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Development of Linear Programming Model for Crop Water Planning to Maximize Benefit During Deficit Years in Appapuram Channel Command of Krishna Western Delta – A Case Study

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ABSTRACT

The computer simulation model CROPWAT was applied to estimate crop water requirement in Appapuram Channel Command under Krishna Western Delta in Andhra Pradesh for the years 2000 to 2010. In the model, the Penman – Monteith method for evapotranspiration calculation was used. It was estimated that the gross water requirement for Appapuram Channel Command area to irrigate 8880 ha registered and 4000 ha unregistered ayacut during kharif season and maize 4000 ha during rabi to be 82.68 M.cum. The canal operation plan was prepared for estimated gross water requirement for different scenario. Linear Programme was developed to maximize benefit during deficit years.

Key words : Actual evapotranspiration, Available soil water index, Crop coefficients, CROPWAT, Potential evapotranspiration,Relative yield ratio.

Efficient use of water in the state of Andhra Pradesh is becoming an important issue due to increasing irrigation water requirements as well as environmental sustainability. Since 1850s, the Krishna basin has seen an increasing mobilization of its water resources and dramatic development of irrigation, with little regard to limits of available water resources. This progressively lead to closure of basin (zero or minimal discharge to ocean) during 2001-2004 and surface water resources were almost entirely committed to human consumption uses, increasing ground water abstraction contributed to the decrease in surface water base flows and discharge to the ocean was almost zero. Despite evidence of basin closure, the three states that share the Krishna water continue to strongly promote their agriculture and irrigation sectors. The downstream areas of Krishna basin largely depend on the action of upstream water users. The lower Krishna basin is one of the first regions to be adversely affected by any hydrological changes that take place elsewhere in the basin and to witness both severe water shortages and a spatial redistribution of water during the times of drought. This development path can no longer be sustained without impinging on existing water use and affecting the security of supply for existing uses. In the present study, attempt was made to develop a linear programming model for crop water planning and to maximize benefit during deficit years in Appapuram Channel Command of Krishna Western Delta, India.

MATERIAL AND METHODS

The steady area was Appapuram channel commanded area which branch from Kommamur branch of Krishna Western Main Canal. The steady area was located in Krishna western delta in Guntur district of Andhra Pradesh and is located at 16^0 04' N latitude and 80^0 34' E longitudes. The details of the commands were given in Table 1. The cropping pattern followed was paddy-maize-fallow. The average rainfall from 2001 to 2010 was 974 mm. Crop water demand was estimated using CROPWAT simulation program. Various input parameters fed to CROPWAT program were average monthly minimum, maximum temperature, relative humidity, sunshine hours, rainfall and wind speed.

CROPWAT is a programme that uses the Penman-Monteith method (FAO 2002; FAO, 1992) for calculating reference crop evapotranspiration. This estimate was used in crop water requirements and irrigation scheduling calculations. CROPWAT calculates the irrigation water requirements (either per month or for a week period of as required) of a cropping pattern in an irrigated area of various stages of crop development throughout the crop growing season. The input data of CROPWAT are organized through three files, a data file on the irrigated area, a meteorological data file and a cropping pattern data, CROPWAT creates tables and graphs giving reference evapotranspiration crop irrigation requirements on a seven day or monthly basis, effective precipitation etc.

Table 1. Key indicator values.

	Gross Irrigation Requirement (GIR) M.Cum	Effective Rainfall (EF) M.Cum	Gross Water Requirement (GWR) M.Cum	Per cent contribution of Ef
Good year	55.97	66.85	122.82	54.43%
Normal year	75.01	52.08	127.10	40.98%
Defict year	80.65	52.08	132.70	39.24%
Decennial average	60.99	63.40	124.39	50.96%

Figure 1. Sensitivity analysis of the developed Linear Programming Model.

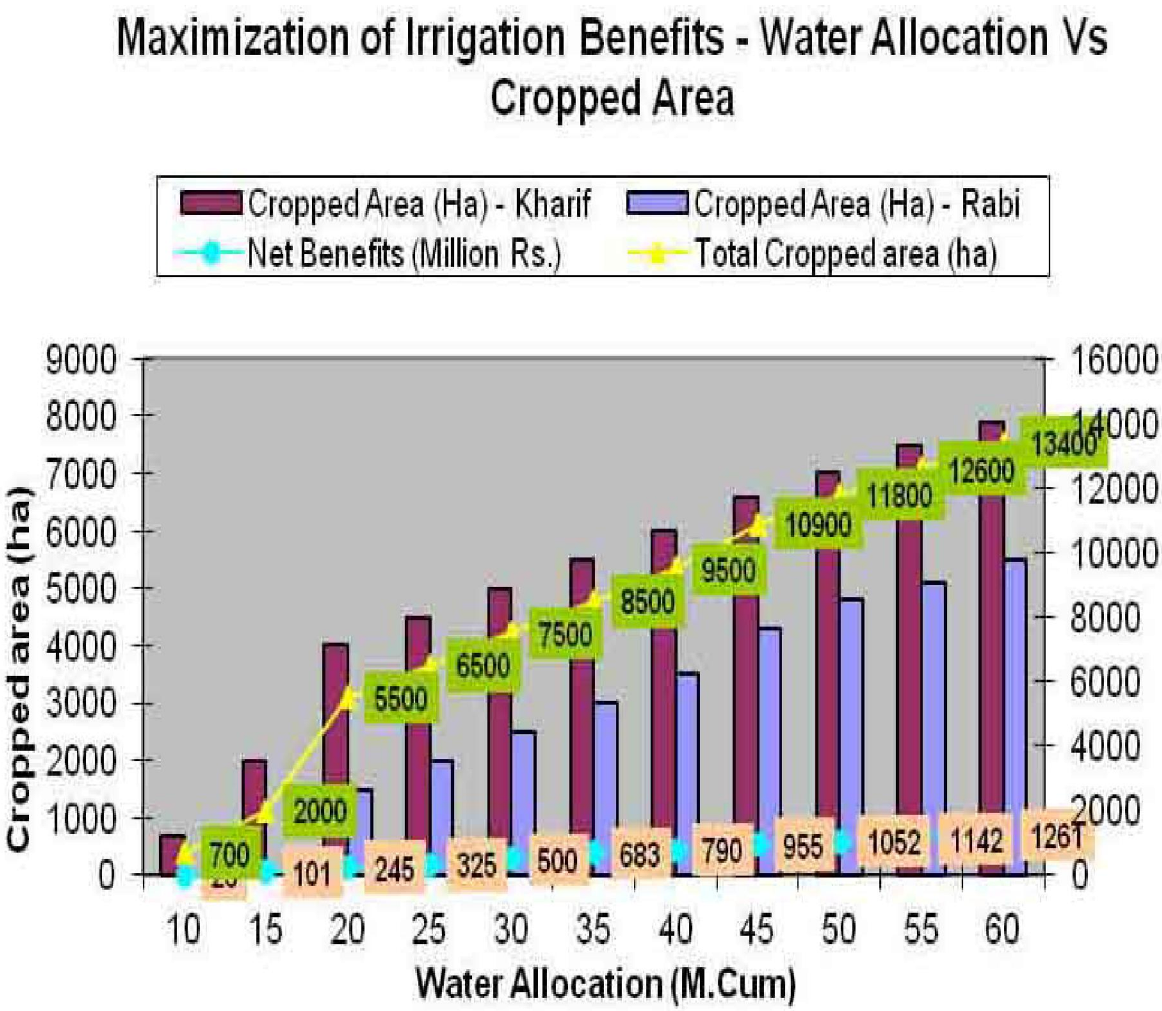

Table 2. Irrigation scheduling and canal operation plan of Appapuram command area for Deficit year Canal Operation Plan for Appapuram distributory of Krishna Western Delta main Canal (Deficit rainfall year)

				1 Day	5 Day	2 Day	3 Day	4 Day	6 Day	7 Day
Full	368	10.421	F	0.9003	4.5017	1.8007	2.7010	3.6013	5.4020	6.2509
3/4th	276	7.815	T	0.6752	3.3762	1.3505	2.0257	2.7010	4.0515	4.6882
Half	184	5.210	H	0.4502	2.2508	0.9003	1.3505	1.8007	2.7010	3.1255
40%	147	4.163	P	0.3596	1.7982	0.7193	1.0789	1.4386	2.1579	2.5004
CA	Month	Total Cropped Area	UCA	N and LP	I R at FL	C W D at FL (m3)		E R	I R at FL	SL I in Main canals
		Ha	Ha	mm	mm	mm	total	mm	M cum	M cum
1	2	4	5	6	10=8-9	7	8=7+6	9	Col 11 = Col 10 X (Col 5 + Col 6) X 10/ (1000000)	12
N	2-Jul	2954.7	1330.9	71.75	34.05		71.8	37.70	1.46	0.44
N	9-Jul	5745.8	2588.2	71.75	34.05		71.8	37.70	2.84	0.44
N	16-Jul	8189.2	3688.8	71.75	34.05		71.8	37.70	4.04	0.44
N /LP/V	23-Jul	8880.0	4000.0		6.80	10.54	10.5	3.74	0.88	0.44
N /LP/V	30-Jul	8880.0	4000.0		14.56	25.55	25.6	10.99	1.88	0.44
N /LP/V	6-Aug	8880.0	4000.0		19.52	39.46	39.5	19.94	2.51	0.44
N /LP/V	13-Aug	8880.0	4000.0		17.82	41.58	41.6	23.76	2.30	0.44
N /LP/V	20-Aug	8880.0	4000.0		15.05	40.02	40.0	24.97	1.94	0.44
N /LP/V	27-Aug	8880.0	4000.0		13.16	38.51	38.5	25.35	1.70	0.44
N /LP/V	3-Sep	8880.0	4000.0		8.00	37.02	37.0	24.95	1.03	0.44
V/ F	10-Sep	8880.0	4000.0		11.65	35.52	35.5	23.87	1.50	0.44
V/ F	17-Sep	8880.0	4000.0		11.72	34.04	34.0	22.32	1.51	0.44
V/ F	24-Sep	8880.0	4000.0		12.06	32.59	32.6	20.53	1.55	0.44
V/ F	1-Oct	8880.0	4000.0		12.38	31.14	31.1	18.76	1.59	0.44
V/ F	8-Oct	8880.0	4000.0		12.45	29.71	29.7	17.26	1.60	0.44
V/ F	15-Oct	8880.0	4000.0		12.13	28.33	28.3	16.20	1.56	0.44
F /YF	22-Oct	8880.0	4000.0		11.43	27.09	27.1	15.66	1.47	0.44
F /YF	29-Oct	8880.0	4000.0		10.37	25.93	25.9	15.56	1.34	0.44
F /YF	5-Nov	8880.0	4000.0		8.93	24.51	24.5	15.58	1.15	0.44
F /YF	12-Nov	8880.0	4000.0		7.67	22.78	22.8	15.11	0.99	0.44
R	19-Nov	8880.0	4000.0		7.61	20.61	20.6	13.00	0.98	0.44
R	26-Nov	6972.6	3140.8		8.09	14.35	14.4	6.26	0.82	0.44
R / H	3-Dec	4805.1	2164.5		6.56	7.01	7.0	0.45	0.46	0.44
R / H /SM	10-Dec	1306.2	738.4		1.59	1.59	1.6	0.00	0.03	0.44
R / H /SM	17-Dec	2930.4	300.0		2.01	2.01	2.0	0.00	0.06	0.44
V/ F	24-Dec	4351.2	400.0		3.02	3.02	3.0	0.00	0.14	0.44
V/ F	31-Dec	4351.2	400.0		0.44	0.44	0.4	0.00	0.02	0.44
V/ F	1-Jan	4351.2	400.0		3.24	3.24	3.2	0.00	0.15	0.44
V/ F	8-Jan	4351.2	400.0		4.12	4.12	4.1	0.00	0.20	0.44
V/ F	15-Jan	4351.2	400.0		6.35	6.35	6.4	0.00	0.30	0.44
V/ F	22-Jan	4351.2	400.0		9.57	9.57	9.6	0.00	0.45	0.44
V/ F	29-Jan	4351.2	400.0		13.20	13.20	13.2	0.00	0.63	0.44
YF	5-Feb	4351.2	400.0		16.76	16.76	16.8	0.00	0.80	0.44
YF	12-Feb	4351.2	400.0		19.10	19.10	19.1	0.00	0.91	0.44
YF	19-Feb	4351.2	400.0		20.32	20.32	20.3	0.00	0.97	0.44
YF	26-Feb	4351.2	400.0		21.39	21.39	21.4	0.00	1.02	0.44
YF	5-Mar	4351.2	400.0		22.41	22.41	22.4	0.00	1.06	0.44
YF	12-Mar	4351.2	400.0		22.92	22.92	22.9	0.00	1.09	0.44
R	19-Mar	4351.2	400.0		21.81	21.81	21.8	0.00	1.04	0.44
R	26-Mar	4351.2	400.0		19.27	19.27	19.3	0.00	0.92	0.44
R	2-Apr	4351.2	400.0		16.33	16.33	16.3	0.00	0.78	0.44
H	9-Apr	4351.2	400.0		11.33	11.33	11.3	0.00	0.54	0.44
H	16-Apr	4351.2	400.0		4.05	4.05	4.1	0.00	0.19	0.44

Table 2. conti.............

Full
3/4th
Half
40%

CA	W A at DL per period M Cum	G W A at D incl. MUS per period M. Cum	Irrigation supply		ISM and FC		
			NoD	Duration	M	Supply from the canal (M cum)	C
1	13 =11+ 12	14 = 13 X 1.2	15	16	17	18	19
N	**1.90**	**2.28**	7	July 2 - 8	P	2.50	Con
N	**3.28**	**3.93**	6	July 9 - 14	T	4.05	Con
N	**4.48**	**5.38**	6	July 16 - 21	F	5.40	Con
N /LP/V	**1.31**	**1.58**	5	July 23 - 27	P	1.80	Int
N /LP/V	**2.31**	**2.78**	6	July 30 -Aug 4	H	2.70	Con
N /LP/V	**2.95**	**3.54**	4	Aug 6 - 9	F	3.60	Int
N /LP/V	**2.73**	**3.28**	5	Aug 13 - 17	T	3.38	Int
N /LP/V	**2.38**	**2.85**	7	Aug 20 - 26	P	2.50	Con
N /LP/V	**2.13**	**2.56**	7	Aug 27 - Sep2	P	2.50	Con
N /LP/V	**1.47**	**1.76**	5	Sep 3 - 7	P	1.80	Int
V/ F	**1.94**	**2.33**	7	Sep 10 - 16	P	2.50	Con
V/ F	**1.95**	**2.34**	7	Sep 17 - 23	P	2.50	Con
V/ F	**1.99**	**2.39**	7	Sep 24 - 30	P	2.50	Con
V/ F	**2.03**	**2.44**	7	Oct 1- 7	P	2.50	Con
V/ F	**2.04**	**2.45**	7	Oct 8 - 14	P	2.50	Con
V/ F	**2.00**	**2.40**	7	Oct 15 - 21	P	2.50	Con
F /YF	**1.91**	**2.29**	7	Oct 22 - 28	P	2.50	Con
F /YF	**1.77**	**2.13**	6	Oct 29 - Nov 3	P	2.15	Con
F /YF	**1.59**	**1.91**	3	Nov 5 - 7	H	2.03	Int
F /YF	**1.43**	**1.71**	5	Nov 12 - 16	P	1.80	Int
R	**1.42**	**1.70**	5	Nov 19 - 23	P	1.80	Int
R	**1.26**	**1.51**	5	Nov 26 - 30	P	1.80	Int
R / H	**0.89**	**1.07**	3	Dec 3 - 5	P	1.08	Int
R / H /SM	**0.47**	**0.56**	2	Dec 10 - 11	P	0.72	Int
R / H /SM	**0.50**	**0.60**	2	Dec 17 - 18	P	0.72	Int
V/ F	**0.58**	**0.70**	2	Dec 24 - 25	P	0.72	Int
V/ F	**0.46**	**0.55**	2	Dec 31 - Jan 1	P	0.72	Int
V/ F	**0.59**	**0.71**	2	Jan 7 - 8	P	0.72	Int
V/ F	**0.63**	**0.76**	2	Jan 14 - 15	P	0.72	Int
V/ F	**0.74**	**0.89**	3	Jan 21 - 23	P	1.08	Int
V/ F	**0.89**	**1.07**	3	Jan 28 - 30	P	1.08	Int
V/ F	**1.06**	**1.28**	3	Feb 4 - 6	P	1.08	Int
YF	**1.23**	**1.48**	4	Feb 11 - 14	P	1.44	Int
YF	**1.35**	**1.61**	4	Feb 18 - 21	P	1.44	Int
YF	**1.40**	**1.68**	4	Feb 25 - 28	H	1.80	Int
YF	**1.45**	**1.74**	4	Mar 4 - 7	H	1.80	Int
YF	**1.50**	**1.80**	4	Mar 11 - 14	H	1.80	Int
YF	**1.53**	**1.83**	4	Mar 18 -21	H	1.80	Int
R	**1.47**	**1.77**	4	Mar 25 - 28	H	1.80	Int
R	**1.35**	**1.62**	4	April 1 - 4	P	1.44	Int
R	**1.21**	**1.46**	4	April 8 - 10	P	1.44	Int
H	**0.98**	**1.17**	3	April 14 - 16	P	1.08	Int
H	**0.63**	**0.76**	2	April 17 - 18	H	0.90	Int
		80.65				82.68	

CA: Crop Activity, UCA:Unregistered cropped area, N and LP: Nursery and Land preparation, CWD at FL: Crop Water Demand at Field level, EF: Effective Rainfall, SL: Seepage Losses, W A at D: Water allowance at Distributory, GWA at D: Gross water allowance at Distributory Level, ISM and FC: Irrigation supply mode and flow condition, NoD: No of days, M: Mode, C: Conditions, Con: Continuous, Int: Intermittent, N:Nursery, N/LP/V: Nursery / Land Preparation /Vegetatuvem V/F : Vegatative/ Flowering, F/YF: Flowering / Yeild Formation, R: Ripending, R/H/SM: Ripening / Harvesting / Sowing maize.

Using CROPWAT simulation programme. Using this data an attempt was made to prepare canal operation plan with an objective of matching supply versus demand. Essentially canal operation plan has been the process of realizing; conveying and dividing the water in the canal system to ensure predetermine flows at prescribed time for specified durations at demarcated points at delivery.

Optimization Model

The linear programming model proposed in the present study integrates the reservoir level and a field level decision. It considers the soil-moisture status and the reservoir storage as the state variables and the applied irrigation depths as decision variables. The objective was to maximize the actual evapotranspiration rate to minimize the deficits in the yields.

LP model formation for optimal cropping pattern:-

The objective function is

$$MaxZ = C1\,X1 + C2\,X2 + C3\,X3 \quad \text{---------} (1)$$

In the conceptual model for the Crop-Soil-Water-Atmosphere system, the basic assumption was that the soil acts as a reservoir, the main inputs to the reservoir were rainfall, irrigation, and the main outputs are evapotranspiration, percolation and drainage. The next fortnight, the soil moisture status must be updated with the applied irrigation and actual climatic factors. The formulation for crop simulation is as follows. *(Azhamathulla et al., 2009)*

$$\theta_i\, ED_i^{k+1} - \theta^k_i\, ED_i^k - IRR_i^k + ET_{ai}^k = P_e^k \quad \text{------}(2)$$

$$\theta_i^k = \theta_i^{k-1}\left[ED_i^{k-1} - \frac{Fkc_i^k\,APET}{2.0}\right] + \frac{Fkc_i^k\,APET}{2.0} Zw + ARF^k + IRR_i^k - \frac{Fkc_i^k\,APET}{2.0} \div ED_i^k \quad \text{----} (3)$$

After the estimation of fortnightly soil moisture status, actual evapotranspiration was estimated with the help of Available Soil moisture Index (ASI) using the equation 3. (FAO, Irrigation and Drainage Paper No.56) The ASI indicated the part of the month when available soil water was adequate for meeting full crop water requirements ($ET_a = ET_m$). A combination of ASI value, maximum evapotranspiration (ET_m) and remaining available soil water [(1-p) Sa.D] provides an estimate of the actual evapotranspiration (ET_a).

$$ASI = I_n + P_e + W_b - ((1-p)\, S_a D)/ET_m \quad \text{----------} (4)$$

(3) **Relative yield ratio**

The yield of a crop is affected by water deficits and their rate of evapotranspiration. The rate of evapotranspiration tends to decrease depending on the available moisture content. The relative yields are computed on the basis of the expression given by Doorenbos and Prvin (1977).

$$\frac{Y_{ai}}{Y_{mi}} = 1 - Ky^k\left(1 - \frac{AET_i^k}{PET_i^k}\right) \quad \text{----------------} (5)$$

RESULTS AND DISCUSSION

In the present study, crop water planning at field level has been estimated for Appapuram Channel command on weekly basis. Crop water requirement during deficit year was estimated using meteorological data of the deficit year and weekly water demand was presented in Table 2. Gross total water requirements was estimated to be 52.08 mm. Gross Irrigation Requirement to be applied was estimated to be 80.65 mm (Table 1).

Maximization of crop production during deficit years

To maximize the production (benefit) during deficit years, linear programming methodology was developed. For computation purpose, deficit year was considered as per water releases into the canal system. Net profit coefficients for paddy & maize were obtained from the A.P.Water Management Project, Bapatla. The average yield of paddy was estimated to be 5.78 t ha^{-1} and net profit Rs. 25242 per ha, similarly for maize average yield was estimated to be 9 t ha^{-1} and net profit Rs. 15431 per ha (Refer Anonymous, 2007, Anonymous, 2008, Anonymous, 2009 and Anonymous, 2010)). The objective was to maximize the actual evapotranspiration rate to minimize the deficits in the yields. The available soil moisture at any time period in the objective function was indirectly maximized. Since Appapuram channel command is not deriving water from a storage structure, an arbitrary actual water releases during deficit year to the command was considered as storage limiting constraint. So the limiting constraints were

- Water allocation to the command less than or equal to 35 M. cum (Actual release during 2002)
- Command area (A) = A1 + A2 + A3 + ------ less than or equal to 12880 ha for Kharif and 4000 ha for Rabi seasons (including registered and unregistered command).

A program was written on spread sheet to represent the linear programming formulation. During cropping period, the total PET was estimated to be 805.44/two seasons. Initial soil moisture for the crop during start of fortnight was assumed as zero (mm/cm) and at the end of the fortnight final moisture was computed using equation 2. Irrigation gifts were applied as per the availability of irrigation water and critical stages during which peak water was in demand. Available Soil Moisture Index (ASI) was computed using equation 3.6. Based on the ASI, remaining available soil water and maximum evapotranspiration, the AET values were interpolated. Based on estimation of AET, yield reduction factors were computed using equation 4. Water balance on supply side and demand side were maintained so that maximum benefits were derived during deficit years.

Sensitivity analysis of the developed Linear Programming Model

It was observed from Table 4 and Figure 1 the Net benefits increases from Rs. 23 Million to Rs. 1261 Million with increase in water allocation from 10 M. cum to 60 M. cum and total cropped area increased from 700 to 13400 ha.

CONCLUSIONS

The following conclusions were drawn from the study.

1. Gross Water Requirement (GWR) under Appapuram Channel Command was estimated to be ranging from 123-133 M.cum. The contribution of effective rainfall towards GWR ranged from 52-67 M.cum indicating the fact that almost 40% - 50% if GWR was met from the effective rainfall itself.

2. The major findings of the present research had clearly demonstrated that the average percentage of excess water released was estimated to be 32-101% and there was considerable scope to improve the match between irrigation demand and canal supply. To match the irrigation supply vs demand, irrigation water measurements should be made mandatory at head regulator and at branch canals and distributories. The modernization works of Appapuram Channel should therefore be focused on addressing these issues.

3. Linear Programme was developed and was effective tool to optimize benefit during deficit years. Sensitivity analysis of the developed LP model was carried out for various water allocations to the command area ranging from 10 to 60 M.Cum. Analysis showed that total cropped area was ranged from 700 ha to 13400 ha with net benefit estimated to range in between Rs. 23 millions to Rs. 1261 millions.

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