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Surface Water Yield Model Part II: Application and Economic Analysis of Storage Reservoirs

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Abstract : *A surface water yield model (SWYMOD) developed by Reddy (1993) was used with long term rainfall data in kharif season to generate information on the temporal distribution of the availability of stored runoff in small reservoirs of a few selected microwatersheds in Chotanagpur region of Upper Damodar Valley, Bihar. The availability of runoff in the reservoirs was compared with the estimated gross deficits in the water requirements of three commonly grown crops in the study area, viz, paddy, maize and pigeon pea. On the basis of this comparison and using linear programming model, several crop plans were studied and an optimal crop plan was identified. The optimal crop plan comprised growing maize and pigeon pea on 18.69 ha and 0.33ha of the total irrigable area respectively. The benefit-cost ratio for 5 to 15 years amortization periods varied from 4.4 to 6.7 and 5.6 to 7.9 correspondingly when the reservoir cost is included and excluded from the analysis.*

INTRODUCTION

Land and water are the two critical natural resources that may enhance or jeopardise the agricultural production and productivity depending on whether these are managed properly or not. Though land resources are fixed, it is observed that the water resource is highly variable in time and space (Singh, 1990). Water storage reservoirs are useful in terms of checking soil erosion, flood control, irrigation, fisheries and ground water recharge. The construction of such reservoirs was undertaken in River Valley Projects in the country alongwith soil and water conservation on watershed basis as a measure of sediment control. The quantity of water to be stored in storage reservoirs and its distribution over time are more important in terms of its localised use for irrigation in crop production and better economic benefits to the farmers. Several research workers have observed that the adoption of in-situ moisture conservation techniques in the microwatersheds has increased the agricultural production (Stegmen et al. 1980, Verma, 1987 and Varma, 1990). Agnihotri et al. (1990) observed that the watershed management programme without rain water harvesting and recycling resulted in increased gross returns with low benefit-cost ratio. However, the economic benefits from the small storage structure within microwatersheds

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have not been sufficiently investigated. In the present study, an attempt was made to investigate the localised use of excess runoff stored in small reservoirs for crop production and their optimal returns by selecting the commonly grown crop activities in the Chotanagpur region of Upper Damodar Valley, Bihar, through a modelling approach.

MATERIAL AND METHODS

Project Area

The project area in the present study is located in the subcatchment 8 which is being referred as watershed no. 8/5 in Upper Damodar Valley. The project site is situated near the village Urgi in watershed no, 8/5, which is 42 km away from Hazaribagh and 2 km from Bishnugarh. The latitude and longitude of Urgi are 24°2′ N and 85° 43′ E respectively with an elevation of 485 m above MSL. The Engineering Division of Soil Conservation Department, DVC, Hazaribagh constructed several earthen dams as waterstorage reservoirs, to store the excess runoff coming from the microwatersheds. Out of these five earthen dams, their upstream reservoirs, the contributing microwatersheds and their downstream command area were selected for the present study. The five earthen dams were named as ED5, ED14, ED18, Ed19 and Ed21. These structures were constructed across the main drainage channel and its sub-channels (Fig.1). Hereafter, the selected micro-watersheds are designated by their respective reservoir number as MW5, MW14, MW18, MW19 and MW21. The structures ED18, Ed19 and Ed21 are the upstream reservoirs of ED5 and ED14.

Assesment of Water Availability in the Reservoirs

A surface water yield model (SWYMOD) developed by Reddy (1993) was used to generate the information on storage volumes of reservoirs throughout the kharif season for 20 years. The SWYMOD develops curve numbers (CN) for prevalent land uses in the selected microwatersheds and provides information on volume of excess runoff stored in the reservoirs. The model was operated individually over each selected microwatershed by taking the developed CN for different land uses. The CNs were assumed to be constant throughout the season as there was no historical data available to know any changes in CN values with respect to time.

While applying the SWYMOD over MW5 and MW14, the model was modified to account for spill volumes coming as inflow into storage reservoirs ED5 and RD14. In the modified SWYMOD, spill volume coming from Ed18, ED19 and Ed21 on a particular day of computation was treated as overland flow spreading over the entire agricultural land lying above ED5 reservoir. To account for the losses in overland flow, the total spill volume of Ed18, Ed19 and Ed21 was multiplied with the runoff: rainfall ratio on the particular day of spill occurence to obtain actual spill volume as inflow into Ed5. Subsequently, the spill volumes from ED5 were directly added to the runoff volume coming from the area contributing to ED14.

The storage volumes thus generated for the kharif season for the 20 years were subjected to probability analysis by using Weibull's equation which is widely adopted for most of the practical purposes (Mutreja, 1990). The probability analysis was done by selecting minimum assured volume of water in the structure in different standard weeks for the 20 years. The availability of assured water in the selected reservoirs was

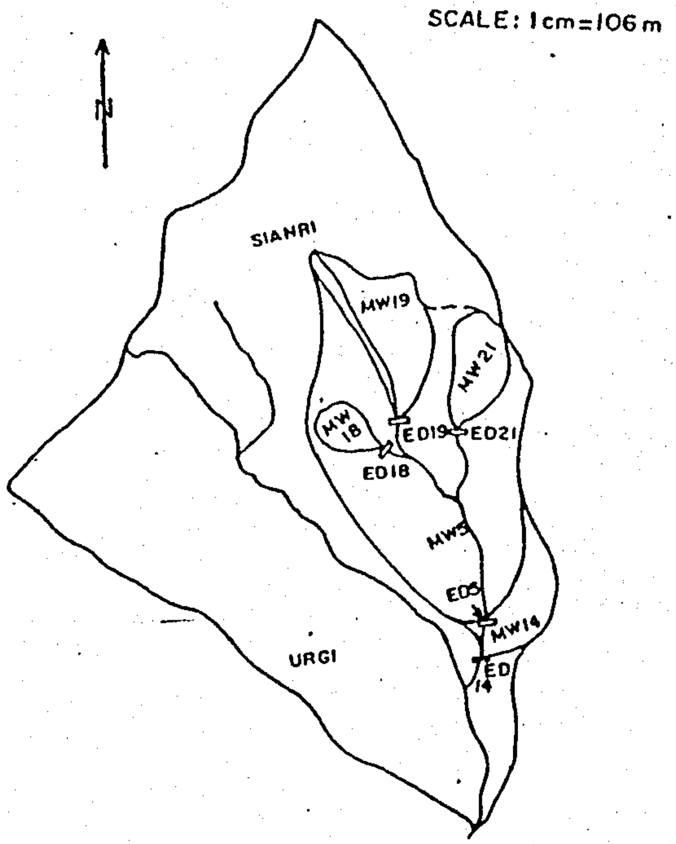

Fig. 1. Location map of microwatersheds in sub-watershed 8/5.

estimated at 75% probability of exceedance in every week of the crop season.

Estimation of Gross Water Deficits of Different Crops

In the selected site, the area available for cultivation was 19.02 ha in MW5. The commonly grown crops under rainfed farming are paddy, maize and pigeon pea. The water deficits for these crops are estimated on weekly basis by using the water balance equation:

$$R+Sp = WR_o + ET_c + PERCO \pm S \quad (1)$$

where,

R = Rainfall, mm

Sp = Absorbed spill depth, mm

WR_o = Weighted runoff, mm

ET_o = Crop evapotranspiration, mm

PERCO = Deep percolation, mm and

S = Surplus (+ve) or Deficit (-ve), mm

The weekly total of rainfall, runoff and absorbed spill depth were obtained from the modified version of SWYMOD. The crop evapotranspiration was calculated by considering the total area of 19.02 ha under crop selected for the total season by using equation:

$$ET_c = K_c * K_p * E_p \qquad (2)$$

where,

K_c = Crop coefficient,

K_p = Pan coefficient and

E_p = Pan evaporation, mm/day.

The crop coefficient for paddy was taken as 1.10 and the pan coefficient as 0.7 (Michael, 1978). The crop coefficients for maize and pigeon pea in different growth periods were obtained from FAO manual (Crithley and Siegert, 1991) and the Division of Agronomy, IARI (Anonymous, 1993) respectively. Also, deep percolation of 7 mm/day was used for sandy loam soils under paddy cultivation (Vamadevan, 1978). The gross deficits were estimated for paddy, maize and pigeon pea at different standard weeks (i.e. 25 to 42nd week) in Kharif season, with irrigation application efficiency of 65% in sandy loam soils (Hukkeri and Pandey, 1977), at 75% probability level of exceedance. The gross deficits at 75% probability level were matched with total water availability in storage reservoirs.

Estimation of Maximum Crop Returns

Based on the information available on crop production, cost of product and cultivation and the gross deficits in different weeks of crop season, the maximum return from crop activities was estimated by using the linear programming (LP) model formulated as:

$$\text{Maximize } Z = \sum_{j=1}^{4} C_j X_j$$

Subjected to,

$$\sum_{i=1}^{17} \sum_{j=1}^{4} a_{ij} x_j \le 19.02 \qquad (4)$$

$$\sum_{i=1}^{17} \sum_{j=1}^{4} D_{ij} X_j \le V_i$$

$$x_j \ge 0 \qquad (6)$$

where,

Z = Maximum net crop return, Rs

C_j = Return of net cultivation cost(in which irrigation cost was not included) of jth crop, Rs/ha

x_j = jth crop activity, (j = 1 for paddy, j = 2 for maize, j = 3 for pigeon pea and j = 4 for rainfed crop)

a_{ij} = Land required per unit of jth crop activity, ha

D_{ij} = Gross deficit of jth crop in ith week, mm

V_i = Total water availability in ith week, ha. mm

i = 26th to 40th week i.e 1 to 13 for paddy

= 25th to 39th week i.e 1 to 15 for maize

= 25th to 41st week i.e 1 to 17 for pigeonpea

In the above formulation, the rainfed crop was taken as little millet with local name Gundli in project area. The above LP model was used for two optimal crop plans. One was imposing no restriction on any of four crop activities selected and second with restriction on paddy to an extent of 2.83 ha. area. The two optimal crop plans were obtained with their maximum net crop return. For these two optimal crop plans, the economic feasibility of irrigation in the project area for different amortization periods was worked out based on the market prices of inputs and the produce in 1993.

RESULTS AND DISCUSSION

Assured Water Availability in the Reservoirs

The causative factor of rainfall and the consequent outcome in the form of runoff are stochastic hydrologic events. To estimate the runoff at the desired degree of assurance, one would require long term runoff data recorded over many years at the study site. It is needless to mention that such data are seldom available. Hydrologic modelling as in the present case of operation of SWYMOD helps to generate long term runoff data corresponding to long term rainfall data which is usually available.

The minimum weekly storage volumes at 75% probability of exceedance for all the selected reservoirs are presented in Table 1. In general, it is seen from the Table 1 that the possible contribution of water for irrigation from the reservoirs ED18, ED19 and ED21 is less when compared to the reservoirs ED5 ad ED14. This is due to the reason that the available maximum total storage in reservoirs ED18, ED19 and ED21 accounts for only 31% of maximum total storage available in all the five reservoirs (Table.2). Also the losses in these reservoirs were observed to be more when compared to ED5 and ED14 (Reddy, 1993).

Gross Water Deficit Analysis

The gross water deficits estimated at 75% probability of exceedance are presented in Table 3 for the three crops viz, paddy, maize and pigeon pea, The Table 3 shows that paddy has deficits in all the weeks of growing period (28th to 40th week) varying from 13.2 to 65.1 mm with minimum in 29th week and maximum occurring in 39th week. This is due to the reason that paddy needs more water to meet the demand of crop evapotranspiration and deep percolation in sandy loam soils and under local climate. Similarly, the gross deficits varied from 5.6 to 16.5 mm with minimum in 35th week and maximum in 34th week for maize during its growing period (25th to 39th week) and 4.8 to 6.3 mm with minimum in 40th week and maximum in 41st week of growing season (25th to 41st week) for pigeon pea respectively.

Optimal Crop Planning

A maximum of four crop activities viz, paddy, maize, pigeon pea and little millet were considered in the study. Of these four, little millet is a rainfed crop requiring no allocation of water from the reservoirs. The data given in the Table 4 were used as basic information in the linear programming model. The LP model was tried for two imposed conditions of crop activities, namely, no restriction on the area under any of the four crops and with restriction on the area under paddy crop. The results of the LP model are presented in Table 5 for the two imposed conditions on selected crop activities. The crop plan comprising maize and pigeon pea gives the maximum return when compared to the crop plan comprising paddy, pigeon pea and rainfed crop of little millet. The difference in the return between two crop plant is Rs 6510.72/ha. In the second crop plan, paddy cultivation was made compulsory to the extent of 2.83 ha (which was the maximum irrigable area for paddy with available storage volume) keeping in

TABLE 1
Assured water availability in the reservoirs at 75% probability level

Standard	Storage volume (cu. m)					Total Volume
week No.	ED 5	ED 14	ED 18	ED 19	ED 21	(cu.m)
23	437.9	370.0	0.0	24.5	0.0	832.4
24	360.2	253.5	0.0	12.4	0.0	626.1
25	336.7	228.6	0.7	11.3	0.0	577.4
26	460.2	207.7	19.6	15.7	0.0	703.2
27	741.5	260.1	25.1	25.0	0.0	1051.7
28	819.3	265.2	34.0	38.3	2.6	1159.4
29	924.2	292.7	46.9	91.4	4.5	1359.7
30	2004.1	655.0	68.9	121.9	14.6	2864.5
31	2255.4	1000.1	56.7	83.0	3.0	3398.2
32	2279.7	1164.3	108.9	134.6	12.3	3699.8
33	2953.1	1872.4	123.1	155.9	8.8	5113.3
34	2267.0	1714.4	53.5	74.8	5.5	4115.2
35	1635.8	1280.8	35.2	30.1	0.2	2982.1
36	1330.1	969.9	28.0	19.5	0.0	2347.5
37	1747.1	839.9	33.6	33.8	2.0	2656.4
38	1365.7	730.2	34.2	32.0	2.2	2164.3
39	1139.6	657.2	27.0	27.1	0.0	1850.8
40	1037.5	601.1	22.4	18.4	0.0	1679.5
41	1016.9	504.8	20.9	10.9	0.0	1553.5
42	711.0	379.2	15.1	7.4	0.0	1112.7
43	741.7	306.1	13.0	5.6	0.0	1066.4
44	594.0	212.5	10.1	3.7	0.0	820.3

TABLE 2

Maximum water spread area and capacity of the reserviors.

Reservoir identification	Maximum water spread area (sq. m.)	Maximum capacity of reservoir (cu.m.)	
ED 5	3600.0	6510.0	
ED 14	2800.0	5550.0	
ED 18	1210.0	1600.0	(A)
ED 19	1570.0	1580.0	(B)
ED 21	1040.0	930.0	(C)
		Total : 16,170.0	(D)

Note : The total of A + B + C is about 31% of D.

TABLE 3

Gross water deficits of the crops at 75% probability level

Week No.	Available water depth @19.02 ha (mm)	Gross water deficit, mm		
		Paddy	Maize	Pigeon pea
25	3.0	-	S	S
26	3.7	-	S	S
27	5.5	-	S	S
28	6.1	27.4	S	S
29	7.1	13.2	S	S
30	15.1	16.4	S	S
31	17.9	29.8	S	S
32	19.4	28.4	S	S
33	26.9	14.5	S	S
34	21.6	28.7	16.5	5.0
35	15.7	24.9	5.6	S
36	12.3	33.0	S	S
37	14.0	43.4	7.8	S
38	11.4	43.4	11.6	S
39	9.7	65.1	8	S
40	8.8	55.3	-	4.8
41	8.2	-	-	6.3
42	5.9	-	-	-

Note :
1. S = Surplus
2. Gross water deficits are considered upto one week prior to harvesting for each crop.
3. Gross water deficits in the weeks 25, 26 and 27 (nursery) are not included in the analysis for paddy as the area under nursery will be very small.

TABLE 4

Cost details of different crops in the project area

Sl. No.	Name of crop	*Cost of cultivation Rs./q	Cost of product Rs./q	Crop yield q/ha	Return net of Cultivation cost Rs./ha
(1)	(2)	(3)	(4)	(5)	(4) x (5) - (3)
1.	Paddy	2500	300	27.5	5750
2.	Maize	1250	400	25.0	8750
3.	Pegeon pea	1000	600	10.0	5000
4.	Little millet	250	100	12.5	1000

Note:
1. Little millet is taken as rainfed crop.
2. Values in columns 3, 4 and 5 were obtained from the personal enquiries with local farmers.
3. *Excluding irrigation cost.

TABLE 5

Cropping plans and the corresponding returns (Maximum area : 19.02 ha)

	Crop plan	Area under the crop (ha)				Return*	
		Paddy	Maize	Pigeon pea	Rainfed crop	Total (Rs.)	Per hectare (Rs.)
1.	Imposing no restriction on any of 4 maximum crop activities.	—	18.69	0.33	—	1,65,195.00	8685.33
2.	Imposing restriction on paddy to the maximum possible area of 2.83 ha.	2.83	—	2.22	13.97	41,360.95	2174.60

Net of cultivation cost only.

TABLE 6

Benefit-cost ratio for crop plan comprising maize and pigeon pea for different amortization periods

Amortization Period (years)	Annual capital cost (Rs./ha)		Annual running cost Rs./ha	Annual capital and running cost (Rs./ha)		Annual benefit (net of cultivation cost) (Rs./ha)	Annual net benefit (Rs./ha)		Benefit-cost ratio	
	A	B		A	B		A	B	A	B
5	996.93	707.54	599.72	1596.65	1307.26	8685.33	7088.68	7378.07	4.4	5.6
10	640.89	454.85	599.72	1240.61	1054.57	8685.33	7444.72	7630.76	6.0	7.2
15	534.07	379.04	599.72	1133.75	978.76	8685.33	7551.58	7706.57	6.7	7.9

A: Inclusive of reservoir cost.
B: Exclusive of reservoir cost.

TABLE 7

Benefit-cost ratio for crop plan comprising paddy, pigeon pea and little millet for different amortization periods

Amortization Period (years)	Annual capital cost (Rs./ha)		Annual running cost Rs./ha	Annual capital and running cost (Rs./ha)		Annual benefit (net of cultivation cost) (Rs./ha)	Annual net benefit (Rs./ha)		Benefit-cost ratio	
	A	B		A	B		A	B	A	B
5	659.65	370.26	1297.76	1957.41	1668.02	2174.60	217.19	506.58	0.10	0.30
10	424.06	238.02	1297.76	1721.82	1535.78	2174.60	452.78	638.82	0.26	0.42
15	353.38	198.35	1297.76	1651.14	1496.11	2174.60	523.46	678.49	0.32	0.45

A: Inclusive of reservoir cost
B: Exclusive of reservoir cost

mind the natural choice of the farmers in the study area. Due to this restriction, there is substantial area of 13.97 ha left for little millet which is commonly grown in the study area without irrigation and gives very low return. A small area of 0.22 ha goes to pigeon pea and no area goes to maize. The overall effect of imposing the paddy area is a drastic reduction in the return from total production. This is an undesirable feature with respect to the overall development of the conditions of tribal farmers in the study area.

Economic Feasibility of Irrigation by the Reservoirs

The economic analysis was done for both the optimal crop plans obtained by the LP model. In the economic analysis, the rates existed in 1993 are considered for various inputs required for proposing lift irrigation scheme as gravity irrigation is not feasible as the command area is at the upstream of reservoirs of ED5 and ED14. The life period of diesel engine, pump along with accessories and pvc pipe line in taken as 15 years. The depreciation cost, repairs and maintenance cost of diesel engine and pump with accessories are taken as 10% and 5% of their initial costs respectively. Desiltation of reservoirs ED5 and ED14 is done every year to maintain the storage capacity at its original level. The value of land or its possible enhancement due to the provision of irrigation facility have not been considered in the present analysis.

In the economic analysis, the reservoir capacities of ED5 and ED14 were only considered due to the reason that these reservoirs constitute about 90% of total water availability in the study area when compared to the upstream reservoirs of ED18, Ed19 and Ed21. The total quantity of water to be pumped from the reservoirs of Ed5 and Ed14 was estimated based on the gross deficits of crops multiplied with their respective areas in both the crop plans. The results of economic analysis for different assumed amortization periods are presented in Table 6 and Table 7 for both the crop plans. In these tables, the benefit-cost ratios were worked out for two options of annual costs (i.e., inclusive and exclusive of the reservoir cost).

A comparison between Table 6 and Table 7 reveals that the annual running cost (including the cost of diesel, labour, desiltation, depreciation and repairs and maintenance of diesel engine and pump) of Rs. 1297.76 /ha (i.e., 2 times of former) of the crop plan comprising maize and pigeon pea and little millet as rainfed crop. This is because of the total pumping period and hence pumping cost is much higher when paddy is grown, which faces water deficit in every week during its growth period. Also, the annual net benefit, i.e., the difference between annual benefit net of cultivation cost and sum of annualised capital cost and running cost is substantially more in former crop plan when compared to the latter in all the amortization periods. The benefit-cost ratios in both the options of including and excluding reservoir cost are more than 1 with increasing trend as amortization period increased in the crop plan comprising maize and pigeon pea (Table 6). In the crop plan comprising paddy, pigeon pea and little millet, the annual net benefits are low with benefit: cost ratio < 1 for all amortization periods. This indicates the crop plan with compulsory inclusion of paddy is not economically beneficial to the local farmers.

CONCLUSIONS

The Surface Water Yield Model (SWYMOD) was used to generate information on availability of water in the selected reservoirs for 20 years during kharif season. The gross water deficits were estimated using water balance approach. The two crop plans for two imposed conditions are identified by LP model. The crop plan comprising maize and pigeon pea gave more returns when compared to the crop plan comprising paddy, pigeon pea and little millet. The economic analysis showed that the benefit: cost ratio for all the considered amortization periods and for two cases when reservoir cost is included and excluded from the analysis are always greater that one for the crop plan excluding paddy. The benefit: cost ratios are less than one for all the amortization periods when paddy is included in the crop plan, corroborating the infeasibility of the adoption of paddy as an economic option.

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