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HYDROLOGICAL ANALYSIS FOR A PREPARED AGRICULTURAL WATERSHED

R N Adhikari* and S Chittaranjan*

ABSTRACT

From the observed rainfall and resultant runoff stored behind a storage structure in the G.R.Halli red soil watershed, different hydrological elements have been computed. Water balance of the watershed has been used as on tool to analyse the performance of the system and to locate the problems in the water harvesting process. The water lost due to seepage, deep percolation etc., have been quantified. Threshold values of rainfall for causing runoff in the watershed have also been worked out. The watershed having been treated with sound and scientific conservation measures, has produced only 1.45 and 0.69 t/ha of soil and 1.4% and 1.3% of runoff during 1985 and 1986 respectively.

INTRODUCTION

Moisture stress is one of the major limiting factors of crop production in the semi-arid tropics. Water storage in arid zones is caused due to low and unfavourable distribution of rainfall rates in the summer months. In an untreated agricultural watershed, it is obvious that runoff water from upper reaches flows unresisted on the surface of agricultural land and then into the nallahs causing enormous damage by means of erosion taking the soil out of the watershed, thereby reducing the effective rainfall and water storage capacity of the soil. A number of options for management of runoff water are available to improve the utilization efficiency to increase and stabilise production. Water harvesting is one of the water management aspects in which surface runoff from catchment area is collected to improve infiltration and reduce sediment loss. Construction of water harvesting cum gully control structures can be made to store excess rainfall. In addition to the potential improvement of the moisture status of catchment areas by proper utilization of the runoff water, the frequency and magnitude of the flood flows can be reduced. The techniques of water harvesting is specially useful in arid and semi-arid regions where irrigation water is either not available or is costly. To exploit and maximize the utilization of the water resource in the watershed itself, the flood runoff flowing in the main water courses is to be impounded by means of suitable conservation structures at appropriate locations. The flood water thus impounded would not only provide water for supplemental irrigation to dry crops but also increases ground water recharge. Incidentally this also reduces the itensity of gully formation on the demonstration side of the structure.

The results of the hydrological monitoring in one of the sub-catchments of the 314 ha red soil watershed of G.R.Halli (Chitradurga Dist.) in the semi-arid tract of Karnataka are presented in this paper.

* Central Soil and Water Conservation Research and Training Institute, Research Centre, Bellary-583 104(Karnataka)

MATERIAL AND METHODS

The study was conducted on one of the three subcatchments of G.R.Halli Watershed, Chitradurga District (Lat. 14°17'30" N; Long. 76°23'55" E. and 724 M.S.L.) Karnataka State falling under semi arid dryland zone of Karnataka. Because of average annual rainfall of only about 600 mm, the moisture stress exists almost throughout the year (rainfall distribution shown in fig.1) Which limits the crop yield. Table-1 shows the return period values for rainfall for different year.

The soils of the watershed are red loam and vary in depth and extent of gravelliness, shallow and very shallow gravelly soils occur at the base of foot-hills. Denuded and exposed rocks occur near the ridges of the hillocks. The valleys have deeper soils.

The G.R.Halli watershed in the Chitradurga District in Karnataka, was selected as one of the 72 watersheds under the Drought Prone Area Programme, to be treated with soil and water conservation measures, to serve as a pilot project. With average slope of 3% (class II: class III: class IV) and non arable area with 10 - 20% slopes. The area was subjected to topographic, soil, vegetative and socio economic surveys during 1976 and a master plan was prepared by the CS and WCR and TI, Research Centre, Bellary to be implemented by different departments of the State Govt. Accordingly graded bunds of m^2 cross section were provided over 116 ha and in the non-arable land, besides in contour trenches/trench mounds in 198 ha of hill peak, a diversion drain of 2250 m length of 0.75 m^2 cross section, stone checks (52 nos.) across the nala, in the hilly portion, one each of drop inlet and drop structures were provided on the A and B nalas in the watershed during 1976-81. Since then the changes in the watershed are being monitored.

The present paper deals with the observations recorded during 1985 and 1986 at the drop structure with a 120 ha catchment and a drop inlet structure with 69.5 ha catchment on the B nala and extrapolating the data to 4 years (1981-84) in respect of different hydrological aspects using the following methods/procedures:

1. Frequency analysis of rainfall data using the double exponential Gumbel distribution formula.
2. Estimation of average watershed slopes by contour lengths method equations.
3. Depth-storage relationships.
4. Rainfall runoff relationships separately for high and low rainfall and API.
5. Estimation of Antecedent Precipitation Index.
6. Water balance analysis.
7. Estimation of soil loss.

and the same are presented and discussed below.

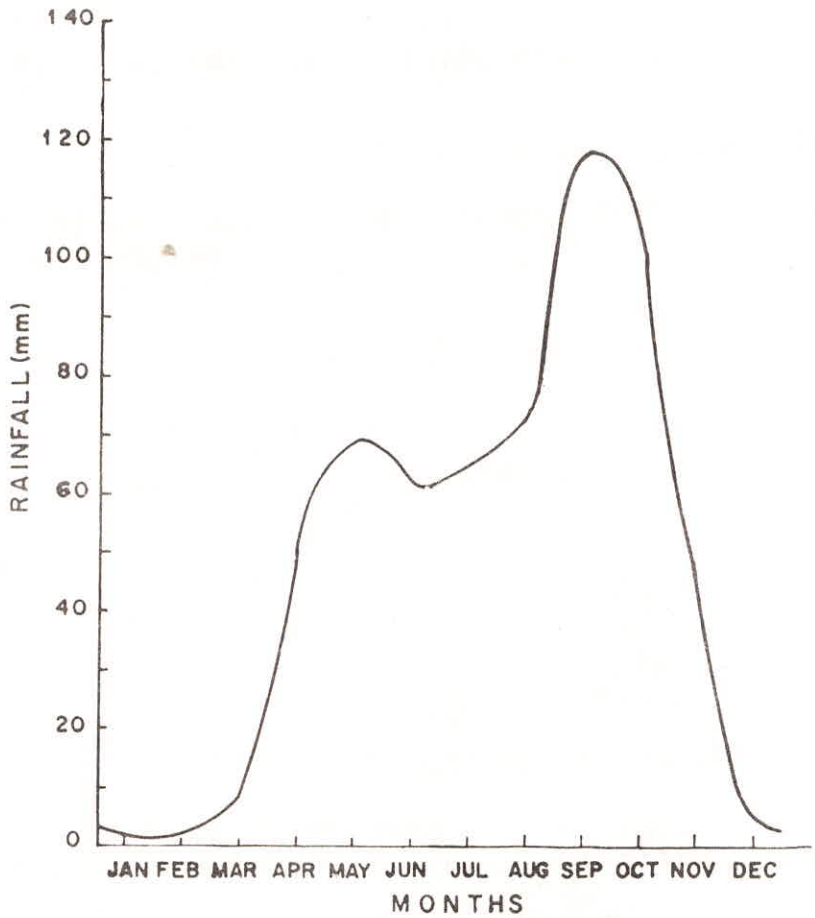

Fig. 1. MONTHLY DISTRIBUTION OF RAINFALL (Average 1971-86), CHITRADURGA

RESULTS AND DISCUSSION

Frequency analysis of rainfall data

Analysis of daily or monthly rainfall to arrive at the expected rainfall amount for different return periods is essential for designing of different soil conservation structures, crop planning etc. Hence the rainfall data over a 15 year period (1971-85) collected at Chitradurga was utilised for the purpose, using the Double exponential Gumbel Distribution method given by $X_T = \bar{X} - 0.45\, s + 0.78\, s(YT)$

where $YT = -\log_e \log_e(T/T-1)$

$\bar{X}$ = is the mean of the series for max.monthly or daily rainfall.

S = is the standard deviation of the series or daily rainfall.

T = is the return period and

X_T = is the rainfall amount for the return period T years. The monthly and daily rainfall for different return periods are given in table-1.

Table-1: Monthly and daily rainfall for different return periods

T (Return period)	X_T (Monthly rainfall) (mm)	X_T (Daily rainfall) (mm)	Remarks
2	151	55	
5	201	68	Annual rainfall of Chitradurga is 601mm
10	235	77	
25	277	88	
50	309	96	
100	340	104	

Estimation of average watershed slope :

Using the contour map of the area under study, the average watershed slope was estimated with the formula

(i) $S = \left(\sum_{i=1}^{n} S_i \times DA_i \right) / D.A.$ ... (2)

where $S_i = (H\,(LC_J + LC_{J+1})/2 \times DA_i) \times 100$ ... (3)

S is the average slope percent of the watershed area.

S_i is the av. slope percent between the contours j and J+1

H is the difference in elevation between contours.

LC_J and LC_{J+1} is the length of contour J and J+1

DA_i is the drainage area between the contour J and J+1 and (ii) $S = \frac{0.25\ Z\ (LC_{25} + LC_{50} + LC_{75})}{DA}$ ... (4)

where Z is the total watershed height.

LC_{25}, LC_{50} and LC_{75} is the contour length at 25, 50 or 75% of Z.

The average percentage of slopes upto the end of the agricultural land as per the above formulae is about 2.5% extending upto about 15% of slope on an average it is 10% slope.

Depth storage relationship

From the observations recorded at the drop structure 'B' nala, a depth - storage relationship of the type $Y = ax^b$ has been established where Y is the volume of water (m^3) and X is the depth of water (cm) with a and b values being 0.1136 and 1.8119 respectively and is presented in fig.2. This relationship facilitates to know the volume of water available at the drop structure after each rain storm.

The storage capacity of the four major storage structures taken up on the watershed are presented in table-2.

Table-2: Catchment and storage details of different storage structures in G.R.Halli Watershed

Name of the structure	Catchment area(ha)	Storage capacity(m^3)	Water spread area(ha)
A nala			
Drop structure	48.0	75.0	0.0114
Drop inlet structure	31.0	1259.0	0.0896
B nala			
Drop structure	120.0	2344.0	0.1968
Drop inlet structure	69.5	2000.0	0.1328
		5678.0	

It could be seen that in the post project period, a storage of 5678 m^3 has been developed which would otherwise have gone outside the watershed area and being not available for overland utilisation in the form of supplemental irrigation or for recharging the wells adjacent to the structures.

Antecedent precipitation Index (A.P.I.)

It is a linear combination of preciptation that occurred a few specified no. of days prior to the storm under consideration. It is generally expressed by $API = b_1p_1 + b_2p_2 + ... + b_t$ ..(5)

where b_t is a constant and P_t is the amount of precipitation which occurred t days prior to the storm. When everyday values of index is required there is considerable advantage is assuming that b_t decreases with t according to logarithmic recession. In other words $(API)_t = (API)_0 k^t$ ..(6)

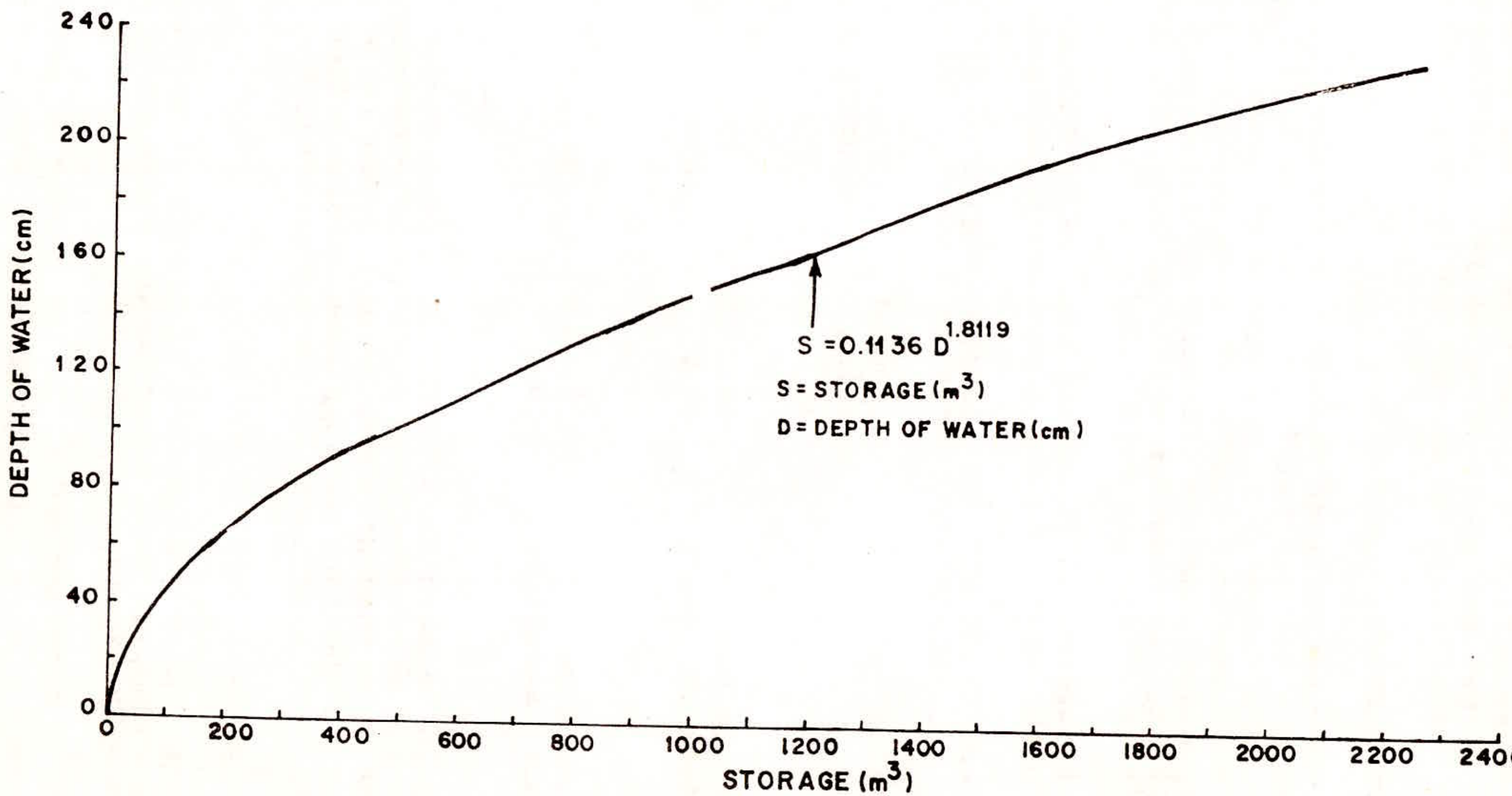

Fig. 2 DEPTH-STORAGE CURVE FOR DROP STRUCTURE OF "B" NALA G.R.HALLI WATERSHED, CHITRADURGA

where$(API)_o$ is the initial value of Index and $(API)_t$ is the value of Index after t days.

Letting t = 1 the equations becomes $(API)_1 = K\ (API)_o$ .. (7)

It has been found that the factor K varies from one region to another by a value of 0.85 to 0.95. As the antecedent precipitation factor is an index value of moisture deficiency and not an absolute measurement of it, the use of approximate value of K may not seriously affect the results. The K factor has been adopted as 0.9 m in the present study.

Rainfall runoff relationships :

Runoff from a catchment is dependent on rainfall amount and intensity topography surface conditions, antecedent precipitation index (API) etc. In the absence of rainfall intensity, particulars, linear and non-linear regression model has been applied based on API. From the values of rainfall and stored runoff observed during 1985 and 1986 two equations have been developed, one for high API and fairly good amount of rainfall and another for low API and low rainfall. It was found that runoff (Y) was related with daily rainfall (X) through the equations (1) and (2) viz.

$Y = 68.91\ X - 907.6$ for $x > 50$mm or $API > 25$ ... (8)

and $Y = 472 - 65.86\ X + 2.05\ X^2$ for $21.4 < X < 50$mm and $API < 25$ ... (9)

It is observed that the threshold value of rainfall to cause runoff is 14mm and 22mm respectively under the conditions specified for the equations 1 and 2. Since the catchment is practically undisturbed since 1981, the equations 1 and 2 have been extended to the earlier years of 1981 to 1984 for estimating the daily runoff and overflows and the actual/estimated runoff and overflows from 1981 to 1986 for the drop structure on B nala are presented in table-3.

Water balance of the watershed :

It is essential to know as to what is happening to the water recrived in the watershed through rainfall and or overland flow and also as to know the same is being accounted for. Water balance can be used as a tool to analyse the performance of the system is given by $P+I=R+A$ ... (10)

$R+A = E+S_G+O+W+ET+D_P$ ... (11)

has been used for arriving at the annual water balance for the watershed,

where P is the precipitation

I is the moisture retained in the soil

R is the runoff water collected at the storage structure

A is the portion of the rainfall, retend in the catchment areas

E is the evaporation from the stored water

ET is the evapotranspiration from the watershed area

S_G is the ground water recharge in the open well due to seepage loss

O is the o verflow over the structure

W is the increase in water storage in the soil profile and

D_P is the deep percolation.

Each of the components of the water balance equation are accounted for as follows: for precipitation, annual precipitation over the watershed has been considered, volumes of runoff from each individual event were added to get the total R for the season, Day to day fluctuations in the water level were recorded at drop structure to obtain the losses occuring due to seepage and for evaporation; evaporation losses have been separated out from the total storage losses using the value presented by I.M.D. Anonymous ____ as 5 mm/day during October to January, 6.0 mm/day during July, August and September, 7.0 mm/day in June and 8.0mm/day between March and May and it has been estimated that during 1985 and 1986 the evaporation from the open surface of stored water at drop structure is as much as 681 and 856 m^3 respectively corresponding to 13% and 9% of the runoff during respective years. As the watershed falls under a dry zone, it has been assumed that the balance amount of P-R has gone into the soil and is lost/utilised as soil evaporation/evapotranspiration, ground water recharge and deep percolation. The term S_G has been estimated by monitoring the changes in the water levels in the well adjacent to the storeage structure, and the W, the change in the water storage in the profile and I the moisture retained in the soil are assumed to be zero.

Daily variation in the depths of water alongwith the rainfall data for 1986 are presented in fig.3. It is observed that there were about 8 occasions when water level increased due to runoff. Further, heavy storage loss was observed whenever the water level was more than 0.5 m and at 0.5m and below the loss was less, suggesting that the seepage losses are more with increasing depths of water. This is also reflected in the increased depths of water in the well adjoining the storage structure, compared to low depth of water away from the structure, indicating recharge or lateral percolation of water stored in the structure. The approximate measurement at the adjacent wells are taken as 2267 m^3 on 1986 and 250 m^3 on 1985. The storage loss is initially very high, gradually attaining a constant rate varying between 1.5 to 2.2 cm/day with an average value of 1.7 cm/day. A typical curve indicating the storage loss during 1985, is presented in fig.4.

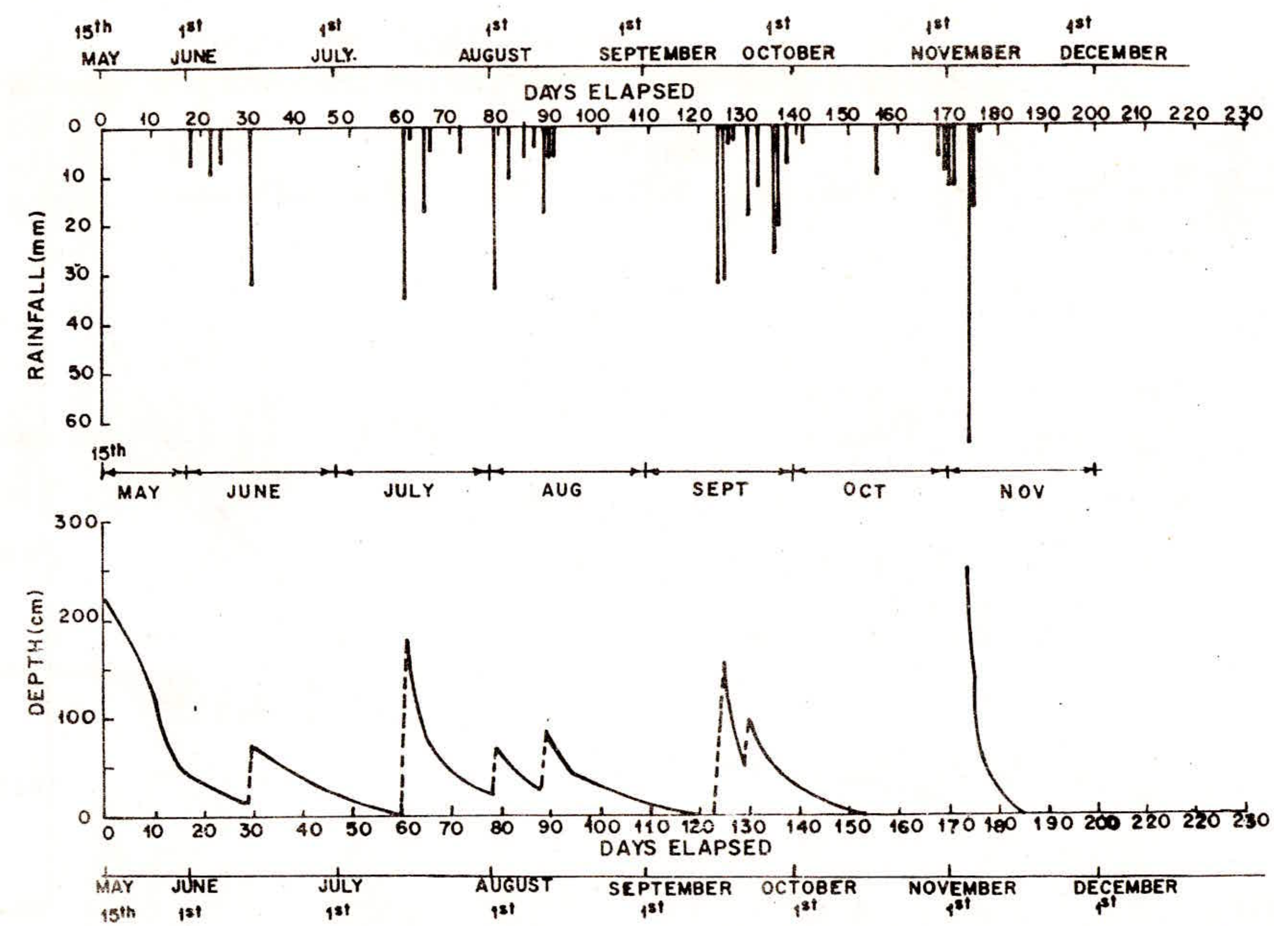

Fig 3. VARIATION OF DEPTH OF WATER WITH TIME (ALONG WITH RAINFALL) AT DROP STRUCTURE OF 'B' NALA G.R.HALLI WATERSHED, CHITRADURGA (1986).

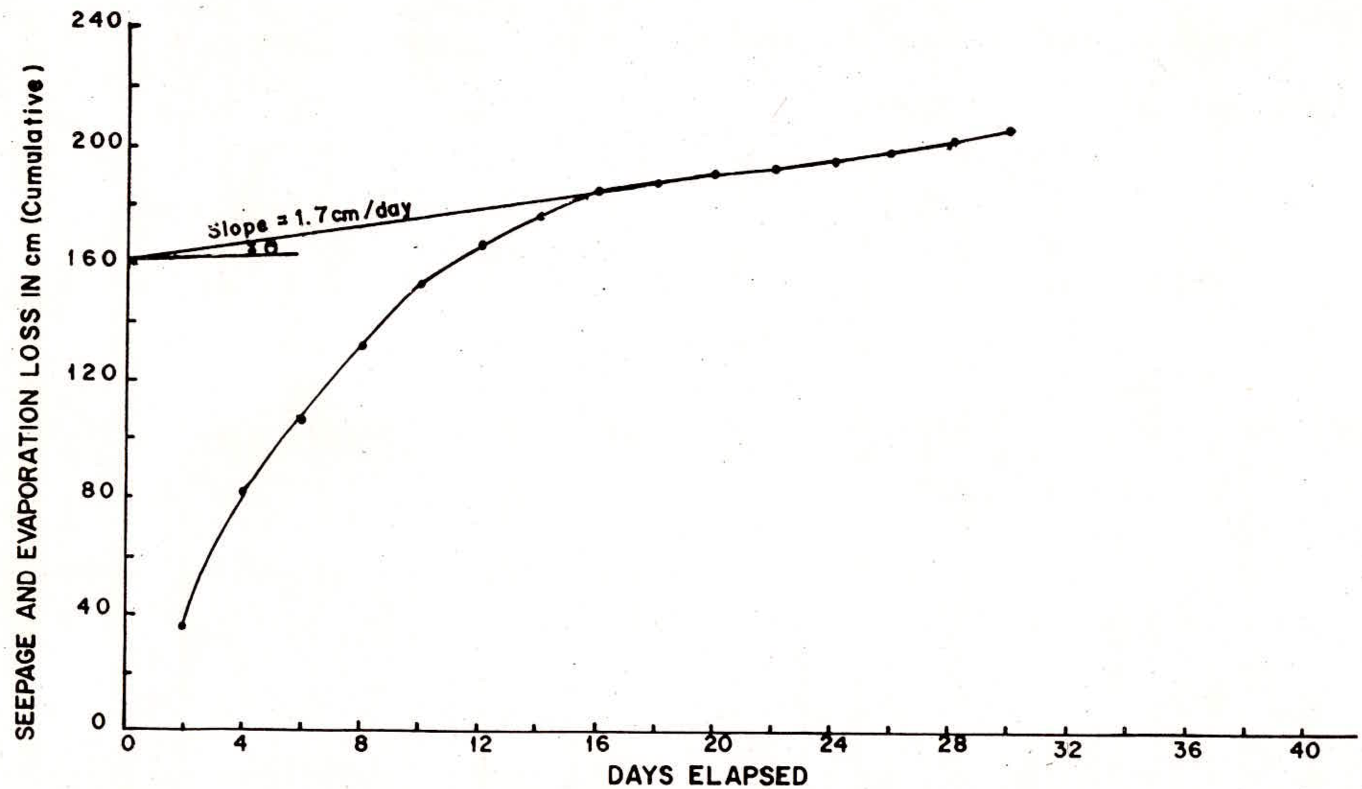

Fig. 4. SEEPAGE AND EVAPORATION LOSS FROM A STORAGE STRUCTURE
(G.R.HALLI, CHITRADURGA)

Estimation of soil loss

For big catchments such as the G.R.Halli watersheds, it would not be possible to install silt samples as in the Research Farm, to find out the extent of soil loss, Grid survey was conducted before and after the monsoon during 1985 and 1986 to arrive at the changes in the elevation due to possible soil deposition between the drop inlet and drop structures along the B nala. It was observed that in both the years there was no change in the elevation along the nala bed. However there was soil deposition at the drop structure amounting to 72.5 and 34.5 cu.m. from a catchment area of 120 ha accounting for a soil loss of 1.45 and 0.69 t/ha respectively for 1985 and 1986. Such low figures of soil loss could be attributed to scientific land use comprising of graded bunds, contour trenches, afforestation, stone checks and drop inlet structure in the catchment area compared to manifold and increased soil losses in the untreated red soil catchments.

CONCLUSIONS

Annual runoff was observed to be 1.45% and 1.33% for 1985 and 1986 with the corresponding soil loss values being 1.45 and 0.69 t/ha. Such low values could be mainly attributed to conservation measures in the catchment area on sound and scientific lines.

Threshold values of rainfall to generate runoff were 14.0mm and 22.0mm respectively for high and low antecedent moisture contents.

Major portion of the annual rainfall is absorbed in the soil of the watershed. Table-4 presented the two years water balance.

Based on the observed runoff values for 1985 and 1986 runoff has been estimated for the years 1981-84.

Average storage loss was found to be 1.7 cm/day from the water stored behind the drop structure on 'B' nala.

Approximate ground water recharge as recorded in the well adjoining the storage structure was observed to be 250 and 2267 cu.m. respectively in 1985 and 1986. It is also realised that there is 3% and 9% of total runoff is lost as evaporation from stored water at drop structure.

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Table-3: Details of rainfall and runoff for a small sub-catchment(area 120 ha) at G.R.Halli watershed, Chitradurga

Year	Total rainfall (mm)	No.of runoff events when Rainfall 50 mm A.P.I.25	Rainfall 50 mm A.P.I.25	Daily rainfall 50 mm and above	Runoff water flowed over the drop	Runoff water stored at drop structure(m^3)	Total runoff in m^3	Total runoff in mm	Runoff percentage of annual rainfall	Remarks
1986	598	5	4	64 mm for one event and 50 mm for one event	Nil	9514	9514	7.93	1.33	Observed runoff
1985	308	3	2	76 mm for one event	1986	3369	5355	4.46	1.45	
1984	463	2	3	Nil	Nil	3673	3673	3.06	0.7	Estimated runoff
1983	543	1	5	Nil	Nil	4794	4794	4.0	0.7	
1982	509	7	2	54.8 mm for one event	525	7422	7947	6.6	1.3	
1981	540	5	5	53.6 mm for one event	442	8501	8943	7.45	1.4	

Table-4: Water balance of the sub-catchments for 1985 and 1986

	Precipitation (P)	Moisture retained on the soil (I)	Evaporation from stored water (E)	Ground water recharge in the open well (SG)	Overflow from the structure (O)	Increase in water storage in soil profile (W)	Deep percolation+Evapotranspiration (D.P. + E.T)
1985	308	0	0.6	0.21	1.7	0	305.5
1986	598	0	0.71	1.9	0	0	595.4

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