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Allocation of Canal Water Optimally Employing OPTALL Model

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Introduction

Water is one of the most important inputs for agricultural production. But due to wide variation in its spatial and temporal availability, it is not always possible to apply it to the crop when it is essentially required. Sometimes, in spite of sufficient water availability in the reservoir, water is not released, distributed and allocated timely, adequately and equitably among the farmers due to many technical, hydraulic, socio-economic, institutional, financial and managerial problems as mentioned by Upadhyaya [1] and discussed in detail by Upadhyaya [2]. This leads to wide gap between water supply and water requirement in the canal command, resulting in either water logging or agricultural drought. Both the situations are detrimental and adversely affect the crop yield. This clearly indicates that there is sufficient scope to made water available to farmers in adequate quantity at right time, if canal managers properly plan, manage and release water as per crop water requirement. Upadhyaya [3] has mentioned number of water management technologies in agriculture to improve water productivity. In this paper, optimal and equitable releases of water in the distributaries of Patna Main Canal under various scenarios of water availability by employing OPTALL model have been presented and gap between actual and optimal releases has been assessed for conjunctive use planning.

OPTALL Model and its Capabilities

In order to equitably allocate water among farmers, total water availability, water requirement and a mathematical model capable of optimally and equitably allocating water are required. There are number of approaches to solve the optimization problem. These included dynamic programming, linear and non-linear programming. Of these, dynamic programming and non-linear programming (quadratic) have the potential to solve such problems in a better way because the optimization approach can offer significant benefits in terms of potential water saving, equity in water allocation subject to system constraints. OPTALL model developed at University of Edinburgh has the capability to allocate water optimally and equitably in various offtakes of Patna Main Canal keeping in view the requirement and system constraints (Figure 1). Development of objective function in problem formulation is very important. Since the problem addressed was related to irrigation water management and in particular to ensuring optimal and equitable allocation of irrigation water for farmers, the most appropriate objective function as defined by Wardlaw et al. was as follows [4]:

$$Minimize\ Z = \sum_{i=1}^{n} \frac{(d_i - x_i)^2}{d_i}$$

where n is the number of irrigation schemes, d_i the irrigation demand for scheme i, and x_i the irrigation supply to scheme i. The above equation is subject to canal capacity constraints, continuity constraints, and of course supply constraints defined mathematically as:

$$x_{i,w} \le D_i$$

$$\frac{x_{i,w}}{d_{i,w}} \le 1.0$$

$$\frac{x_{1,w}}{d_{1,w}} = \frac{x_{2,w}}{d_{2,w}} = \frac{x_{3,w}}{d_{3,w}} = \frac{x_{n,w}}{d_{n,w}}$$

Where D_i is design discharge capacity of off-take point 'i', $x_{i,w}$ is irrigation supply in i^{th} off-take in 'w^{th}' week, and $d_{i,w}$ is demand in i^{th} off-take in 'w^{th}' week (Figure 1).

OPTALL was used by Wardlaw et al. [5] to model systems with complex distribution systems and has been demonstrated to be very robust. Wardlaw [6] presented the optimization approach and procedure to solve real time optimization of water for better water allocation. Wardlaw et al. [7] applied a genetic algorithm (GA) to the water allocation problem also, and while acceptable results were produced, they concluded that the GA offered no advantage over quadratic programming for this particular problem.

Data requirement of OPTALL model includes a schematic diagram of Patna Main Canal system network, which is first prepared manually and then with the help of software. Information about various reaches, irrigation schemes, nodes, branches, their capacity, seepage loss/gain and length is required to prepare the network input file. Other input files need weekly water demand in m^3/s at all the nodes as defined in network file. Input file for weekly actual inflows diverted at the head of canal is also one of the input files.

With this input data OPTALL computes optimum and equitable release in the canal offtakes subject to system constraints. The optimal releases not only minimize the gap between water availability and water requirement but also give opportunity to equitably allocate and efficiently utilize the precious water in the command. This model is robust, relatively easy to apply, and has potential as a tool in decision support for real-time irrigation system operation. This approach can be used by scheme managers to improve the equity of their water distribution under various scenarios of water availability.

Actual and optimal canal water supply and comparison with irrigation requirement

Actual and optimal water releases in various distributaries of Patna Main Canal were studied and compared with irrigation requirement considering average, 75% dependable and actual rainfall of 2014 during Kharif and Rabi seasons in head, middle, tail and whole Patna Main Canal. Results are presented graphically for whole Patna Main canal in Figures 2-5.

Number of weeks having excess and deficit release in Patna Main Canal based on actual and optimal supply of canal water over irrigation requirement in head, middle and tail reaches as well as whole canal and range of variation have been summarized from graphs and are presented in Table 1 below. It may be observed from the figures that in case of actual water supply there is a wide gap between supply and irrigation requirement. In some weeks supply is excessively higher

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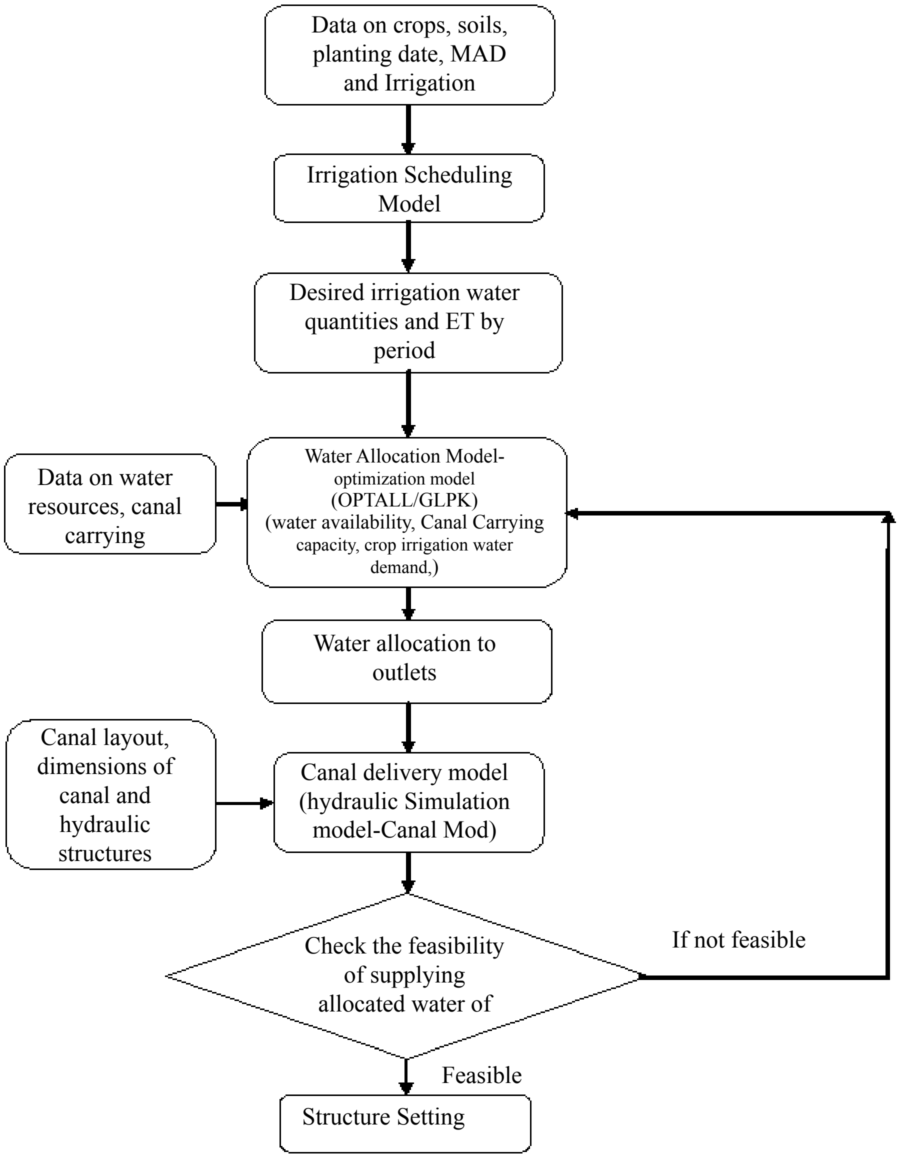

Figure 1: Flow chart of OPTALL.

than requirement, whereas in other weeks it is excessively lower than demand. Table 1 reveals that in case of actual release, during Kharif season number of weeks having excess supply of canal water than irrigation requirement are less than number of weeks having deficit supply of water, whereas during Rabi season trend is opposite and number of weeks having excess supply are more than the number of weeks having deficit supply. The range of deficit supply is less than the range of excess supply, which indicates that there is scope to increase area under irrigation during Rabi period. In case of optimal release of canal water, none of the weeks have excess water supply and number of weeks having deficit water supply are most of the time less than the case of actual release. The range of deficit water supply in case of optimal release is always less than the case of actual release. In Kharif season, deficit supply over irrigation requirement was highest for the case when irrigation requirement was computed considering 75% dependable rainfall followed by the cases of actual and average rainfall. There is significant variation in excess and deficit supplies in head, middle and tail reaches also. Results clearly indicate that optimal releases obtained after employing OPTALL model never show excess supply and number of weeks having deficit supply as well as range of deficit supply reduce significantly and gap between supply and irrigation requirement minimizes in case of optimal release.

Actual and optimal supply-demand ratios in distributaries

Supply-demand ratios for all the distributaries of Patna Main Canal were computed for actual and optimal canal water supply as well as irrigation requirement considering average, 75% dependable and actual rainfall of 2014 during Kharif and Rabi seasons. Summary of distributaries with their supply-demand ratios in various weeks is presented in Table 2. It may be observed from this Table that in case of actual water supply, supply-demand ratios excessively exceeds 1.0 in many weeks in head, middle and tail reaches, whereas it is varying between 0.1 to less than 1.0 in other weeks. Only in very few weeks it is 1.0. On the other hand in case of optimal water supply, the supply-

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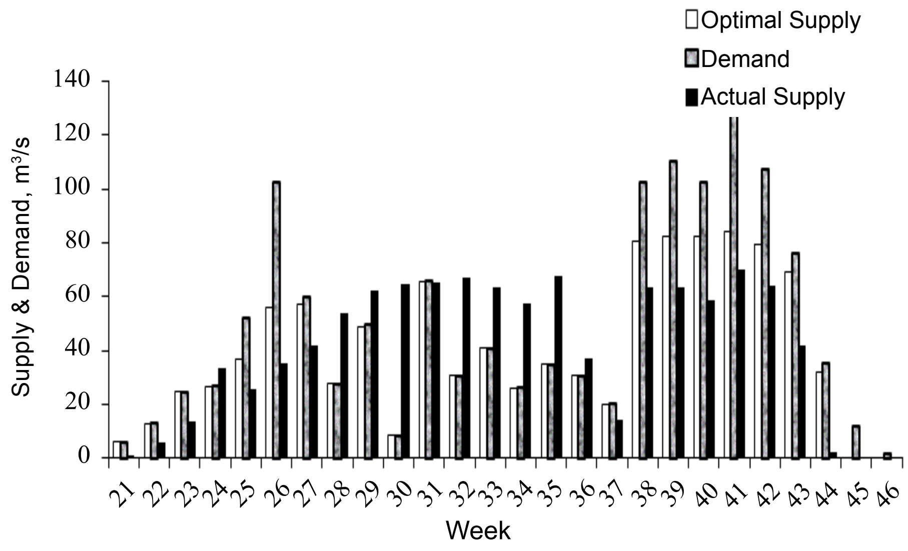

Figure 2: Weekly optimal and actual supply as well as demand considering average rainfall in PMC.

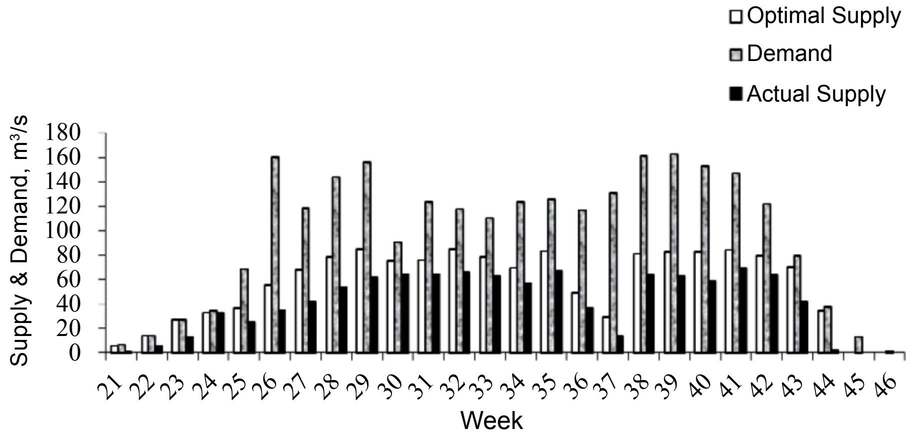

Figure 3: Weekly optimal and actual supply as well as demand considering 75% dependable rainfall in PMC.

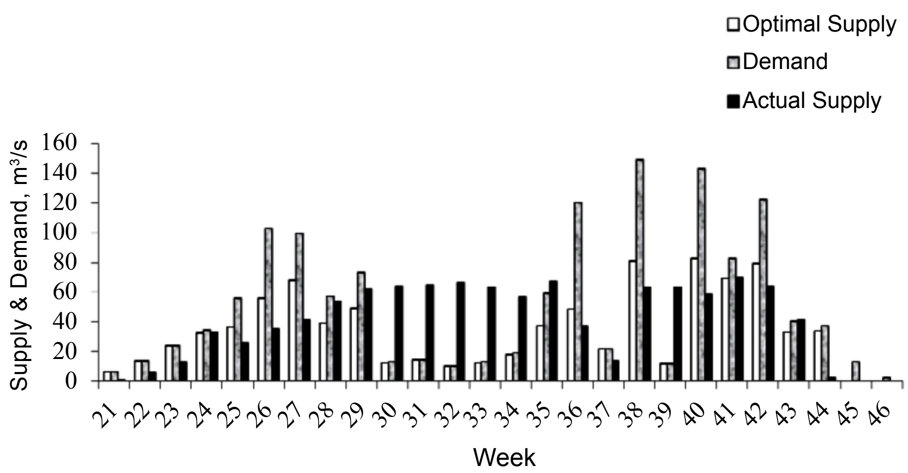

Figure 4: Weekly optimal and actual supply as well as demand considering actual rainfall of 2014 in PMC.

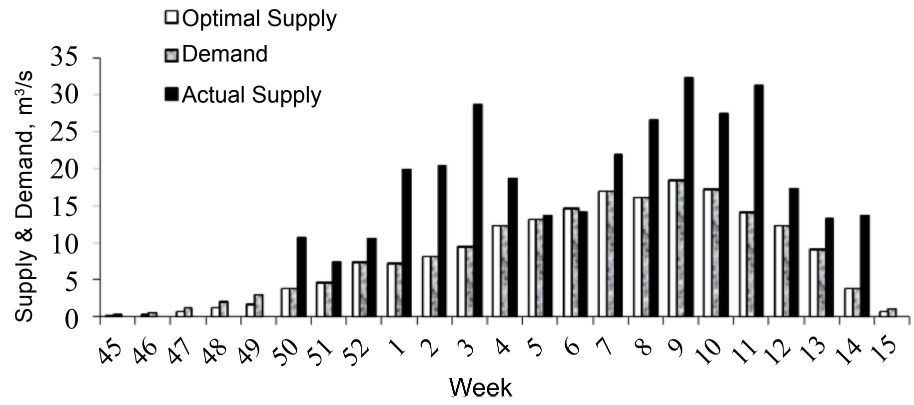

Figure 5: Weekly optimal and actual supply as well as demand during Rabi season in PMC.

	During Kharif considering average rainfall			During Kharif considering 75% dependable rainfall			During Kharif considering actual rainfall of 2014			During Rabi seson		
	Actual release		Optimal release	Actual release		Optimal release	Actual release		Optimal release	Actual release		Optimal release
	Excess over irrig-ation req. No. of weeks and Range (m³/s)	Deficit over irrig-ation req. No. of weeks and Range (m³/s)	Deficit over irrig-ation req. No. of weeks and Range (m³/s)	Excess over irrig-ation req. No. of weeks and Range (m³/s)	Deficit over irrig-ation req. No. of weeks and Range (m³/s)	Deficit over irrig-ation req. No. of weeks and Range (m³/s)	Excess over irrig-ation req. No. of weeks and Range (m³/s)	Deficit over irrig-ation req. No. of weeks and Range (m³/s)	Deficit over irrig-ation req. No. of weeks and Range (m³/s)	Excess over irrig-ation req. No. of weeks and Range (m³/s)	Deficit over irrig-ation req. No. of weeks and Range (m³/s)	Deficit over irrig-ation req. No. of weeks and Range (m³/s)
Head	11 (31.69-0.94)	15 (60.38-0.30)	10 (36.29-0.30)	1 (6.07)	25 (100.40-0.15)	22 (78.36-0.20)	13 (37.72-0.40)	13 (62.92-0.46)	10 (42.98-0.20)	15 (9.37-0.51)	5 (0.77-0.11)	6 (0.43-0.01)
Middle	9 (21.90-0.21)	17 (20.10-0.22)	13 (15.55-0.07)	-	26 (39.77-0.22)	23 (31.95-0.17)	7 (23.29-2.43)	19 (27.75-0.23)	16 (23.36-0.17)	15 (8.64-0.31)	7 (2.12-0.16)	6 (0.88-0.02)
Tail	11 (10.53-0.87)	13 (17.36-1.28)	14 (8.56-0.04)	5 (6.89-0.40)	19 (21.13-1.28)	23 (13.90-0.05)	7 (6.89-1.18)	17 25.07-0.67)	18 (16.32-0.05)	10 (4.24-0.38)	9 (0.80-0.02)	9 (0.04-0.01)
PMC	9 (55.70-5.86)	17 (67.33-1.13)	16 (46.25-0.15)	-	26 (125.80-1.13)	24 (104.73-0.37)	8 (56.37-1.26)	18 (86.07-1.13)	19 (68.92-0.37)	16 (19.24-0.48)	6 (2.98-0.16)	13 (1.35-0.01)

Table 1: Number of weeks and range of variation in excess as well as deficit in release over irrigation requirement in PMC.

demand ratio never exceeds 1.0. It is 1.0 in many weeks. It is also less than 1.0 in the weeks when canal water is available in limited quantity. It is most of the time greater than 0.5 and equitable in all the distributaries subject to the system constraints. It shows that OPTALL model not only allocates water optimally but equitably also, which may lead to efficient and effective utilization of canal water.

Gaps in optimal water supply and demand

Though, compared to actual water supply, optimal water supply could meet the demand equitably and optimally in many weeks during Kharif season and almost in all the weeks during Rabi season, yet during Kharif season in few weeks demand could not be met fully as shown in Figures 2-5. In order to meet this gap there is a need to explore the possibility of ground water use and promote the concept of conjunctive use of rain, surface and ground water in the canal command to improve yields.

Conclusions

In order to minimize the gap between water supply and irrigation requirement OPTALL model based on quadratic programming technique was employed and optimal as well as equitable water allocation plan to meet the irrigation requirement computed after considering average, 75% dependable and actual rainfall for various distributaries of Patna Main Canal under Sone Canal system was developed. The optimal water allocation schedule was found much better than actual release because in no case supply-demand ratio was more than 1.0, whereas in case of actual release it was excessively higher than 1.0 in many distributaries of Patna Main Canal showing inequitable water distribution. In order to utilize canal water equitably, efficiently and judiciously, canal operation schedules need to be developed and reviewed in consultation with water users under various situations of water availability. Through frequent meetings, interactions/dialogues between canal managers and water users and technical back stopping through such decision support tools, most of the water conflicts can be resolved. The gap between optimal water release and irrigation requirement indicates that there is a need to promote ground water utilization and explore the possibility of conjunctive use of rain, surface and ground water in canal command to minimize the gap and improve the yield.

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Reach	Supply-Demand Ratio	During Kharif considering average rainfall				During Kharif considering 75% dependable rainfall				During Kharif considering actual rainfall of 2014				During Rabi seson			
		Actual Release		Optimal Release		Actual Release		Optimal Release		Actual Release		Optimal Release		Actual Release		Optimal Release	
		Weeks	No. of Dist. (Range)	Weeks	No. of Dist. (Range)	Weeks	No. of Dist. (Range)	Weeks	No. of Dist. (Range)	Weeks	No. of Dist. (Range)	Weeks	No. of Dist. (Range)	Weeks	No. of Dist. (Range)	Weeks	No. of Dist. (Range)
Head	> 1.0	23	1-13	-	-	15	1-8	-	-	18	1-13	-	-	17	4-10	-	-
	1.0	9	1-2	16	13	6	1-2	5	13	4	1	8	13	7	1-2	20	3-13
	Partial	22	2-11	7	13	24	2-13	19	12-13	15	2-13	8	13	15	1-5	-	-
	0.0	5	1-9	1	13	8	1-9	-	-	6	1-9	8	13	21	1-13	8	1-13
Middle	> 1.0	22	1-10	-	-	11	1-9	-	-	19	1-10	-	-	17	1-10	-	-
	1.0	7	1-2	13	10	6	1-2	3	10	4	1	13	1-10	2	1	20	4-10
	Partial	19	1-8	7	1-10	22	2-10	21	1-10	15	2-10	14	1-10	8	1-5	-	-
	0.0	7	1-10	-	-	7	2-10	-	-	8	1-10	6	1-10	20	1-10	7	2-6
Tail	> 1.0	15	1-10	-	-	12	1-10	-	-	13	1-10	-	-	17	1-10	-	-
	1.0	4	1-2	7	10	4	1	2	2-3	4	1-2	9	2-10	4	1	19	3-10
	Partial	12	1-10	12	1-10	17	2-10	21	2-10	14	3-10	16	2-10	11	1-4	-	-
	0.0	7	1-10	8	1-10	6	1-10	6	1-10	5	7-10	6	1-10	16	1-10	15	1-10

Table 2: Summary of distributaries partially or fully meeting out demands in various weeks and supply-demand ratios.

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