Groundwater Externalities of Surface Irrigation Transfers Under National River Linking Project: Polavaram – Vijayawada Link

Bharat R. Sharma[1], *K. V. G. K. Rao*[2] *and Sylvain Massuel*[3]
[1] *International Water Management Institute, New Delhi, India*
[2] *Indwa Technologies, Hyderabad, India*
[3] *International Water Management Institute, Hyderabad, India*

Introduction

A large spatial variation exists in the availability of water resources in the different basins of India (Amarasinghe et al. 2005). Moreover, rainfall is mostly confined to the monsoon season and is unevenly distributed both in space and time. As a result, frequent droughts and floods continue to be annual features in most parts of the country. Realizing the need for providing water security in the water deficit areas, the Government of India formulated, in the year 1980, the National Perspectives for Water Resources Development, proposing therein the establishment of various long distance inter-basin water transfer links for transferring water from the water surplus basins of the country to the deficit areas/ basins. The plan has two main components: the Himalayan component and the peninsular component. The peninsular rivers development component envisages, as its first part, the diversion of surplus flows from the Mahanadi River to the Godavari system and then, the transfer of surplus waters from the Godavari system to the water short Krishna, Pennar and Cauvery basins. This would benefit the drought-prone areas of Andhra Pradesh, Karnataka, Maharashtra, Orissa and Tamil Nadu. The award given by the Godavari Water Disputes Tribunal (GWDT) stipulates, among other provisions, that 2,265 Mm^3 (80 TMC) of Godavari waters, from the Polavaram Project proposed by Andhra Pradesh, be diverted to the Krishna Basin above the Prakasam Barrage at Vijayawada. The Right Main Canal (Polavaram – Vijayawada Link, Indira Sagar Right Main Canal) will be 174 km long, and is envisaged to provide irrigation to a ‘culturable’ command area (CCA) of about 1.40 lakhs ha, in addition to the transfer of 2,265 Mm^3 of Godavari waters to Krishna (NWDA 1999).

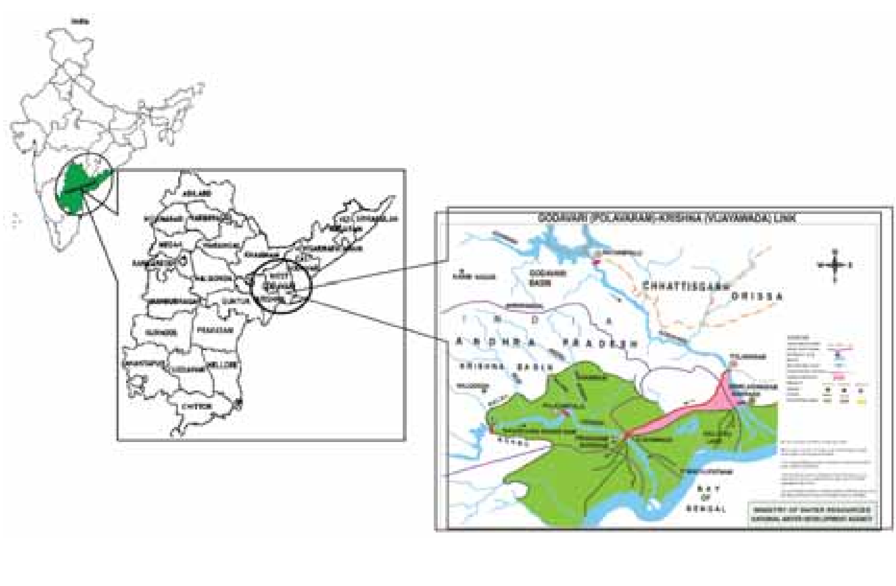
The provision of a canal distribution system and the application of surface water to such a large area, besides providing direct irrigation benefits, assist in the modification of the groundwater regime. Such groundwater externalities may generate positive results by providing additional recharge and improving the water table in a water-stressed area, but may also have a negative impact on the basins within the canal distribution system by creating waterlogging and increasing soil salinity in previously water congested pockets. These groundwater externalities are not adequately understood and factored into the project's feasibility reports. This paper has described: a) the proposed P-V Link's irrigation system; b) the geo-hydrological and agro-climatic soil conditions of the area; c) irrigation sources, cropping pattern and returns based on a primary farm survey; and d) the prognosis of the post project scenario of groundwater conditions.

Polavaram – Vijayawada (P-V) Link

The Polavaram Project (Figure 1) has been planned by the State of Andhra Pradesh as a multi-purpose project: a) to provide irrigation benefits to the upland areas; b) to provide a water supply to the industries in Visakhapatnam city, including the Steel Plant, for the generation of hydropower; and c) for the development of navigation and recreation facilities. The Polavaram Project envisages the construction of an earth-cum-rock filled dam that is 1,600 m long across the Godavari River at Polavaram, and about 42 km upstream of the Godavari Barrage at Dowlaiswaram. The dam will have a maximum height of 50 m in the deep course of the river and 38 m above average bed level. A 754 m long spillway on the right flank saddle is designed to regulate a flood discharge of 1.02 lakhs cumecs. A 560 m long and 58 m high masonry non-overflow dam accommodates the powerhouse and river sluices on the left flank.

The dam reservoir will create a live storage capacity of 2,130 Mm^3. The project envisages two canals, one on the left side and the other on the right side. The Left Main Canal will be

Figure 1. Location of Polavaram Project in Andhra Pradesh (INDIA).



208 km long and will provide irrigation to a CCA of 1.75 lakhs ha in the upland area of East Godavari and Visakhapatnam districts. The canal will also provide a water supply to Visakhapatnam. In addition, the Left Main Canal will also have provision for accommodating navigational requirements.

The Right Main Canal (Polavaram – Vijayawada, P-V Link) or Indira Sagar Right Main Canal (ISRMC))l is designed to carry 5,325 Mm^3 of water, of which 3,501 Mm^3 is to be transferred to the Krishna delta (2,265 Mm^3 as per GWDT award and an additional transfer of 1,236 Mm^3); 1,402 Mm^3 for providing irrigation to an extent of about 1.40 lakhs ha (CCA) en route; 162 Mm^3 for meeting the domestic and industrial needs of the command area; and with 260 Mm^3 to be the allowance for transmission losses. The canal irrigates areas in the Polavaram, Kovvur, Gopalapuram, Devarapalli, Nallajerla, Dwaraka Tirumala, Pedavegi, Denduluru, and Pedapadu *mandals* of the West Godavari District and Bapulapadu, Gannavaram, Vijayawada urban and rural *mandals* of the Krishna District (Table 1).

Table 1. Proposed command of Indira Sagar (Polavaram Project) Right Main Canal, Andhra Pradesh.

Sl. No.	Mandal, West Godavari District	Command Area, ha	Mandal, Krishna District	Command Area, ha
1.	Polavaram	3,188	Bapulapadu	4,713
2.	Gopalapuram	8,568	Nuzivedu	251
3.	Tallapudi	9,578	Gannavaram	12,436
4.	Devarapalli	7,377	Agiripalli	128
5.	Kovvur	9,047	Vijayawada (Rural)	4,366
6.	Dwaraka Tirumala	2,146	Vijayawada (Urban)	4,817
7.	Nallajerla	2,120	*Sub total*	*26,711*
8.	Chagallu	11,488		
9.	Tadepalligudem	15,236		
10.	Nidadavolu	10,717		
11.	Pedavegi	7,780		
12.	Unguturu	5,434		
13.	Denduluru	8,662		
14.	Bhimadolu	5,434		
15.	Pentapadu	172		
16.	Eluru	2,481		
17.	Pedapadu	3,313		
	Sub total	*112,741*		
	Total			139,452
	Total (Less 7.5% common lands)			128,993

Source: Office of ISRMC Circle, Eluru, Andhra Pradesh

P-V Link Command Area Features

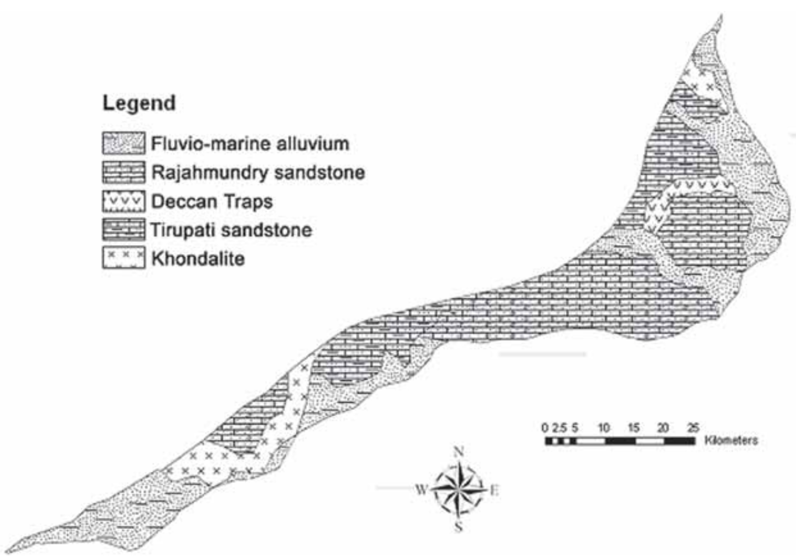
Climate and Topography

The Polavaram–Vijayawada (P-V) Link's canal command area falls under the Krishna-Godavari agro-climatic zone. The area has a hot and semi-arid to sub-humid tropical climate. The average annual rainfall is about 1,000 mm. About 70 % of the rainfall is received during the 4 months (June to September) of the southwest monsoon season, and 20 % in the northeast season (October to December). The temperature varies from about 44 ^{o}C (maximum) in May to about 22 ^{o}C (minimum) in December. The general topography of the area (through which the P-V Link is aligned with the en route command area) is mostly plain with a few local high mounds and sporadic hills. In general, the topsoil within the area is mainly of red earth, black cotton soils and river alluvium.

Geo-hydrological Conditions

A wide variety of the geological formations, ranging in age from the Achaeans to recent alluvium, occur in the West Godavari and Krishna districts (Figure 2). The geological formations in the P-V Link's canal command mainly belongs to Achaean group of rocks, which are represented by Khondalites, and Gondwanas, which in turn are represented by Chintalapudi, Gollapalli, Tirupathi and the younger Rajahmundry sandstones of the Mio-Pliocene age (GWD 1999; GWD 2003). The Khondalites are compact, hard and impervious in nature due to the absence of a primary porosity and permeability at certain places. With the development of secondary porosity, resulting from weathering, fracturing and re-joining, the Khondalites become groundwater repositories at selected pockets. The vertical extension of weathered/fractured zones varies widely from very shallow depths near the hill slopes to depths as great as 30 m in the valleys and topographic lows. The occurrence and movement of groundwater is

Figure 2. Geological map of P-V Link command.



controlled by the degree of interconnection between the secondary pores/ voids, which are developed through fracturing and weathering. In general, the Khondalite group of rocks has a poor groundwater yield. Groundwater occurs in these rocks under water table conditions, mainly in the weathered and fractured zones, and exploitable groundwater is found within the first 30 to 40 m of depth below ground level. The yields of the wells vary from 100 to 500 lpm. All the sandstone formations are continuous and provide as extensive aquifers but for intervening clays. In these sedimentary formations, groundwater is associated mainly with a primary porosity. The porosity and, hence, the storage capacity of these sandstones vary with the extent of shale and clays present in them. The Gollapalli sandstones, which have a high occurrence of shale, have poor groundwater potentials while the Chitalapudi and Tirupati sandstones possess good aquifers owing to their relatively more porous and permeable nature. Generally, the groundwater in these sedimentary formations occurs under semi-confined to confined conditions, and is exploited by means of dug-cum bore wells and tubewells of varying depths form 60 to 300 m below the ground, yielding 500 to 8,000 lpm. Rajamundry sandstones form the best aquifers in the district. The depth of wells constructed in these sandstones varies from 70 to 250 m below ground level and their yield ranges from 500 to 9,000 lpm.

Agriculture and Irrigation

Land Use

The net sown area in the *mandals* (through which the P-V Link right canal is aligned and proposed to irrigate parts of their lands) is about 55 % out of a geographical area of 4.9 lakhs ha in 2004-05 (CPO 2005). The area under forests is about 9.5 % with wastelands occupying about 67,000 ha and accounting for 14 % of the geographical area. Current fallow is about 5 %.

Groundwater Irrigation and Conditions

Presently, groundwater is the major source of irrigation for the proposed command of the P-V Link. Rain-fed farmers or the areas not receiving any irrigation were peculiarly absent from the study. All the farmers surveyed (excepting three) are irrigating their crops either under tubewells or canals (Table 2). As high as 85 % of the farmers depend solely on tubewell irrigation, while about 7 % of farmers depend on groundwater in conjunction with canal water. Thus, about 75.8 % of the area of the surveyed farmers is under tubewell irrigation and 11.6 % under the conjunctive use of groundwater and surface water. About 11 % of the farmers are using canal irrigation for 11.2 % of the irrigated area. The canal irrigation is from the Godavari delta irrigation system. The assessment of the NWDA had also showed groundwater as the major source of irrigation in the area.

As indicated by the source-wise irrigated area, groundwater irrigation is predominant in this area. Most of the area is under semi-consolidated formations, while the other geo-hydrological formations in the area are consolidated and unconsolidated (alluvium). Using the criteria of the ‘Ground Water Estimate Committee (GE)-1997’, the AP State Groundwater Department (GWD, 2006) has classified: four *mandals* as ‘Over Exploited’; four as ‘Critical’; and three as ‘Semi-Critical’ out of the 23 *mandals* of the West Godavari and Krishna districts, where the P-V command is located (Table 3).

Table 2. Mandal-wise sampled area under different sources of irrigation.

Sl No	Mandal	Canal				Tubewell				Conjunctive use				Rain-fed			
		Farmers	Kharif ha	Rabi ha	Annual Crops ha	Farmers	Kharif ha	Rabi ha	Annual Crops Ha	Farmers	Kharif ha	Rabi ha	Annual Crops ha	Farmers	Kharif ha	Rabi ha	Annual Crops ha
1.	Agiripally	-	-	-	-	10	17.4	-	-	1	4	4	-	-	-	-	-
2.	Devarapally	-	-	-	-	6	8.4	8.4	25.6	1	0.4	-	-	3	6.4	-	-
3.	Eluru	5	11.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.	Gannavaram	-	-	-	-	26	57.8	-	-	-	-	-	-	-	-	-	-
5.	Kovvur	-	-	-	-	-	-	-	-	7	30	30	16.4	-	-	-	-
6.	Nidadavolu	1	1	1	-	4	1.2	1.2	14	-	-	-	-	-	-	-	-
7.	Nuzivedu	-	-	-	-	18	26.4	2.4	4.8	-	-	-	-	-	-	-	-
8.	Pedavegi	-	-	-	-	16	25.6	25.6	48.8	-	-	-	-	-	-	-	-
9.	Polavaram	-	-	-	-	11	9.4	-	-	2	2.8	-	-	-	-	-	-
10.	Tadepallygudum	5	18	18	-	17	30	25.6	10.8	-	-	-	-	-	-	-	-
11.	Tallapudi	-	-	-	-	15	27.8	-	4	-	-	-	-	-	-	-	-
12.	Unguturu	6	20.8	20.8	-	9	23.2	21.6	8	-	-	-	-	-	-	-	-
13.	Vijayawada	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	-
	Total	17	51.4	39.8	0	132	227.2	84.8	122	11	37.2	34	16.4	3	6.4	0	0
	Percentage	11	16	25	0	85	71	53	88	7	12	21	12	2	2	0	0
	Cropping intensity	177				124				163				100			

Source: Authors' estimation based on the primary survey

Table 3. Groundwater assessment of West Godavari and Krishna districts.

Serial no.	Mandal	Groundwater availability ha-m			Groundwater utilization ha-m			Groundwater balance ha-m			Stage of development (%)			Category		
		C	NC	Total	C	NC	Total	C	NC	Total	C	NC	Total	C	NC	Total
	West Godavari District															
1.	Polavaram	0	3,383	3,383	0	830	830	0	2,553	2,553	NA	25	25	NA	Safe	Safe
2.	Tallapudi	0	2,038	2,038	0	1,699	1,699	0	399	399	NA	83	83	NA	SC	SC
3.	Gopalapuram	0	4,393	4,393	0	5,357	5,357	0	-964	-964	NA	122	122	NA	OE	OE
4.	Dwarakatirumala	0	3,285	3,285	0	2,959	2,959	0	326	326	NA	90	90	NA	Cri	Cri
5.	Nallajarla	0	3,643	3,643	0	3,451	3,451	0	192	192	NA	95	95	NA	Cri	Cri
6.	Devarapalli	0	5,314	5,314	0	5,283	5,283	0	31	31	NA	99	99	NA	Cri	Cri
7.	Chagallu	0	2,040	2,040	0	1,476	1,476	0	564	564	NA	72	72	NA	SC	SC
8.	Kovvuru	0	1,959	1,959	0	2,437	2,437	0	-478	-478	NA	124	124	NA	OE	OE
9.	Nidadavolu	0	2,868	2,868	0	3,298	3,298	0	-430	-430	NA	115	115	NA	OE	OE
10.	Tadepalligudem	1,022	2,304	3,326	116	1,944	2,060	906	361	1,267	11	84	62	Safe	SC	Safe
11.	Unguturu	1,807	1,883	3,690	96	974	1,069	1,711	909	2,621	5	52	29	Safe	Safe	Safe
12.	Bhimadolu	2,633	1,421	4,054	15	946	962	2,618	474	3,093	1	67	24	Safe	Safe	Safe
13.	Pedavegi	0	4,349	4,349	0	5,745	5,745	0	-1,396	-1,396	NA	132	132	NA	OE	OE
14.	Pedapadu	2,898	840	3,737	15	391	405	2,883	449	3,332	1	47	11	Safe	Safe	Safe
15.	Eluru	3,323	177	3,500	77	241	318	3,246	-64	3,182	2	136	9	Safe	OE	Safe
16.	Denduluru	2,401	1,949	4,351	0	2,763	2,763	2,401	-814	1,587	0	142	64	Safe	OE	Safe
17.	Pentapadu	2,890	0	2,890	0	0	0	2,890	0	2,890	0	NA	0	Safe	NA	Safe
	District	75,861	73,050	148,910	2,483	68,761	71,244	73,378	4,288	77,666	3	94	48	Safe	Cri	Safe
	Krishna District															
18.	Vijayawada (Rural)	2,943	948	3,891	690	826	1,516	2,253	122	2,376	23	87	39	Safe	SC	Safe
19.	Vijayawada (Urban)	1,676	0	1,676	242	61	304	1,434	-61	1,372	14	NA	18	Safe	NA	Safe
20.	Gannavaram	1,694	1,186	2,880	160	526	686	1,534	660	2,194	9	44	24	Safe	Safe	Safe
21.	Agiripalli	0	2,475	2,475	11	1,148	1,159	-11	1,328	1,316	NA	46	47	NA	Safe	Safe
22.	Nuzvid	0	3,211	3,211	0	2,658	2,658	0	553	553	NA	83	83	NA	SC	SC
23.	Bapulapadu	6,865	1,895	8,760	238	1,639	1,877	6,626	256	6,882	3	86	21	Safe	SC	Safe
	District	151,679	53,153	204,832	21,574	28,394	49,968	130,105	24,759	154,864	14	53	24	Safe	Safe	Safe

The piezometers show that the depth of groundwater piezometric levels range from 4.65 to 43.5 m, with an average of 22.5 m during the pre-monsoon period. During the post-monsoon season the range is 1.01 to 37.39 m, with an average of 16.5 m. Waterlogging conditions also prevail in certain *mandals* with 40 % of the observation wells showing post-monsoon levels of less than 2.0 m.

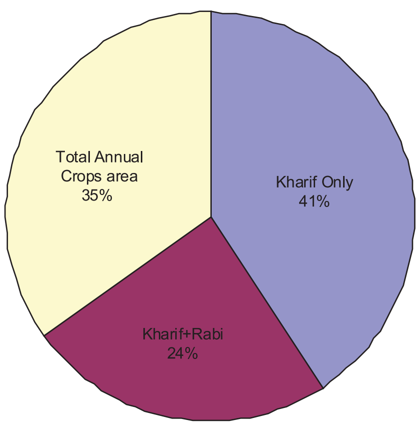
Cropping Pattern

As a part of this study, a survey on the positive and negative externalities of groundwater use and expected benefits from the proposed link has been conducted among 155 farmers spread across the proposed command area of the P-V link through a questionnaire by Sakti, a Hyderabad-based NGO with field offices in the project area. The cropping pattern as reported by District Handbooks of Statistics (CPO 2005) and deduced from the Farm Survey is somewhat similar.

The availability of water on demand and precision in its application encourage farmers in crop diversification and in the adoption of high-value crops. As such, in tubewell irrigated areas, a wide variety of crops are cultivated. Annual crops like tobacco, sugarcane, coconut, oil palm and mango gardens occupy about 35 % of the area of the surveyed farmers (Figure 3). The remaining 65 % of the irrigated area is under various kharif crops. Due to the limited water availability, rabi crops are grown only in about 24 % of the area covered under kharif crops. Thus the cropping intensity under the canal-irrigated area is 177 %, under tubewell it is about 124 %, and under rain-fed conditions only kharif crops are grown (Table 2). Sugarcane (12.2 %) and tobacco (6 %) are the major annual crops in the surveyed area (Table 4).

About 88 % of the area under annual crops is under tubewell irrigation and the remaining 12 % under conjunctive use. The area under canal irrigation is under field crops only. This confirms the earlier assumption that an assured and controlled water supply is a pre-requisite for crop diversification and the adoption of high-value crops under the traditional cropping systems. As such, the additional area proposed to be brought under surface irrigation with

Figure 3. Cropped area under tubewell irrigation – P-V Link.



Source: Authors' estimates based on primary survey

Table 4. P-V Link kharif cropping pattern for the surveyed farmers.

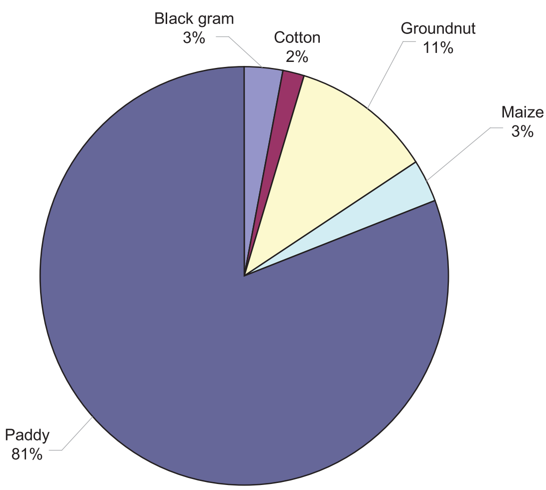
Crop	Total cultivated area ha	Canal	Conjunctive use	Rain-fed	Tubewell	Area, ha	% to Total cultivated area
Sugarcane		-	16.4		40	56.4	12.2
Coconut		-			40.8	40.8	8.9
Mango		-			6	6	1.3
Palm oil		-			8	8	1.7
Tobacco		-			27.2	27.2	5.9
Total annual crops	461		16.4		122	138	
Black gram		-			7	7	1.5
Cotton		-			3.6	3.6	0.8
Groundnut		-			25.6	25.6	5.6
Maize		-	0.8		7.2	8	1.7
Paddy		51.4	36.8	6.4	183.6	278.2	60.3
Kharif area		51.4	37.6	6.4	227	322	

Source: Authors' estimation based on the primary survey

canal irrigation shall be mainly under traditional grain crops and, it is only through enhanced supplies and coverage of groundwater that much of the additional areas under crop diversification, dairy and other remunerative enterprises are likely to develop.

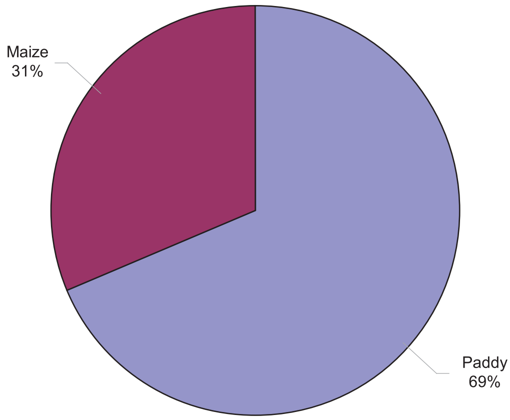
Canal irrigation promotes the wide-scale adoption of paddy in Andhra Pradesh. Paddy in kharif followed by paddy in rabi is the cropping pattern under canal irrigation, as in the rest of the Godawari delta irrigation system. Even under tubewell irrigation, paddy is the predominant crop in the kharif season (Figure 4), and is cultivated in about 81 % of the area followed by

Figure 4. Kharif cropping under tubewell irrigation – P.V. Link.



Source: Authors' estimation based on the primary survey groundnut, maize, black gram and cotton. In the rabi season mainly two crops are grown; paddy in about 69 % and maize in the rest of the irrigated area (Figure 5). Most of the rabi paddy is grown in Tadepallygudem and Unguturu *mandals,* which are close to the delta irrigation system. Only about 34 % of the total kharif area is also under rabi cropping. During a field visit to the command, the farmers indicated that tubewell water is adequate to supplement rainfall for the kharif crops, but it is not enough to irrigate an additional rabi crop.

Figure 5. Rabi crops area under tubewell irrigation – P.V. Link



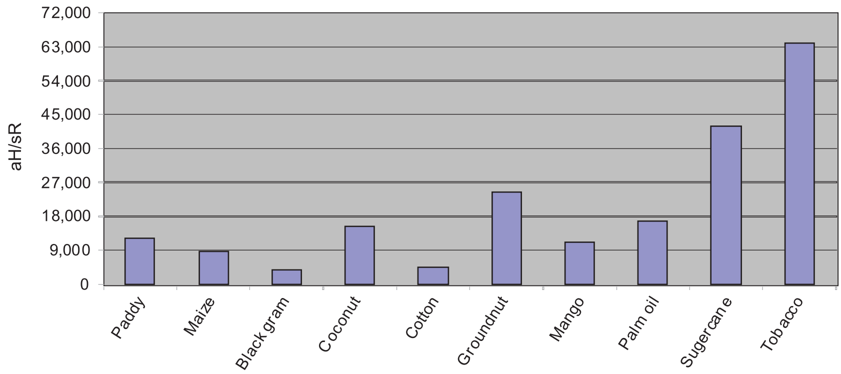
Source: Authors' estimation based on the primary survey

Crop Yields and Net Returns

The average paddy yields are similar under canal and tubewell irrigation (5.0 t/ha) during the kharif season. However, the yields are higher under canal irrigation at 7.2 t/ha in the rabi season. For the large number of tubewell-owning farmers, insufficient groundwater supplies and little support from rainfall constrain their paddy yields to 5.9 t/ha during the rabi season. However, with conjunctive use irrigation in the rabi season paddy yields improve to 6.9 t/ha. The paddy yields under rain-fed irrigation are the lowest at 3.5 t/ha. The data points to an urgent need for the replacement of water-intensive paddy with less water-intensive but more remunerative rabi crops like black gram, groundnut and maize. In the water-stressed Krishna delta area, black gram is the major crop during the rabi season, raised with only one/two irrigations and generating high financial returns.

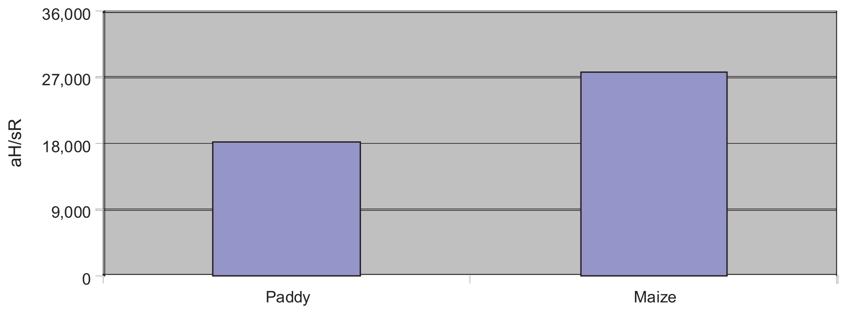
Tobacco gives the highest average net return with about Rs. 63,916/ha, followed by sugarcane with Rs 41,859/ha (Figure 6a). Among the seasonal crops, groundnut yields an average net return of Rs. 24,496/ha and maize Rs. 8,800/ha in the kharif (Figure 6a) and Rs. 27,803/ha in the rabi season (Figure 6b). The average net return of paddy, the largest cultivated crop, is about Rs. 12,158/ha. When both seasons are considered, the net return for paddy under tubewell irrigation, is about Rs. 30,378/ha, and under canal irrigation it is Rs. 40,728/ha (Figure 7). Even though the paddy yields are only slightly different under the canal and tubewell irrigation, the wide variation in the net returns is due to higher tubewell

Figure 6a. Average kharif net returns for different crops.



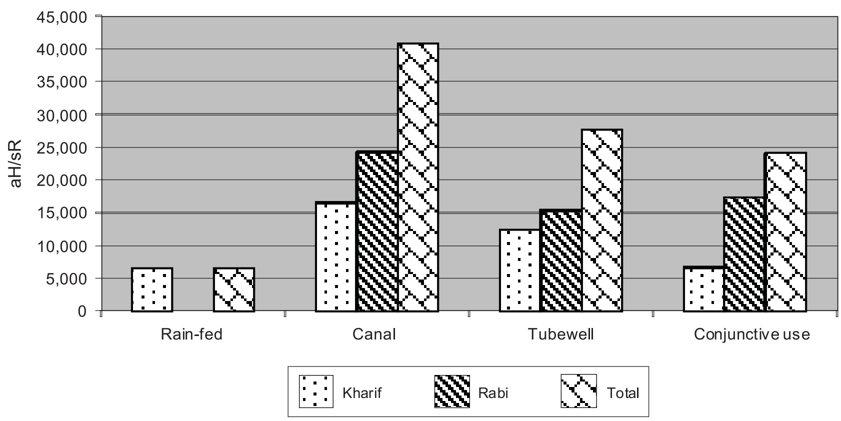
Source: Authors' estimates based on the primary survey

Figure 6b. Average rabi net returns for different crops.



Source: Authors' estimates based on the primary survey

Figure 7. Average net returns with paddy under different irrigation sources.



Source: Authors' estimates based on the primary survey maintenance costs. Groundnut in the kharif, followed by maize, may give the highest returns of about Rs. 52,299/ha/yr among the seasonal crops. Simple economic sense also points out that paddy crop should not be cultivated only with tubewell water during the rabi season, despite the fact that the state provides free power to the farmers for pumping groundwater. Maize has higher net returns and lower water requirements even under the existing situations.

Groundwater Model Studies: Prognosis of Change

The introduction of canal irrigation is known to enhance the recharge of groundwater, which can be used for irrigation through conjunctive use; and also to cause waterlogging conditions and soil salinity in poor quality groundwater regions (Sondhi and Kaushal 2006). A groundwater model study has been conducted using MODFLOW for predicting the groundwater externalities arising from the irrigation in the P-V Link's command. Satellite images from Google Earth and Digital Elevation Models have been used in demarcating the command boundaries, land use and topography. The information on lithology and groundwater depths and quality collected by the AP State Groundwater Department has been used in the model study. The following hydrodynamic parameters have been used (see Table 5).

Table 5. Common hydrodynamic values of different geological formations.

Geological formation*	Permeability (K $m.s^{-1}$)	Storagitivity (%)
Alluvium	10-4 to 10-7	8 to 9
Sandstone	10-3 to 10-6	2 to 15
Fractured basalt	10-2 to 10-5	8 to 10
Fractured granite	10-2 to 10-7	0.1 to 2

Note: *compilation of various sources

The hydrological year is divided into two main trends in groundwater levels: a) a trend of rising water levels during the monsoon season (recharge); and b) a trend of declining water levels during the dry season. To characterize the two different states of the water table, the ends of each season are selected as initial levels (May and November) for each model, respectively.

Calibration is performed only on the MR1 model (rabi season model before P-V Link canal), where the direct groundwater recharge from rainfall does not occur. This minimizes the uncertainty of fixed variables and leads to an easier calibration of aquifer characteristics—only permeability and specific storage parameters are fine tuned. The discrepancies between simulated and observed water table levels are minimized by optimization of an objective function (Root Mean Square), based on 14 piezometric control points selected for the quality of the measurement and their representativeness. A good fitting is obtained with observed water level values. Root Mean Square Error (RMSE) is 3.79 m, which remains quite satisfactory for such a large zone with a complex geological pattern. For validation, the

MK1 (kharif season model before P-V Link canal) model is run applying the direct groundwater recharge from rainfall, all other things being equal. The MK1 simulation flow efficiency is calculated in reference to the piezometric values of the kharif season. The fitting between observed and calculated heads remains good (RMSE = 4.2m). Therefore, the MK1 model confirms the reliability of the MR1 model calibration.

According to the groundwater model in a steady state, the PV-link canal has a significant influence on the groundwater budget: (i) directly by the canal seepage; (ii) indirectly by the irrigation return flow; and (iii) additional groundwater draft due to extension of the command area. Groundwater recharge increases by 28 % due to the supplementary irrigation return flow in the new ISRMC command area. Annual estimated recharge from ISRMC seepage is 130 mm/yr, around 183 Mm^3/yr, which is consistent with the estimations of designed total transmission losses of 260 Mm^3/yr. The annual (rabi + kharif) balance between the situations before and after ISRMC shows a net increase in recharge of 73 mm. Assuming an average aquifer effective porosity of 4 % can explain a water table rise of 1.83 m.

Assuming the addition of 73 mm on water availability, all other things being equal, it appears that the groundwater development status of the five *mandal* categories will change with the additional recharge: ‘Over exploited’ becomes ‘critical’ for two *mandals* (Kovvuru and Nidadavolu); ‘critical’ becomes ‘semi-critical’ for one *mandal* (Dwarakatirumala); and ‘semi-critical’ becomes ‘safe’ for two *mandals* (Chagallu and Tallapudi).

According to the simulations, the potential area of waterlogging (<2m bgl) could increase by 16 % in the rabi and by 19 % in the kharif season, and cover 342 km^2 and 390 km^2 ,respectively, out of the 1,582 km^2 of the inter-canal area. The expansion occurs mainly in the vicinity of the P-V Link canal and, particularly, in the Gannavaram Mandal. The MODFLOW cannot simulate perched local water tables, as such, the presented estimates could underestimate the extent of waterlogged areas.

Expected Crop Production Benefits from P-V Link

The National Water Development Agency in its P-V Link evaluation study has assessed that currently approximately 96,785 ha is under irrigated crops and another 4,032 ha area is under rain-fed crops (Table 4). An area of about 35,953 ha needs to be developed before surface irrigation is introduced. At present the cropping intensity in tubewell and canal irrigated area of the contemplated command area is about 124 %. The farmers’ survey results on the net benefits have been used to estimate the current agricultural net returns and the expected benefits in the future after the commissioning of the P-V link project. Annually, the net returns from groundwater dependent agriculture in the proposed command is about Rs. 162 crores (INR 1.62 billion), which is threatened due to a diminishing resource and declining groundwater levels. After the commissioning of the P-V Link, not only the groundwater irrigated area will be sustainable but also the remaining rain-fed area that will come under irrigation. Overall, the cropping intensity is expected to increase to 150 %. The projected estimates show that the total current benefits of about Rs. 16,872 lakhs/year are likely to increase to Rs. 27,853 lakhs/year—an increase of about Rs. 11,000 lakhs/year (due to enhanced crop production from more area under irrigation and increased cropping intensity, (see Table 6).

Table 6. Projected net returns in P-V Link command.

Crop	NWDA assessed area under crops			Irrigated Area			Unirrigated Area			Current net returns (Rs. in lakhs)	Projected net returns after P-V Link (Rs.in lakhs)
	Irri-gated area ha	Unirri-gated area, ha	Total ha	Yiel-dt/ha	Net Returns, Rs/ha	Total Net Returns, Rs in lakhs	Yiel-d,t/ha	Net Returns, Rs/ha	Total Net Returns Rs in lakhs		
Rice	60,672	713	61,385	5.0	12,158	7,377	1.69	7,473	53	7,430	7,463
Black Gram	6,150	1,465	7,615	0.6	9,995	615	0.4	7,465	109	724	761
Maize	2,553	201	2,754	4.8	8,800	225	1.87	3,153.8	6	231	242
Chillies/Cotton	2,972	25	2,997	1.0	11,145	331	0.5	5,676.2	1	333	334
Groundnut	6,786	810	7,596	3.1	24,496	1,662	1.58	7,299.4	59	1,721	1,861
Tobacco	1,728	0	1,728	1.9	63,916	1,104		0	-	1,104	1,104
Sugarcane	9,258	0	9,258	86.7	41,859	3,875		0	-	3,875	3,875
Fruits/Mango	0	3,945	3,945	0	0	-	25.8	10,954	432	432	432
Palm oil, Coconut	6,339	0	6,339	-	16,103	1,021		0	-	1,021	1,021
Sub-total	96,458	7,159	103,617		16,805	16,210		9,247	662	16,872	17,094
Unirrigated area to be developed		35,953	35,953								5,931
Total expected net returns											23,025
Total expected net returns with cropping intensity of 150 %											27,853

Assumptions:

(1) Cropping intensity shall increase from the current level of 124 % to 150 % after the project

(2) The existing unirrigated area after the project will have a similar cropping pattern as that of the current irrigated area

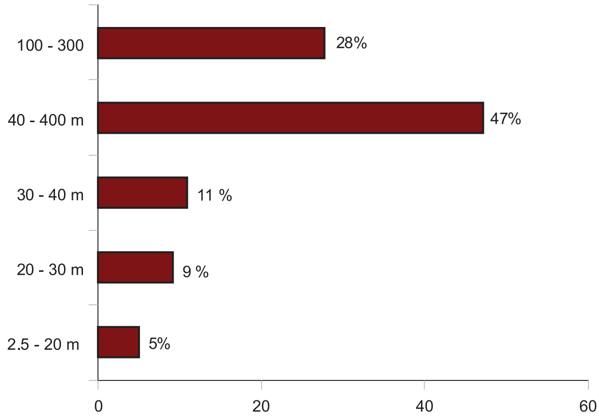
Source: Authors' estimation based on the primary survey

Sustainability Issues of the P-V Link Command

Groundwater Irrigation

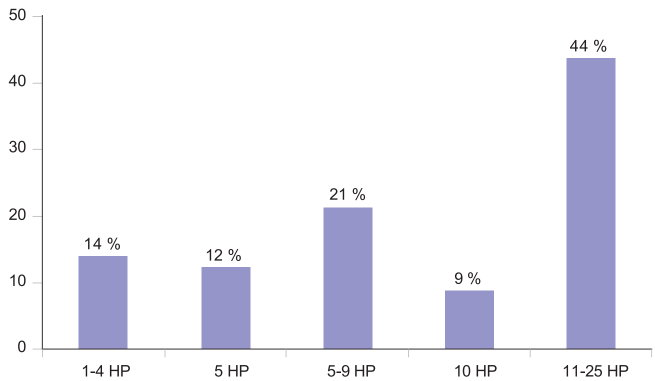
Groundwater irrigation has been reported to be beneficial in terms of higher productivity and cropping intensity, as compared to rain-fed agriculture. However, groundwater irrigation through tubewells in the consolidated and semi-consolidated formations of the area is already threatened with declining groundwater levels and over-exploitation. More than 75 % of tubewells are deeper than 40 m (Figure 8), and 28 % of them are deeper than 100 m. The deep tubewells have necessitated the installation of higher capacity pump sets. More than 53 % of the pump sets used are of a capacity as high as 10 HP or more (Figure 9), sometimes even as high as 25 HP. The cost of tubewell installation and the cost of maintenance are also very high and on average costs Rs. 1,46,000 and Rs. 3,000/ha, respectively (Table 7).

Figure 8. Depths of tubewells in the P-V Link area.



Source: Authors' estimation based on the primary survey

Figure 9. Tubewell pumpset capacity in P-V Link area.



Source: Authors' estimation based on the primary survey

Table 7. Cost of tubewell construction and pump-set and maintenance cost per ha.

Tubewell + Pump-set Cost Rs.	No. of tubewells	Tubewell maintenance cost Rs. / ha	No. of tubewells
25,000 - 50,000	10	1,000-2,000	22
50,000 - 100,000	31	2,000-3,000	69
100,000 - 150,000	41	3,000-4,000	16
150,000 - 200,000	22	4,000-5,000	17
200,000 - 250,000	15	5,000-9,000	7
>250,000	12	Cost not known	4
Cost not known	4	Total tubewells	135
Total tubewells	135	Average	Rs. 3,000/ha
Average cost	Rs. 1,46,000		

Source: Authors' estimation based on the primary survey

The cost of tubewell installation and pumpsets of 67 % of the 135 tubewells in the area is more than Rs. 100,000 for farmers. Presently, the power supply is fully subsidized and the farmers are not paying any electricity charges in Andhra Pradesh. However, the state has to reimburse these costs to the APTRANSCO (State Power Supply Agency). In calculating the net returns only the cost of tubewell maintenance has been considered. If the interest on capital cost and the opportunity cost of power supply are considered, the viability of tubewell irrigation from such deep groundwater bodies may become decline and ultimately become unviable. Recharges to the groundwater body from the surface water to be brought into the area through the P-V Link are likely to reduce the stress on groundwater and is likely to become less costly.

Waterlogging and Soil Salinity

Even though 51 farmers (33 %) reported some sort of soil salinity problem and of having to adopt coping measures such as gypsum application, FYM application etc. (Table 8), the problem of soil salinity is not serious, as indicated by the crop yields - the paddy yields from the supposedly soil salinity affected areas are as good as normal soils. However, due to the presence of hard-rocks and clayey layers at shallow depths, waterlogging problems may occur in the command, as happened in the neighboring Nagarjuna Sagar Left Canal command, where about 7.0 % of the command area is reported to be suffering from groundwater levels less than 2.0 m below ground level. Model studies have made a prognosis of the extent and location of the expected waterlogging problem in the proposed command.

Table 8. Cost of coping measures for soil salinity and waterlogging.

Soil Salinity (SS) Coping Measures	Average Cost, Rs/ ha	Range, Rs/ha
Scrapping of salts	543	400 – 1,000
Gypsum application	739	250 – 2,500
FYM application	1,045	500 – 2,800
Additional expenditure due to soil salinity	1,519	250 – 3,475
Additional expenditure due to waterlogging	500	500

Recommended Agriculture Strategy under the P-V Link

The strategy for realizing the benefits of bringing canal irrigation under the P-V Link to this water-stressed and predominantly groundwater irrigated area has to focus on improving agricultural production, sustaining the infrastructure (tubewells, electricity connections, micro-irrigation systems, processing facilities, etc.) that is already built and safeguarding the livelihoods of farmers resident in these areas. The following points need attention.

- In the sampled area, 135 out of the 155 farmers own a tubewell, and incur heavy investments on tubewell construction and pump sets. Even after the introduction of canal irrigation, conjunctive use of surface and ground waters needs to be promoted to provide better irrigation facilities to the crops, to make use of the farmer-owned infrastructure and to prevent waterlogging and consequent soil salinity problems.

- When the seasonal and annual crops are considered, about 40 % of the irrigated area is under crops other than paddy. About 12 % of the area is under horticulture and many of the horticulture farms have been installed with micro-irrigation systems. Similarly, tobacco cultivators in the area have established post crop processing facilities for drying, packing and transporting tobacco to factories. Necessary policies need to be in place to promote the utilization of these facilities and further expand this cropping system to reduce the dependency on the paddy crop—a highly water-intensive grain crop.

- Groundnut in the kharif followed by maize in the rabi, seems to be a good combination for less water use and high net returns. Similarly, the project area has a large area under annual crops and plantations, but yield levels of these enterprises are sub-optimal and need to be significantly improved to realize higher values per unit of water utilized.

- Introduction of surface irrigation systems in the sub-basin is likely to improve the groundwater regime and, yet, may not be sufficient enough to sustainably meet the current and future water requirements. The conjunctive management of surface and groundwater resources and a scientific demand management through optimization of cropping systems have the potential to effectively harness the benefits of this river-linking initiative.

- About 16 % of the proposed command is likely to witness waterlogging, especially in the Gannavaram block. And if appropriate remedial measures, such as proper planning of groundwater use in the affected and adjoining areas, are not put in place, this will become a serious negative externality of the project. However, the worst affected areas can be put under paddy-paddy crop rotation for higher economic benefits.

- Since the proposed command area is already agriculturally well developed, the introduction of canal irrigation should aim at sustaining the agriculture in the water-stressed area without leading to major changes in the cropping pattern, and ensuring better livelihoods.

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