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RESEARCH PAPER

Estimation of Flood Hydrograph for Aquban Catchment Area Using Two Models.

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A B S T R A C T:

The construction of the flood hydrograph in an ungagged catchment area is a challenging portion of the hydrological analysis for design any hydraulic structure. The geomorphologic instantaneous unit hydrograph (GIUH) and Hydrologic Engineers Center (HEC-1) models are widely used for this purpose. The GIUH model simulates flood hydrographs, and the parameters are influenced by the geomorphological features of the area which is based on the probability density function of excess rainfall reaching the catchment. The flood hydrograph is also generated using the HEC-1 model, which is a deterministic hydrological model for simulating rainfall-runoff processes. The nearest station to the Aquban catchment area is Shaqlwa meteorological station that recorded maximum daily rainfall 128.5mm in 2016. The resulting flood hydrographs for the Aquabn catchment area are compared between the GIUH model and the HEC-1 model, with peak discharge and time to peak being the main parameters analyzed. The peak flow of GIUH model is 303.7 m3/s with a time to peak of 1.2 hours, while the HEC-1 model produced a peak discharge of 293.6 m3/s with time to peak of 1.33 hours.

KEY WORDS: Unit hydrograph, Flood Hydrograph, GIUH, HEC-1
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1. INTRODUCTION:

Careful figuring out of hydrologic processes such as rainfall-runoff transformation is a key for accurate estimation of size, peak, and duration of a flood, and one of the most widely used technique in simulation of floods is unit hydrograph. The idea of unit hydrograph is considered as most important technique in designing hydraulic structures which can be defined as a hydrograph that produced from precipitating one centimeter of excess rainfall distributed uniformly over a specific watershed for an effective period (Chow et al., 1988). Ungagged catchment areas that do not have insufficient hydrological metrological observation to be enough for hydrological analysis in term of quantity, quality, and spatial and temporal scales such as precipitation, evaporation, relative humidity, and wind speed, stream flow perdition becomes challenging because so many factors must take in consideration (Sivapalan et al., 2003). In this study, two models adopted to simulate synthetic flood hydrographs which are HEC1, and geomorphologic Instantaneous unit hydrograph (GIUH). HEC1 model developed by Hydrologic Engineering Center of US-Army Corps Engineers in 1968 to simulate surface runoff processes by defining twin hydrologic-hydraulic components in the system due to certain storm in a specific catchment area (Center and Center, 1981). The geomorphologic concept of watershed that used for developing instantaneous unit hydrograph firstly introduced by (Rodríguez- Iturbe and Valdés, 1979). This methodology refers to estimate peak discharge and time to peak of unit hydrograph based on the Horton’s stream order ratio (Horton, 1945). This geomorphologic Instantaneous unit hydrograph (GIUH), which

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parameters derived directly from physical situation and drainage network of the catchment area, is highly used in ungagged catchment areas (Ellouze-Gargouri and Bargaoui, 2012). The GIUH technique is used worldwide for developing unit hydrograph (Singh and Sarkar, 2013) investigated partially gaged catchment in North-East India for developing unite hydrograph then compared result with Central Water Commission Synthetic Unit Hydrograph CWC-SUH. (Gehbrehiwot and Kozlov, 2019) worked on the ungagged catchment area Eritrea by coupling Nash conceptual model with GIUH to deriving GIUH-Nash for varies storm events. (Bamufleh et al., 2020) studied four different arid and semi-arid catchment areas in Saudi Arabia by using equivalent Horton-Strahler ratios for creating GIUH from Nash and Fréchet model. (Kumar et al., 2007) for ungagged catchment area in Ajay Catchment area in India, developed GIUH based on Nash and Clark models for ten storm events then compared the result of the GIUH with HEC-1 model. The main aim of this study is to estimate flood hydrographs based on the maximum daily rainfall data available in the catchment using two different popular hydrological models, which are markedly utilized for ungagged catchments.

2. MATERIALS AND METHODS

For any local hydrological analysis, the procedure of analysis starts from delineation of the catchment area; the basic approach of catchment area delineation for any selected outlet before developing computer and digital elevation and terrain models was done based on the topographical map and aerial photography of the area which tarts form drawing divide from right and left of the outlet (Dingman, 2015). Nowadays, delineation of catchments and stream networks conducted by using digital elevation models (DEM) by taking advantage of the computation power of computer in the geographical information system (GIS) – (ArcGIS) software (Vimal et al., 2012).

In the current work, an attempt has been made to derive and compare two different techniques for flood hydrographs for the Aquban catchment area which lie in Kurdistan Region resulting from direct runoff separated from maximum daily rainfall over the catchment; these two techniques are GIUH and HEC-1. The runoff generation in the catchment mostly comes from rainfall, and the maximum daily rainfall is used.

The Aquban catchment is located in Aquban village in Shaqlawa distinct, Erbil Governorate, Iraq which is about 53 km in north-east of Erbil city. The outlet of the catchment is located in the coordinate of 36° 21' 00.0996" N, 44° 25' 52.3097" E according to the Geographic (Latitude/Longitude) coordinate system. The drainage area is 27.15 km^2. The catchment classified according to the topography of the catchment as mountainy area and the elevation of the catchment varies between 911m and 1743m above mean sea level Figure 1. Because the watershed is ungagged, precipitation can be taken from Shaqlawa metrological station which is the nearest one to the catchment, and its maximum daily precipitation between 41 mm to 110 mm. Temperature and wind speed are other climatic data of the Aquban area; the recorded maximum average monthly temperature is about 33.57 Co in July and minimum average monthly temperature is 5.84 Co in January, and the maximum wind speed is 2.38 m/s which frequently happen in June. The characteristics of the catchment area is shown in the Table 1.

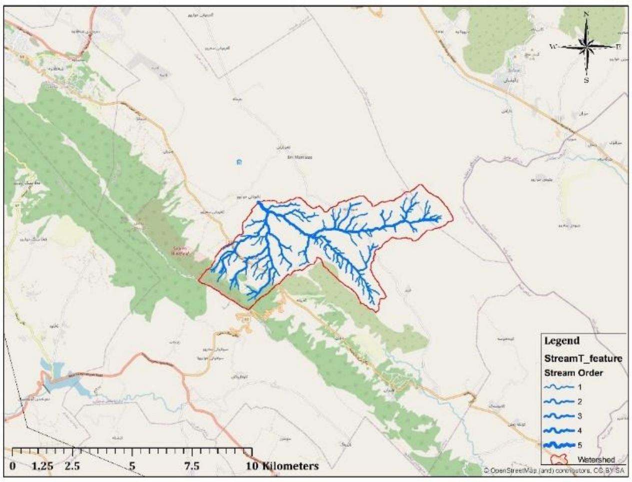

Figure 1: The location of the catchment area

Table (1) Aquaban Catchment area properties

Catchment parameters	Value	
Area of Watershed	27.15	km^2
Average overland flow distance	266.4	*m*
Watershed Overland Slope	0.249	*m/m*
Watershed length along main channel from outlet to the upstream boundary	9494.4	*m*
Watershed slope along main channel from outlet to the upstream boundary	0.084	*m/m*
Maximum flow (watercourse) length	8831.4	*m*
Maximum flow (watercourse) average slope	0.065	*m/m*
The mean catchment elevation	1139.1	*m-AMSL*
Watershed Perimeter	41841.3	*m*
Weighted Curve Number	84.5	

2.1.Geomorphological Instantaneous Unit Hydrograph (GIUH)

The geomorphologic instantaneous unit hydrograph GIUH characteristics, such as peak discharge, base time, and time to peak, are function of geomorphological characteristics of the catchment area which is intuition concept. Basically, the GIUH methodologies defined by (Rodríguez- Iturbe and Valdés, 1979). The formulation of a GIUH is based on the probability density function of the temporal pattern of a randomly selected unit of excess rainfall that reaches the accumulated to the hypothetical catchment which is defined as Nash based GIUH. Horton's stream order laws, which are derived from ArcGIS software, have intensive influent on the development of the GIUH (Bamufleh et al., 2020). According (Rodríguez- Iturbe and Valdés, 1979), the peak flow, time to peak, and base time of instantaneous unit hydrograph which are function of Horton's stream order laws are given as follow:

$$q_p = 1.31\, R_L^{0.43} \frac{V}{L_\Omega} \quad (1)$$

$$t_p = 0.44 \left(\frac{L_\Omega}{V}\right)\left(\frac{R_B}{R_A}\right)^{0.55} R_L^{-0.38} \quad (2)$$

$$t_b = 2/q_p \quad (3)$$

Where, q_p = peak flow in units of inverse hours(h^{-1}); t_p = time to peak in hours (h); t_b = base time in hours (h); V = dynamic parameter velocity (m/s); L_Ω = length of the highest order stream in the basin (km); and R_L, R_B and R_A = Horton's stream length ratio, bifurcation ratio and stream area ratio respectively.

Stream length ratio is referring to the length of each order's channels. The average length of channels of each higher order increases geometrically as the order rises, which can also be explained by the fact that first order channels are the shortest of all the channels.

$$\bar{L}_i = \bar{L}_1\, R_L^{i-1} \quad (4)$$

$$R_L = \bar{L}_{i+1} / \bar{L}_i \quad (5)$$

Where $\bar{L}_i$ is the average length of channel of order i, R_L is the stream-length ratio.

For the Bifurcation ratio, the surface of a drainage catchment determines its channel order that means channel order for any catchment is a direct function of the drainage density of the catchment. The more soil material infiltrates the basin, the fewer pathways are needed to transmit the remaining runoff water. Each channel order drains less area as its number increases. Bifurcation ratio, a dimensionless quantity dependent on channel order, defines watershed response.

$$R_B = N_i / N_{i+1} \quad (6)$$

where R_B is bifurcation ratio, N_i and N_{i+1} are the number of streams in order i and $i+1$ respectively, i =1, 2, 3, ..., Ω and Ω is highest stream order in the catchment.

The stream-area ratio is related to the channel area of order i; The watershed region that contributes to the channel segment of order i and all lower order channels can be called the channel area of order i as follow:

$$\bar{A}_i = \bar{A}_1\, R_a^{i-1} \quad (7)$$

$$R_a = \bar{A}_{i+1} / \bar{A}_i \quad (8)$$

Where $\bar{A}_i$ is the average area of order i and R_a is the stream area ratio.

The basics of instantaneous unit hydrograph IUH is taken from the Nash Model (Nash, 1957) which is consist of a series of linear reservoirs with equal storage coefficient in such a way that the outflow in the first reservoir becomes the inflow for the second and so on. The shape of the hydrograph is derived based on the Gamma distribution function (Singh, 2004).

$$u(t) = \frac{1}{k\,\Gamma(n)}\left(\frac{t}{k}\right)^{n-1} e^{-t/k} \quad (9)$$

where $u(t)$ is ordinate of IUH ($hour^{-1}$), t is time interval (hour), $\Gamma(n)$ is Gamma function [$\Gamma(n) = (n-1)!$], n is the number of linear reservoirs, and k

is the storage coefficient (hour); n and k are Nash model parameters (Nash, 1957).
The parameters of Nash model evaluated according to the (Rosso, 1984, Himanshu et al., 2015) based on the geomorphic parameters of Horton's stream laws.

$$n = 3.29 \left(\frac{R_B}{R_A}\right)^{0.78} R_L^{\;0.07} \tag{10}$$

$$k = 0.7 \left(\frac{R_A}{R_B\, R_L}\right)^{0.48} \frac{L_\Omega}{v} \tag{11}$$

$$v = 0.8562\, L^{0.23}\, S^{0.385} \tag{12}$$

Where v = dynamic parameter velocity in *m*/*s*, L = length of the main stream from the most remote point to the outlet of the catchment in *m*, and S = mean slope of the catchment area in *m*/*m*
The stream orders, and elevation variation of the Aquban catchment is shown in the Figure 2

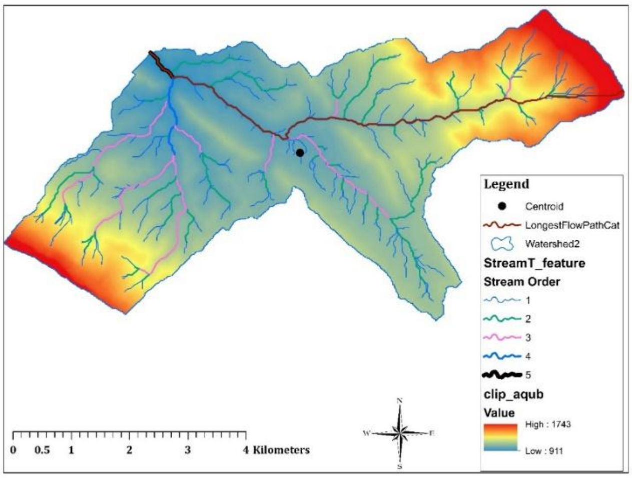

Figure 2: Drainage network map of Aquban catchment with stream order.

2.2.HEC-1

The HEC-1 model is developed by the Hydrological Engineering Center (HEC) of the US Army Corps of Engineers, which considered deterministic hydrological model for simulating rainfall-runoff processes. The HEC-1 is integrated in the Watershed Modeling System (WMS) software. The model is intended to predict the surface runoff response of a river basin to precipitation by modeling the basin as a system of interrelated hydrologic and hydraulic components. Each component represents an aspect of the precipitation-runoff process within a sub basin. The representation of a component needs a collection of parameters that characterize the component's specific properties and mathematical relations that describe the physical processes. The outcome of the modeling method is the computing of streamflow hydrographs at specified river basin locations. (Center and Center, 1981, Sui, 2005).

There are several parameters intended in the HEC-1 model, such as watershed area, precipitation depth and its temporal distribution during the storm, loss method such as the Soil Conservation Services Curve Number (SCS-CN), uniform loss, or infiltration equations, type and parameters of unit hydrograph methods, and snow melt data if available.
The most important input factors for the model that play a big role in the result of the model are precipitation depth and the loss method that SCS-CN utilizes to separate runoff from rainfall.
The HEC-1 model is embedded in the Watershed Modeling System (WMS) software, and from the software, the HEC-1 model is implemented.

3. RESULTS AND DISCUSSIONS

To evaluate surface runoff for design purposes, the maximum daily rainfall is used. The Shaqlwa metrological station is the closest to the Aquban catchment area. The maximum daily rainfall at the station from 1991 to 2020 is shown in Table 2.

Table (2) Maximum daily rainfall in Shaqlwa station

Year	Max. Daily Rainfall (mm)	Year	Max. Daily Rainfall (mm)
1991	80	2009	46.5
1997	43	2010	60
1998	48	2011	82
1999	58	2012	44
2000	92	2013	148
2002	54	2014	88
2003	70	2015	50.5
2004	41	2016	128.5
2005	110	2017	94
2006	72	2018	88
2007	59	2019	74
2008	59	2020	56

The maximum daily rainfall that has been recorded from 1991 to 2020 was 128.5 mm, which took place in 2016. This rainfall is used to simulate the flood hydrograph for the Aquban catchment area. To generate flood hydrographs in both models, the effective rainfall (runoff depth) must be evaluated; the SCS-CN is used to separate runoff from the total rainfall. (Mishra and Singh, 2003).

$$S = \frac{25400}{CN} - 254 \qquad (13)$$

$$Q = \frac{(P-0.2\,S)^2}{P+0.8\,S} \qquad (14)$$

Where S representing the potential maximum retention depends upon the soil–vegetation–land use [mm], CN is Soil Conservation Service's Curve Number, Q is the maximum daily runoff [mm], and P is the maximum daily rainfall [mm]. Q cannot take place if the P not exceed 0.2S which is considered as initial abstraction.

The Aquban catchment area consist of different soil textures and various land-use/land cover. For that reason, the catchment divided into 12 sub catchment areas to evaluate the weighted average curve number CV based on equation 15 and Figure 3. The calculated curve number has an average value in terms of the Antecedent Moisture Condition (AMC), which is called CNII, and a value in between the dry curve number (CNI) for AMC-I and the wet curve number (CNIII) for AMC-III. The CNI and CNIII are calculated based on the CNII. The selecting value of the CN is a direct function of the rainfall depth in the past 5 days and the agricultural season (dormant or growing) (Subramanya, 2015).

$$CN_{AVG} = \frac{\sum_{i=1}^{n} CN_i\, A_i}{\sum_{i=1}^{n} A_i} \qquad (15)$$

Where CN_{AVG} is the weighted average Curve Number, CN_i is the i-th sub-catchment Curve number, and A_i is the i-th sub-catchment area.

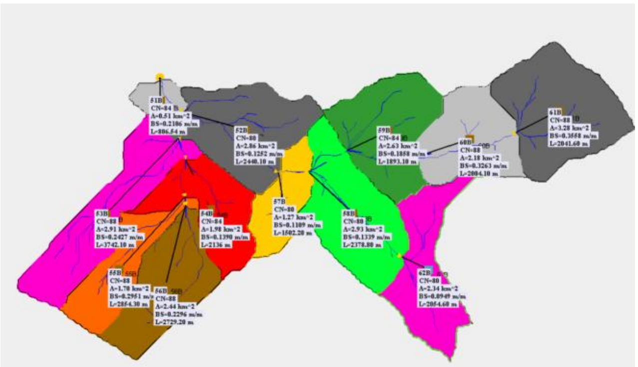

Figure 3: distribution CN based on the soil texture and land-use/landcover of the catchment

Depending on the slope, hydrological condition, and Hydrologic Soil Group (HSG), three distinct sorts of regions may find (USDA, 2004):

a. Non- cultivated agricultural land Pasture or range, No mechanical treatments, poor hydrological condition, HSG type D, CN = 88

b. Non- cultivated agricultural land Pasture or range, No mechanical treatments, Fair hydrological condition, HSG type D, CN≈84.

c. Non- cultivated agricultural land Pasture or range, No mechanical treatments, good hydrological condition, HSG type D, CN≈80.

Table (3) CN of the sub basin

Catchment ID	Area (km^2)	CN	Area*CN
51B	0.51	84	43.2
52B	2.86	80	229.2
53B	2.91	88	256.5
54B	1.98	84	166.7
55B	1.70	88	150.0
56B	2.44	88	215.1
57B	1.27	80	102.0
58B	2.93	80	234.8
59B	2.63	84	221.3
60B	2.18	88	192.2
61B	3.28	88	289.0
62B	2.34	80	187.6
SUM	**27.1**		**2287.4**

The weighted average CN is equal to 84.5 and from the equations 13 and 14 the maximum runoff is 85.7 mm for 128.5 mm rainfall.

The GIUH model parameters obtained from the geomorphological parameters of the catchment which can be derived based on GIS analysis. The streams in the catchment classified into five order streams according to the Horton's stream law. the geomorphological characteristics of the Aquban catchment shown in the Figure 4.

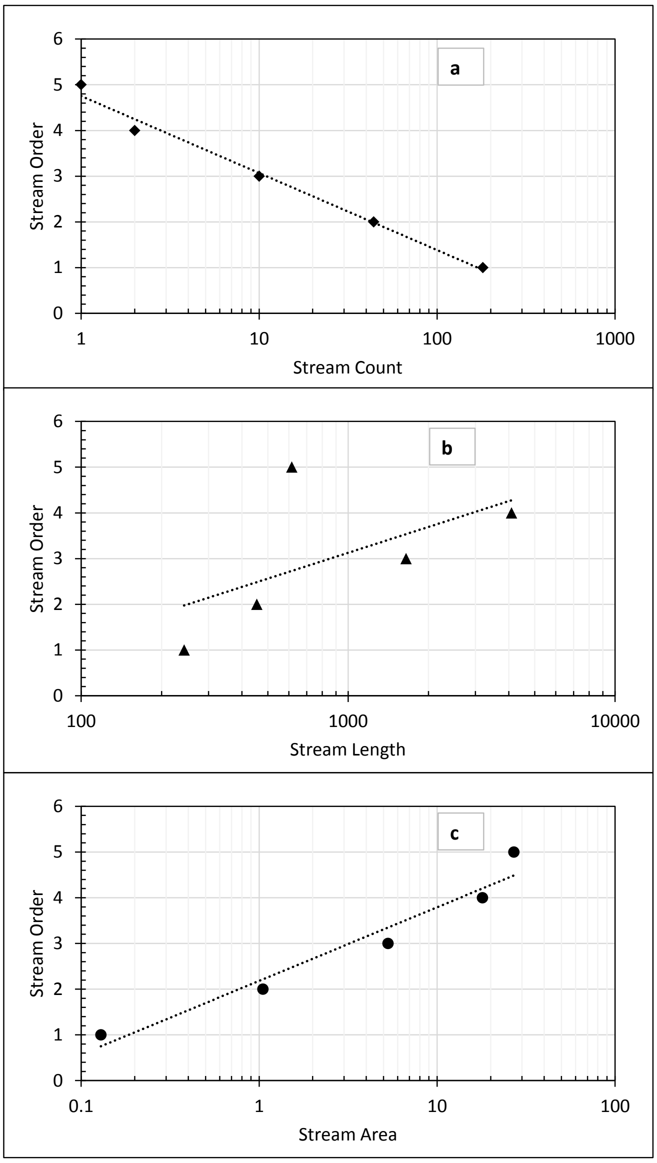

Figure 4: Aquban geomorphological characteristics; (a) Number of streams; (b) Average stream length; (c) Average stream area.

The Nash's model parameters n and k are evaluated based on the geomorphological characteristics of the catchment in the Equations 10, 11, and 12 which n = 3.068, and k = 0.567 where R_L, R_B and R_A =2.032, 3.878, 4.521 respectively and v = 0.582 m/s.

The resulting flood hydrograph depending on the GIUH is shown in the Figure 5. As shown the peak flow is 303.7 m^3/s and time to peak is 1.2 hour.

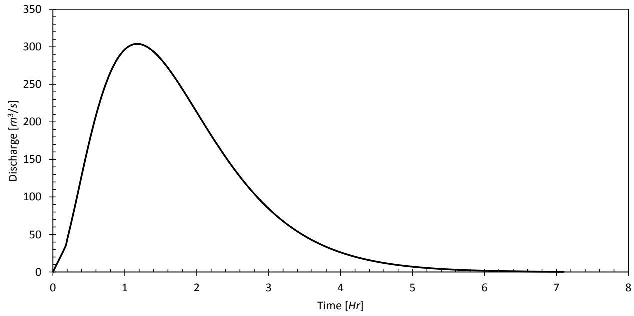

Figure 5: Flood hydrograph of the Aquban catchment based on the GIUH model.

The HEC-1 model is integrated in the MWS (Watershed Modeling System) software and based on kinematic wave equations, single hydrologic event, using the CN for loss method, precipitation amount and definition of its temporal distribution, the SCS for unit hydrograph method, and the Kripich formula (Equation 16) for time concentration of the catchment (Hydrologic-Engineering-Center, 1981) (Duru and Hjelmfelt Jr, 1994).

$$T_c = 0.0195\, L^{0.77}\, S^{0.385} \quad (16)$$
$$T_{lag} = 0.6\, T_c \quad (17)$$

Where T_c is Time concentration [min], L is length of overland flow [m], S is average overland slope [m/m], T_{lag} is lag-time [min].
From equations 16 and 17 the values of the T_c and T_{lag} are 58.4 min and 35.04 min respectively.

The resulting hydrograph of the HEC-1 model is shown in the Figure 5 with the peak discharge of 293.6 m^3/s and time to peak of 1.33 hr.

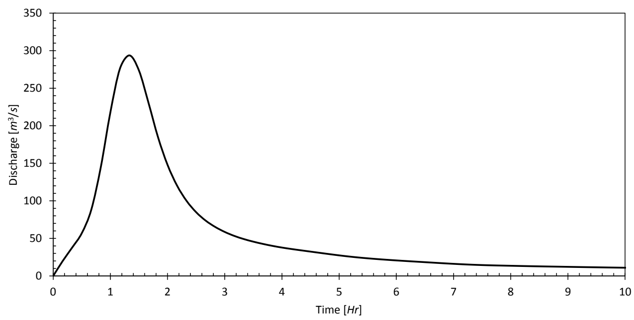

Figure 6: Flood hydrograph of HEC-1 model.

4. CONCLUSIONS

Design of hydraulic structures discipline significantly take care of computation, and spatially and temporally distribution of floods. Usually, a flood takes place when heavy rainfall precipitates over a catchment, passes through the drainage network system of the catchment, and then comes to its outlet. The transformation of rainfall into runoff flow is considered an uncertain phenomenon, and many models have been developed to handle this problem. Two of the most popular models are the GIUH and HEC-1 models. Unit hydrograph is an effective way for producing flood hydrograph. The GIUH method depends on the physical situation of stream distribution within the catchment, while the HEC-1 model develops based on kinematic wave equations, single hydrologic event, rainfall depth, rainfall distribution, slope, and length of the main stream of the catchment. In this study, both models were applied to the Aquban catchment area, they are successfully simulating the flood hydrograph and the results were approximately close to each other; the peak flow and the time to peak of the GIUH are 303.7 m^3/s and 1.2 hr, respectively, and in HEC-1, the peak flow and the time to peak are 293.6 m^3/s and 1.33 hr respectively. The two hydrographs are shown in Figure 7.

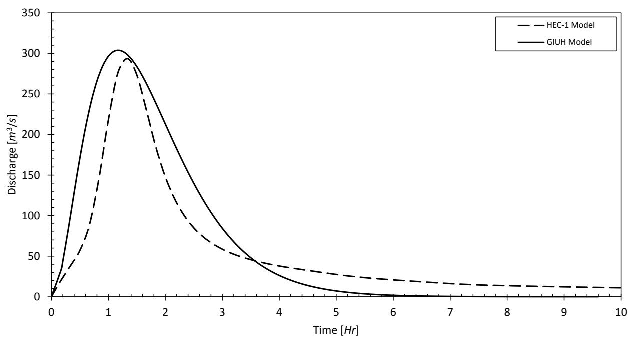

Figure 7: GIUH and HEC-1 Models Flood hydrographs for Aquban Catchment.

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