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Study of Synthetic Unit Hydrographs for an Ungauged Catchment Area

Ms. Bhakti V. Tikare[1], Ms. Puja S. Jotawar[2] & Mr. Harshad P. Gadgil[3]
[1] Lecturer, Sanjay Bhokare Group of Institute Miraj, Maharashtra, India
[2] Lecturer, Sanjay Bhokare Group of Institute Miraj, Maharashtra, India
[3]Lecturer, Sanjay Bhokare Group of Institute Miraj, Maharashtra, India

***Abstract**: Synthetic unit hydrographs, which assume uniform rainfall excess distribution and static watershed conditions, are frequently used to estimate hydrograph characteristics when observed data are unavailable. The present study critically reviews the synthetic unit hydrograph (SUH) methods available in hydrologic literature. The aim of this study is to determine the appropriate method of synthetic unit hydrograph for various ungauge watershed characteristics, where each method specified in range of validity based on characteristics parameter and will be presented inthe form of synthetic unit hydrograph methods. Characteristics of the watershed that is used as aparameter are watershed area, the length of the main river and the slope. The results showed that SCS method has accurate estimation than the other methods and it can be used for peak flow estimation in the similar condition watersheds. The statistical analysis and graphical comparison inferred that SCS method can be used to estimate flow ordinate required for the development of peak runoff hydrograph of different return periods for the watersheds. Based on the results obtained so far for the ungauged watershed, it could be seen that the generation of unit hydrograph through synthetic methods has been found useful and effective. The statistical evaluation of the synthetic unit hydrograph flows obtained in this study from the two methods employed have indicated that there were significant differences in the methods. Though all the two methods employed have been found useful in one way or the other, but Snyder's and SCS method have been considered distinct and more important since they both utilize most major unit hydrograph characteristics and watershed characteristics in the generation of unit hydrographs. These two methods were found simple, requiring only an easy determination of watershed and land use characteristics.*

1. Introduction

A hydrograph is a graph showing stage, discharge, velocity or other properties of water flow with respect to time. When the discharge is shown against time, the graph is a discharge hydrograph. Hydrographs or some elements of them, such as peak rates, are used in the planning and design of water control structures. They are also used to show the hydrologic effects of existing or proposed watershed projects and land use changes. Formatting Your Paper

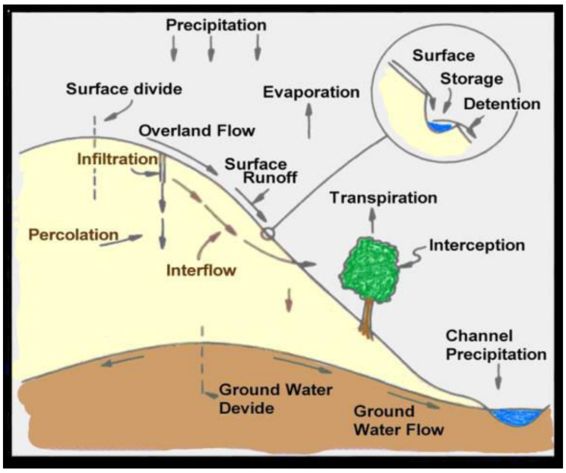

Fig. 1

Unit Hydrograph:-

The unit hydrograph is defined as the hydrograph resulting from an isolated storm unit duration occurring uniformly over the entire catchment area and producing unit (i.e. 1 cm) depth of direct runoff. The unit duration is usually expressed in hours and it is prefixed to unit hydrograph.

Synthetic Hydrograph:-

To develop UH to a catchment, detailed information about the rainfall and the resulting flood hydrograph are needed. However, such information would be available only at a few locations and in a majority of catchments, especially at remote locations; the data would normally be very scanty. In order to construct UH for such areas, empirical equations of regional validity which relate the salient hydrograph characteristics to the basin characteristics are available. Unit hydrographs derived from such relationships are known as synthetic unit hydrograph.

Factors Affecting Hydrograph and its shape:-

A) Slope of basin-

The steeper the slopes, the lower the rate of infiltration and faster the rate of run-off when the soil is saturated (saturated overland flow) or when rainfall intensity (rate per unit of time) is high (infiltration excess over land flow).

B) Permeability and rock type-

Run-off will occur quickly where impermeable rocks are exposed at the surface or quickly when they underlay soils (limited amount of infiltration). Soils with large amounts of clay do absorb moisture but only very slowly – therefore their permeability is low. The deeper the soil the more water can be absorbed. Soils which have larger particle sizes (e.g. those derived from the weathering of sandstones) have larger infiltration capacities.

C) Drainage density -

This ratio is the length of river course per area of land. The larger the streams and rivers per area the shorter distance water has to flow and the faster the rate of response.

D) Urbanization–

Impermeable road surfaces, sloping roofs, guttering, and underground sewer and drainage systems help transfer water in an urban area to rivers quickly. The increase of house building in towns and villages as people have opted to move from large settlements (counter- urbanization) especially on river flood-plains has contributed to the increase responsiveness of river systems.

The methods that were used in the generation of synthetic unit hydrograph for the watershed includes

1) Snyder’s method
2) SCS method, and
3) Gray’s method
4) GIS method
5) Clark’s method

2. Research Methodology

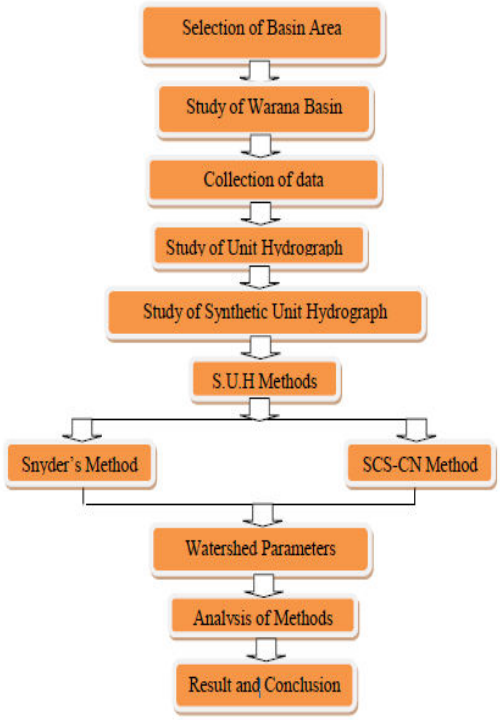

Fig. 2

3. Data collection and processing

Procurement of land use maps

The Survey of India toposheet covering the Warna watershed was selected as base map and geo-referencing of other maps to bring them in a single platform, ILWIS GIS. The land use/land cover maps were prepared by visual interpretation of satellite imageries IRS 1A LISS-II data for the year 2001 and IRS 1D LISS- III data for the year 2007 by CE & AMD, SGSITS Bangalore and MPCOST, Maharashtra respectively. The spatial information on landuse at level-1 Classification was extracted from these maps for computation of the SCS Curve Number.

Changes in spatial distribution of the landuse have been presented in table. The results reveal that scrubs with cultivation and agriculture inside forest have been mostly converted into agricultural area, which has doubled during the reported period. The major land-use categories in the area are as follows (Census 2001):

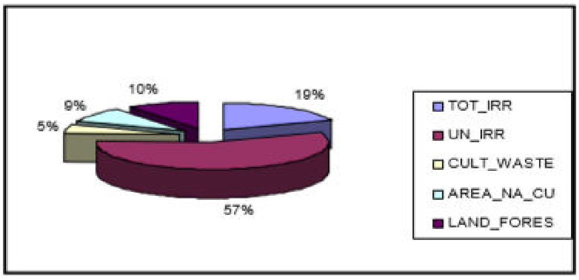

Fig. 3

Table 1: Land-use classes (census 2001)		
Land use category	**Area (ha)**	**Percentage**
Forest Land	18,755.00	10.00
Irrigated (crop) land	33,715.00	18.00
Unirrigated (crop) land	106,868.00	58.00
Culturable wasteland	8,308.00	5.00
Area not available for cultivation	16,554.00	9.00
Total	184,200.00	100.00

4. Case Study

Geo-physical setting and Salient features:-

- **Total basin area :** 2095sq km.
- **Lat/long :** 16° 47' 00 "to 17°15'15" and 73°30'45" to 74°30'00".
- **Toposheets :** 47G/11, G/12, G/15, G/16, 47H/13, 47K/4, 47L/1, L/5, L/9**.**
- **Elevation difference :** 540m to 1100m from MSL.
- **River origin :** Warana arises in Sahyadri, near Patherpunj in Patan block of Satara distt. Of Maharashtra at an altitude of 914 m from MSL
- **Flow direction :** Waranariver flows in south east ward direction.
- **Total length :** Total length of the river is around 150 Km.
- **River confluence :** It joins Krishna near Haripur village in Sanglidistt. At an Altitude of 548m.
- **District & Blocks :** Kolhapur.
- **District :** Shahuwadi, Panahala, Hatkanangale, &Shirol blocks.
- **Sangli district :** Shirala, Walwa, and Miraj blocks Satara.
- **District :** Patan block Ratnagiri distt – Sangameshwar blocks.
- **Major tributaries :** Morna and Meni join from North Kadavi and Kansa join from West.
- **Contour pattern :** Contours are closed and closely spaced in the upper part of the basin shows various hillocks and undulating topography. In lower part widely spaced contours indicates the flat terrain.
- **Geology :** The area completely covered by Deccan Trap (volcanic Basaltic rock). Its weathered form Laterite /bauxite also found at higher altitude. Loose sand found on river banks.
- **Rainfall :** Rainfall varies from more than 4000 mm to less than 600 mm in the area.
- **Landuse pattern :** 61.10% is under agriculture, 14.84% is under forest land
- **National Park :** Chandoli initially declared as Wild Life Sanctuary [WS], in 1985, with an area of 308.97 Km2, was Up-graded to National Park in May, 2004, with an area of 317.67 km2. It Hasnow become part of Sahyadri Tiger reserve in May 2007.

ANALYSIS AND DISCUSSION OF METHODS

Snyder's Method:-

The Snyder’s Method was used to compute the unit hydrograph characteristics such as lag time or basin lag, unit hydrograph duration, peak discharge, time base, or base period and hydrograph time widths at 50% and 75% of peak flow. Determination of all these parameters allows for the development of unit hydrograph. Snyder’s considered the shape and area of the basin and gave the following empirical equations after analyzing large number of hydrographs from drainage basins of areas from 25 to 25000 km2 (2009).

Objectives of Snyder’s Method:

A) To determine the coefficient ‘Ct’ and ‘Cp’ of Snyder’s equations for various sub catchments of the Indus River Basin using the rainfall and runoff data of gauged streams.

B) To verify the derived parameters by computing the synthetic hydrographs and comparing them with observed hydrographs.

C) To examine the limitations of base length ‘T’ taken three days in Snyder’s method

D) To verify the applicability of method by US Army crops of engineer’s for time lag and time width of unit hydrograph at 50% and 75% peak discharge.

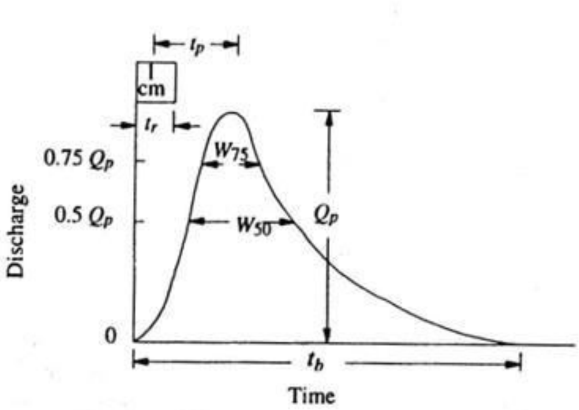

Fig. 4 Synder's Method

Watershed characteristics/parameters.
For the first time Snyder established a set of empirical relationships, which relate the watershed characteristics which are given in following table.

Summary of the results obtained for the watershed Characteristics/parameters.

Watershed characteristics/parameters	Values obtained
Watershed area (A)	2095 Km^2
Watershed slope (S)	0.37 %
Length of main river (L)	150 Km
Length along the main channel from the outlet to a channel point nearest the watershed centroid (Lc)	90 Km

Table No. 2 Characteristics/parameters.

Analysis synthetic unit hydrograph Snyder's Method

Determination of coefficients Ct and Cp :-

Basin lag time (tp):-

$$tp = Ct\ (L * Lc)^{0.3}$$

Where,

tp= the basin lag (hours),

Ct=a coefficient which depends upon the characteristics of the basin,
L= length of the main stream of the catchment (km),
Lc= distance from the basin outlet to a point on the stream which is nearest to the centroid of the area of the basin (km).

Duration of rainfall excess (D)

$$D = tp / 5.5$$

Where,

tp= the unit duration of rainfall of storm (hours),
D = the basin lag (hours)

Peak discharge (Qp):-

$$Qp = 640\ Cp\ A$$

Where:

Qp=the peak discharge (m3/s),
Cp= the coefficient which depends upon the retention and storage characteristics of the basin (Values of Cp varies from 0.3 to 0.93),
A= area of the basin (km2),
tPR= the basin lag (hours).

Time base or base period (Tb):-

$$Tb = 3 + tP / 8$$

Where:
T= the base period (days),
tp= the basin lag (hours)

The width of unit hydrograph (W %):-
The co-relation equations for time width unit hydrograph at 50% and 75% of peak discharge developed by U.S.Army crops of engineers (1959) are given below,

$$W50 = 770\ (Q/A)^{-1.08}$$
$$W75 = 440\ (Q/A)^{-1.08}$$

D (hrs)	Tp (hrs)	Tb (hrs)	Qp (cfs)
4.73	26.03	6.254	11932.8
6	26.35	6.29	11788.97
12	27.85	6.48	11153.96
18	29.35	6.67	10583.86
24	30.85	6.86	10069.21

Table no. 4 Summirised Synder's record for different duration

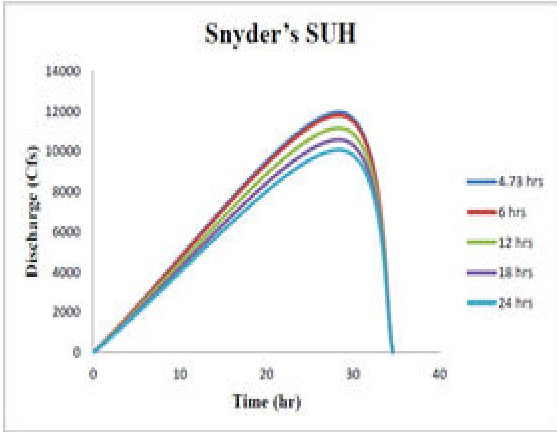

Fig.5 Summirised Synder's Graph for different duration

Analysis of synthetic unit hydrograph by SCS-CN Method:-

Lag time is given by

$$t_p = \frac{L^{0.8}\left(\frac{1000}{CN} - 9\right)^{0.7}}{19000y^{0.5}}$$

Where,
L= length to divide (ft),
Y= average watershed slope (in present),
CN= curve number for various soil/land use.

6.5.3. Time of rise (TR):-

The rise of the hydrograph is given by;

$$T_R = \frac{D}{2} + t_p$$

Where,
D= rainfall duration (hr),
tp= lag time from centroid of rainfall to QP

6.5.4. Peak flow:-

Then find Qp using the following eq, for given catchment area as;

$$Q_p = \frac{0.75vol}{T_R} = Q_p = \frac{0.75(640)A(1.008)}{T_R}$$

$$Q_p = \frac{484A}{T_R}$$

where,
A= area of basin (sq mi),
TR = time of rise (hr),

The volume of direct runoff:-

To complete the graph, it is also necessary to know the time of fall B. The volume is known to be 1 in. of direct runoff over the watershed.
So, from equation of volume of direct runoff, find out the time base

$$Vol = \frac{Q_pT_R}{2} + \frac{Q_pB}{2} \quad \text{OR} \quad Vol = \frac{Q_pT_R}{2} + \frac{Q_pB}{2}$$

Where B is given by,

$$B = 1.67T_R$$

SCS- CN SUH for 6 hrs, 12hrs, 18 hrs and 24hrs

D (hrs)	Tp (hrs)	T_R (hrs)	B(hrs)	Qp (cfs)
6	79.12	82.12	135.06	4767.38
12	79.12	85.12	139.99	4599.36
18	79.12	88.12	144.93	4442.78
24	79.12	91.12	149.86	4296.51

Table no. 5 Summirised SCS-CN record for different duration

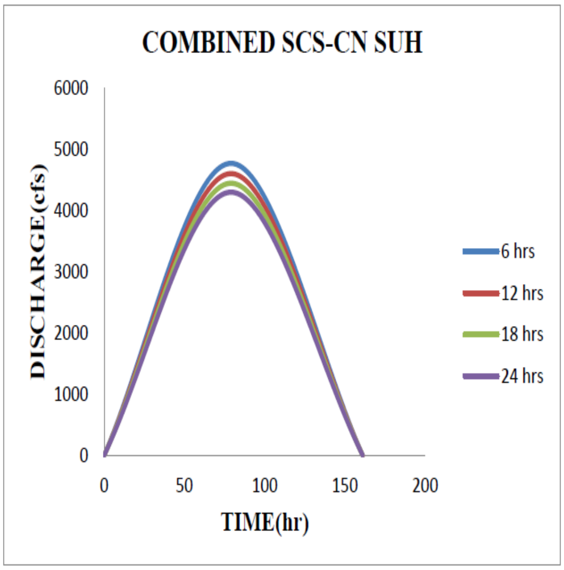

Fig. 6 Summirised SCS-CN graph for different duration

RESULTS:

Comparison of Snyder's and SCS-CN Graph's

The results indicated that there were significant differences in the methods, but based on the

percentage difference, it can be summarized that the SCS method can be useful in the generation of unit hydrograph ordinates required for the development of unit hydrograph within the catchment under consideration.
From that, it can concluded that SCS method can be used to estimate ordinates required for the development of synthetic unit hydrograph of different return periods of rivers as it was done in the present study.
By using watershed parameters of Warana basin, we have drawn the hydrographs for various rainfall durations such as 6 hrs, 12 hrs, and 18 hrs. And 24 hrs. Corresponding to the Snyder's and SCS-CN synthetic unit hydrograph methods. Shows the comparisons between the two methods Snyder's and SCS-CN methods. According to the table and graphs, peak discharge for Snyder's method are more due to watershed coefficient Ct and Cp. Whereas , peak discharge for SCS-CN method are less because of curve number which is depends on the soil type, land use, geology etc. and slope of watershed.

Conclusion

Based on the results obtained so far for the ungauged watershed, it could be seen that the generation of unit hydrograph through synthetic methods has been found useful and effective. The statistical evaluation of the synthetic unit hydrograph flows obtained in this study from the two methods employed have indicated that there were significant differences in the methods.
By the comparative analysis of the two methods (SCS and Snyder), concluded that the methods are corresponding. However, the computed hydrographs by the SCS have smoother peak limb, but the computed hydrographs by Snyder simulate well the recession limb.
The underestimated peak runoff and the total volume of Snyder's method can be calibrated rising the CN's values. The Snyder method though needs the peak time tp and the peak coefficient Cp but, the peak coefficient is a parameter indefinite in real watershed. For all reasons, in the present application, the evaluation indicates the best Unit Hydrograph method of Soil Conservation Service.

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