and water related issues in the Krishna Basin include:

- 1) The basin is 80 percent closed due to irrigation development, and streamflow to the ocean from 1995-2005 was only 20 percent of pre-irrigation discharge (1900-1960). Total reservoir capacity is approximately equal to annual average runoff, and total demand exceeds sanctioned allocations by nearly double. Basin closure is happening in tributaries as well as at the outlet to the ocean, resulting in interstate conflicts over scarce water resources.
  - 2) Groundwater irrigated area exceeds surface water irrigated area in the basin. Rapid groundwater irrigation development will likely decrease surface water availability by drawing down regional aquifers and enhancing infiltration along streams. Current water allocation policy considers groundwater and surface water separately, which could lead to over-estimation of surface flow volumes and over-allocations of surface water.
  - 3) A majority of the basin area has very low runoff coefficients (<10%). The Western Ghats dominate runoff in the basin due to high precipitation and high runoff coefficients, so upstream development on tributaries draining the Ghats has particular significance for downstream areas.
- Future research in the hydrology of the basin could emphasize:
- 1) Monthly estimates of precipitation and evaporation, and how these affect runoff, soil moisture, and crop production in rainfed and irrigated areas. This would require a more elaborate model of evaporation, soil moisture, and runoff in the basin.

# Annexure A-35

ResearchGate

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## Krishna River Basin, India - Case Study

Working Paper · October 2014

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## Introduction

India is a country with particularly strong historical religious and cultural linkages with water. From the glaciers of the Himalaya, to the holy river Ganges and bordered by life giving oceans, Indians place water as an essential element in all parts of their lives. Although irrigation practices in the basin began millennia ago, it is only in the last 50 years that water extractions have caused a systematic reduction in water availability.

The Krishna River Basin is one of the largest in the world, covering over 250,000 square kilometres; almost 8 percent of India’s land mass. The Basin supports a population of more than 18 million persons. More than 90% of the total water available from the Krishna River is used for irrigation.



Figure 1: Rice Paddy Irrigation in the Krishna River Basin (Dancey 2008)

Due to a long history of unsustainable water allocations, the river has regularly stopped flowing to the sea. The basin is now considered to be almost “closed”. In a closed basin, annual rainfall matches the extractions from the basin, and no water flow reaches the ocean. According to Biggs (2007), the cause of the reduction in flow was almost completely from irrigation expansion. Discharge at the Vijayawada gauging station downstream from the diversion to the Krishna Delta had reduced from 56 km<sup>3</sup> in the 1960’s, to 13km<sup>3</sup>, despite no significant reduction in rainfall(Biggs, 2007). By the late 1990s the total reservoir capacity in the Krishna River basin approximated the annual run-off volume.

The River Basin is shared between three Indian States, Karnataka, Maharashtra and Andhra Pradesh. Traditionally more than 90% of water extractions from the river were for agriculture, but with the rise of urbanization in India, residential and commercial demand for water is forecast to rise to 20% by 2035 (Veettil et al., 2011).

The current allocations by sector are listed in Table 1.

Table 1: Water Allocation in Krishna Basin, adapted from Grafton and Hussey, 2011

Water for Irrigation	62 km <sup>3</sup> per annum	92.8%
Water for Industrial	1.6 km <sup>3</sup> per annum	2.3%
Water for Domestic	3.2 km <sup>3</sup> per annum	4.7%
<b>Total</b>	<b>66.8 km<sup>3</sup> per annum</b>	<b>100%</b>

In 1969 the Indian Government implemented a Water Plan developed by the Krishna Water Disputes Tribunal (KWDT), which has had some redistributive effect but has been largely ineffective in managing the sustainable use of the River Basin and groundwater.



Land, Water and Ecosystems Management  
in the Krishna River Basin

Phase 1 (May 2006-March 2007) – DRAFT VERSION

Various authors



11

Willcocks' remarks about the benefits of irrigation with silt laden water are confirmed by Dutch agronomist Den Berger, who investigated the effects of silt loads of irrigation water on soil fertility and rice yields (Berger 1915). The defense of his PhD thesis was held at the Technical University in Delft, because the Agricultural school in Wageningen did not have academic status at that time (1915).

The thesis includes 12 propositions, two of which correspond with the recommendations made by Howard in the same year (refer to preceding section/chapter):

- Proposition VIII: 'The irrigation works in the Dutch Indies should be managed by agriculturists'.
- Proposition IX: 'It is recommended to collect irrigation fees from cultivators, local as well as European'.

### 3.3.5 Developments after Independence

*'Still, after the record of British failure, the government of India might have looked back at the British irrigation works and wondered at the obstinacy that led the Raj to continue building projects that were crippled the day they were finished.'*

*'India after 1947 did not ask these questions. The result was that no effort was made to prevent India from falling into a variation of the colonial trap. Instead of foreign masters who could not seek advice from villagers, India now developed a bureaucracy that was even more hierarchical and dismissive of the people it served.'* (Wallach 1985)

The projects in the Krishna Basin that Wallach refers to are what he calls 'high-tension' projects, which are designed to spread the available water thinly over a large area, in order to reach as many farmers as possible. This only works when each farmer takes less water than would be needed to cover the water requirements on all of his land. For Wallach, 'the real culprit' responsible for the 'crippled' projects referred to in the above quote, was 'the weakness of the political institutions needed to ration water.'

Wallach quotes N.V. Gadgil, who was the first minister of public works under Prime Minister Nehru and told the parliament in 1950: "the main problem of this country as everybody knows is that of food" and "unless irrigation facilities are increased a hundred fold the problem of food is not going to be solved."

In the Krishna River Basin, the area under irrigation increased about five fold, due to impressive works such as Nagarjunasagar, proudly advertised as 'the world's biggest masonry dam'. Wallach comments: "The dams and canals are splendid monuments, but as water-distribution systems they are rarely able to deliver water to more than half of their commands, or service areas. The problem is partly an engineering one, with leaky, undersized canals; more fundamentally however, the problem is political, for the government is unable to prevent farmers at the upper or head ends of the distribution system from taking so much water that the tail end runs dry. Despite a decade of efforts of stopping this kind of irrigation abuse, there is much pessimism.'

completed areas. In spite of these huge expectations, the agricultural component of the project was only a mere 2.5 % of the total budget.

### 3.3.8 Discussion

As in the colonial era, the GOAP and the Irrigation Department are eager to expand irrigable area by building new canals, even though irrigation water in the existing systems hardly ever reaches the tail ends. The World Bank assists in making it plausible that the additional irrigation water needed for the expanded area can be obtained by simultaneously improving the productivity\* and the efficiency\* of water use in the existing command. If effective, this combination results in more value being produced with less water.

This miracle can be accomplished if the large majority of farmers shift from rice to a less water demanding, higher value crop. The key to performing the miracle is more reliable irrigation services; this is perhaps best appreciated by comparing water management for rice cultivation with that of other crops. Rice is one of the few crops that tolerate – and sometimes even benefit from - submergence of their root system for a prolonged period of time. By simply maintaining a shallow layer of water in the field, farmers obtain optimal moisture conditions.

More importantly, this water acts as an on-farm storage reservoir, which offers farmers a degree of protection against unreliable irrigation services or inadequate rainfall. Farmers will only be prepared to give up this insurance when they are fully convinced that they can rely on the irrigation agency to provide them with timely and sufficient irrigation water. In addition, farmers need to adopt other water management and cultivation practices:

- **Need for more irrigation ditches.** When practicing rice cultivation with inundated fields, irrigation water can flow from field to field. If fields are not submerged, small irrigation channels are required to transport water. These channels take up land, which could otherwise be cultivated. This is even more problematic when farmers have to give up land for the construction of canals that distribute water to other farmers;
- **More effort in land preparation.** Even distribution of irrigation water in a non-submerged field requires greater accuracy in land leveling and/or preparation of irrigation furrows or borders;
- **More difficult to assess adequacy of on-farm irrigation.** In order to achieve optimal moisture conditions, farmers must apply a volume of irrigation water that is just adequate to replenish the rootzone of the plant to its maximum moisture holding capacity. Any excess volume applied will leach out nutrients, under-irrigation may lead to moisture deficiency before the next irrigation application is due.

Farmers in AP generally do not have the means of knowing the moisture holding capacity of their field and the actual moisture content prior to

## 7 Scope for improvement of ecological benefits by allocative water management

*Ingrid Gevers<sup>20</sup> en Willem Brandenburg<sup>21</sup>*

### 7.1 General outline

For a triple P (people, planet, profit) development of the Krishna estuary, the coastal resources have to be restored, conserved and sustainably managed. This may conflict with the interests of local communities and other stakeholder groups depending on the coastal resources for their livelihoods. The establishment of integrated multi-trophic aquaculture systems, producing both plants and animals for local income generation may lead to stakeholder support.

### 7.2 Backgrounds of degradation of deltaic ecosystems

The coastal waters of Southeast Asian countries have some of the world's richest ecosystems characterized by extensive coral reefs and dense mangrove forests. These waters are further enriched with nutrients from land which enables them to support a wide diversity of marine life.

The coastal zones are subjected to increasing population and economic pressure pressures manifested by a variety of coastal activities such as fishing, coastal aquaculture, waste disposal, salt-making, tin mining, oil drilling, rural construction and industrialisation. Indiscriminate logging and mining in upland areas impact on low land activities such as fisheries, aquaculture and coastal tourism. Unregulated fishing effort and the use of destructive fishing methods have caused serious destruction of fish habitats and fish stocks. Indiscriminate cutting of mangroves for aquaculture development, fuel wood and timber has brought temporary gains in fish production, fuel wood and timber supply but losses in nursery areas and commercially important fish and shrimp, coastal erosion and land accretion.

The Krishna River basin in India, covering an area of 258,000 km has a combined population of 67 million and is spread across three large southern states—Karnataka, Maharashtra, Andhra Pradesh. It is one of India's largest domestic waterways and supplies water to important food production areas including the "Rice Bowl" region in the Krishna delta. Water extractions for agriculture, industry, and domestic uses from the Krishna continue to grow to support one of the fastest developing regions of peninsular India. Rapid urbanization in the basin also makes demands on water supplies, resulting in

<sup>20</sup> Wageningen International, P.O. Box 88, 6700 AB Wageningen, The Netherlands

<sup>21</sup> Plant Research International, P.O. Box 16, 6700 AA Wageningen, The Netherlands

adverse social, economic and environmental impacts. As the three states share the shrinking water resource, basin closure has resulted in interstate water conflicts.

The Krishna river is a critical component of the delta estuary coastal sea ecosystem. The river run-offs provide energy for a number of vital processes in downstream estuaries, delta and coastal areas, upon which healthy fisheries are dependent. These processes include transport of nutrients, organic matter and nutrient-rich silt, oxygen enrichment, entrainment of nutrients in bottom sediments, dilution and flushing of pollutants, etc.

The storage capacity in the Krishna basin has increased significantly since the independence of India. At that time 3.2 km<sup>3</sup> of the total water flow was stored upstream. Nowadays, the increased fresh water need for mainly drinking water, irrigation and industrial purposes in the upstream areas of the river basin has led to an increased total storage capacity of 34.5 km<sup>3</sup>. This has resulted in a significant decrease of fresh water flow into the Krishna estuary and an increase of saline water intrusion. Bouwer et al (2006) have studied the combination of this increased water use in the upper Krishna river basin in view of the expected climate change. They concluded that the impact of salt water intrusion will increase even more in the next decennia.

Conversion of mangroves in the delta of the Krishna river basin for agriculture, aquaculture and salt pans resulted in saline soils and loss of biodiversity due to environmental degradation. The reduced fresh water has had a large impact on the growth and regeneration of mangroves. Land-use activities such as agriculture cause pollution and drainage of the tidal areas is problematic.

### 7.3 Coastal ecosystems, saline aquaculture and agriculture

Coastal mangrove ecosystems are the natural nursing grounds for hundreds of aquatic species including economically important fish and shellfish. Mangroves play an important role in controlling erosion caused by flooding and storm surges. They also act as a barrier during cyclones and protect the coastline. Thus it is necessary to conserve the existing mangroves and plant mangroves where ever they can be grown near the shrimp ponds. Mangroves will also help in reducing the impact of sea level rise anticipated due to global warming and will protect the adjacent farming lands.

Salinisation in the coastal zones of Andhra Pradesh is increasing. Such is very obvious in the lower Krishna River Basin. Andhra Pradesh is the main state producing aquaculture shrimp for export purposes. Both larger companies and small scale farmers have invested in this business. For the construction of ponds large parts of the natural coastal zone vegetation has been removed.

# Annexure A-37

See discussions, stats, and author profiles for this publication at: [https://www.researchgate.net/publication/228111111](#)

## Water Scarcity Effects on Equitable Water Distribution and Land Use in a Major Irrigation Project—Case Study in India

**Article** in *Journal of Irrigation and Drainage Engineering* · February 2006  
DOI: 10.1061/(ASCE)1082-0159(2006)32:2(101)

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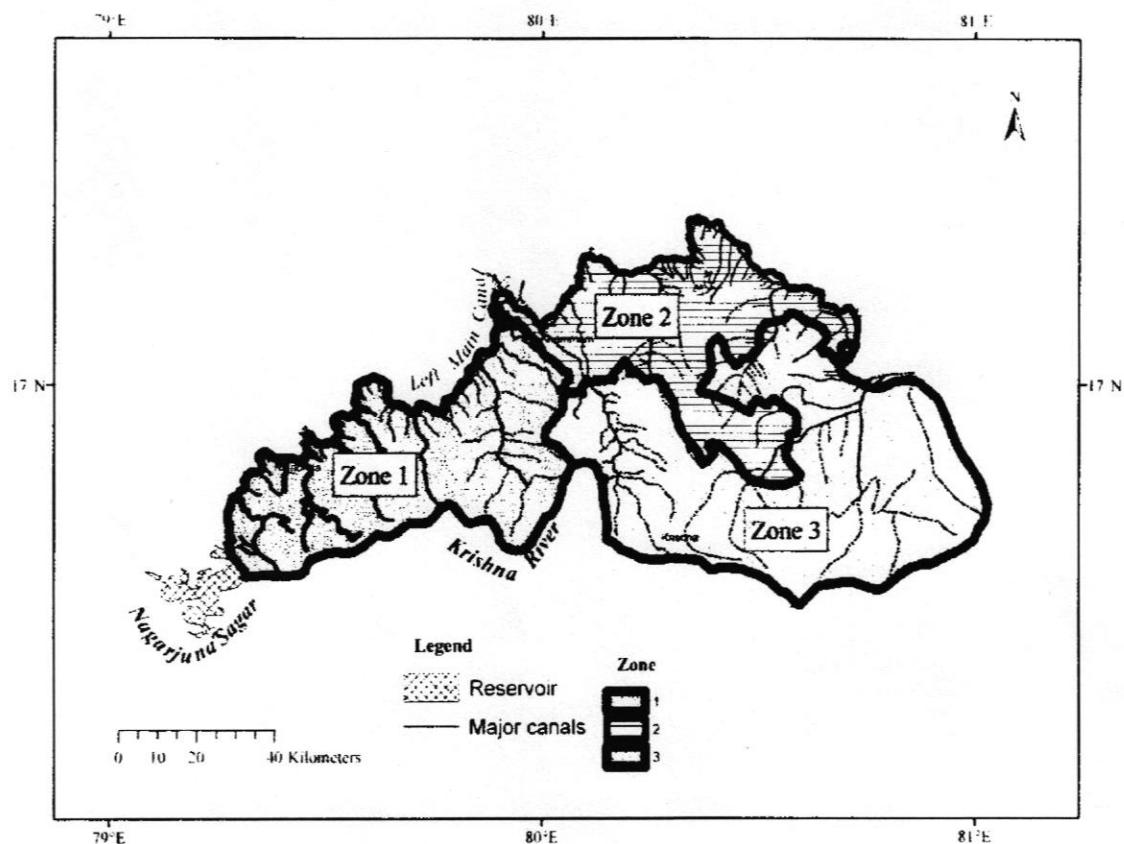


Fig. 1. Nagarjuna Sagar left main canal command area with zones (the zones refer to district boundaries)

the effect of water supply shocks may be measured using several methods. First, canal flows directly measure water supply to the command area (Bhutta and Van der Velde 1992). Census data on agricultural production provide a coarse view of how cropped areas change under irrigation supply fluctuations, and satellite imagery can provide spatially detailed maps of where cropping patterns changed the most for a given variation in water supply (Thiruvengadachari et al. 1997). Satellite imagery has been increasingly used to quantify water use and productivity in irrigation systems (Bastiaanssen and Bos 1999; Thiruvengadachari and Sakthivadivel 1997), but has less frequently been used to identify parts of irrigated command areas that change in response to inter-annual variations in water supply.

The Nagarjuna Sagar reservoir is one of the largest and most important irrigation projects in the lower Krishna basin in India. Continued rapid surface and groundwater development throughout the basin resulted in historically low inflows to the Nagarjuna Sagar reservoir during a recent severe drought period 2002–2004. This hydrological drought presented challenges to allocate water equitably among different irrigation zones and water use sectors. Due to continuing upstream development, the frequency of such events will increase in the future (Biggs et al. 2007). A drastic change was reported in both canal supplies and land use in the irrigation project. This paper presents an integrated approach to assess changes in the spatial equity of canal flow and land use with water supply shocks in the head, middle, and tail reaches of the left main canal command (359,200 ha) of Nagarjuna Sagar during water surplus, normal, and deficit years. We combine flow

data for 3 water years from 107 canals with crop data from the agricultural census and multitemporal satellite imagery, in order to document the effect of changing canal flows on the spatial distribution of water supply and cropping patterns. The spatial distribution of cropping changes was mapped using multitemporal imagery from the moderate resolution imaging spectrometer (MODIS), which can identify areas in single, double, or continuous cropping (Biggs et al. 2006). The integrated approach is used to test the hypothesis that a reduction in canal releases to the main canals in large irrigation systems increases the spatial inequality of water distribution and has the largest effects on the tail and middle portions of the command area.

### Materials and Methods

#### Description of Study Area

The Nagarjuna Sagar (NJS) project (16° 34' 24" N, 79° 18' 47" E) is one of the major multipurpose reservoirs in South India (Fig. 1). It is located in the lower Krishna Basin, which is the fifth largest river basin in India. The gross capacity of the reservoir is 11,557 Mm<sup>3</sup> at a full storage level of +179.832 m above sea level, and live storage capacity is 6,841 Mm<sup>3</sup> with dead storage of 4,716 Mm<sup>3</sup> at 121.92 m. Dam construction was completed in 1974, although canals started serving the command from 1967. The NJS reservoir, in conjunction with the upstream hydropower reservoir, Srisailem (8,720 Mm<sup>3</sup>), provides irrigation to the NJS

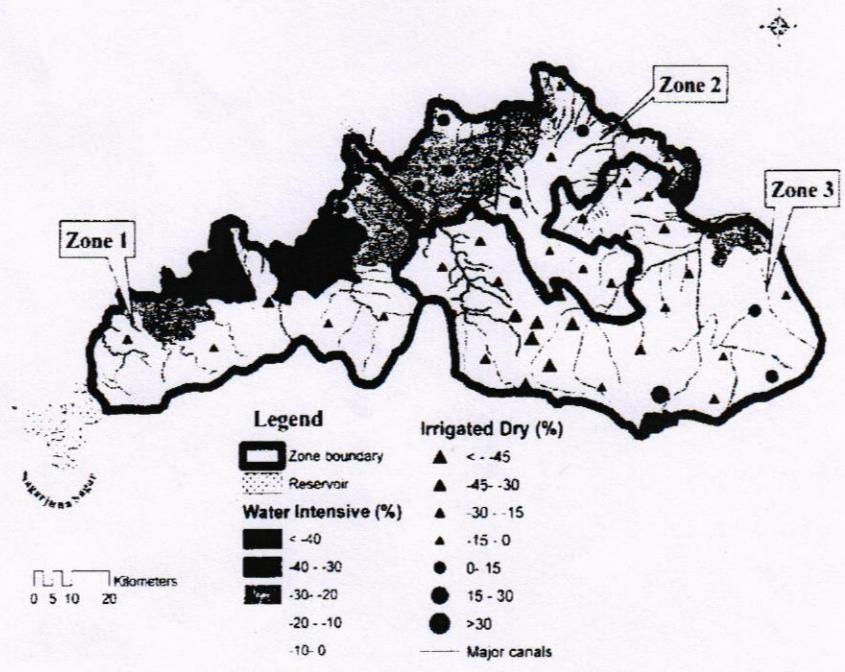


Fig. 5. Change in annual cropping intensity (census) from 2000–2001 to 2002–2003 in three zones of Nagarjuna Sagar left canal command

observed by MODIS away from canals. The cropping intensity of WI crops in Zone 3 declined from 18 to 12% during the deficit year. There were no major changes in total canal supply during water surplus and deficit years and the cropping changes were more likely due to lower rainfall (Table 3) than changes in canal water supply from NSLC. Another dominant crop, mangoes, did not show any change, as it is primarily dependent on rainfall and groundwater and does not respond to annual water supply fluctuations unless drought is severe enough to kill the trees. In contrast to census data, MODIS data showed an increase in the WI cropped area. This reverse trend can be attributed to mixing of orchard, paddy, and other vegetation within one 500 m<sup>2</sup> MODIS pixel.

Both MODIS and census statistics indicated a large impact of irrigation supplies on land use: primarily a decline in the WI cropped area in Zones 1 and 2. MODIS identified areas with changes and delays in the WI cropped area, which is critical in

assessing the impact of canal operations. The WI cropped area was more concentrated at the head of each major canal or closer to tanks and balance reservoirs in Zones 2 and 3. Zone 1 had relatively large WI cropped areas (60% of total cropped area in a surplus year) therefore shift from WI cropping to fallow was the largest in Zone 1 due to variability in canal supplies and low precipitation. Large canals operated more frequently and supplied more water than small major canals taking off from the main canal. All the performance parameters documented in our study indicated that the major impact fell on Zone 1 and less on Zone 2. Zone 3 is less dependent on canal flows and is more governed by rainfall patterns and secondary or local sources.

**Summary and Conclusions**

Continued rapid development of surface and groundwater throughout the Krishna Basin in southern India resulted in histori-

Table 5. Cropping Intensities (CI) by Zone from Municipality-Level Agricultural Statistics

Water year	Crop	Zone 1	Zone 2	Zone 3	Left main canal command
Geographical area (ha)		276,990	219,815	421,012	917,817
Reference year <sup>a</sup>	Water intensive	30	28	18	24
	Irrigated dry/rainfed	19	28	41	31
	Total	49	56	60	56
Deficit year (2002–2003)	Water intensive	11	11	12	11
	Irrigated dry/rainfed	15	27	28	24
	Total	26	38	40	35
Change (deficit-reference)	Water intensive	-20	-17	-6	-13
	Irrigated dry/rainfed	-3	-1	-14	-8
	Total	-23	-18	-20	-20

<sup>a</sup>2001–2002 for Zone 1 and 2000–2001 for Zones 2 and 3.

**Table 6.** Zone Wise Cropping Intensity Interpreted by MODIS Images

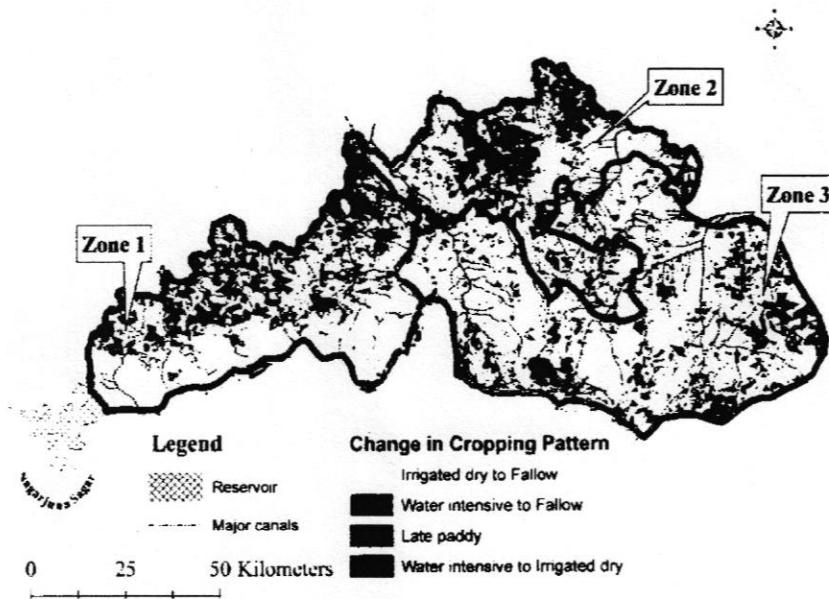
Parameters	Crop type	Zone 1	Zone 2	Zone 3	Main canal command
Geographical area (ha)	—	276,990	219,815	421,012	917,817
Surplus year (2000–2001)	Water intensive	46	48	30	39
	Irrigated dry/rainfed	42	44	68	54
	Total	87	92	98	93
Normal year (2001–2002)	Water intensive	46	56	26	39
	Irrigated dry/rainfed	45	60	64	57
	Total	91	117	90	97
Deficit year (2002–2003)	Water intensive	27	37	33	32
	Irrigated dry/rainfed	34	58	48	46
	Total	61	96	80	78
Change (deficit-reference year) <sup>a</sup>	Water intensive	-19	-11	3	-7
	Irrigated dry/rainfed	-10	14	-20	-8
	Total	-29	4	-17	-15

Note: Numbers indicate percentage of geographical area of each zone in each crop type

<sup>a</sup>Reference year is 2001–2002 for Zone 1 and 2000–2001 for Zones 2 and 3.

cally low inflows during a recent drought event, particularly in lower Krishna reservoirs. The study demonstrates how data on canal flows, census data on cropped areas, and satellite imagery can be used to document spatial variations in water supply and its consequences for land use in a large irrigated command area in the lower Krishna basin. The integrated approach was used to assess changes in the spatial equity of canal flow and land use with water supply shocks in the head, middle, and tail reaches of the left main canal command (359,200 ha) of Nagarjuna Sagar during water surplus (2000–2001), normal (2001–2002), and deficit (2002–2003) years. In normal and surplus years, the water distribution was highly inequitable with very large flows in the head zone (1,722 Mm<sup>3</sup>) and very low flows (198 Mm<sup>3</sup>) in tail reaches. During surplus and normal years, 33–40% (1,990 Mm<sup>3</sup>) of water supplied from the head regulator of the main canal was

lost through the canal distribution network, which reduced to 17% during the deficit year. Contrary to expectation (and hypothesis), the spatial distribution of canal flows among the three major zones of the command area was more equitable during the low-flow year. This was due to decreased flow in the headreach of the canal and less canal distribution losses, which reduced the skewed water use of normal and surplus years. During the water deficit year, a 60% reduction in water availability resulted in 40% of the cropped area being fallowed in the left canal command. MODIS images identified areas impacted by low canal releases and showed a widespread shift from double to single cropping, particularly in the head and middle zones during the deficit year; from normal sowing paddy variety to late sowing paddy variety and to rainfed crops or fallow. The head reach of the command (Zone 1) had larger spatial and temporal variability in canal sup-



**Fig. 6.** Change in cropping pattern interpreted by MODIS images during surplus (2000–2001) and deficit (2002–2003) years

# Annexure A-38

IRRIGATION AND DRAINAGE  
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## URBAN AND INDUSTRIAL WATER USE IN THE KRISHNA BASIN, INDIA<sup>†</sup>

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### ABSTRACT

Regional urbanization and industrial development require water that may put additional pressure on available water resources and threaten water quality in developing countries. In this study we use a combination of census statistics, case studies, and a simple model of demand growth to assess current and future urban and industrial water demand in the Krishna Basin in southern India. Water use in this "closed" basin is dominated by irrigation (61.9 billion cubic metres (BCM) yr<sup>-1</sup>) compared to a modest domestic and industrial water use (1.6 and 3.2 BCM yr<sup>-1</sup>). Total water diversion for non-irrigation purposes is estimated at 7–8% of available surface water in the basin in an average year. Thermal power plants use the majority of water used by industries (86% or 2.7 BCM yr<sup>-1</sup>), though only 6.8% of this is consumed via evaporation. Simple modelling of urban and industrial growth suggests that non-agricultural water demand will range from 10 to 20 BCM by 2030. This is 14–28% of basin water available surface water for an average year and 17–34% for a year with 75% dependable flow. Although water use in the Krishna Basin will continue to be dominated by agriculture, water stress, and the fraction of water supplies at risk of becoming polluted by urban and industrial activity, will become more severe in urbanized regions in dry years. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: Krishna Basin; urban water use; industrial water use; modelling

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### RÉSUMÉ

L'urbanisation régionale et le développement industriel demandent de l'eau, ce qui peut augmenter la pression sur les ressources en eau disponibles dans les pays en développement. Dans cette étude nous utilisons une combinaison de données de recensement, des études de cas et un modèle simple de croissance de la demande pour évaluer la demande en eau urbaine et industrielle actuelle et future dans le bassin Krishna en Inde du sud. Les usages de l'eau dans ce bassin « fermé » sont dominés par l'irrigation (61,9 milliards de m<sup>3</sup>/an) alors que les usages domestiques et industriels sont modestes (1,6 et 3,2 milliards de m<sup>3</sup>/an). L'eau utilisée en dehors de l'irrigation est estimée à 7–8% de l'eau de surface disponible dans le bassin en année moyenne. Les centrales thermiques utilisent la plus grosse partie de l'eau allouée aux industries (86% ou 2,7 milliards de m<sup>3</sup>/an) bien que seulement 6,8% de cette quantité soit consommé par évaporation. Une modélisation simple de la croissance urbaine et industrielle suggère que la demande non-agricole d'eau variera de 10 à 20 milliards de m<sup>3</sup>/an d'ici à 2030. C'est 14–28% de l'eau de surface disponible du bassin en année moyenne et 17–34% de l'écoulement garanti à 75%. Bien que l'utilisation de l'eau dans le bassin Krishna continue à être dominée par l'agriculture, la tension sur l'eau peut devenir plus sévère en année sèche dans les régions urbanisées avec en outre le risque d'une pollution par l'activité urbaine et industrielle. Copyright © 2008 John Wiley & Sons, Ltd.

MOTS CLÉS: Bassin Krishna; utilisation urbaine de l'eau; utilisation industrielle de l'eau; modélisation

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L'utilisation urbaine et industrielle de l'eau dans le bassin Krishna, Inde.

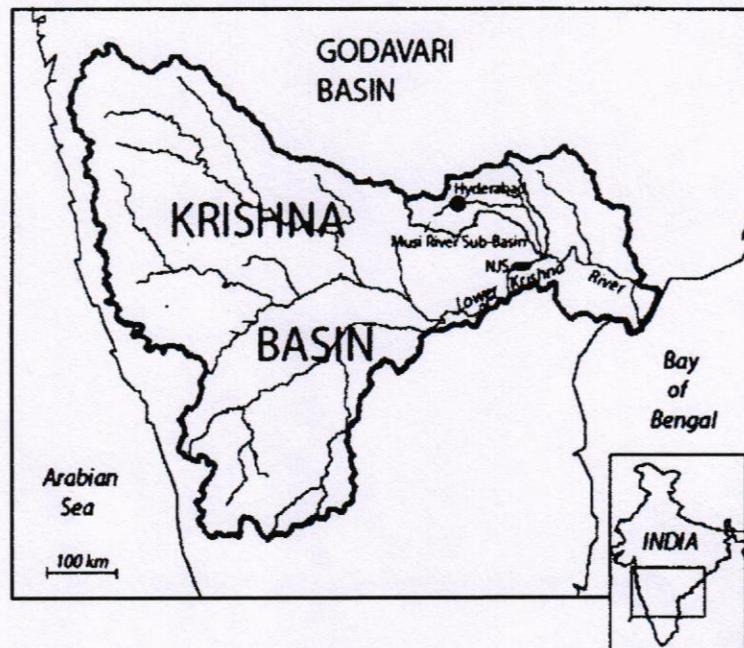
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Figure 1. Map of the Krishna Basin

## INTRODUCTION

Water demands for rapid industrial development and population growth in many developing countries put increasing pressure on freshwater resources. In a fully allocated basin, this demand can only be met by reallocation away from existing uses, most commonly from irrigated agriculture and by reuse of return flows, including an increased use of urban wastewater in irrigation. The negative impacts of reallocation emerge strongly in dry periods in regions where large industries and urban agglomerations share the same water source as an irrigation scheme, although the scale of impact depends on the size of the water source. The impact of additional urban water use on irrigation depends crucially on the size of the shared source (Van Rooijen *et al.*, 2005). For example, the phased pumping of water from the Nagarjuna Sagar reservoir in southern India to meet projected demands of the city of Hyderabad is large compared to historic water supply patterns, but it remains a relatively low volume when compared to what is allocated to irrigation each year.

Competition for water between agriculture and the urban–industrial sector may occur at a variety of scales, including the basin scale. The Krishna Basin, in southern India (258 514 km<sup>2</sup>), has experienced increasing water scarcity due to rapid irrigation development (see map, Figure 1). The basin faces strong inter-seasonal and spatial variations in rainfall (Biggs *et al.*, 2007), which can cause acute scarcity and competition during dry years. Water availability varies considerably by sub-basin, and large projects that were built to increase water storage capacity have fuelled disputes among the three basin states: Karnataka, Andhra Pradesh and Maharashtra. Industrial development, urbanization and water pollution contribute to making available water scarcer and the chance of conflicts higher. Tensions among farmers have emerged when additional water, originally intended for irrigation, has been withdrawn for Hyderabad (Lakshimipathi, 2001). As a first step to mitigate water scarcity in the basin, it is necessary to know the scale and concentration of current non-agricultural water use. In order to better understand the dynamics of water use in the basin, it is necessary to map spatial concentrations and temporal peaks of water use in relation to dry areas or drought periods. When these dynamics are better understood, more integrated regulation of water use and reuse can contribute to creating a more sustainable future for water users in the basin.

## URBAN AND INDUSTRIAL WATER USE IN THE KRISHNA BASIN

Table VII. Actual thermal power generation in the Krishna Basin for selected months in 2003 and 2004, system-wise and state-wise

Plant by state	April 2003	April 2004	May 2003	May 2004	Oct 2003	Oct 2004	Nov 2003	Nov 2004	Average annual 03-04		Water use MCM
	GWH		10 <sup>6</sup> MWh		MCM						
<b>Andhra Pradesh</b>											
K'gudem	383	389	418	432	316	480	302	447	4 751	4.8	380
K'Gudem New	331	371	359	362	253	291	363	357	4 030	4.0	322
Vijaywada	800	895	883	868	882	743	761	838	10 004	10.0	800
Kondapali	180	183	197	184	195	190	196	204	2 293	2.3	183
Total (56% of KB area)	1 694	1 838	1 857	1 846	1 646	1 704	1 622	1 845	21 078	21.1	1 686
<b>Karnataka</b>											
KPCL Raichur	992	1 052	956	1007	917	825	948	985	11 523	11.5	922
Torangallu IMP Jindal	72	64	72	50	70	22	68	37	683	0.7	55
Belgaum	16	36	14	3	7	-	8	6	135	0.1	11
Total (33% of KB area)	1080	1152	1042	1060	994	847	1024	1028	12 341	12	987
<b>Maharashtra</b>											
Parli	407	282	296	243	349	437	387	480	4 322	4.3	346
Total (11% of KB area)	407	282	296	243	349	437	387	480	4 322	4.3	346
Total Krishna Basin	3181	3272	3195	3149	2989	2988	3033	3354	37 742	37.7	3 019

Source: Numbers derived from Central Electricity Authority Operation and Monitoring Division.

Table VII identifies all thermal power plants in the Krishna Basin, with actual power production numbers given for the months April, May, October and November in 2003 and 2004. Data could only be found for these months in both years. It is assumed that power generation in the four months is representative of the whole year. This assumption will be most problematic during the irrigation season, when farmers use pumps for groundwater irrigation; however, our data include some months of active pumping (April, October, November) and the four months should be representative of a yearly average. The table shows that 37.7 million MWh yr<sup>-1</sup> were generated on average for the years 2003 and 2004, of which 60% of the thermal power was in Andhra Pradesh, 30% in Karnataka and 10% in Maharashtra. This gives an annual thermal water use of 3.02 BCM (Equation 2b). State-level calculations of water use in power generation give lower values: 29 million MWh using and consuming 2.32 and 0.16 BCM of water. The average per capita thermal power use in India gives alternative values of 2.08 and 0.14 for thermal water use and consumption respectively. A comparison of results from using the three different estimation methods is displayed in Table VIII. The first method is considered best as it is based upon data of (all) thermal power that is produced in the basin while the other two methods are inevitably less reliable as extrapolation took place either from state- or India-level data to the basin.

#### Agro-industrial water use

Table IX gives the most important agricultural industries that have been identified in the basin. They are cotton, sugar and rice. The full amount produced is assumed to be processed as well. At present, the total volume of water used in processing sugarcane, cotton and rice is estimated at around 0.4 BCM. This amount is considerable when compared with domestic (1.6 BCM) or industrial water use (2.7 BCM), but it accounts for only 1% of average annual basin available water. Agro-processing is now regarded as the sunrise sector of the Indian economy in view of its large potential for growth and likely socio-economic impact on employment and income generation (Kachru, 2007).

#### Non-agricultural water use scenarios in the Krishna Basin

As the basin is considered nearly closed, average annual basin water availability can be determined as annual average runoff, which is around 58.3 BCM (Biggs *et al.*, 2007). The 75 and 50% annual dependable flow of water in