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556·535 (282·253)0

Estimation of water balance of lower Sutlej catchment upto Bhakra dam site by Thornthwaite's method

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ABSTRACT . Water balance by Thornthwaite's method of lower Sutlej catchment between Rampur and Bhakra dam site has been discussed. Maps showing the monthly water deficit, water surplus, soil moisture utilisation and soil moisture recharge for the years 1964-68 have been prepared. An estimation of the annual runoff in river *Sutlej* on the basis of the water balance parameters for the same period has been attempted and presented in the paper.

1. Introduction

The concept of Book keeping procedure using meteorological parameters for the estimation of climatic water balance was developed by Thornthwaite (1948). The climatic water budget developed was modified by Thornthwaite and Mather (1955) to make it more useful over a wide range of soil and vegetation conditions. For this, field capacity of the soil was increased from 10 cm to 30 cm and the rate of soil mositure decrease was found to follow an exponential decay law. Suba Rao and Subrahmanyam (1961) in their paper on estimation of yields from river basins by a modification of water balance procedure of Thornthwaite have estimated monthly and yearly runoff from *Mahanadi*, *Kosi* and *Ashni* rivers. Rao *et al.* (1970), have computed climatic water balance for about 350 stations in India on the basis of methodology developed by Thornthwaite and his associates. The above procedure has therefore been utilized broadly in the present study to find the moisture status of the Sutlej basin.

The study of the water balance provides values of potential evapotranspiration, water deficit and water surplus and estimation of runoff in a basin. A knowledge of the moisture deficit facilitates the understanding of the economic feasibility of irrigation, and that of the water surplus provides information on the recharge of ground water or runoff in streams or rivers. Similarly, the magnitude of evapotranspiration gives the limit of field irrigation for optimum crop production. All these parameters thus provide useful information for assessing irrigation requirements and in judging the hydrological and agricultural potential of the basin.

2. Methodology

In computing the water balance, the precipitation (P) is compared with potential evapotranspiration (P_E) on a monthly basis. ($P—P_E$) can be zero, positive or negative. The positive value of ($P—P_E$) indicates the amount of excess water which is available during certain periods in the year for soil moisture recharge and runoff. It is only when precipitation adds to the soil moisture upto its maximum value of water holding capacity that the resultant water turns into runoff. Further, the value of actual evapotranspiration (A_E) is equal to potential evapotranspiration (P_E) when ($P—P_E$) is positive, as evapotranspiration can proceed unhindered because of the adequacy of available moisture. When ($P—P_E$) is zero, the potential loss of moisture due to evapotranspiration is fully supplied by the precipitation. But this is the hypothetical situation which may not always be realised in actual practice. Lastly the negative value of ($P—P_E$) indicates the amount by which the precipitation falls short of the supply to the potential water needs of the vegetation covered area. The value of actual evapotranspiration is then equal to precipitation *plus* the amount of water drawn from the soil moisture storage. The amount of soil moisture thus utilized is the change in storage. The accumulated value of ($P—P_E$) gives an estimate of the moisture stored in the soil at the end of the negative ($P—P_E$) period.

Fig. 1. Sutlej Catchment from Rampur to Bhakra Dam

$$\text{Storage } (S) = \text{Field capacity} \times e^{\frac{\Sigma-(P-P_E)}{\text{Field Capacity}}}$$

The amount by which the actual and potential evapotranspiration ($P_E - A_E$) differ in any month is the moisture deficit for the month. On the other hand when the soil moisture storage reaches the field capacity, any excess precipitation makes the moisture surplus resulting in surface runoff. For medium basins like lower Sutlej catchment with somewhat steep gradient it is assumed that the contribution to the runoff in any month is 70 per cent of the surplus water available in the basin and the remaining 30 per cent is retained in the catchment as storage which may be available for runoff during the subsequent months.

3. Data used

Water balance of lower Sutlej catchment from Rampur to Bhakra dam site shown in Fig. 1 has been studied by utilizing the following data.

(*i*) Mean monthly rainfall in the catchment estimated on the basis of available data of 18 stations in the catechment shown in Fig. 1.

(*ii*) Monthly normal evaportranspiration of Simla which is the only station for which data are available.

(*iii*) Monthly rainfall data of 18 stations on the catchment have been taken from daily rainfall tables for the year 1964-68. Normal monthly evapotranspiration data have been taken from the publication *Handbook of Hydrology*, Ministry of Agriculture & Irrigation. The field capacity of the representative soil has been assumed to be 200 mm.

4. Discussion and Results

Utilizing the data stated above, Table 1 (a to f) have been computed giving the magnitude of the various parameters of the water balance equation. These values have also been represented graphically for the years 1964-68 showing the monthly progress in Figs. 2 to 6 respectively. As may be seen the potential evapotranspiration is minimum being of the order of 30·0 mm during winter months of December and January. It increases gradually, becoming a maximum of the order of 130·0 mm in the summer month of May. It remains more or less constant during the rainy period from July to September.

For the year 1964, the various water balance parameters are given in Table 1(a) and represented graphically in Fig. 2. Computation of soil moisture retention has been started from the dry months of 1963, thus taking into account the change in storage in July as reckoned from June 1963. The

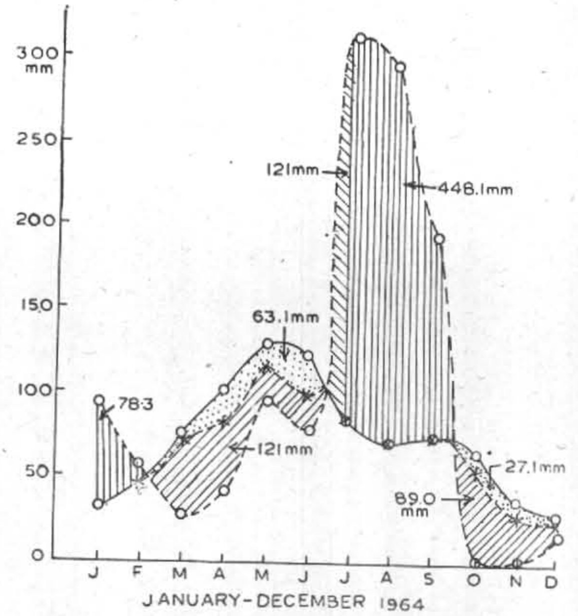

Fig. 2. Water balance of lower Sutlej Catchment

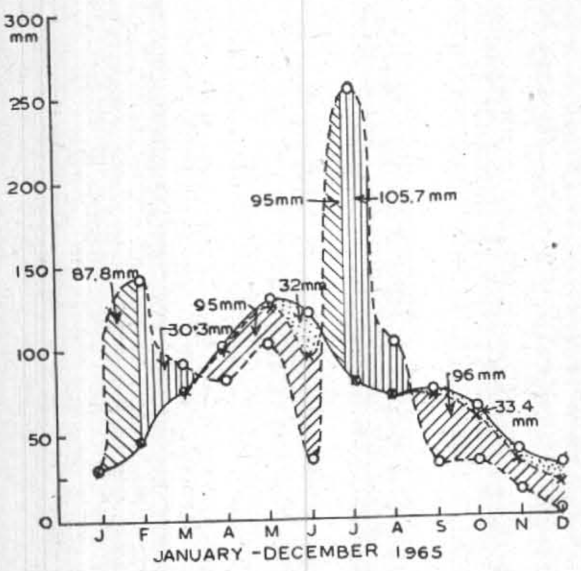

Fig. 3. 1965

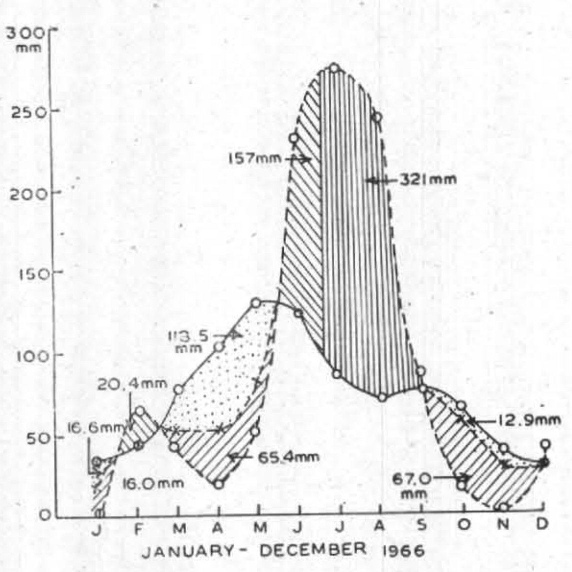

Fig. 4. 1966

Water balance of lower Sutlej Catchment for different years

soil reaches its field capacity in July and again in December 1963. The detention of water in December 1963 has been carried over to January 1964. It may be seen that the potential evapotranspiration (P_E) varies through the entire period of study from low values of 30·3 and 32·6 mm in the months of December and January respectively to maximum values of 129·6 and 123·7 in the months of May and June respectively. It ranges from 72·0 and 83·5 mm during the monsoon period. The precipitation (P) varies from a low value of 0·0 mm in November to a high value of 311·4 mm in July. During the year the excess precipitation gives surplus water of 526·4 mm and this excess water is available for runoff. The storage which is at field capacity of 200·0 mm in the winter month of January and February and again in the monsoon months of July, August

TABLE 1

Water balance of Sutlej Catchment

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
							(a) 1963						
P							351·3	398·4	187·8	105·8	36·0	37·8	
P_E							83·5	72·0	75·3	65·6	37·7	30·3	
$(P\text{-}P_E)$							267·8	326·4	112·5	40·2	−1·7	7·5	
Acc. $(P\text{-}P_E)$							..	..	..	..	−1·7	..	
(135·2) June													
S							200	200	200	200	199·0	200	
$\triangle S$							64·8	0	0	0	−1	1	
A_E							83·5	72·0	75·3	65·6	37·0	30·3	
W_D							0	0	0	0	0·7	0	
W_S							203·0	326·4	112·5	40·2	0	6·5	
R_T							60·9	116·2	68·6	32·7	9·8	4·9	
R_O							142·1	271·1	160·1	76·2	22·9	11·4	
							(b) 1964						
P	95·4	59·1	26·3	42·5	95·2	81·5	311·4	293·4	195·1	0·3	0·0	17·2	1217·4
P_E	32·6	43·6	75·1	101·2	129·6	123·7	83·5	72·0	75·3	65·6	37·7	30·3	870·2
$(P\text{-}P_E)$	62·8	15·5	−48·8	−68·7	−34·4	−42·2	227·9	221·4	119·8	65·3	−37·7	13·1	..
Acc. $(P\text{-}P_E)$	..	..	−48·8	−107·5	−141·9	−184·1	..	..	..	−65·3	−103·0	−116·1	
S	200	200	155·0	116·0	97·0	79·0	200·0	200	200	144·0	119·0	111·0	
$\triangle S$	0	0	−45·0	−39·0	−19·0	−18·0	121·0	0	0	−56·0	−25·0	−8·0	
A_E	32·6	43·6	71·3	81·5	114·2	99·5	83·5	72·0	75·3	56·3	25·0	25·2	780·0
W_D	0	0	3·8	19·7	15·4	24·2	0	0	0	9·3	12·7	5·1	90·2
W_S	62·8	15·5	0	0	0	0	106·9	221·4	119·8	0	0	0·0	526·4
R_T	20·3	10·7	3·2	1·0	0·3	0·1	32·1	76·0	58·7	17·6	5·3	1·6	
R_O	47·4	25·1	7·5	2·2	0·7	0·2	74·9	177·5	137·1	41·1	12·3	3·7	529·7
							(c) 1965						
P	23·8	142·0	94·8	83·5	109·1	34·9	254·1	102·1	30·3	32·1	14·3	2·8	933·8
P_E	32·6	43·6	75·1	101·2	129·6	123·7	83·5	72·0	75·3	65·6	37·7	30·3	870·2
$(P\text{-}P_E)$	1·2	98·4	19·7	−17·7	−20·5	−88·8	170·6	30·1	−45·0	−33·5	−23·4	−27·5	
Acc. $(P\text{-}P_E)$	..	..	..	−17·7	−38·2	−127·0	..	..	−45·0	−78·5	−101·9	−129·4	
S	112·2	200	200	183·0	165·0	105·0	200	200	159·0	134·0	119·0	104·0	
$\triangle S$	1·2	87·8	0	−17·0	−18·0	−60·0	95·0	0	−41·0	−25·0	−15·0	−15·0	
A_E	32·6	43·6	75·1	100·5	127·1	94·9	83·5	72·0	71·3	57·1	29·3	17·8	804·8
W_D	0	0	0	0·7	2·5	28·8	0	0	4·0	8·5	8·4	12·5	65·4
W_S	0	10·6	19·7	0	0	0	75·6	30·1	0	0	0	0	136·0
R_T	0·5	3·3	6·9	2·1	0·6	0·2	22·7	15·8	4·7	1·4	0·4	0·1	
R_O	1·1	7·8	16·1	4·8	1·5	0·4	53·1	37·0	11·1	3·3	1·0	0·3	137·5
							(d) 1966						
P	0·0	64·0	41·2	19·8	61·1	229·5	272·3	244·2	86·5	18·6	4·8	40·2	1082·2
P_E	32·6	43·6	75·1	101·2	129·6	123·7	83·5	72·0	75·3	65·6	37·7	30·3	870·2
$(P\text{-}P_E)$	−32·6	20·4	−33·9	−81·4	−68·5	105·8	188·8	172·2	11·2	−47·0	32·9	9·9	

All values in mm

P=Precipitation
P_E=Potential Evapotranspiration
Acc. $(P\text{-}P_E)$=Accumulated Potential Water Loss

S=Storage
$\triangle S$=Change in Storage
A_E=Actual Evapotranspiration

W_D=Water Deficit
W_S=Water Surplus
R_T=Retention
R_o=Runoff

TABLE 1—(*contd*).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
							(d) 1966						
Acc. $(P\text{-}P_E)$	—162·0	(—121)	—154·9	—236·3	—304·8	..	..	..	..	—47·0	—79·9	(—66)	
S	88·0	108·4	91·0	60·0	43·0	148·8	200	200	2·00	158·0	133·0	142·9	
$\triangle S$	—16·0	20·4	—17·4	—31·0	—17·0	105·8	51·2	0	0	—42·0	—25·0	9·9	
A_E	16·0	43·6	58·6	50·8	78·1	123·7	83·5	72·0	75·3	60·6	29·8	30·3	722·3
W_D	16·6	0	16·5	50·4	51·5	0	0	0	0	5·0	7·9	0	147·9
s	0	0	0	0	0	0	137·6	172·2	11·2	0	0	0	321·0
R_T	0	0	0	0	0	0	41·3	64·0	22·6	6·8	2·0	0·6	
$R_{\ddot{O}}$	0·1	0	0	0	0	0	96·3	149·5	52·6	15·8	4·8	1·4	320·4
							(e) 1967						
P	1·3	42·3	162·4	9·0	22·0	124·0	412·5	452·0	128·2	30·8	29·4	161·4	1,575·3
P_E	32·6	43·6	75·1	101·2	129·6	123·7	83·5	72·0	75·3	65·6	37·7	30·3	870·2
$(P\text{-}P_E)$	—31·3	—1·3	87·3	—92·3	107·6	0·3	329·0	380·0	52·9	34·8	—8·3	131·1	
Acc. $(P\text{-}P)_E$	—97·3	—98·6	..	—92·2	—199·8	..	..	..	..	—34·8	—43·1	..	
S	122·0	121·0	200	125·0	73·0	73·3	200	200	200	168·0	161·0	200	
$\triangle S$	20·9	—1·0	79·0	—7·50	—52·0	0·3	126·7	0	0	—32·0	—7·0	39·0	
A_E	22·2	43·3	75·1	84·0	74·0	123·7	83·5	72·0	75·3	62·8	36·4	30·3	782·6
W_D	10·4	0·3	0	17·2	55·6	0	0	0	0	2·8	1·3	0	87·6
W_S	0	0	8·3	0	0	0	202·3	380·0	52·9	0	0	92·1	735·6
R_T	0·2	0·1	2·5	0·7	0·2	0·1	60·7	132·2	55·5	16·6	5·0	29·1	
R_O	0·4	0·1	5·9	1·8	0·5	0·1	141·7	308·5	129·6	38·9	11·6	68·0	707·1
							(f) 1968						
P	425·3	64·0	42·8	46·2	20·5	123·0	362·2	202·3	15·5	53·8	3·9	50·5	1410·0
P_E	32·6	43·6	75·1	101·2	129·6	123·7	83·5	72·0	75·3	65·6	37·7	30·3	870·2
$(P\text{-}P_E)$	392·7	20·4	—32·3	—55·0	—109·1	—0·7	278·7	130·3	—59·8	—11·8	—33·8	20·2	
Acc. $(P\text{-}P_E)$	..	..	—32·3	—87·3	—196·4	—197·1	..	..	—59·8	71·6	—105·4	..	
S	200	200	170·0	128·0	74·0	74·0	200	200	148·0	139·0	118·0	138·2	
$\triangle S$	0	0	—30·0	—42·0	—54·0	0	126·0	0	—52·0	—9·0	—21·0	20·2	
A_E	32·6	43·6	72·8	88·2	74·5	123·0	83·5	72·0	67·5	62·8	24·9	30·3	775·7
W_D	0	0	2·3	13·0	55·1	0·7	0	0	7·8	2·8	12·8	0	94·5
W_S	392·7	20·4	0	0	0	0	152·7	130·3	0	0	0	0	696·1
R_T	126·5	44·1	13·2	4·0	1·2	0·4	45·9	52·9	15·9	4·8	1·4	0·4	
R_O	295·3	102·8	30·9	9·2	2·8	0·8	107·1	123·3	37·0	11·1	3·4	1·0	724·7

All values in mm.

P=Precipitation
P_E=Potential Evaportranspiration
Acc.$(P\text{-}P_E)$=Accumulated Potential Water Loss

W_S=Water Deficit
W_S=Water Surplus
R_O=Runoff
R_T=Retention

S=Storage
$\triangle S$=Change in Storage
A_E=Actual Evapotranspiration

and September decreases in the post monsoon period and during summer, as more and more water is removed from the soil to meet the requirement of at least some of the consumptive water needs. The lowest value of storage is reached in June as 79·0 mm being about 39 per cent of the field capacity. As precipitation in excess of water needs is retained in the upper layers of the soil, the actual evapotranspiration (A_E) or the actual water loss equals to potential water loss in January, February and from July to September, when precipitation exceeds potential evapotranspiration. But when (P) is less than (P_E), actual water loss is equal to sum of precipitation and water removed from the soil. The total potential evapotranspiration in the catchment in the year 1964 is 870·2 mm, while the actual evapotranspiration is 780·0 mm only resulting in a deficit of 90·2 mm.

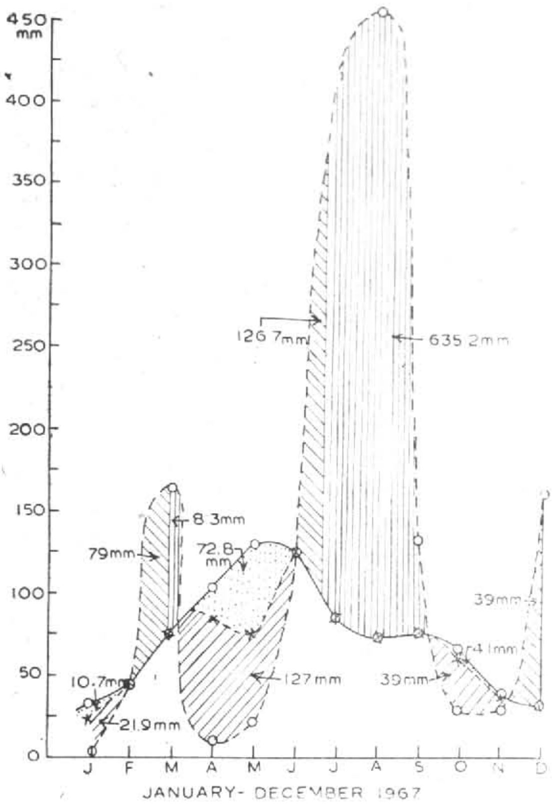

Fig. 5, 1967

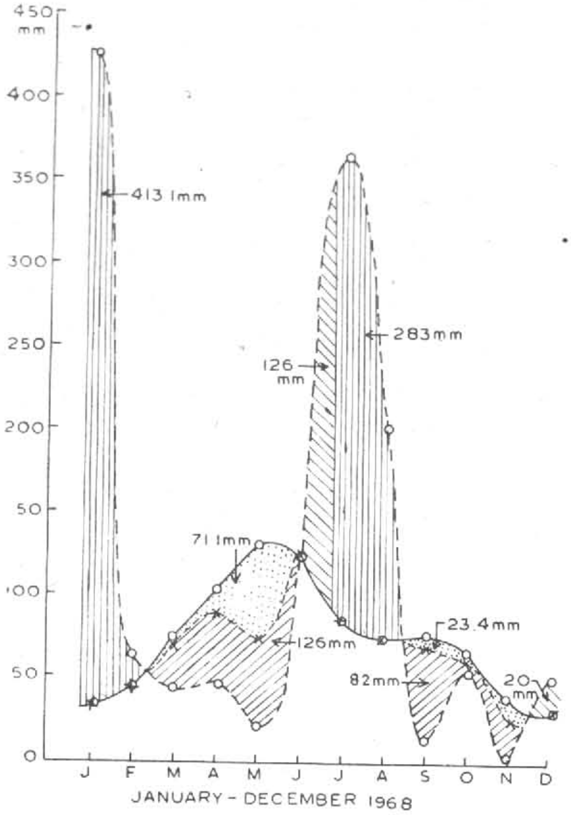

Fig. 6. 1968

TABLE 2

Water balance of Sutlej Catchment (1964 to 1968)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	111·2	74·3	73·5	40·2	61·6	118·6	322·6	258·8	91·1	27·1	10·5	54·4	1243·9
P_E	32·6	43·6	75·1	101·2	129·6	123·7	83·5	72·0	75·3	65·6	37·7	30·3	870·2
$(P\text{-}P_E)$	78·6	30·7	—1·6	61·0	—68·0	—5·1	239·1	186·8	15·8	—38·5	—27·2	24·1	
Acc. $(P\text{-}P_E)$	..	..	—1·6	—62·6	—130·6	—135·7	..	..	..	—38·5	—65·7	..	
S	200	200	199·0	145·0	103·0	100·0	200	200	200	164·0	143·0	167·1	
$\triangle S$	32·9	0	—1·0	—54·0	—42·0	—3·0	100·0	0	0	—36·0	—21·0	24·1	
A_E	32·6	43·6	74·5	94·2	103·6	121·6	83·5	72·0	75·3	63·1	31·5	30·3	825·8
W_D	0	0	0·6	7·0	26·0	2·1	0	0	0	2·5	6·2	0	44·4
W_S	45·6	30·6	0	0	0	0	139·0	186·8	15·8	0	0	0	417·8
R_T	13·7	13·3	4·0	1·2	0·4	0·1	41·7	68·5	25·3	7·6	2·3	0·7	
R_O	31·9	31·0	9·3	2·8	0·8	0·3	97·4	160·0	59·0	17·7	5·3	1·6	417·8

Further March, April, May, June, October, November and December are the months when the potential water needs of the basin are not supplied by precipitation. On the other hand January, February , July, August and September are the months when surplus water is available. Considering the year as a whole, surplus water amounting to 526·4 mm is available for runoff and the total water deficit during the year is 90·2 mm only. It, therefore, implies that sufficient water is available for consumptive needs through the year.

Similar features are noticed in other years as depicted in the Figs. 3 to 6.

5. Average conditions in the basin

The average monthly progress of water supply (precipitation) and water need (potential evapotranspiration) in the portion of Sutlej catchment under study had been taken into consideration for water budgeting. The average monthly values are given in Table 2 along with other parameters involved in the water budget. Fig. 7 shows monthly progress of the parameters of the water budget graphically. As may be seen the potential evapotranspiration (P_E) varies continuously through the year from the low value of 30·3 mm in the month of December to a high value of 129·6mm in the month of May. Total water need for the year is 870·2 mm. The precipitation (P) is much more variable through the year than potential evapotranspiration (P_E). It is as low as 10·5 mm in the month of November and as high as 322·6 mm in the month of July. The average annual precipitation in the catchment under study is 1243·9 mm of which the maximum occurs during the month of July and August. The demand for water in terms of potential evapotranspiration is very much in excess of precipitation during the months from March to June. A comparison of precipitation with potential evapotranspiration on a monthly basis reveals that the precipitation in the rainy and winter seasons is much higher than the potential evapotranspiration and this results in the soil attaining the field capacity. Any precipitation contributing to water surplus ultimately becomes runoff. Thus the months of January and February are characterized by water surplus followed by water deficit during the months from March to June. Again appreciable water surplus builds up in the months of July and August and it becomes marginal in the month of September followed again by a phase of water deficit in October and November. The soil moisture remains at field capactiy of 200 mm in January and February and from July to September and some water is added each month to the surplus. March is the first month in the year when the rapidly rising demands for water exceed the supply of water from precipitation. The precipitation falls short of the water needs by 1·6 mm, in March. On an average, the water deficits in March, April, May and June are 0·6, 7·0, 26·0 and 2·1 mm respectively. The total average deficit for the year is 44·4 mm and the total average water surplus is 417·8 mm. Thus sufficient water surplus is available to have continuous run off in the basin under study.

6. Soil moisture utilization

During non-rainy months from March to June and October & November evapotranspiration needs are not fully met by precipitation in the catchment. This residual need is, however, met from the moisture stored in the soil. Accumulated need for water is 181·1 mm which is the deficiency in storage, *i. e.*, the negative values of $\triangle S$. Positive changes in storage of 32·9 mm in January, 100·0 mm in July and 24·1 mm in December, compensate for the storage deficiency during the non-

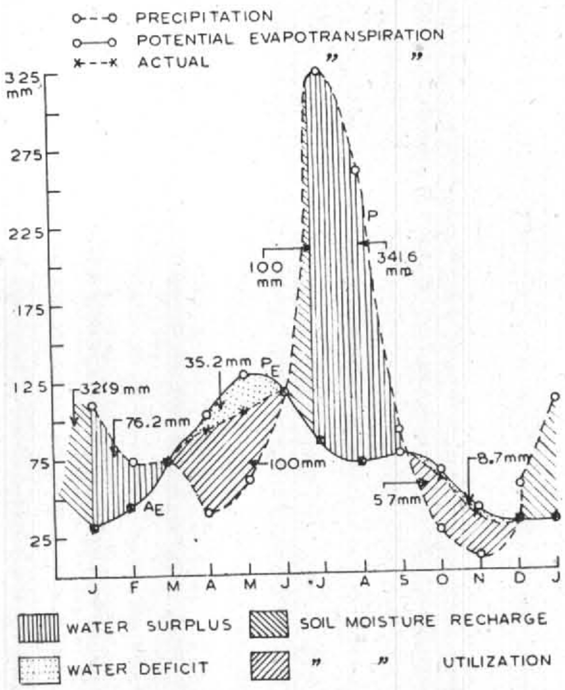

Fig. 7. Average water balance of lower Sutlej Catchment 1964—68

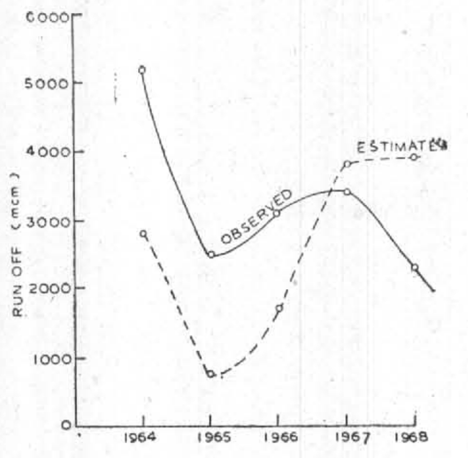

Fig. 8. Comparison of observed and estimated discharge at Bhakra Dam site

TABLE 3

Computed and measured run off

Year	Measured (M.C.M.)	Computed (M.C.M.)
1964	5,200·4	2,862·0
1965	2,487·7	739·8
1966	3,101·0	1,728·0
1967	3,411·9	3,817·8
1968	2,315·6	3,915 0

rainy months and hence no change in storage is observed.

7. Estimation of run off

An attempt has also been made to estimate runoff in the river *Sutlej* on the basis of the available parameters in the hydrologic cycle. The results are shown in Fig. 8. It may be seen that the trend of annual discharge at Bhakra Dam site brought out though the magnitude of the estimated discharge, is somewhat different from the actual value (Table 3). This difference may be attributed to various factors like inadequacy of the network, general catchment characteristics, sedimentation, seepage losses and effluent discharge etc. These factors are under investigation.

8. Conclusion

A year to year analysis of the data shows that March to June is the period when the basin falls short of the potential water needs for the crops and vegetation. The post-monsoon period October and November is also prone to water deficit. To some extent the months of January and February are also short of water supply except in years when appreciable amount of precipitation occurs in the basin during December, January and February due to passage of western disturbances. The monsoon months of July, August and September are the period when sufficient water surplus is available as storage and for runoff. The maximum surplus of water is generally available in the month of August and the maximum water deficit occurs in the month of May.

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