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Application of curvilinear base flow recession model for estimating storage losses in a red soil watershed*

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सार – जल भण्डारन संरचना में एकत्रित बह गए जल से जल भण्डारन में होने वाली हानि से सम्बन्धित वक्ररेखी प्रतिसार, जी. आर. हाल्ली वाटरशेड, जिला चित्रादुर्गा, कर्नाटक में उत्तम प्रेक्षण लिए गए हैं । इस शोधपत्र में निदर्श प्राचलों के आकलन की पद्धति प्रस्तुत की गई है । भण्डार से सम्बन्धित एक दिन पूर्व किया गया जल भण्डारन इस जल ग्रहण क्षेत्र के जल सन्तुलन की अधिक सूचना देता है । आँकड़ों से यह देखा गया है कि अधिक ध्यान संरक्षण के उपायों की तरफ किया जाना चाहिए ।

ABSTRACT. The curvilinear recessions relating to storage losses with runoff water collected at storage structure, G.R. Halli watershed, Chitradurga district, Karnataka fitted best with the observations. The method of estimation of the model parameter is presented in the paper. Relating storage to storage on preceding day gives more information about water balance of this catchment. It is observed from the data that more emphasis is to be given for *in situ* conservation measures.

Key words — Runoff water, Watershed project, Water management, Curvilinear recession model.

1. Introduction

In modern technology land and water conservation has provision for rain water harvesting and storage by constructing gully *cum* water harvesting structures. Apart from collection of runoff water, management of harvested water is also a major problem specially in arid or semi-arid zones of India. Soil and water conservation treatment by itself is not a solution for land development but post treatment management will decide the failure or success of a watershed project.

From every significant rain storm, the storage structure will receive water. For proper management of this harvested water, it is important to know as to how this standing water is getting depleted day by day with change in the depth of stored water. Between the storms, the behaviour of storage recessions affect the planning of water management of the watershed. Like rainfall runoff relationship, storage to storage loss relationship is also an essential hydrological phenomenon for proper estimation of water balance of watershed. Keeping this point in view, an attempt is made in this paper to develop a suitable model for predicting day to day storage losses from given storage amount at one of the water harvesting structures in a treated watershed located in semi-arid red soil region of Karnataka.

2. Materials and method

2.1. *G.R. Halli watershed*

Daily water level observations during 1985, 1986 and 1987 in one of storage structures with a sub-catchment of 120 hectare area of G.R. Halli watershed (Lat. 14°17′ 30″ N, Long. 76° 23′ 55″ E and 724 m above msl), located in Chitradurga district, is a semi-arid tract of Karnataka, were collected and analysed and the results are presented in this paper. Because of average annual rainfall of only 612 mm, moisture stress exists almost throughout the year. The soils of the watershed are red loam and vary in depth and extent of gravelliness with shallow and very shallow gravelly soils occurring at the base of foot hills. Denuded and exposed rocks occur near the ridges of the hillocks. The valleys have deeper soils.

This watershed is treated with soil and water conservation measures such as graded bunds of 0.75 sq m cross-section provided over an area of 116 hec of arable land. In the 198 hec non-arable lands, besides contour trenches/trench mounds, a diversion drain of 2250 m length of 0.75 sq m cross-section, stone checks (143 nos.) across the *nallah*, in the hilly portion, one each of drop inlet and drop structures were provided on two major *nallahs* in the watershed during 1976-1981 (Anonymous 1981).

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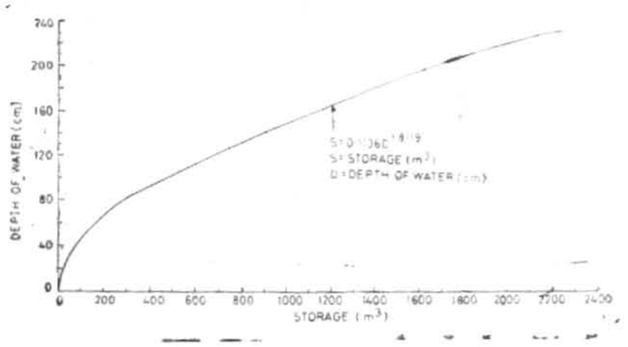

Fig. 1. Depth-storage curve for drop structure of "B" *nallah* G.R. Halli watershed, Chitradurga

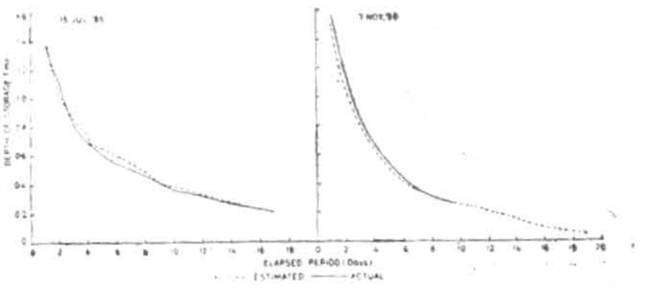

Fig. 2. Two typical cases of day to day storage losses from drop structure on "B" *nallah* at G.R. Halli during 1986

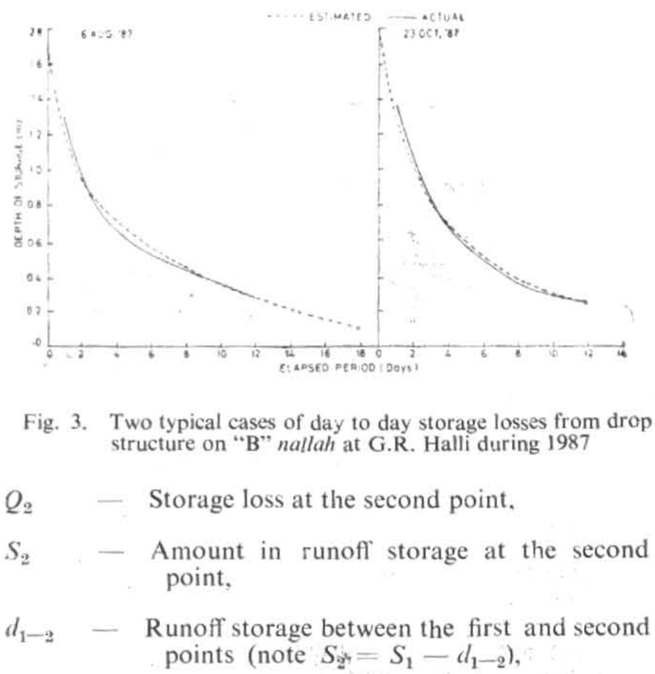

Fig. 3. Two typical cases of day to day storage losses from drop structure on "B" *nallah* at G.R. Halli during 1987

2.2. *Depth storage relationship*

From the observations of closed grid point capacity survey at the drop structure under study, a depth storage non-linear relationship of type :

$$Y = aX^b \tag{1}$$

was established, where, Y is the volume of water (cu. m) and X is the depth of water (cm), a and b are constants.

2.2.1. *Method of estimation of a and b*

Simple non-linear regression technique is applied to obtain the value of a and b. All values of Y and X were transformed into logarithmic values for linearising the equation. Following equations are used :

$$\log Y = b \sum \log X + Na \tag{2}$$

$$\log X \log Y = b \sum (\log x)^2 + a \sum \log X \tag{3}$$

where, N is total number of observations and other notations are as mentioned in Eqn. (1). With two Eqns. (2) & (3) and two unknowns (a and b) values of a and b are got by solving the equations. This relationship facilitates to know the volume of water available at the drop structure after each rain storm by knowing the depth of standing water.

2.3. *Curvilinear recession model*

The simplest form of curvilinear recession equation adopted by Boughton (1986), relating storage to storage loss is used in this paper.

The model is $Q = aS^b$ (4)

where, a and b are constants and S is runoff storage. To fit a storage loss recession equation, values must be found for constants a and b and for runoff storage S.

As there are three unknowns, three points on the recession are needed to get unique values of a, b and S.

Q_1 — Storage loss at earliest point,

S_1 — Amount in runoff storage at the earliest point,

Q_2 — Storage loss at the second point,

S_2 — Amount in runoff storage at the second point,

d_{1-2} — Runoff storage between the first and second points (note $S_2 = S_1 - d_{1-2}$),

Q_3 — Storage loss at the third point,

S_3 — Amount in runoff storage in the third point,

d_{1-3} — Runoff storage between first and third points (note $S_3 = S_1 - d_{1-3}$).

Eqn. (4) is converted to logarithmic form :

$$\log Q = \log a + b \log S \tag{5}$$

Taking the three points on the recession :

$$\log Q_1 = \log a + b \log S_1 \tag{6}$$

$$\log Q_2 = \log a + b \log (S_1 - d_{1-2}) \tag{7}$$

$$\log Q_3 = \log a + b \log (S_1 - d_{1-3}) \tag{8}$$

Subtracting Eqns. (7) and (8) from Eqn. (6) and rearranging, we get :

$$\frac{\log Q_1 - \log Q_2}{\log Q_1 - \log Q_3} = \frac{\log S_1 - \log (S_1 - d_{1-2})}{\log S_1 - \log (S_1 - d_{1-3})} \tag{9}$$

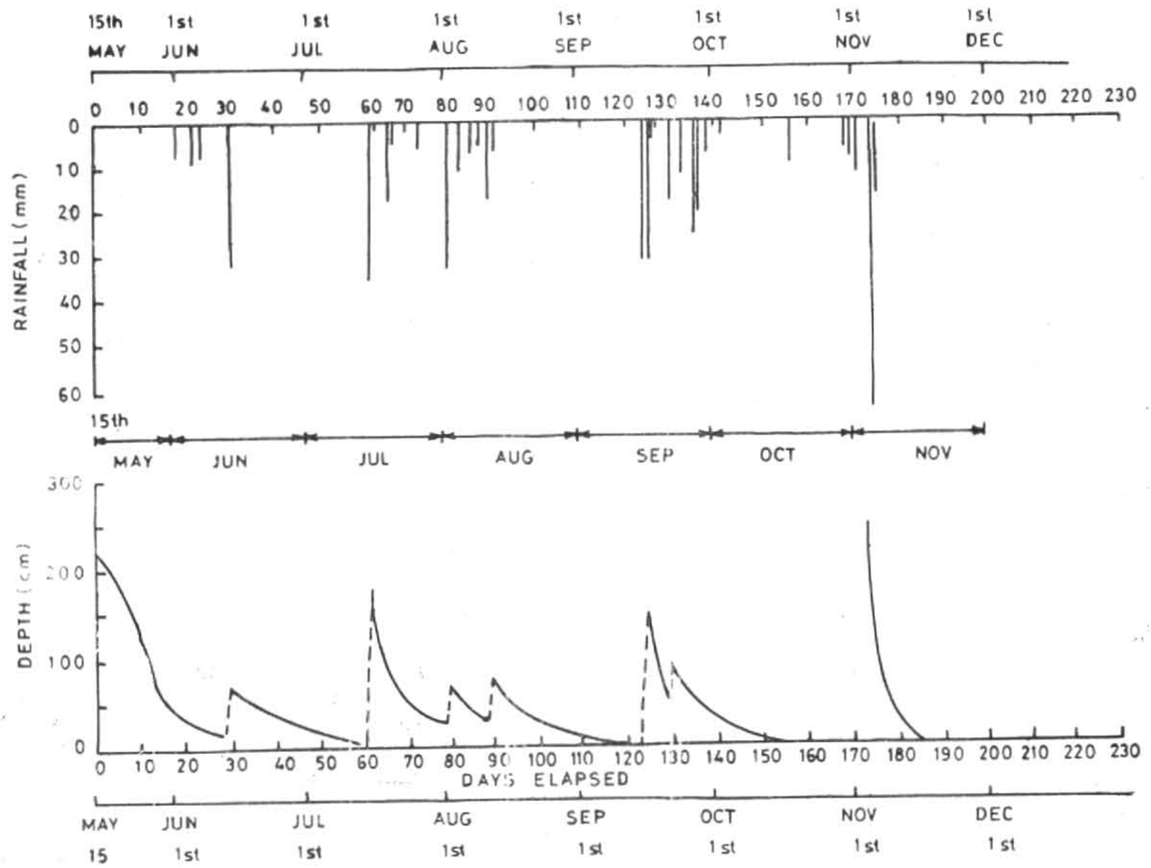

Fig. 4. Variation of depth of water with time (alongwith rainfall) at drop structure of "B" *nallah*, G.R. Halli watershed, Chitradurga (1986)

Given values of Q_1, Q_2, Q_3 and d_{1-2} and d_{1-3} the only unknown in Eqn. (9) is S_1. Eqn. (9) is solved by trial and error to find S_1. Exponent 'b' can be solved from Eqns. (6) and (7). Eqn. (4) is then used to find the value of 'a'.

This relationship will be helpful to compute the day to day storage losses from standing water held at drop structure.

3. Results and discussion

From the observations of closed grid point capacity survey and available data on day to day water level at drop structure of one of the major *nallahs* of the watershed and based on the methodology described above, the following equations have been developed :

$$Y = 0.1136\ X^{1.8119} \quad (10)$$

$$Q = 33.546\ S^{0.7885} \quad (11)$$

$$Q = 33.546\ S^{0.7885} - 1 \quad (12)$$

where,

Y = Runoff volume in cu. m,

X = Depth of water in cm,

S = Runoff storage in mm, and

Q = Daily storage loss is mm/day.

The Eqn. (11) will be applicable for water level up to 0.55 m from the full storage level and Eqn. (12) will be utilised in case of water level between 0.55 & 0.3 m. Below 0.3 m depth of water, the storage loss attains a constant loss rate of 17 mm/day. The only input of the model is depth of water, whereas output is storage loss. Utilising the Eqn. (10) the volume of water stored at the structure could be found out from the observed depth of water, which could then be converted into runoff storage (S) in mm by dividing the volume by the catchment area of the structure. Daily storage losses could be found out using Eqns. (11) or (12).

For example, if X, depth of water is recorded as 100 cm, then from Eqn. (10) Y is calculated as 478 cu. m which is to be divided by 120 hec catchment area to get the depth of storage (S) as 0.4 mm. Now since depth of storage is 1 m which is more than 0.55 m, so we are required to use Eqn. (11) to get the value of storage loss Q which is obtained as 160 mm/day. The Eqns. (11) and (12) have been developed based on the data collected on 1985 and it has been tested with the data observed in 1986 and 1987. Prediction of storage losses along with the observed values for two typical situations of each of the year 1986 and 1987 are presented in Figs. 2 and 3. It shows that observed and estimated values from equations is well matched. However, it is suggested that after few years of data collections, parameters of the equations can be updated. The daily water level alongwith rainfall observations for 1986 and 1987 are presented in Figs. 4 and 5 respectively. Most of the stored water is percolated and a small portion is lost as evaporation. The depth storage relationships are presented graphically in Fig. 1. It is observed from this study that there is considerable amount of storage loss when depth of water is more. So in a similar type of red soil watershed, the utilisation of surface water collected in water harvesting structure for overland use, is less prospective because sufficient harvested water will not be available for supplemental irrigation when plants need it most. However, as the percolation rate is high, the valuable stored water will be conserved underground through ground water recharge to increase the water table in the open well, which in turn helps in more water being drawn through bores or pumpsets for irrigating the dryland crops. So it may be suggested that more emphasis be given for *in situ* moisture conservation from ridge to valley. Countour trench, grass plantation, diversion drain, contour plantations on non-arable lands, contour cropping, graded bund in arable land finally stone and vegetative checks and smaller size masonry gully reclaimation structures in gully and *nallah* areas at specified intervals and suitable locations will help in reducing the velocity of surface runoff water giving more opportunity time for infiltration, which would improve the moisture status of catchment areas and ground water recharge in well to increase the vegetation and crop yield. Recommendation can also be given for installation of bore wells or for in-well bores in the dugout wells fitted with pumpsets on the down stream side of the water shed.

4. Conclusion

Relating runoff storage amount to storage loss illustrated in this paper can provide detailed information about the amount of water that can be collected at a drainage point and the storage loss information can be

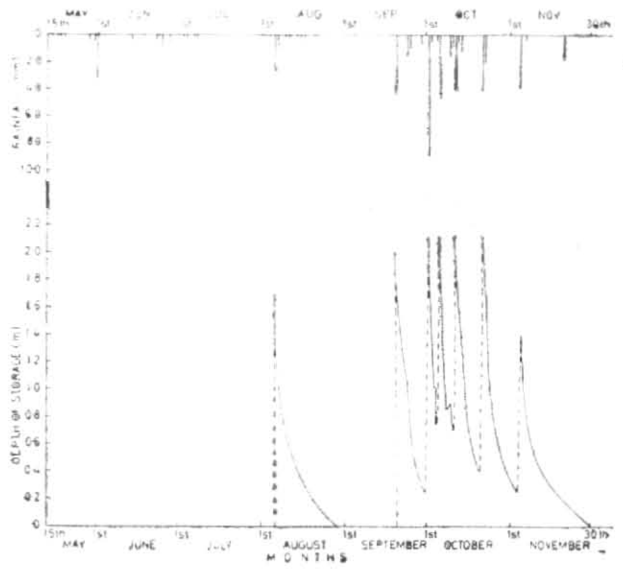

Fig. 5. Daily storage losses from drop structure on "B" *nallah* alongwith daily rainfall at G.R. Halli (1987)

used to improve the catchment water balance model. The observations and results also show that priority is to be given for *in situ* conservation measures for improvement of ground water recharge for similar type of other red soil watersheds in this region. The results and recommendations could be used for similar such soil and agroclimatic situations for planning and execution of important water, resources management project, specially in dryland areas where limited or nil information is available.

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