

DEVELOPMENT OF STORM HYDROGRAPHS FOR THREE RIVERS WITHIN DRAINAGE NETWORK IN KWARA STATE, NIGERIA USING SNYDER'S METHOD

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ABSTRACT

This paper presents the development of unit and storm hydrographs for Rivers Moro, Asa and Oyun catchment. Snyder's method was used to develop the unit hydrographs; while the SCS Curve Number method was used to estimate excess rainfall values from rainfall depth of different return periods. The design storm hydrographs corresponding to the excess rainfall values were determined based on the unit hydrograph ordinates established through convolution. The design storm hydrograph obtained for Moro River catchment based on 5-yr, 20-yr, 50-yr, 100-yr and 200-yr return period ranged between 245.29m³/s and 685.84m³/s. That of Asa River catchment varied from 301.34m³/s to 846.46m³/s and the design storm hydrograph flows obtained for Oyun River catchment varied from 257.29m³/s to 723.56m³/s. The design storm hydrograph flows obtained can be recommended for sizing hydraulic structures within Kwara State drainage network.

Keywords: Unit hydrograph, storm hydrograph, storm duration, River catchment and recurrence interval

1.0 INTRODUCTION

In the design of dams, drainages, sewers, culverts, bridges, reservoirs, spillways and flood control structures, it is important to know the precipitation and runoff relationship to get the peak discharges of stream flow from the peak rainfall for the design of the structures. The peak discharges of stream flow from rainfall can be obtained from the design storm hydrographs developed from unit hydrographs generated from

Warren et al. (1972) described hydrograph as a continuous graph showing the properties of stream flow with respect to time, normally obtained by means of a continuous strip recorder that indicates stages versus time which is then transformed to a discharge hydrograph by application of a rating curve. Wilson (1990) observed that with an adjustment and well measured rating curve, the daily gauge readings may be converted directly to runoff volume. It was also emphasized that catchment properties influence runoff and may be present to a large or small degree.

The catchment properties include area, slope, orientation, shape, altitude and stream pattern. Arora (2004) defined 1-hr unit hydrograph as the hydrograph which gives 1 cm depth of direct runoff when a storm of 1-hr duration occurs uniformly over the catchment.

A vast amount of literature exists treating the various unit hydrograph methods and their development. Jones (2006) reported that Sherman in 1932 was the first to explain the procedure for development of the unit hydrograph and recommended that the unit hydrograph method should be used for watersheds of 2000 square miles (5000 km²) or less. Chow et al. (1988) discussed the derivation of the unit hydrograph and its linear systems theory. Furthermore Viessman et al. (1989), Wanielista (1990) and Arora (2004) presented the history and procedures for several unit hydrograph methods. Wilson (1990) also reported that in 1938, McCarthy proposed a method of hydrograph synthesis but in that same year Snyder proposed a better known method by analyzing a larger number of basins in the Appalachian mountain region of the United States. Ramirez (2000) reported that the synthetic unit hydrograph of Snyder in 1938 was based on the study of 20 watersheds located in the Appalachian Highlands and varying in size from 25 to 25000 km².

Ogunlela and Kasali (2002) applied four methods of unit hydrographs generation to develop unit hydrograph for an ungauged watershed.

The outcome of the study revealed that Snyder's method was the most appropriate method for that watershed. This study applied Snyder's method to develop unit hydrographs of different storm durations and subsequently used to generate design storm hydrographs of rainfall depth of various return intervals for the design of hydraulic structures within the River catchments. Bilewu and Salami (2009) applied Snyder's synthetic unit hydrograph method to estimate the unit hydrograph ordinates for determination of peak stream flows of 1 hr, 2 hr and 3 hr storm durations and different return periods for River Asa, Ilorin, Nigeria. It was discovered that the design storm hydrograph obtained based on 1 hr gave the highest values and was recommended for sizing hydraulic structures within the catchment. Salami et al. (2009) evaluated three methods of synthetic unit hydrograph for some rivers in South-West, Nigeria. The basin parameters of eight rivers within the catchment were analyzed. The synthetic unit hydrograph methods considered were Snyder, Soil Conservation Service (SCS) and Gray methods. The analysis showed that the values of peak flows obtained by Gray and SCS methods for five watersheds were relatively close, while the values of peak flows obtained by Gray and Snyder methods for two watersheds were relatively close and the values of peak flows obtained by Snyder and SCS methods for only one watershed was relatively close. This inferred that SCS method can be used to estimate ordinate required for the development of peak storm hydrograph of different return periods for the river watersheds considered.

The methods considered are Snyder, SCS and Gray methods, the statistical analysis, conducted at the 5% level of significance indicated significant differences in the methods except for Snyder and SCS methods which have relatively close values.

2.0 MATERIAL AND METHODS

2.1 Study Area

Figure 1.1 is the map of Nigeria showing Kwara State and the study area, while Figure 1.2 is the catchment area of the Rivers considered. River Moro catchment is about 581.5 km² with a length of 46.8 km and is a left-hand tributary of River Asa. The catchment of Asa River is located between latitude 8°36' and 8°24' North and Longitudes 4°36' and 4°10' East. Its total area is 906.0 km² and it lies within Kwara and Oyo States with one third of the basin area in Oyo State. The length of the river is about 57.5 km. Asa river runs from south to north of Ilorin to join with Oyun river. The catchment of Oyun River is located between latitudes 9°50' and 8°24' North and Longitudes 4°38' and 4°03' East. Its total area is 800.0 km² with a length of 71.4 km and it lies within Kwara State.

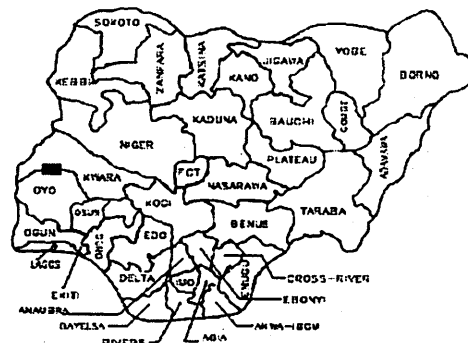


Figure 1.1 Map of Nigeria showing location of river catchment

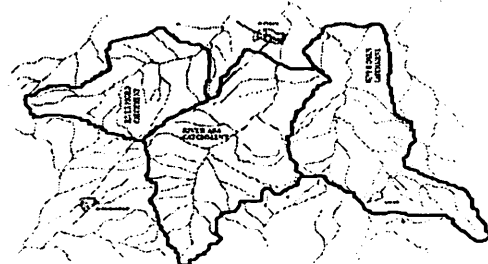


Fig. 1.2 Rivers Moro, Asa and Oyun Catchments

2.2 Development of Synthetic Unit Hydrograph

Snyder's method was used to determine the peak discharge, lag time and the time to peak by using characteristic features of the watershed. Ramirez (2000) reported that the hydrograph characteristics are the effective rainfall duration, t_r , the peak direct runoff rate Q_p , and the basin lag time, t_l . From these relationships, five characteristics of a required unit hydrograph for a given effective rainfall duration may be calculated. The five characteristics are the peak discharge per unit of watershed area, q_p , the basin lag t_l , the base time, t_b , and the widths, w (in time units) of the unit hydrograph at 50 and 75 percent of the peak discharge. The unit hydrograph parameters were estimated in accordance to Ramirez (2000) and Arora (2004) as follows:

Lag time

$$(t_l) = C_t (L * L_c)^{0.3}$$

where t_l is lag time (hr) and C_t is a coefficient representing variations of watershed slope and storage. (Values of C_t range from 1.0 to 2.2, Arora (2004)). An average value of 1.60 was assumed for this catchment. L is the length of the river channel and L_c is the length of river channel from a control point to the centroid of the catchment.

Unit-hydrograph duration, t_r (storm duration)

$$t_r = \frac{t_l}{5.5} \quad (2)$$

From equation (2) the duration of the storm was obtained. However, if other storm durations are intended to be generated for the watershed, the new unit hydrograph storm duration (t_r), the corresponding basin lag time (t_l) can be obtained from equation (3) as

$$t_l = t_r + \left(\frac{t_r - t_l}{4} \right) \quad (3)$$

Peak discharge, Q_p

The peak discharge (Q_p) was obtained

$$Q_p = 2.78 \frac{C_p * A}{T_p} \quad (4)$$

where C_p is the coefficient accounting for flood wave and storage conditions. (Values of C_p range from 0.3 to 0.93 (Arora (2004)). A value of 0.62 was assumed for this catchment.

2.3 Base Time

The base time was obtained from equation (5)

$$t_b = 3 + 3 \left(\frac{t_l}{24} \right) \quad (5)$$

The time width W_{50} and W_{75} of the hydrograph at 50% and 75% of the height of the peak flow ordinate were obtained based on equations (6) and (7) respectively. U.S Army Corps of Engineer (Arora, 2004). Also the peak discharge per area (cumec/km²) is given by equation (8)

$$W_{50} = \frac{5.9}{(q_p)^{1.08}} \quad (6)$$

$$W_{75} = \frac{3.4}{(q_p)^{1.08}} \quad (7)$$

$$q_p = \frac{Q_p}{A} \quad (8)$$

The parameters for the unit hydrograph for the three catchments are presented in Table 1.
 Table 1 Synthetic unit hydrograph parameters for the rivercatchments

River	t_l (hr)	t_r (hr)	Q_p (m ³ /s)	q_p (m ³ /s/km ²)	T_b (hr)	W_{50} (hr)	W_{75} (hr)
Macro	2.12	11.65	86.01	0.15	106.96	46.48	26.56
Asa	2.73	15.02	104.01	0.12	117.04	61.11	34.92
Ogun	2.84	15.62	88.27	0.11	118.87	63.75	36.43

2.3 Development of design storm hydrographs

The established unit hydrographs were used to develop the storm hydrographs due to actual rainfall event over the watershed. Design storm hydrographs for selected recurrence intervals (5yr, 20yr, 50yr, 100yr and 200yr) were developed through convolution. The maximum 24-hr rainfall depths for these recurrence intervals for the catchment under consideration are 85.0 mm, 107.0 mm, 125.0 mm, 140.0 mm and 155.0 mm respectively (Olofinloye et al. 2009).

Convolution involves multiplying the unit hydrograph ordinates (U_n) by incremental rainfall excess (P_n), adding and lagging in a sequence to produce a resulting storm hydrograph. The SCS Type II curve was used to divide the different rainfall data into successive equal short time events and the SCS Curve Number method was used to estimate the cumulative rainfall for storm depths of 5yr, 20yr, 50yr, 100yr and 200yr return periods. The incremental rainfall excess was obtained by subtracting sequentially, the rainfall excess from the previous time events. The equations that were applied to the SCS Curve Number method are given below (SCS, 2002).

$$Q_d = \frac{(P' - I_a)^2}{P' + 0.8S} \text{ for } P' > 0.2S \quad (9)$$

$$Q_d = 0 \text{ for } P' \leq 0.2S$$

where

Q_d = cumulative rainfall excess (mm); p = cumulative rainfall depth (mm)

I_a = initial abstraction $I_a = 0.2S$

S = basin potential storage (mm)

$$S = \frac{25400}{CN} - 254 \quad (10)$$

CN is the basin Curve Number

With the $CN = 75$ based on hydrologic soil group B, small grain and good condition, S was estimated as 84.67 mm, while I_a was 16.94 mm. This implies that

The storm hydrograph ordinates based on the rainfall depth of desired recurrence intervals were estimated from the unit hydrographs. The storm hydrograph ordinates for the watershed due to Moro, Asa and Oyun Rivers were extracted and used to plot the storm hydrographs as presented in Figures 2 to 4.

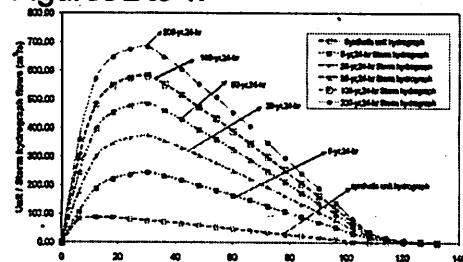


Figure 2 Unit and storm hydrographs of different return periods (Moro Catchment)

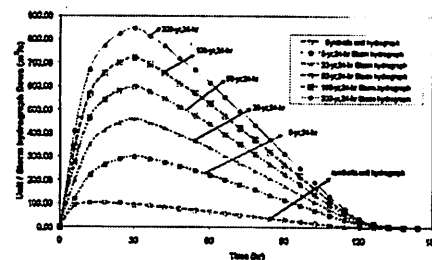


Figure 3 Unit and storm hydrographs of different return periods (Asa Catchment)

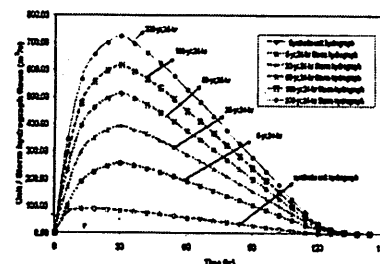


Figure 4 Unit and storm hydrographs of different return periods (Oyun Catchment)

The peak storm hydrograph of different return periods for the three basins are presented in Table 2. The peak flow values are useful for flood structure sizing of hydraulic structures within the catchment.

Table 2 Storm hydrograph peak flows (m^3/s) for the catchment of the rivers

Rivers	Storm return periods				
	5yr, 24hr	20yr, 24hr	50yr, 24hr	100yr, 24hr	200yr, 24hr
Moro	245.29	354.86	487.01	585.04	685.84
Asa	301.34	460.39	600.22	721.60	846.46
Oyun	257.29	383.29	512.89	616.73	723.56

3.0 RESULTS AND DISCUSSION

The synthetic unit hydrograph parameters for the three catchment areas are presented in Table 1, while the storm hydrograph peak flows are presented in Table 2. The result shows that the unit hydrograph peak flows for the River catchment ranges between 86.0 m³/s and 104.0 m³/s, while the time to peak ranged between 11.0 hr and 16.0 hr. Also from the results, the values of the design storm hydrograph having return periods of 5-yr, 24-hr has peak flows ranging from 245.0 m³/s to 302.0 m³/s, while the time to peak is 30 hr. For the 20-yr, 24-hr storm hydrographs, the peak flows ranged from 350.0 m³/s to 460.5 m³/s, while the time to peak is between 25 hr and 30.0 hr. For the 50-yr, 24-hr storm hydrographs, the peak flows ranged from 487.0 m³/s to 600.5 m³/s while the time to peak is between 28 hr and 30 hr. For the 100-yr, 24-hr storm hydrographs, the peak flows ranged from 585.0 m³/s to 721.6 m³/s while the time to peak ranges from 28 hr to 30 hr and for the 200-yr, 24-hr storm hydrographs, the peak flows ranged from 685.8 m³/s to 846.5 m³/s while the time to peak ranges from 28 hr to 30 hr. The unit and storm hydrographs of various return periods are presented in Figures 2 to 4.

4.0 CONCLUSIONS

The developed unit and storm hydrographs can be used to compute the peak flows for the design of hydraulic structures within the catchments of the rivers considered.

The selection of peak storm hydrograph flows of the desired return period depend on the type of hydraulic structure being constructed. Hence, the developed storm hydrograph can be adopted for the estimation of desired peak flow for the design of bridges, dam spillways, drainage culverts and minor bridges.

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