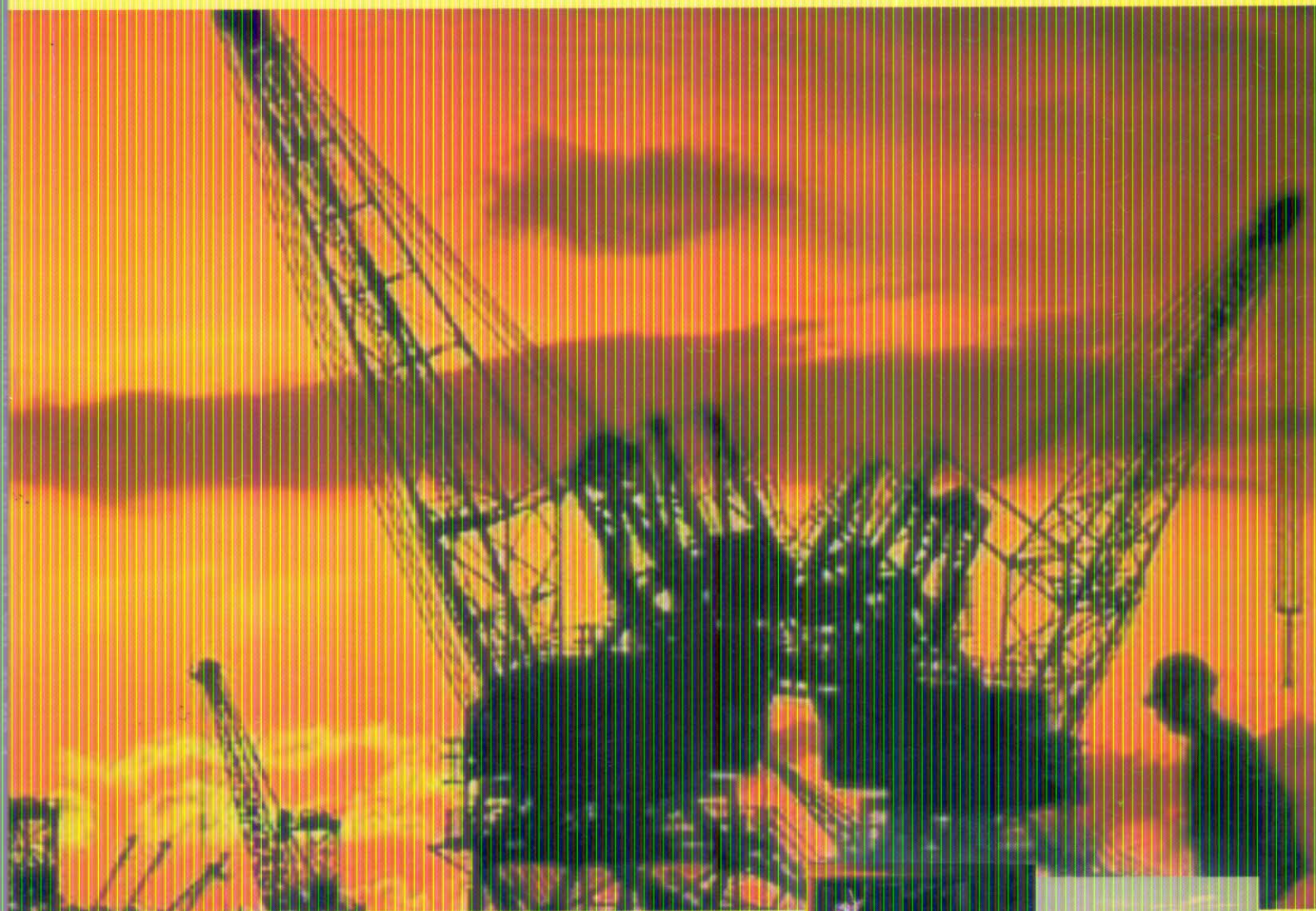




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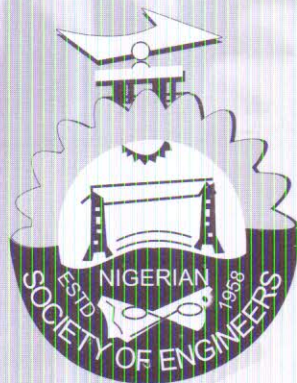


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## ESTIMATION OF PEAK FLOWS FROM EXTREME RAINFALL: CASE STUDY OF RIVERS WITHIN KWARA STATE DRAINAGE NETWORKS IN NIGERIA

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### Abstract

This paper presents the estimation of peak flow for the catchment of River Asa, Oyun and Moro. Unit hydrographs were developed based on Snyder, SCS and Gray methods. The peak flows obtained based on the unit hydrograph ordinate determined by Snyder for 5-yr, 20-yr, 50-yr, 100-yr and 200-yr return period varies from 230.0m<sup>3</sup>/s and 806.0m<sup>3</sup>/s, while those based on the SCS varies from 260.0m<sup>3</sup>/s and 1053.0m<sup>3</sup>/s and those based on Gray varies from 208.0m<sup>3</sup>/s and 861.0m<sup>3</sup>/s for the three watersheds. However, the analysis shows that for Asa watershed the values of peak flows obtained by Snyder and Gray methods is fairly close (5.99%), while the percentage difference shows that for Oyun watershed the values of peak flows obtained by Snyder and SCS method is fairly close (7.70%) and the percentage difference shows that for Moro watershed the values of peak flows obtained by Snyder and Gray method is fairly close (11.31%). This inferred that Snyder method can best be used to estimate ordinates required for the development of peak runoff hydrograph of different return periods.

**Keywords:** Synthetic unit hydrograph, runoff hydrograph, storm duration, River catchment and recurrence intervals

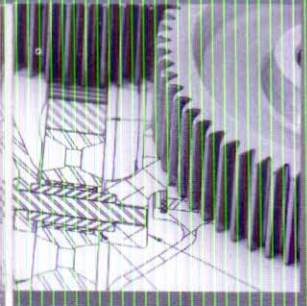
### 1.0 Introduction

In the design of hydraulic structures it is required to know the rainfall-runoff relationship to obtain the peak discharges for the design of the structures. The peak discharges of stream flow from rainfall can be obtained from the design runoff hydrographs developed from unit hydrographs. 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

and 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. The catchment properties required in the synthetic unit hydrograph development include area, slope, orientation, shape, altitude and also stream pattern in the basin. The unit hydrograph of a drainage basin, according to Varshney (1986) is defined as the hydrograph of

$\eta$

$\dot{m}_r$



direct runoff resulting from one unit of effective rainfall of a specified duration, generated uniformly over the basin area at a uniform rate. Arora (2004) also 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 km<sup>2</sup>) or less. Chow et al, (1988) discussed the derivation of unit hydrograph and its linear systems theory. Further more Viessman et al, (1989), Wanielista (1990) and Arora (2004) presented the history and procedures for several unit hydrograph methods. 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 25000.0 km<sup>2</sup>.

Ramirez (2000) reported that the dimensionless unit hydrograph was developed by the Soil Conservation Service and obtained from the UH's for a great number of watersheds of different sizes and for many different locations. It was also stated by Ramirez (2000) that the SCS dimensionless hydrograph is a synthetic UH in which the discharge is expressed as a ratio of discharge,  $Q$ , to peak

discharge,  $Q_p$  and the time by the ratio of time,  $t$ , to time to peak of the UH,  $t_p$ . Wilson (1990) also reported that in 1938, Mc Carthy 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. Ogunlela and Kasali (2002) applied four methods of unit hydrographs generation to develop unit hydrograph for an ungaged watershed. The outcome of the study revealed that both Snyder and SCS methods were not significantly different from each other. Salami (2009) evaluated three methods of storm hydrograph development for the catchment of lower Niger River basin at downstream of Jebba Dam. 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. This study applied Snyder, SCS and Gray methods to develop unit hydrographs and subsequently used to generate design storm hydrographs of rainfall depth of various return intervals through convolution.

## 2.0 Material and Methods

### 2.1 Study area

River Moro catchment is about 581.5 km<sup>2</sup> 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 km<sup>2</sup> and it lies within Kwara State and Oyo State with about 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 latitude 9°50' and 8°24' North with Longitudes

4°38' and 4°03' east. Its total area is 800.0 km<sup>2</sup> with a length of about 71.4 km and it lies within Kwara State. Figure 1 is the map of Nigeria showing Kwara State and the study area painted, while Figure 2 is the catchment area of the Rivers considered. The characteristics of the three Rivers are presented in Table 1.

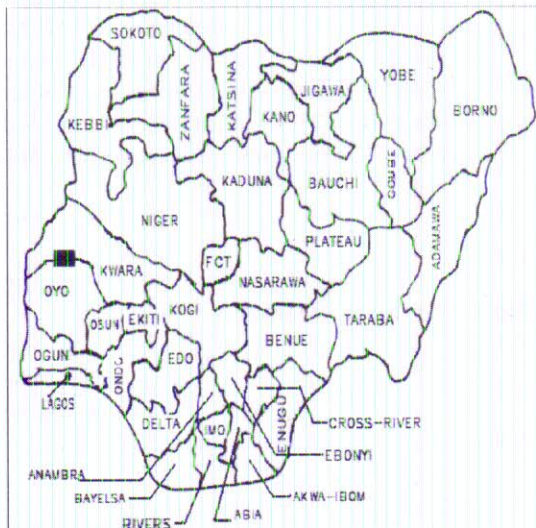


Fig. 1 Map of Nigeria showing location of river catchments

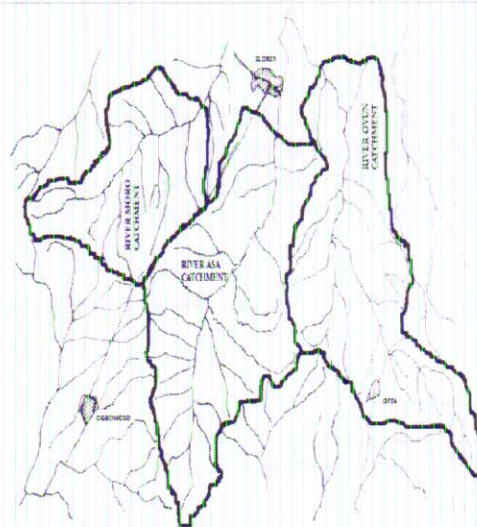


Fig. 2 Rivers Moro, Asa and Oyun Catchments

Table 1 Catchment characteristics

| Watershed | L (km) | L <sub>c</sub> (km) | A (km <sup>2</sup> ) | Sc     |
|-----------|--------|---------------------|----------------------|--------|
| Asa       | 57.50  | 30.31               | 906.00               | 0.0025 |
| Oyun      | 71.40  | 27.86               | 800.00               | 0.0023 |
| Moro      | 46.80  | 16.00               | 581.50               | 0.0028 |

Where

L = Length of the river Channel (Km)

L<sub>c</sub> = Length of the river from the outlet to a point near the centroid (Km)

A = Watershed area (Km<sup>2</sup>)

Sc = Slope of river channel (m/m)

## 2.2 Application of unit hydrograph methods

The synthetic methods of unit hydrograph adopted include Snyder's, Soil Conservation Service (SCS), and Gray methods.

### 2.2.1 Snyder's method

The 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 are estimated in accordance to Ramirez (2000) and Arora (2004). The Snyder's method was used to compute the lag time, unit hydrograph duration, peak discharge, time base and hydrograph time widths of peak flow by using the watershed characteristics obtained from the topographic map in accordance to Ramirez (2000), Arora (2004) and Salami et al (2009). The parameters obtained are presented in Table 2.

**Table 2 Parameters for the generation of unit hydrograph (Snyder's method)**

| Watershed | $C_p$ | $C_t$ | $t_L$ (hr) | $t_r$ (hr) | $Q_p$<br>( $m^3/s$ ) | $W_{50}$<br>(hr) | $W_{75}$<br>(hr) | $T_b$ (hr) | $q_p$<br>( $m^3/s/km^2$ ) |
|-----------|-------|-------|------------|------------|----------------------|------------------|------------------|------------|---------------------------|
| Asa       | 0.60  | 1.60  | 15.01      | 2.73       | 104.11               | 61               | 35               | 117        | 0.12                      |
| Oyun      | 0.60  | 1.60  | 15.62      | 2.84       | 88.27                | 64               | 37               | 119        | 0.11                      |
| Moro      | 0.60  | 1.60  | 11.65      | 2.12       | 86.01                | 47               | 27               | 107        | 0.15                      |

### 2.2.2 Soil Conservation Service (SCS) method

The peak discharge and the time to peak were determined in accordance to Viessman et al (1989), Wanielista (1990), Ramirez (2000). SCS (2002) and Ogunlela and Kasali (2002). The method of Soil Conservation Service (SCS) for constructing synthetic unit hydrographs was based on a dimensionless hydrograph, which relates ratios of time to ratios of flow (Viessman et al., 1989) and Ramirez (2000). This method

requires only the determination of the time to peak and the peak discharge. The calculated values for parameters  $t_p$  and  $q_p$  were applied to the SCS dimensionless unit hydrograph to obtain the corresponding unit hydrograph ordinates, the estimated unit hydrograph ordinates is presented in Table 3 based on the values of  $t_p=9.95hr$  and  $q_p=189.34 m^3/s$  for Asa river catchment, while  $t_p=12.15hr$  and  $q_p=136.95 m^3/s$  for Oyun river catchment, and  $t_p=8.07hr$  and  $q_p=149.92 m^3/s$  for Moro river catchment respectively.

**Table 3 Parameter for development of unit hydrograph (SCS method)**

| Asa River    |                                     | Oyun River   |                                     | Moro River   |                                     |
|--------------|-------------------------------------|--------------|-------------------------------------|--------------|-------------------------------------|
| Time, t (hr) | Discharge, Q<br>(m <sup>3</sup> /s) | Time, t (hr) | Discharge, Q<br>(m <sup>3</sup> /s) | Time, t (hr) | Discharge, Q<br>(m <sup>3</sup> /s) |
| 0.00         | 0.00                                | 0.00         | 0.00                                | 0.00         | 0.00                                |
| 4.98         | 81.42                               | 6.08         | 58.89                               | 4.03         | 64.47                               |
| 9.95         | 189.34                              | 12.15        | 136.95                              | 8.07         | 149.92                              |
| 14.93        | 124.97                              | 18.23        | 90.39                               | 12.10        | 98.95                               |
| 19.91        | 60.59                               | 24.30        | 43.83                               | 16.14        | 47.97                               |
| 24.88        | 29.35                               | 30.38        | 21.23                               | 20.17        | 23.24                               |
| 29.86        | 14.20                               | 36.45        | 10.27                               | 24.20        | 11.24                               |
| 34.83        | 6.82                                | 42.53        | 4.93                                | 28.24        | 5.40                                |
| 39.81        | 3.41                                | 48.60        | 2.47                                | 32.27        | 2.70                                |
| 44.79        | 1.70                                | 54.68        | 1.23                                | 36.31        | 1.35                                |
| 49.76        | 0.76                                | 60.75        | 0.55                                | 40.34        | 0.60                                |
| 54.73        | 0.00                                | 66.83        | 0.0                                 | 44.37        | 0.00                                |

**2.2.3 Gray's method**

The discharge was obtained through the dimensionalizing of the incomplete Gamma function. The equation is given as (Viessman et al 1989; Ogunlela and Kasali, 2002). The Gray method required the determination of

period of rise  $P_R$ , rainfall duration  $D$ , the volume of the unit hydrograph  $V$ , and the volume of dimensionless graph  $V_D$ . The parameters were obtained in accordance to the procedure stated by Viessman et al (1989), Ogunlela and Kasali (2002) and presented in Table 4.

**Table 4 Parameter for development of unit hydrograph (Gray method)**

| Watershed | $P_R$ (hr) | $P_R/\gamma$ (hr) | $D$ (hr) | $\Sigma cfs$ ( $10^4$ ) | $V=V_D$ ( $10^6$ m <sup>3</sup> ) |
|-----------|------------|-------------------|----------|-------------------------|-----------------------------------|
| Asa       | 36.81      | 12.20             | 9.20     | 2.46                    | 23.00                             |
| Oyun      | 47.69      | 15.80             | 11.92    | 1.67                    | 20.31                             |
| Moro      | 28.02      | 9.28              | 7.01     | 2.07                    | 14.76                             |

**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 interval (5yr, 20yr, 50yr, 100yr and 200yr) were developed through convolution. The maximum

24-hr rainfall depths of the different recurrence interval for the catchment under consideration are 85.0 mm, 107.0 mm, 125.0 mm, 140.0 mm and 155.0 mm respectively (Olofintoye, et al; 2009). The storm hydrograph was derived from a multiperiod of rainfall excess called hydrograph convolution. It 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 depth of 5yr, 20yr, 50yr, 100yr and 200yr return period. The incremental rainfall excess was obtained by subtracting sequentially, the rainfall excess from the previous time events. The equations that apply to the SCS Curve Number method are given below (SCS, 2002).

$$Q_d = \frac{(P^* - I_a)}{P^* + 0.8S} \text{ for } P^* > 0.2S \quad (1)$$

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

$I_a$  = initial abstraction  $I_a = 0.2S$

$$S = \frac{25400}{CN} - 254 \quad (2)$$

With the  $CN = 75$  based on soil group B, small grain and good condition,  $S$  is estimated as 84.67 mm, while  $I_a$  is 16.94 mm. This implies that any value of rainfall less than 16.94 mm is regarded as Zero.

where

$P^*$  = accumulated precipitation (mm)

$Q_d$  = cumulative rainfall excess, runoff (mm).

The storm hydrograph ordinates based on the rainfall depth of desire recurrence interval were estimated from the unit hydrographs. The storm hydrograph ordinates for the watershed due to Snyder, SCS, and Gray methods are extracted and used to plot the storm hydrographs as presented in figures 3a-3c, 4a-4c and 5a-5c for Snyder, SCS and Gray methods respectively.

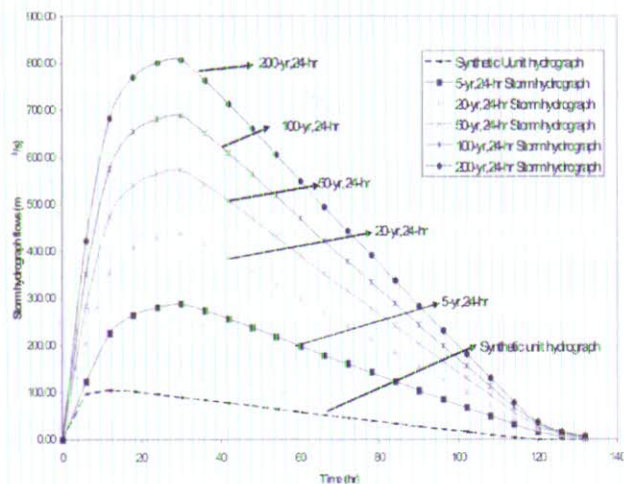


Figure 3a Unit hydrograph with generated storm hydrographs of different return periods for Asa (Snyder method)

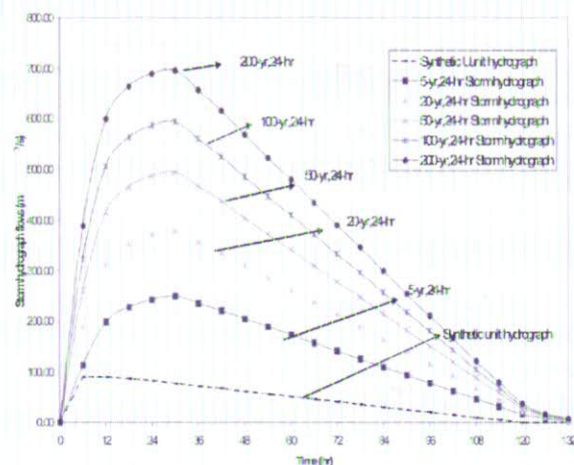


Figure 3b Unit hydrograph with generated storm hydrographs of different return periods for Ogun (Snyder method)

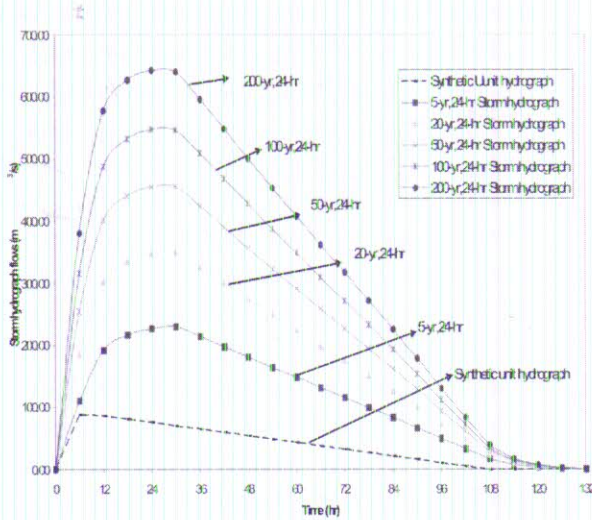


Figure 3c: Unit hydrograph with generated storm hydrographs of different return periods for Moro (Snyder method)

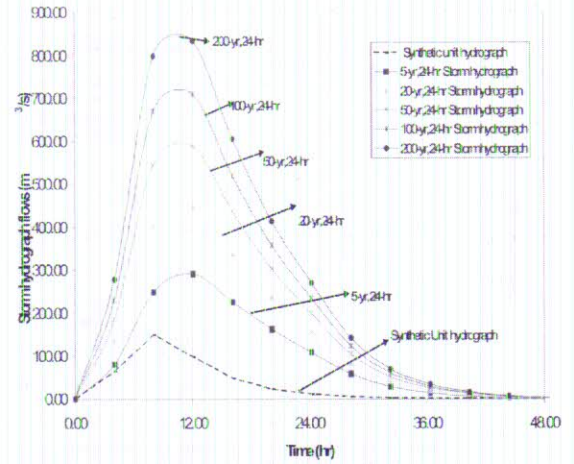


Figure 4c: Unit hydrograph with generated storm hydrographs of different return periods for Moro (SCS method)

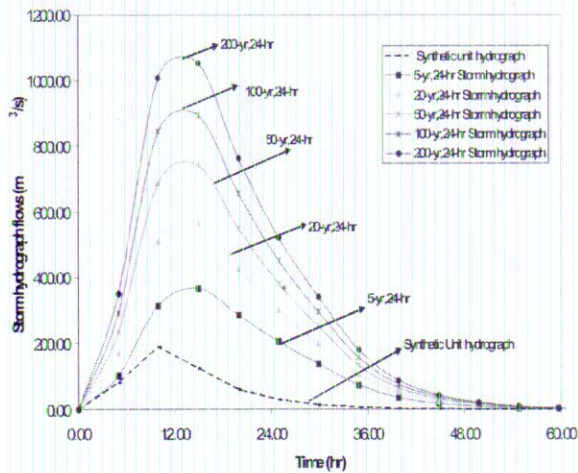


Figure 4a: Unit hydrograph with generated storm hydrographs of different return periods for Asa (SCS method)

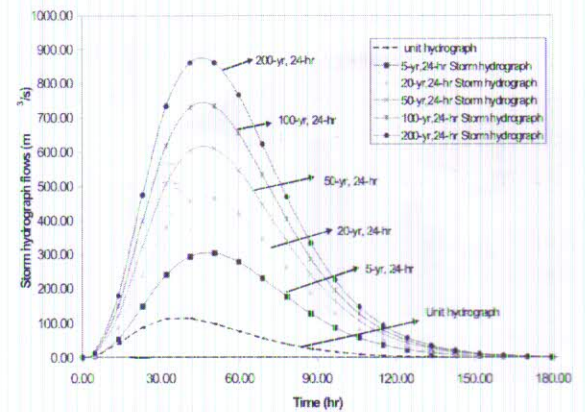


Figure 5a: Unit hydrograph with generated storm hydrographs of different return periods for Asa (Gray method)

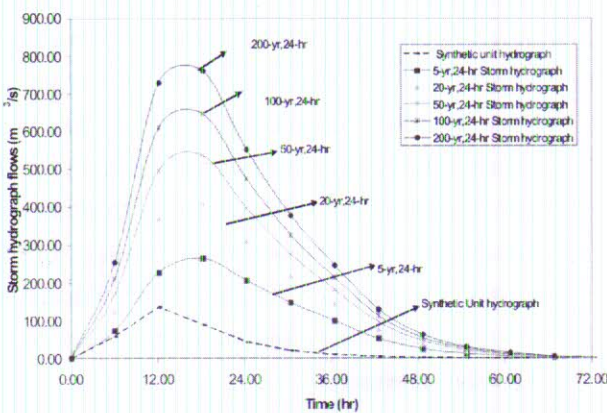


Figure 4b: Unit hydrograph with generated storm hydrographs of different return periods for Oyin (SCS method)

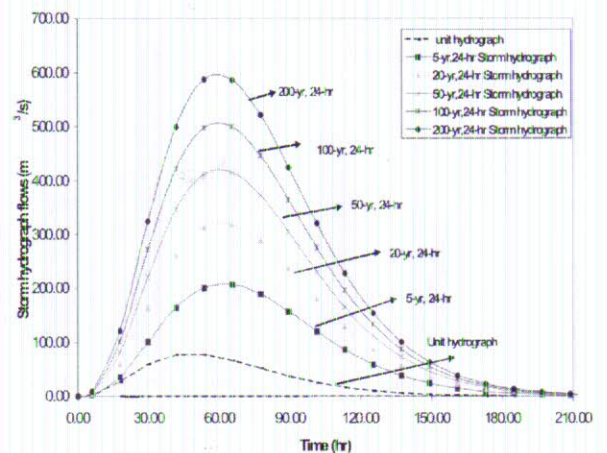


Figure 5b: Unit hydrograph with generated storm hydrographs of different return periods for Oyin (Gray method)

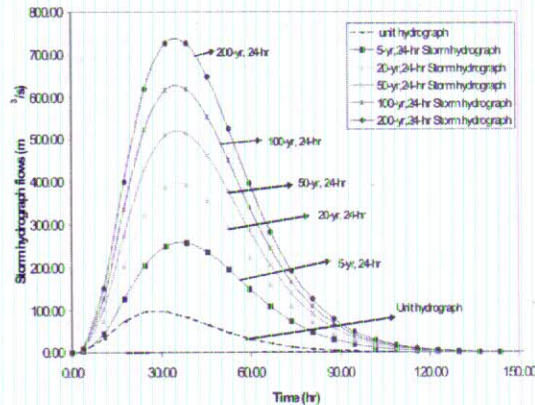


Figure 5c: Unit hydrograph with generated storm hydrographs of different return periods for Moro (Gray method)

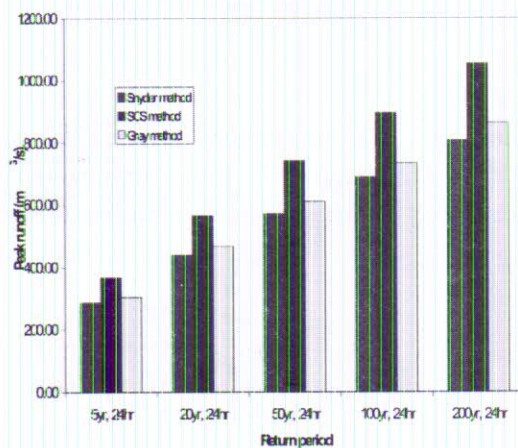


Figure 6a: Comparison of peak storm hydrograph for Asa River

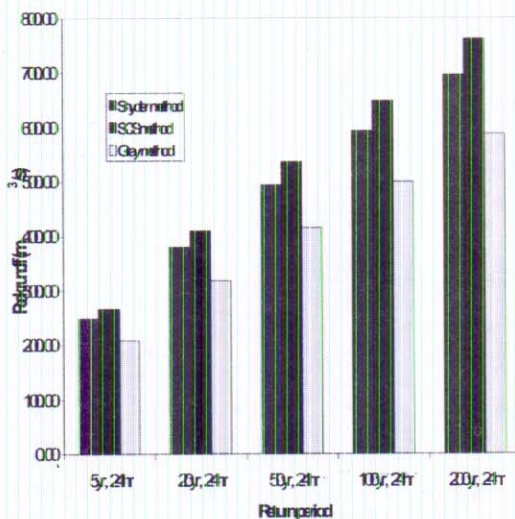


Figure 6b: Comparison of peak storm hydrograph for Oyun River

The peak runoff hydrograph of the same return periods for the catchment of the Asa, Oyun and Moro River basin based on the three methods of synthetic unit hydrograph is presented in Figure 6a, 6b and 6c respectively.

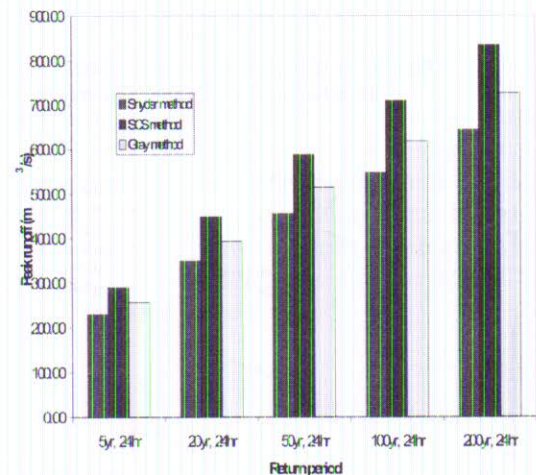


Figure 6c: Comparison of peak storm hydrograph for Moro River

### 3.0 Result and Discussion

The results presented in Tables 5 to 7 and Figure 6 shows that for Asa watershed, the peak flow values obtained for SCS method is higher by 22.62% and 17.70% than those of Snyder and Gray method respectively. While the value obtained with Gray method is higher by 5.50% than that of Snyder method. For Oyun watershed, the result shows that the values obtained for SCS method is higher by 7.70% and 22.46% than those of Snyder and Gray method respectively. While the value obtained

with Snyder method is higher by 15.98% than that of Gray method and for Moro watershed, the result shows that the values obtained for SCS method is higher by 22.28% and 12.37% than those of Snyder and Gray method respectively. While the value obtained with Gray method is higher by 11.31% than that of Snyder method.

However, the percentage difference shows that for Asa watershed the values of peak flows obtained by Snyder and Gray methods is fairly close (5.99%), while the percentage difference shows that for Oyun watershed the values of peak flows obtained by Snyder and SCS method is fairly close (7.70%) and the percentage difference shows that for Moro watershed the values of peak flows obtained by Snyder and Gray method is fairly close (11.31%). This inferred that Snyder method can best be used to estimate ordinate required for the

development peak storm hydrograph of difference return periods. The peak flow values can be useful in the study of flooding problem within the catchment.

#### 4.0 Conclusions

Conclusively, Snyder method is recommended for use on this watershed since it is most comparable to other methods. The established unit and runoff hydrographs can be used to compute the peak flows for the design of hydraulic structures within the catchment. The selection of peak storm hydrograph flows of the desire return period depend on the type of hydraulic structure in mind. For example, peak flow of 100 yr return period is required for the design of bridge, while 20 yr return period can be adopted for drainage culverts and minor bridges.

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