Analysis of the Inter-basin Water Transfer Scheme in India: A Case Study of the Godavari–Krishna Link

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Introduction

The National River Linking Plan (NRLP) was designed to alleviate emerging water scarcity problems in India. Transfers of 'surplus' water from primarily Himalayan rivers to more 'deficient' peninsular rivers have been predicted to reduce imbalances in water availability in the country. The Himalayan component intends to transfer 33 km^3 and the peninsular component 141 km^3 of water through the combined network of 30 links, amounting to a total length of 14,900 km (GOI 1999). The proposed plan, if fully completed, will be the largest ever infrastructure project in the world, costing an estimated 120 Billion US Dollars. The additional benefits claimed by the NRLP include, flood control, drought mitigation, increased irrigation, additional food-grain production and electricity generation. The NRLP, however, remains a controversial issue in India. This is partially due to the non-transparent and, largely, uni-sectoral nature of water resources planning, which places the major focus on irrigation development, as well as a lack of confidence in the characterization of particular river basins as either 'surplus' or 'deficient'.

The main objective of this present study is to independently evaluate the water availability as against the water demand in one of the NRLP links i.e., from the Godavari River (at Polavaram) to the Krishna River (at Vijayawada). This transfer is further referred to in the paper as the 'Polavaram Project'. The Godavari has been characterized as a 'surplus' basin whereas the Krishna Basin as a 'deficit' one (GOI 1999). In Indian engineering practice, 'surplus basins' are defined as those which have a positive balance: i) of 75 % assured annual river flow volume; and ii) in the total annual volume of all water demands, projected up to the year 2050. Basins which have a negative balance of the above two components are classified as 'water deficient'. The analysis to characterize the rivers is done using annual flows (GOI 1999). Smakhtin et al. 2007 have argued however, that this planning process adopted by the Indian Government has ignored the seasonal variability of flow within a year, which is extremely high in monsoon-driven Indian rivers. As a result, much more water is perceived to be originally available at a site of transfer than is the actual case. This paper attempts to examine whether the planned water transfers will satisfy the growing water demands in the Polavaram link command area as well as identify the link's impacts outside of the command area, and uses the

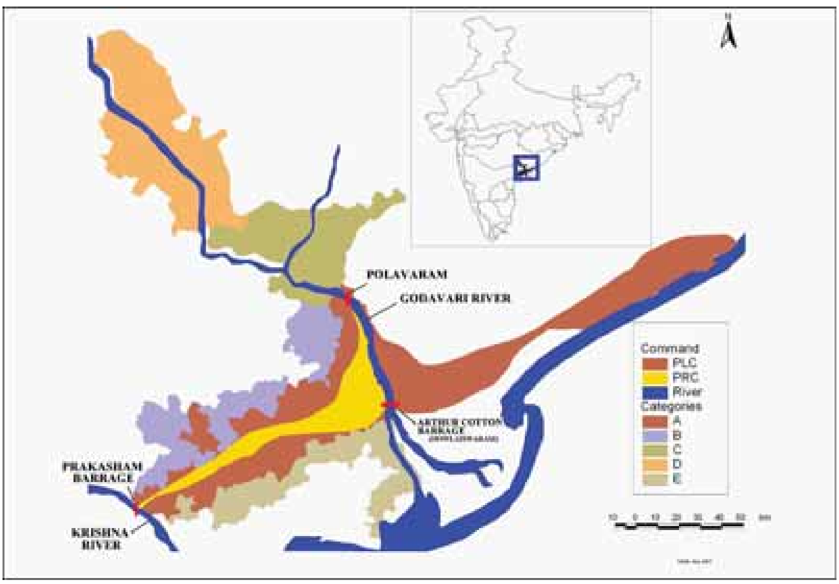
Water Evaluation and Planning Model Version 21 (WEAP 21) for this exercise. Further, in order to examine the effects of seasonal variability, the analysis is done at a monthly time step. The main reason for selecting this particular link is because the Polavaram Project is to be implemented in the near future, regardless of other NRLP water transfers.

Godavari - Krishna Water Transfer and the Polavaram Project

The Godavari River is the second largest river in India with a catchment area of 312,812 km^2 and a long-term average annual surface flow of 110 km^3, of which 76 km^3 is estimated as non-utilizable (NCIWRD 1999). The cultivable area in the basin is about 18.9 million ha. There are already two major diversion structures in the basin. The Sri Ram Sagar Project (upstream of Polavaram) and the Arthur Cotton Barrage (downstream of Polavaram) provide irrigation water to 390,000 ha and 170,000 ha, respectively, in the Lower Godavari Basin. Similar to other parts of India, the use of groundwater to meet irrigation water demands is also a common practice in the Basin. Based on annual water balance calculations as well as the current and projected (for 2025) water requirements, the Central Water Commission (CWC) has concluded that the Godavari Basin has sizeable surpluses that can be transferred to the water-deficit Krishna Basin.

The Krishna River basin is the fourth largest in India with a total catchment area of 258,948 km^2 and a long-term average annual surface flow of 78 km^3, of which 58.0 km^3 is considered to be utilizable (Amarasinghe et al. 2005). The cultivable area in the basin is about 20.3 million ha.

Figure 1. A schematic map of the proposed Polavaram Project. PLC and PRC- the Polavaram left and right bank command areas, respectively.



Note: Category A = the command area for the link canal; Category B = mandals upstream of the link command area; Category C = the area submerged by the proposed reservoir; Category D = mandals upstream of the proposed Polavaram Reservoir; and Category E = the mandals downstream of the link canal command area. Locations A and C will be directly affected by the project. Locations B, D, and E will be indirectly affected by the project

Three large irrigation projects are operational in the basin. The Krishna Delta Project near Vijayawada, which is expected to directly benefit from the Polavaram water transfer, was constructed in 1852 (Figure 1), and was designed to irrigate 530,000 ha of land. The Krishna Delta plays a vital role in the rice economy of the nation and in addition to the major dam, a large number of informal irrigation sources such as groundwater tubewells, tanks and minor reservoirs are spread throughout the area. Due to the massive surface irrigation development and the rapid expansion of groundwater irrigation, the annual river flow at the Krishna outlet has decreased to approximately 36 % of its pre-development level, and certain studies have reported on the 'closure' of the basin (e.g., Biggs 2005).

Several links have been proposed to transfer water from the Godavari to Krishna. Some of them are planned as parts of much longer transfers from the Himalaya to the peninsula. The most 'downstream' link – Polavaram (Godavari River) -Vijayawada (Krishna River) (Figure 1) – can, however, be seen as a 'local' project because the main aim of this link is to transfer, to an already water-deficient and over-utilized Krishna Delta, what is perceived as 'surplus' water from the more water-endowed Godavari River. Furthermore, the project is expected to reduce informal irrigation and the use of groundwater in the Krishna Basin.

The Polavaram Project

The climate in the command area of the Polavaram Project (Figure 1) varies from hot, semi-arid to sub-humid, to tropical. The monsoon season (known as kharif in India) extends from June to October, and the post-monsoon season (rabi) - from November to March with a usual annual dry spell during April to May. Average annual rainfall is 1,000 mm, with over 80 % falling during kharif due to southwest monsoons. The temperature varies from 44 ^{0}C in May to 22 ^{0}C in December. The overall population density in the command area is 543 persons per km^2 with 60 % of the population being dependent on agriculture (GoAP 2003).

Figure 1 shows the proposed project including the site of the Polavaram Reservoir and the command area of the link canal. The project includes two canals, i.e., one on the right and one on the left bank of the Godawari River. The Polavaram –Vijayawada link command area is located on the right bank, with the link canal starting from the proposed Polavaram Reservoir. The left main canal will transfer 3,663 MCM (million cubic meters) for irrigation and industrial needs. The link canal on the right bank will divert 5,325 MCM for irrigation, domestic supply and industrial use. The planned Polavaram Dam is to have a live storage of 2,130 MCM. The annual total water use is, however, estimated to be 8,000 MCM. Since the planned storage is small in comparison to the water use, run-of–the–river flows will be utilized to ensure the expected benefits of the project. Thus the project will function more as a barrage combined with limited storage use. The project also includes a hydropower component (GOI 1999). It has been estimated that the proposed reservoir will submerge around 63,000 ha of land, which at present hosts 250 villages with a total population of 145,000 (Census 1991; GOI 1999; GOI 2006).

The government feasibility report states that the total cultivable area of the Polavaram link canal is 139,740 ha. Of this area, 71 % (99,755 ha) is irrigated by bore wells, tanks and open head channels taking off from the river, and the balance 29 % (39,985 ha) is non-irrigated

(GOI 1999). An independent survey conducted by Bhaduri et al. (2007) in the Polavaram area to assess the irrigation benefits, showed that these figures are outdated and that 95 % of the cultivated area in the link command area is under irrigation at present. Table 1 shows the different sources of irrigation in the link command area. Bhaduri et al. (2007) indicate that all cultivable area is irrigated and the remaining 5 % that is not irrigated is not under cultivation. Therefore, the assumption that 39,985 ha of new irrigated area will develop due to the link canal is overestimated, as the existing Sir Arthur Cotton Barrage in the Godavari, the Prakasham Barrage in the Krishna, and lift irrigation from the main river channel, all supply surface water to the Deltas. Therefore, most of the 'new area', which according to the feasibility study is to be brought under irrigation, already is being irrigated with groundwater and water from either tanks or canals. Table 1 shows that currently 84 % of the command area is irrigated with groundwater and 9 % by canals (Bhaduri et al. 2007).

Table.1 Source of water as percentage of total irrigated area in the Polavaram link area.

Source	Right Bank Location 1 (C,D)	Right Bank Location 2 (E)	Right Bank Location 3 (A)	Right Bank Location 4 (B)	Left Bank Location 3 (PLC)	Left Bank Location 4
Canal	0	100	9	41	20	50
Conjunctive use	0	0	0	1	0	0
Groundwater	97	0	84	50	64	46
Pump irrigation	0	0	0	5	0	2
Rain-fed	2	0	7	0	0	2
Tank	1	0	0	2	16	0

Source: Survey (Bhaduri et.al. 2007)

Note: The letters in brackets correspond to locations in Figure 1
Location of the link: 1= Upstream of the proposed Polavaram Reservoir including the submergence area, 2 = Downstream of the Polavaram Project area, 3= Command area of the link canal, 4 = Outside the command area of the link canal.

Once the link is built, it is proposed that paddy, sugarcane, chilies and pulses should be planted - considering the soil suitability, agro-climatic conditions and local practices (GOI 1999). Furthermore, irrigated crop intensity, which is the ratio between irrigated crop areas (where double or triple cropping areas are counted twice or three times, respectively,) and the physical areas equipped for irrigation, is expected to reach 150 %. The current existing cropping pattern in the command area is dominated by paddy, sugarcane and tobacco during both the kharif and rabi seasons (Bhaduri et al. 2007). Increased upstream development, especially through the construction of reservoirs and irrigation systems in the Krishna, has resulted in a decline in downstream flows, which has affected the cropping patterns in the Krishna Delta. When enough water is available, usually two rice crops are grown per year, but in the Krishna it has been observed that during dry years, only one rice crop is grown with another less water intense crop being grown during the rabi season (Dr. Chandrashekhar Biradar, IWMI, pers. Comm.). In the Godavari Delta on the other hand, two paddy crops are grown but only with supplemental groundwater use.

Methods

Summary of the WEAP 21 Model

The Water Evaluation and Planning Model (WEAP), developed by the Stockholm Environmental Institute (SEI), is designed to evaluate scenarios of water resources development and changes in the bio-physical and socioeconomic conditions of catchments over time (Yates et al. 2005). One of WEAP 21's strengths is that it places the demand side of the water balance equation on par with the supply side. In WEAP, water supply is defined by the amount of precipitation that falls on a catchment or a group of catchments. This supply is progressively depleted through natural processes, human demands and interventions, or enhanced through accumulations/storages. Thus, WEAP 21 adopts a broad definition of water demand, where the catchment itself is the first point of depletion through evapotranspiration. The core of the model is a water balance equation that includes components such as catchment-scale evaporation demands, rainfall-runoff processes, groundwater recharge and irrigation requirements. These are linked to the stream network and water allocation components (demand sites) via the WEAP 21 interface, where a stream network keeps track of water allocations and accounts for streamflow depletion and addition (Yates et.al. 2005). The model optimizes water use in a catchment using an iterative linear programming algorithm, the objective of which is to maximize the water delivered to demand sites, according to a set of user-defined priorities. All demand sites are assigned a priority between 1 and 99, where 1 is the highest priority and 99 is the lowest. When water is limited, the model progressively restricts water allocation to demand sites with lower priority. More details of the model are available in Yates. et al. (2007) and SEI (2001).

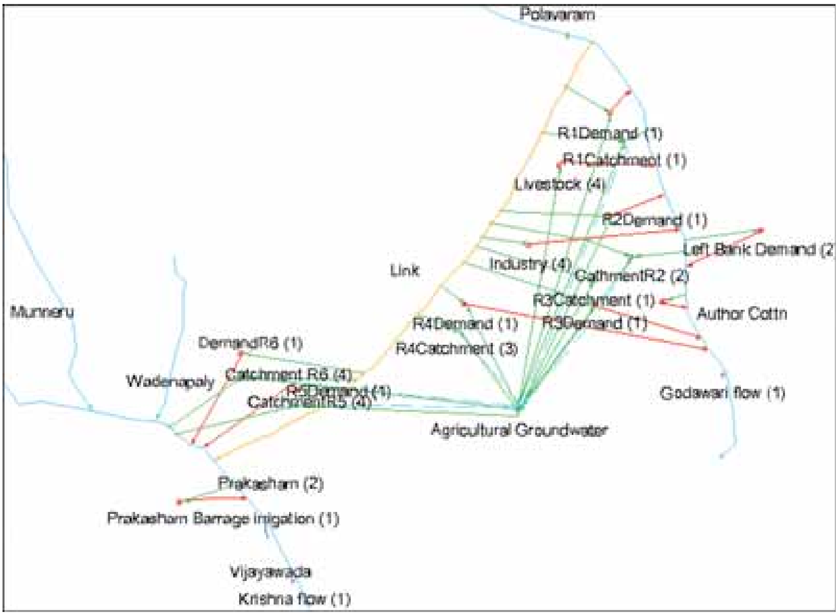
Scenario Formulation

In order to assess the benefits of the proposed Polavaram Project, two main scenarios were developed and simulated.

- *Scenario 1 – Reference Scenario:* water use under the current supply and demand network. The water sources are groundwater and the river channel.
- *Scenario 2 – With the Polavaram Reservoir and link canal*: water supply versus demand after the construction of the Polavaram Project. The water sources are the Polavaram Reservoir and link canal, groundwater and the river channel.

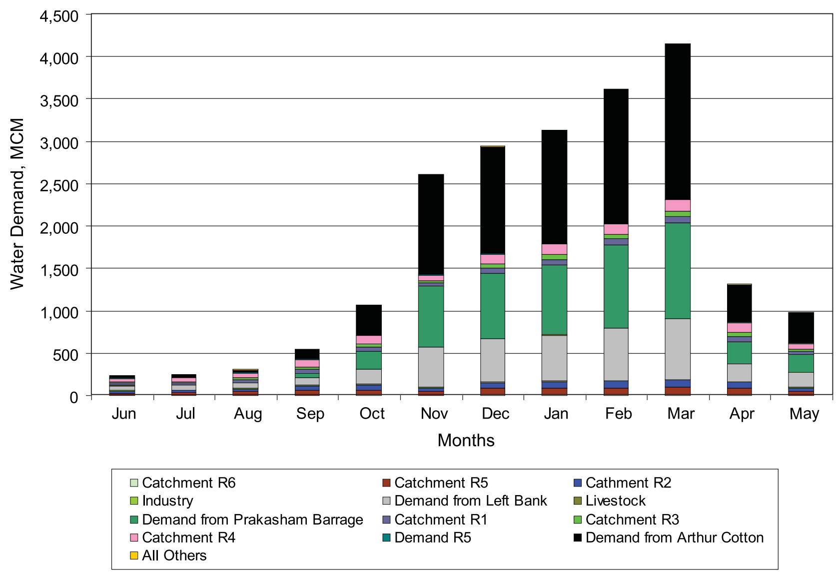
As 95 % of the cultivable area is already under irrigation (Bhaduri et al. 2007), it was assumed that substantial increases in new irrigated area will not be possible. Therefore, in the two scenarios, the agricultural land in the link command area was kept constant. Figure 2 shows WEAP set up with the link canal and reservoir. In both the Krishna and Godavari Deltas, agriculture is still the major water user compared to domestic and industrial demands (Figure 3) and increased agricultural production is the main goal of the Polavaram Project. Therefore, the anticipated benefits of building the Polavaram Reservoir and the link canal system are mainly based on the improved water supply and the subsequent increases in cropping intensity

Figure 2. WEAP set up with Polavaram link canal and reservoir.



Note: R1 till R6 represent the sub-watersheds in the Polavaram command area. The green arrows represent the water inflows from the supply sources and the red arrows are outflows from the demand nodes

Figure 3. Monthly water demands for 2003 from the catchments and other demand sites (excluding losses and reuse).



and yields. The effect of the Polavaram Project was tested by running the above two main scenarios under different crop rotation systems: i) paddy-paddy, ii) paddy- pulses (representing a low water intensity crop) and iii) sugarcane only. Each crop rotation condition was run with and without environmental flow (EF) requirements/demands. These cropping patterns reflect the regional practices of planting two paddy crops or only sugarcane if farmers perceive no water scarcity, and of planting paddy during monsoon and a low water intense crop (e.g., pulses, tobacco) during the dry season, under water-scarce conditions. The domestic, industrial and livestock water demands were kept constant in all runs. The scenario results were compared with each other and discussed in terms of unmet demands.

Defining Supplies and Demands

The starting point of the analysis was the development of catchment water demands. The demands in the study area are from agriculture, domestic sector, industry, and livestock. Each demand in the model is represented by a node. Monthly water demands from each demand node need to be assigned a priority level and linked to its available supply sources. Domestic water demand was given the first priority, followed by agriculture, industry and livestock – in that order.

In reality, each demand node also represents a certain geographical space. Therefore, in the model set up, the link canal command area was divided into sub-catchments based on a drainage map extracted from a digital elevation model (DEM). For the six sub-catchments (Figure 2 shows their boundaries) that fell under the link command area, demand nodes corresponding to agriculture and domestic demand were created. However, as livestock and industrial water demands were minimal, one demand node representing livestock and one demand node representing industrial demand were created for the entire command area. The demand data were available at mandal level (mandals are India’s third-level administrative subdivisions after state and district) whereas in the model, the sub-catchment represents the hydrological demand unit. Therefore, the mandals in the command area were assigned to the six sub-catchments by merging them together using geographic information systems (GIS). The demand nodes which were closer to the supply sources were given higher priorities.

The Agricultural water demand for each sub-catchment was calculated using the FAO Crop Requirements Method option in WEAP (FAO 1998). The domestic, livestock and industrial water demands were calculated using Indian government statistical reports (District at a Glance, 2003).

Water demands outside the link command area and that could be affected by the proposed water transfer were also added to the model set up. These additional demands include:

- Demands from mandals on the left bank command area of the Godavari River (Figure 1), based on the quantity of water to be transferred from the left bank canal (GOI 1999);
- Irrigation demands from the Prakasham Barrage;
- Irrigation demands from the Arthur Cotton Barrage.

The irrigation command areas of the Arthur Cotton and Prakasham barrages lie in the Krishna and Godawari deltas, downstream of the proposed Polavaram Reservoir and command area (Figures 1, 2). These additional demand sites were not represented in the model as catchments but as sites where a fixed quantity of water was extracted from the supply sources on a monthly basis. Each demand site was assigned a priority that determined the water allocation order. In Scenario 1, the Arthur Cotton Barrage command area in the Godavari Delta was given a higher priority than the irrigation demands in the link command area catchments. In Scenario 2, however, the link command area demands were given higher priority than the lower delta.

The supply sources built into the model were precipitation (for the catchments), surface water and groundwater. Precipitation was calculated based on the monthly data obtained from a climate station located in the Krishna Delta. Surface water flows in the Krishna and the Godavari were obtained from river gauging stations upstream of the Polavaram Project. Groundwater in the model was represented by a node and water availability was calculated based on the storage capacity and natural recharge values of the Andra Pradesh Groundwater Report (GoAP 1995; GoAP 2006). Simulations were conducted over the period from June 1991 to May 2005. The Polavaram Reservoir was simulated using the salient features published in the government feasibility report (GOI 1999). According to this report, the link canal is designed to transfer 5,325 MCM of water per annum. The proposed dam operating rules are not described at a monthly time step. Therefore, in the model, the reservoir releases were based on seasonal variations in water demand i.e., more water is transferred during the dry season.

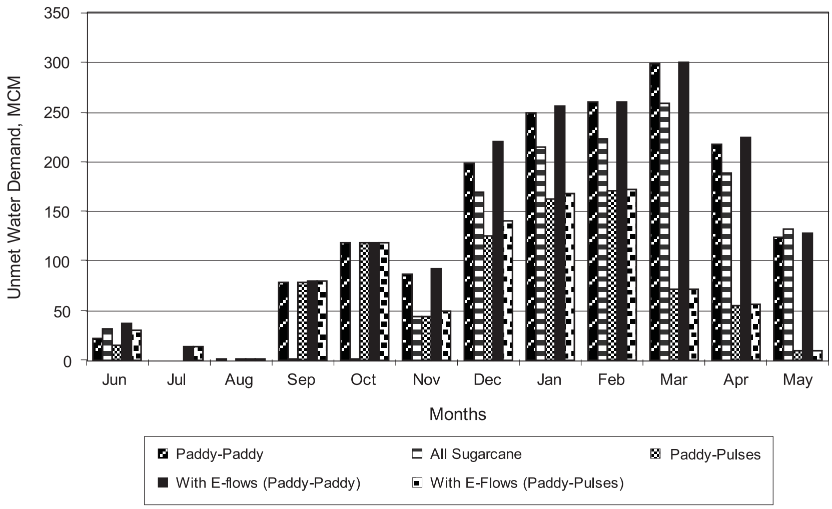
The EF requirements have been estimated using the desktop method described by Smakhtin and Anputhas (2006). The method takes into account the limitations of available hydrological and ecological information in India at present, but ensures that elements of natural flow variability are preserved in the estimated environmental flow time series, as required by the contemporary hydro-ecological theory. The method is based on the use of a flow duration curve – a cumulative distribution function of monthly flow time series. The curve is calculated for several categories of aquatic ecosystem protection – from ‘largely natural’ to ‘severely modified’, and the required EF volume and elements of flow variability are set to progressively reduce with the decreasing level of ecosystem protection. The EF calculated for the least acceptable category, Class D (‘largely modified’ rivers), was used in this analysis. In the model runs with EF requirements, the highest priority was given to environmental demands. The runs with EF requirements used a paddy-paddy and paddy-pulses rotation.

Results

Scenario 1: Reference Scenario with Current Water Use

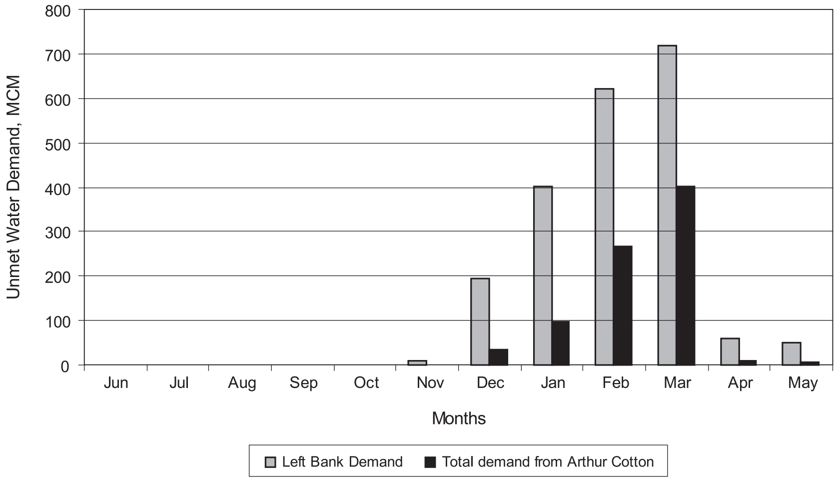
Under the current water use system, the average annual unmet demand for the period from June 1991 to May 2005 in the command area of the link canal is 1,655 MCM for a paddy-paddy system. Figure 4 shows the monthly average unmet demands aggregated for agriculture, domestic use, industry and livestock for the link command area. The unmet demands occur in all months except July and August (peak of the monsoon), and are for surface water as no further withdrawal from groundwater is possible. The maximum withdrawal rates from groundwater were based on the storage capacity and groundwater recharge rates for the area. Changing cropping patterns may decrease the unmet demands. For example, planting only one paddy crop during the rainy season and pulses (a low water intensity crop) during a rabi season will decrease water deficits up to 51 % (Figure 4). As expected, giving EF (even very small ones - corresponding to the least acceptable environmental Class D) a high priority in the water allocation scheme, increased the unmet demands for other users (agriculture, industry, domestic). The unmet demands are highest for the simulation, which combines paddy- paddy rotation and EF requirements (Figure 4).

Figure 4. Scenario 1: Monthly average (1991-2004) unmet demands from agriculture, domestic use, industry and livestock for the sub-watershed falling under the link command area, under different cropping patterns and with the inclusion of environmental flows. All cases include conjunctive surface and groundwater use.



Annual demands from the Arthur Cotton Barrage are 8,199 MCM for irrigation and 378 MCM for domestic and industrial use (GOI 1999). Assuming these demands are coupled with a paddy-paddy cropping system, the mean annual simulated unmet demand for the command area of the Arthur Cotton Barrage in the Godavari Delta would be 818 MCM. This constitutes 10 % of the mean total annual demand. The model also considered loss and reuse during transmission. For the areas outside of the Polavaram link command area, groundwater information was not available. Therefore, the demands in the model were linked to surface water supplies. Bhanduri et al. (2007) showed that groundwater is used in this area (Table 1). Consequently, the unmet demands at present are probably being met by groundwater extraction. The water deficit in the Godavari Delta is in the rabi and dry seasons (December to May – Figure 5). There is no deficit in the months from June to November. Therefore, the analysis shows that although there may be surplus water during the kharif season, in other months, there is a deficit in the Godavari Delta, which is being met by groundwater. In the area supplied by the Prakasham Barrage in the Krishna, the annual total demand is 5,139 MCM (GOI 1999). The model calculated 27 MCM of annual average unmet demand after 2003. Similarly, 2,057 MCM mean annual unmet demand were calculated for the left bank command area in the Godawari. Similar to the Arthur Cotton Barrage command area, water deficit in the left bank command area is only in the rabi and dry seasons (December to May, Figure 5).

Figure 5. Scenario 1: monthly average (1991-2004) unmet demands based on water requirements from Arthur Cotton Barrage and the Polavaram left bank command area.



In order to check if EF requirements are met in the Krishna under present conditions, the estimated EF for Class D were plotted against measured flow from the gauging station at Vijayawada (Figure 6). The Vijayawada gauge is downstream of the Prakasham Barrage. As can be seen from Figure 6, the situation in recent years has worsened as more water is being used upstream for various purposes. Annual analysis for the Godavari showed that within the 14-year modeling period, the EF requirements are not met during the dryer years (based on rainfall data). Figure 7 illustrates that the unmet EF requirements are highest in June, when water demand for agriculture is high. The unmet EF plot seen in Figure 7 is simulated with a paddy- paddy cropping pattern. Delays in the onset of the rainy season will affect water availability for EF. Paddy sowing was assumed to start in June, therefore, if the monsoon does not start in June, irrigation water demand will increase. The EF for class D is met from August to November.

Figure 6. Class D environmental flow requirements plotted against measured flow from the gauging station at Vijayawada.

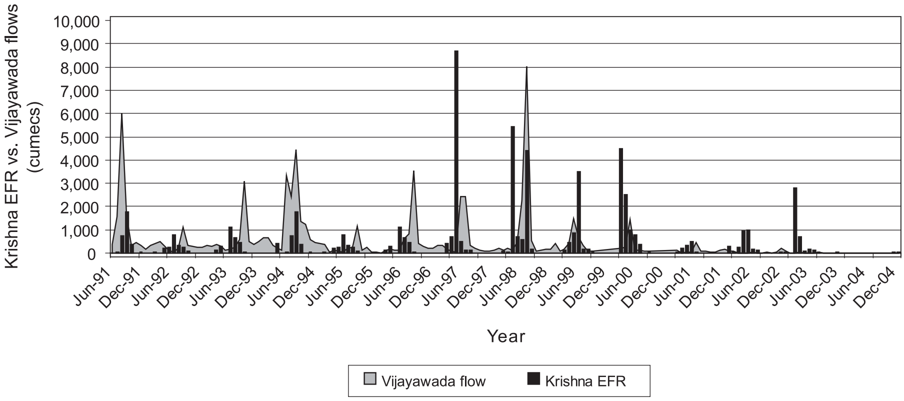
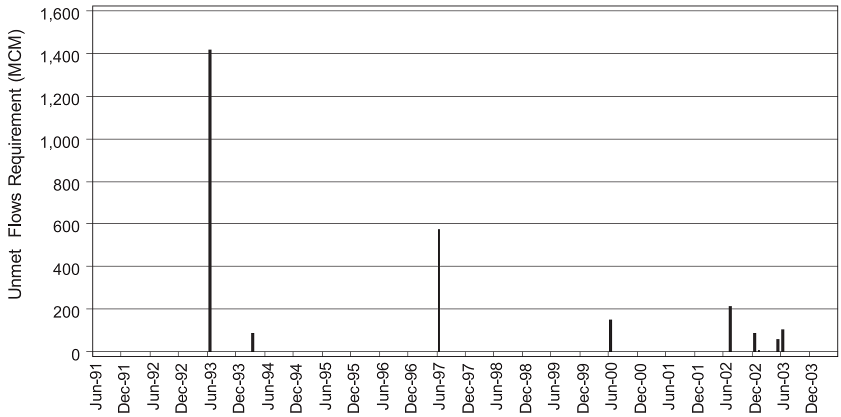


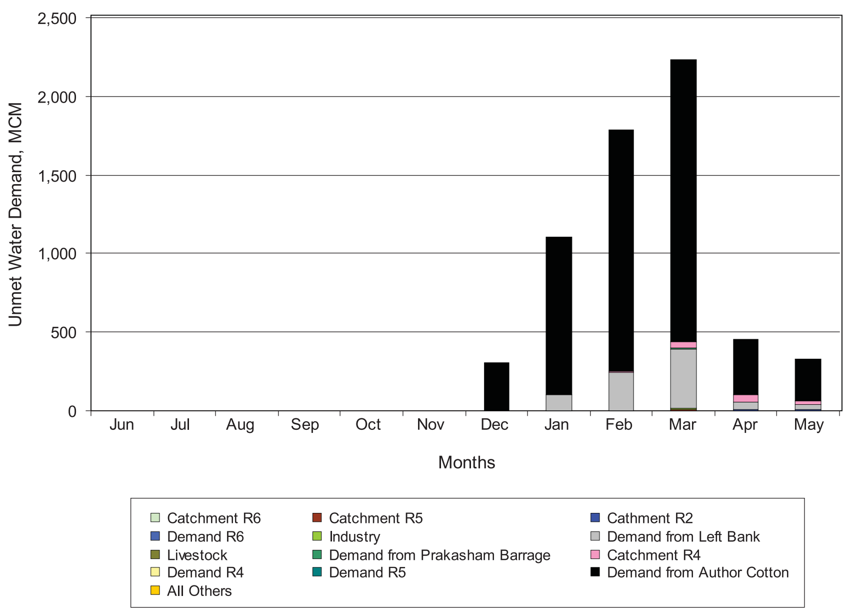
Figure 7. Scenario 1: Unmet environmental water demand under current conditions with paddy-paddy cropping pattern (environmental flow requirement is given the highest priority). The simulation was run with the paddy-paddy cropping pattern.



Scenario 2: With the Polavaram Reservoir and Link Canal

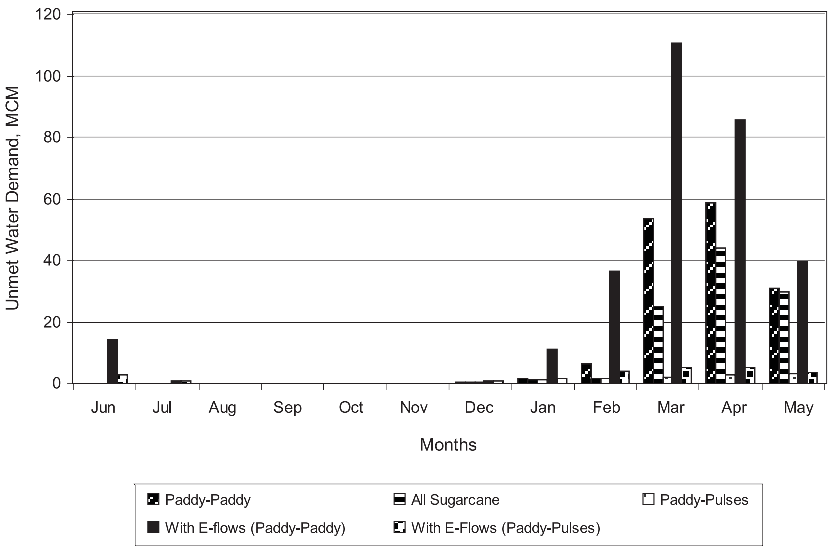
The simulations with the link canal and reservoir show that within the link command area, there are minimal unmet demands for agriculture, domestic, and livestock requirements (Figure 8). Figure 9 shows monthly average unmet demand (for 1991-2004) for agriculture, domestic use, industry and livestock for the link command area under different cropping

Figure 8. Scenario 2: Monthly average (1991- 2005) unmet water demands under paddy-paddy crop rotation. Unmet demands in the link command area are minimal compared to those in Arthur Cotton area and the left bank.



patterns as well as with EF requirements. The unmet demands occur during the period from December to June and changing the cropping pattern to paddy-pulses almost nullifies the unmet demands, which exist under other crop rotations (Figure 9). This is definitely an improvement for the link command area compared with Scenario 1 (Figure 4). Introducing EF for the downstream of the Krishna and the Godavari, especially coupled with a paddy-paddy cropping pattern, increases the unmet demands during the months of January till June (Figure 9). When comparing these values to Scenario 1 in Figure 4, one can conclude that although the water deficit situation improves within the link command area, if and when EF requirements are set, there will be a deficit in the link command area under a paddy- paddy cropping system.

Figure 9. Scenario 2: Monthly average (1991- 2004) unmet demand for agriculture, domestic use, industry and livestock for the link command area under different cropping patterns and with the inclusion of environmental flows. All cases include conjunctive surface and groundwater use.



The mean annual unmet demand for the left bank command area was 799 MCM and the Arthur Cotton command area was 5,270 MCM. Compared to Scenario 1, water deficit is smaller for the left bank command area, but higher for the Arthur Cotton Barrage command area, which is expected since water in the Godawari is being stored and diverted to the Polavaram command area. As with the current situation (Scenario 1), the water deficit in the Arthur Cotton command area is only in the rabi and summer seasons (December to May). The unmet demands situation for the Prakasham Barrage irrigation area shows improvement as there was no water deficit, with the exception of the year 2003, which was a particularly dry year. This water deficit occurs again only in March and can be alleviated by growing pulses or another lower water-intensive crop during the rabi season. Therefore, the analysis with the link canal (Scenario 2) showed that although the pressure on water resources within the left and right bank command area reduces, there will be increased deficit in the Arthur Cotton command area. This deficit is however, only during the rabi and summer seasons.

In this analysis (Scenarios 1 and 2), demands from the mandals in the link command area were also supplied with groundwater but, due to lack of groundwater recharge data from the Arthur Cotton Barrage, Prakasham Barrage and the left bank command area, demands were linked to surface water availability. In reality, however, a part of the unmet demand used in the analysis is met by groundwater. It is possible that increased aquifer recharge due to irrigation in the Polavaram link command area will provide additional groundwater resources for the lower delta where the Arthur Cotton Barrage command area is located. However, more studies are necessary to make accurate predictions on the sustainability of groundwater use. A key objective of the Polavaram Project is also to reduce groundwater use. Therefore, if groundwater pumping in the lower delta is increased (due to less water delivered), in order to maintain the existing levels of agricultural production, then this objective will not be met and the pressure on the natural aquifers will increase.

Figure 10 shows a graph of simulated storage volumes for the Polavaram Reservoir. The monthly net evaporation as published in the government feasibility report was used to calculate the evaporation losses from the reservoir. The reservoir reaches the inactive zone (3,381 MCM) during every dry season, which means that the water stored during each monsoon season will be utilized during the dry season of that same year. The reservoir storage capacity does not provide storage nor ensure water for inter-annual variations.

Analysis for the Godavari showed that within the 14-year modeling period, the EF requirements were not met during June in 1993, 1997, 2000 and 2003. In the simulation presented in Figure 11, EF requirements were set under a paddy-paddy cropping pattern where paddy sowing was set to start in June. Therefore, as the agriculture demands during this month are high, and if the monsoon rains that start usually in June are delayed, there will be unmet

Figure 10. Simulated storage volume of the Polavaram Reservoir.

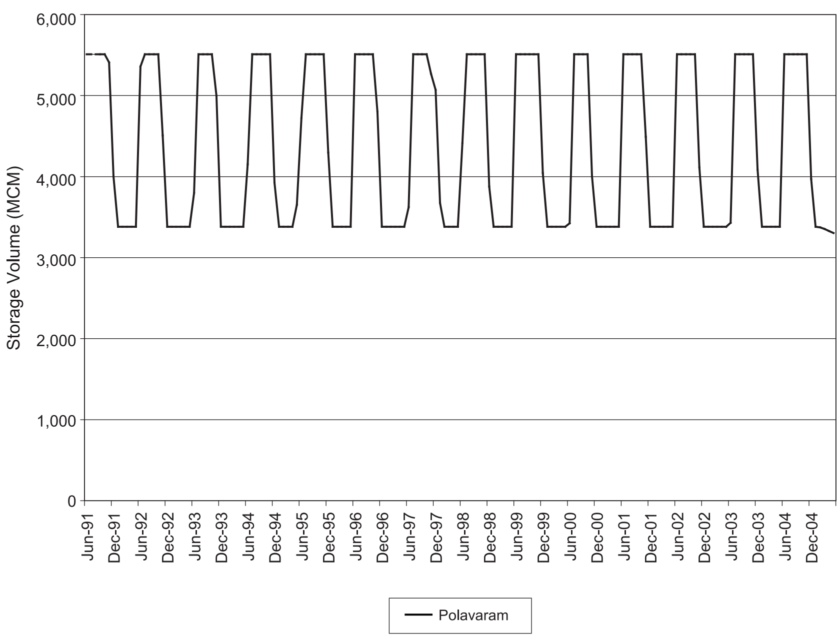
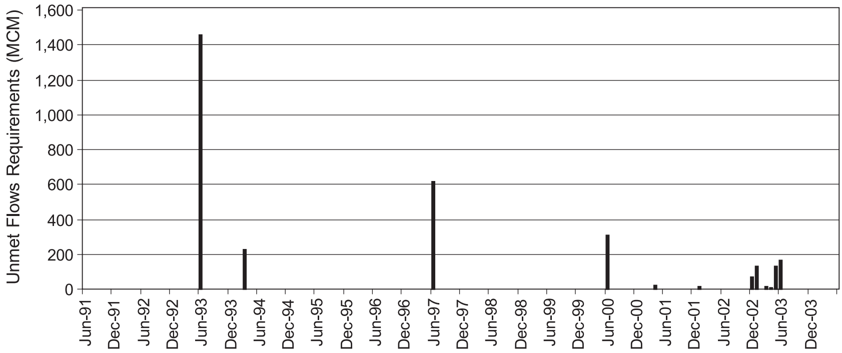


Figure 11. Scenario 2: Unmet environmental demand under a paddy-paddy cropping pattern and with environmental flows having the highest priority.



demands for agriculture as well as for environmental requirements. In both scenarios, June has the highest unmet EF for the Godavari. The storage in the Polavaram, as mentioned above, is utilized within each year, therefore, in this case, the reservoir also does not provide water to compensate for delays in the onset of the monsoon rains. The EF requirement situation, which is more critical in the Krishna (Figure 6), does not improve after the link and water transfer, as most of the water that is transferred will be utilized for en route irrigation demands. In the Krishna, the highest unmet EF demands are also in June and July - at the start of the monsoon season.

Conclusions

This study suggests that water resources management in the region has to be done on a seasonal basis by taking monthly variability into consideration. The simulations show that the proposed Polavaram Reservoir and link canal will reduce the seasonal pressure on water resources for the proposed command area of the reservoir. However, this will result in increased water deficits during rabi and summer months in the Lower Godavari Delta, which is being supplied through the Arthur Cotton Barrage. Therefore, water deficits may simply be transferred from one area to another. The water deficits exist only in the dry months. Changing cropping patterns, such as planting paddy during the monsoon and a low water intensive crop such as pulses in the dry season in the link command area, will decrease unmet demands for the Lower Godavari Delta. However, this will not be enough to continue the present water use patterns in the Arthur Cotton command area.

Similarly, the need to ensure EF should also be considered in the context of seasonal variability, as it is mostly in the dry months that the water allocation problems become critical. In the Godavari, it will not be possible to meet EF requirements in June, just before the start of the monsoon if the onset of the rainy season is delayed. Meeting EF requirements in the Krishna is a bigger problem than in the Godavari and the situation is not likely to improve even after the Polavaram Project, as most of the water that is being transferred will be used for en route irrigation.

In this study, the analysis for the transfer is done purely in hydrological terms as the main justification for the NRLP is based on the transfer of 'surplus' waters to 'deficit' basins. It is however, also recommended to integrate economic analysis into the assessment, whereby the benefits of the project's incremental water supply can be compared against the losses (e.g., second season rice crop in the Godavari Delta). The planning of water transfer schemes should also consider the land and production loss, displacement costs and other impacts associated with water infrastructure development. Despite many attempts, it was not always possible for the authors to acquire the best input data available and, as such, a number of assumptions had to be made. Available economic and social analysis information looks similarly fragmented (GOI 1999).

Inter-basin water transfers have been an integral part of water resources management all over the world. However, without careful integrated planning and analysis, the proposed high-investment schemes might not be able to operate as planned and eventually might not deliver the expected long-term benefits.

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