# Estimation of Design Flood Hydrographs for Osun River at Iwo Control Station in Osun State, Nigeria

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**Abstract**— The unit and storm hydrographs for the catchment of Osun River at Iwo station Osun State, Nigeria were developed. Soil Conservation Service (SCS) and Snyder's unit hydrograph methods were used to develop synthetic hydrographs for the catchment, while the SCS Curve Number method was used to estimate excess rainfall values from rainfall depth of different return periods. The peak storm flows obtained based on the unit hydrograph ordinates using convolution procedures determined by SCS for rainfall events of 10yr, 20yr, 50yr, 100yr and 200yr return periods for the catchment vary from 819.87 $m^3/s$ to 1681.34 $m^3/s$, while those based on Snyder's method for the catchment vary from 551.41$m^3/s$ to 1134.86 $m^3/s$ . The statistical analysis at 5% level of significance indicated that there were significant differences in the two methods. The analysis showed that the total peak flows for different return periods obtained from SCS method is higher than that of Snyder's method by 33.16%. SCS method was recommended for use on the watershed since it incorporates most major hydrological and morphological characteristics of the basins like the watershed area, main channel length, river channel slope and watershed slope.

**Keywords— Design storm hydrograph, River catchment and recurrence interval, Synthetic unit hydrograph**

## 1 INTRODUCTION

THE EU Floods Directive (2007) defined a flood as a temporary covering by water of land not normally covered by water. Heavy and small amount of rainfall that is excessively prolonged can also produce flooding on ground that is fully saturated with water (WMO/GWP, 2008). In the design of hydraulic structures such as dams, drainages, sewers, culverts, bridges, reservoirs, spillways and flood control structures, it is important and essential 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 established methods. 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.

Many literatures exist 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 (5000km2) or less. Chow et al., (1988) discussed the derivation of 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. Ogunlela (1996) developed a unit hydrograph for a small agricultural watershed at the University of Ilorin, using Clark's method to route through an assumed linear reservoir, to account for the storage characteristics of the watershed. He obtained a unit hydrograph peak of 2.97 $m^3/s$ at a time to peak of 0.33 hr, while for the 25-year, 24-hr and 100-year, 24-hr storm hydrographs, he obtained peaks of 4.53 $m^3/s$ (at 0.58hr) and 6.23 $m^3/s$ (at 0.58hr) respectively.

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Ayanshola and Salami (2009) developed a unit hydrograph for the catchment of Asa River, based on Snyder, SCS and Gray methods. They obtained 299.27$m^3/s$, 307.28$m^3/s$ and 2083.40$m^3/s$ as peak unit hydrograph values for Snyder, SCS and Gray methods respectively. The statistical analysis, conducted at the 5% level of significance indicated significant differences in the methods except for Snyder's and SCS methods which were not significantly different from each other. Ogunlela and Kasali (2002), in their study, obtained an attenuation of 0.24 $m^3/s$ for the 25-yr, 24-hr flow while 0.4 $m^3/s$ attenuation was obtained for the 100yr, 24-hr flow. Maximum water elevations were 996.88m and 997.17m for the 25-yr and 100-yr flow respectively.

Salami (2009) evaluated methods of storm hydrograph for the catchment of Lower Niger River basin downstream of Jebba dam. The methods considered were Snyder, SCS and Gray methods, the statistical analysis, conducted at 5% level of significance indicates significant differences in the methods except for Snyder and SCS methods which have relatively close values. Salami et al. (2009) presented the establishment of appropriate method of synthetic unit hydrograph to generate ordinates for the development of design storm hydrographs for the catchment of eight selected rivers located in the South West, Nigeria. The authors concluded that the values of peak flows obtained by Gray and SCS methods for five watersheds were relatively close, while values of peak flows obtained by Snyder and SCS methods for only one watershed were relatively close. The authors 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.

Salami et al. (2011) estimated the peak flows for Asa, Oyun and Moro rivers in Awun drainage area. The value of 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 230.0 $m^3/s$ to 806.0 $m^3/s$, while those based on the SCS varies from 260.0 m3/s to 1053.0 $m^3/s$, and those based on Gray varies from 208.0 $m^3/s$ to

861.0 $m^3/s$ for the three rivers in the Awun drainage basin. The study revealed that the values of peak flows obtained by Snyder and Gray methods for Asa river is fairly close (6.0%), while the percentage difference showed that for Oyun river the values of peak flows obtained by Snyder and SCS methods is fairly close (7.7%) and the percentage difference showed that for Moro river the values of peak flows obtained by Snyder and Gray methods are fairly close (11.3%). This inferred that Snyder method can best be used to estimate ordinates required for the development of peak runoff hydrograph of different return periods.

The main objective of this study was to estimate design flood from extreme rainfall data for the Osun River at Iwo control station. This is to forecast and identify sustainable solutions to flood risks. The peak flows obtained can be used for the design of hydraulic structures within the River catchment.

## 2 METHODOLOGY

### 2.1 Description of the Study Area

Osun State, where the catchment of Osun River at Iwo station is located is situated in the South West of Nigeria. According to Adejumo (2011), Osun State is located between latitude 70 30′ and 70 55′ North, and longitudes 40 20′ and 40 40′ East. Osun State stands at 304.5 meters altitudes above sea level. The State covers an area of approximately 14,875 square kilometers, and is bounded by Ogun, Kwara, Oyo and Ondo states in the South, North, West and East respectively. Figure 1 presents the map of Nigeria showing the location of the river catchment.

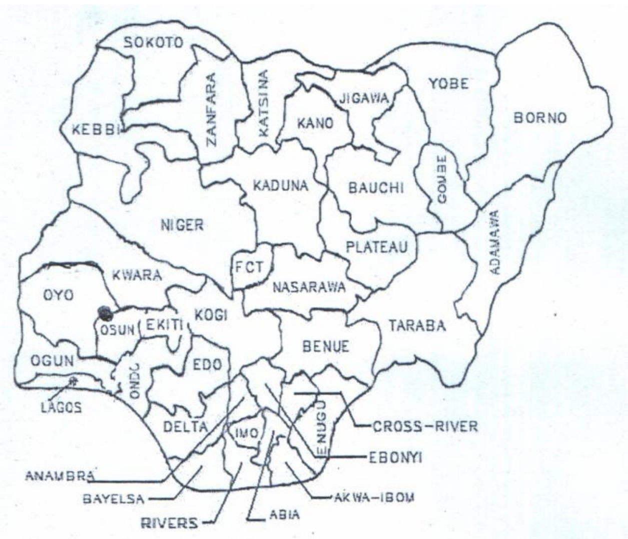


Fig. 1. Map of Nigeria showing location of the river catchment

### 2.2 Data Collection

The data used for the study covered the period from 1975 to 2009, a total of thirty-five (35) years. The Iwo rainfall data (mm) was sourced from the Nigerian Meteorological Station, Ido-Osun, Osun State. The catchment area downstream for the river was traced out from the map obtained from the Ministry of Land and Physical Planning, Osun State.

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### 2.3 Development of Synthetic Unit Hydrograph

The two methods used for the development of synthetic unit hydrographs were SCS and Snyder's methods.

#### 2.3.1 Unit Hydrograph Development by SCS Method

Raghunath (2006) reported that the US Soil Conservation Service in 1971 used many hydrographs from drainage areas of varying sizes and different geographical locations developed a dimensionless unit hydrograph. The peak discharge and the time to peak can be determined in accordance to Viessman et al (1989), Raghunath (2006), Ogunlela and Kasali (2002), Ramirez (2000), SCS (2002) and Wanielista (1990).

**Peak Discharge:**

The peak discharge was estimated from the equation (1)

$$Q_p = \frac{0.208 \times A \times Q_d}{t_p} \qquad (1)$$

Where:

$Q_p$ = peak discharge (m3/s); A =watershed area (km2), Qd = quantity of runoff (1mm for unit hydrograph),
tp = time to peak (hr)

**Time to Peak:**

The time to peak was obtained from equation (2)

$$t_p = \frac{t_c + 0.133 t_c}{1.7} \qquad (2)$$

t is the time of concentration and was obtained from equation (3)

$$t_c = \frac{0.0195 \times L^{0.77}}{S^{0.385}} \qquad (3)$$

L = length of channel (m)
S = slop of channel

#### 2.3.2 Development of Unit Hydrograph by 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.

**Lag time:**

The lag time was obtained from equation (4)

$$t_l = C_t (L \times L_c)^{0.3} \qquad (4)$$

Where tL lag time (hr) and Ct = coefficient representing variation of watershed slopes and storage, (values of Ct range from 1.0 to 2.2, Arora (2004).

**Unit-hydrograph duration, tr (storm duration):**

The storm duration was obtained from equation (5)

$$t_r = \frac{t_l}{5.5} \qquad (5)$$

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 (6).

$$t'_l = t_l + \frac{t_r - t_l}{4} \quad (6)$$

**Peak discharge:**

The peak discharge was estimated from the equation (7)

$$Q_p = \frac{2.78 \times C_p \times A}{t_p} \quad (7)$$

is the coefficient of accounting for flood wave and storage conditions.

**Time to peak:**

The time to peak was estimated from equation (8)

$$t_p = \left(\frac{t_r}{2}\right) + t_l \quad (8)$$

**Base time (days)**

The base time was estimated from equation (9)

$$T_b = 3 + 3\frac{t_l}{24} \quad (9)$$

time width W50 and W75 of the hydrograph at 50% and 75% of the height of the peak flow ordinate were obtained based on equations (10) and (11) respectively in accordance to U.S Army Corps of Engineer (Arora, 2004). The unit of the width is hr.

$$W_{50} = \frac{5.9}{(q_p)^{1.08}} \quad (10)$$

$$W_{50} = \frac{5.9}{(q_p)^{1.08}} \quad (11)$$

Table 1. Parameters for the Development of Unit Hydrograph (SCS Method)

| L (km) | $L_c$ (km) | A(km²) | $t_c$(hr) | D(hr) | $t_p$(hr) | $Q_p$(m³/s) | $S_c$% |
|---|---|---|---|---|---|---|---|
| 136.0 | 72 | 4450 | 31.14 | 4.14 | 20.75 | 301.09 | 0.00213 |

Table 2. Parameters for the Development of Unit Hydrograph (Snyder's Method)

| $T_r$(hr) | $t_L$(hr) | $T_b$(hr) | $Q_p$(m³/s) | $T_p$(hr) | A(km²) | $S_c$% |
|---|---|---|---|---|---|---|
| 4.58 | 25.19 | 138 | 301.09 | 27.62 | 4450 | 0,00213 |

$$q'_p = Q'_p \quad (12)$$

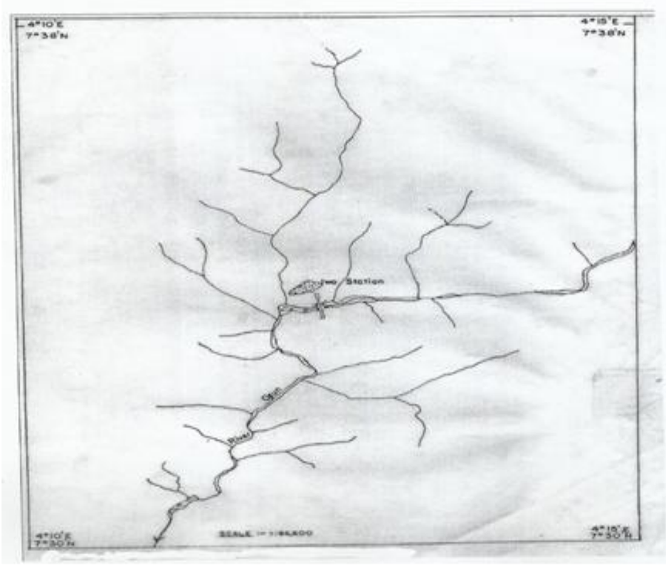


Fig 2. Map of Osun River at Iwo Control Station Catchment Area

### 2.4 Development of Design Storm Hydrograph

The established unit hydrographs were used to develop the storm hydrographs due to the extreme rainfall event over the watersheds. Design storm hydrographs for selected recurrence intervals (10yr, 20yr, 50yr, 100yr and 200yr) were developed through convolution. The storm hydrographs were derived from a multiperiod of rainfall excess called hydrograph convolution. It involves multiplying the unit hydrograph ordinates (Un) by incremental rainfall (Pn), 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 short time events (3 hrs) and the Curve Number method used to estimate the cumulative rainfall excess. The incremental rainfall excess is obtained by subtracting sequentially, the rainfall excess from the previous time events. Rainfall excess $Q_d$ is given as follows:

$$Q_d = \frac{(P - I_a)^2}{(P - I_a) + S} \quad (13)$$

If $P \le 0.2S \quad Q_d = 0$

$$Q_d = \frac{(P - I_a)^2}{(P + 0.8S)} \quad (14)$$

Where ,

P = Accumulated Precipitation (mm), $Q_d$ = Cumulative rainfall excess, direct runoff depth (mm),

S = Maximum potential difference between rainfalls and runoff in mm starting at the time the storm begins.

$I_a$ = Initial abstraction.

$$S = \frac{25400}{CN} - 254 \quad (15)$$

CN is the basin Curve Number.

$$I_a = 0.2S \qquad (16)$$

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

The storm hydrograph ordinates based on the rainfall depth of desired recurrence interval were estimated from the unit hydrographs, The storm hydrograph ordinates for the watershed due to SCS and Snyder's method were extracted and used to plot the storm hydrographs.

### 2.5 Statistical Evaluation of Storm Hydrograph Development

Randomized Complete Block Design (RCBD) statistical analysis (Salako, 1989; Murray and Larry, 2000; Oyejola, 2003) was used to evaluate the two methods of storm hydrograph development for five return periods of 10-yr, 24-hr, 20-yr, 24-hr, 50-yr, 24-hr, 100-yr, 24-hr and 200-yr, 24-hr. The table of observation was developed, the two methods are represented as treatments (T1 and T2) while the return periods are represented as blocks (B1, B2, B3, B4 and B5,). The mean value for each of the storm hydrograph flows of the methods were used to form table 4 for the catchment. An analysis of variance table (ANOVA Table) for the Randomized Complete Block Design (RCBD) was constructed for the statistical analysis.

## 3 RESULT AND DISCUSSION

### 3.1 Results

Two methods of synthetic unit hydrograph, namely SCS and Snyder's were adopted to determine the ordinates for the development of peak storm hydrograph for Osun river at Iwo control station. The parameters for the development of unit hydrographs for both methods were presented in tables 1 and 2. The maximum 24-hr rainfall depths of the different recurrence interval for the catchment under consideration are 94mm, 104mm, 116mm, 126mm and 126mm respectively. The storm hydrograph peak flows for the catchment for the two methods and various return periods are presented in Table 3. The comparison of unit hydrograph with generated storm hydrographs of different return periods for the catchments are presented in figure 3, for the SCS method, while figure 4 presents that of Snyder's method. The analysis showed that the values of the peak flows obtained from SCS method are higher than those of Snyder's method by 33.16%.

An analysis of variance table (ANOVA Table) for the Randomized Complete Block Design (RCBD) was constructed for the statistical analysis by calculating some parameters such as degree of freedom (d.f), sum of squares (SS), mean squares (MS), F-Ratio and coefficient of variance (CV). These parameters are presented in Table 5.

From the statistical table , the F-value is 7.71 and the calculated value for the catchment is 68.38. The calculated value is much higher than the F-value in the table. This indicates that the methods differ significantly from each other.

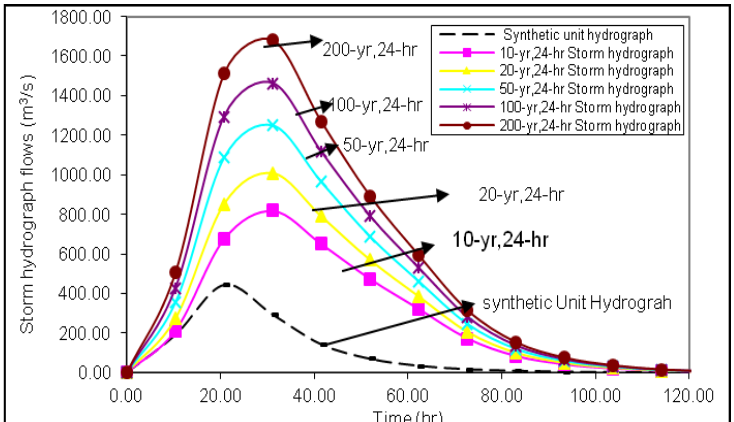


Fig. 3: Comparison of unit hydrograph with generated storm hydrographs of different return periods for Osun River (at Iwo station)- SCS method.

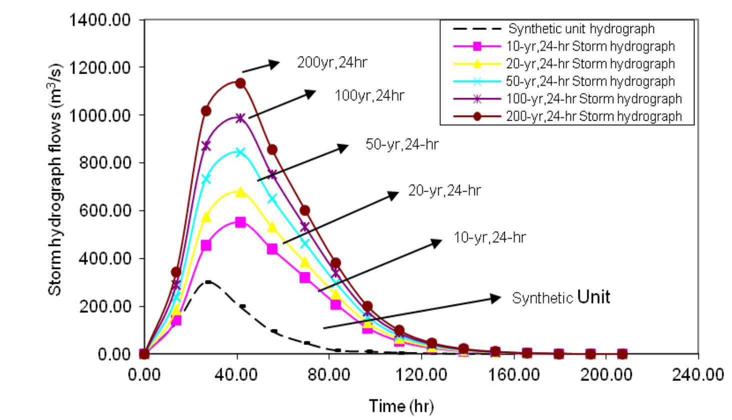


Fig. 4: Comparison unit hydrograph with generated storm hydrographs of different return periods for Osun river (at Iwo control station)- Snyder's method.

Table 3 Values of storm hydrograph peak flows for the catchment based on the two methods and various return periods in $m^3/s$

| Methods | Storm return periods | | | | |
|---|---|---|---|---|---|
| | 10yr,24hr | 20yr,24hr | 50yr,24hr | 100yr,24hr | 200yr,24hr |
| SCS | 819.87 | 1007.94 | 1250.61 | 1462.28 | 1681.34 |
| Snyder's | 551.41 | 680.34 | 844.13 | 987.00 | 1134.86 |

Table 4. Mean values for statistical evaluation for Osun River at Iwo station

| Methods (Treatments) | Return Periods (Blocks) | | | | | Total |
|---|---|---|---|---|---|---|
| | 10-yr, 24-hr | 20-yr, 24-hr | 50-yr, 24-hr | 100-yr, 24-hr | 200-yr, 24-hr | |
| SCS ($T_1$) | 249.35 | 305.20 | 377.20 | 440.15 | 504.47 | 1876.37 |
| Snyder's ($T_2$) | 166.19 | 204.12 | 252.21 | 294.20 | 337.40 | 1254.12 |
| Total | 415.54 | 509.32 | 629.41 | 734.35 | 841.87 | 3130.49 |

Table 5. ANOVA table for RCBD (Osun River at Iwo Station)

| Source of variation SV | Degree of freedom df | sum of squares SS | mean of squares MS | Ratio |
|---|---|---|---|---|
| Treatment | 1 | 38719.50 | 38719.50 | 68.38 |
| Block | 4 | 58129.40 | 14532.35 | |
| Error | 4 | 2265.01 | 566.25 | |
| Total | 9 | 99113.91 | 53818.10 | |

### 3.2 Discussion

Table 3 shows that the peak storm hydrograph estimate occurred at a short duration ranging from 819.87 m3/s to 1681.34 m3/s for Osun river at Iwo control station using SCS method. The table also indicates that peak storm hydrograph, using Snyder's method, ranged from 551.41 m3/s to 1134.86 m3/s for the catchment. From the above, it is shown that for both methods, peak storm hydrograph estimate for Snyder's method is lower than that of SCS method. The results also indicated that runoff was generated at a short duration with high discharge magnitude for the catchment.

The 10-yr, 24-hr storm hydrograph discharges are 819.87 m3/s and 551.41 m3/s for the catchment for both SCS and Snyder's methods. The 20-yr, 24-hr storm hydrograph discharges are 1007.94 m3/s and 680.34 m3/s,for the catchment for both SCS and Snyder's methods. The 50-yr, 24-hr storm hydrograph discharges are 1250.61 m3/s and 844.13 m3/s for Osun River at Iwo control station, for both SCS and Snyder's methods, The 100-yr, 24-hr storm hydrograph discharges are 1462.28 m3/s and 987.00 m3/s for the catchment for both SCS and Snyder's methods. The 200-yr, 24-hr storm hydrograph discharges are 1681.34 m3/s and 1134.86 m3/s, for the catchment for both SCS and Snyder's methods,

The results indicated that there were significant differences in the two methods. Table 4 also shows that the higher the return period, the greater the magnitude of the storm hydrograph generated, for both methods. The unit and storm hydrograph curves of figures 3 and 4 of various return periods for both methods show that the hydrograph pattern is the same with different peak values of storm hydrograph. The analysis showed that the values of the peak flows obtained from SCS method are higher than those of Snyder's method by 33.16%. The peak flow values can therefore be useful in the study of flooding problems within the catchments. The results obtained can be used for flood forecasting, hydraulic structures, watershed simulation and comprehensive water resources planning.

## 4.0 CONCLUSIONS

The study showed that the catchment under consideration has undergone notable eco-hydrological changes due to several developments along its course. these have replaced the natural ground surface, covered with grasses and have influenced its flow pattern. Based on the results obtained, it could be observed that the generation of unit hydrograph through synthetic methods has been found useful and effective. The peak flow values obtained can be used for flood forecasting, hydraulic structures, watershed simulation and comprehensive water resources planning. The two methods are efficient in estimating the parameters of the catchment which are required in the development of the unit hydrograph. The selection of peak storm hydrograph flow of the desired return period depends on the type of hydraulic structure in mind. For example, peak flow of 100yr return period is required for the design of bridge, while 20yr return period can be adopted for drainages, culverts and minor bridges.

Synthetic unit hydrograph methods are suitable for the estimation of ordinates for the development of storm hydrograph for rivers that have small catchment, because it was observed that the bigger the catchment area the more the differences between the values obtained with different methods using the same return periods . Conclusively, SCS method can be used on this catchment since it incorporates most major hydrological and morphological characteristics of the basins like the watershed area, main channel length, river channel slope and watershed slope.

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