Contribution of Rainfall – Runoff Data Measurement to Direct Runoff Hydrograph Computation

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Abstract

Direct runoff hydrograph (DRH) due to local rainfall is necessary in the study of rainfall – runoff relation and design of drainage system of an area. There are 5 methods of DRH computation to be considered in this study. There are 3 methods developed from rainfall – runoff data, i.e., average unit hydrograph, rational method and dimensionless unit hydrograph. The other 2 methods are developed not using rainfall – runoff data, but using physical characteristic of drainage system. The rainfall – runoff data used in this study are measured during August to October in 2000, in 5 study areas located in Bangkok. From the comparison of DRH computation by each method with the observed data, it is found that average unit hydrograph gives the best result to closely fit with the observed data. This result indicates the importance of rainfall – runoff hydrograph data as it can contribute the good computation of DRH as compared to the other methods not using the observed data. This study also presents the modification of Santa Barbara Urban Hydrograph and rational method to adjust the hydrograph shape using the principle of water balance between observed runoff volume and computed runoff volume. The modified hydrograph can be improved to better fit to the observed data.

1. Introduction

Direct runoff hydrograph computation due to local rainfall is necessary in the study of rainfall – runoff relation and design of a drainage system. Direct runoff hydrograph is considered as the outflow hydrograph from each sub – drainage area to the channel which is applied to be side flow hydrograph or internal boundary condition for flow simulation in the channel network. In addition, the peak discharge of direct runoff hydrograph is commonly applied to determine the size of drainage pipe or gutter.

There are a number of methods for direct runoff hydrograph computation [1]. Some methods, such as unit hydrograph method, need to measure rainfall – runoff data in the field in order to compute all parameters required for each method. Other methods, such as Rational method, may not require such data measurement. Instead, they determine the parameters based on the physical characteristics of drainage area and drainage channel as set to be standard parameters in available texts and handbook. The difference in data requirements may affect the accuracy of hydrograph computations. It is thus interesting to investigate the accuracy of each method by comparing the computed hydrograph with the goodness fit test to the observed data.

The objectives of this study are to compare the direct runoff hydrograph computation by each method with the observed data, and to adjust the hydrograph shape based on the water balance between observed runoff volume and computed runoff volume. The obtained results have indicated that, the methods based on rainfall – runoff data such as the Average Unit Hydrograph method and the Dimensionless Unit Hydrograph method give the direct runoff hydrograph most accurately. The methods based on data of physical characteristic of drainage system such as Rational, SBUH and Clark Unit Hydrograph methods yield the computed hydrograph satisfactorily, only if they are applied to small watershed.

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2. Computation of direct runoff Hydrograph

The computational methods of direct runoff hydrograph are described. Also, the adjustment methods of hydrograph shape based on water balance are explained.

2.1 Direct Runoff Hydrograph Computation Method

2.1.1 Average Unit Hydrograph (AUH) is determined from 5 steps (shown in Fig.1), i.e., (a)separate baseflow out from observed runoff hydrograph, (b)calculate depth of direct runoff that is equal to depth of rainfall excess ,(c)calculate loss rate (∅ - index) from difference between rainfall and rainfall excess and then calculate rainfall excess hyetograph by using ∅ - index and (d)apply rainfall excess hyetograph and direct runoff hydrograph to calculate unit hydrograph by deconvolution from (1) {see[2]}, and (e)repeat steps 1 to 4 for all rainfall – runoff events. Several rainfall – runoff events are considered in order to obtain the average unit hydrograph [3]

$$Q_n = \sum_{m=1}^{n \le M} P_m U_{n-m+1} \qquad (1)$$

where Q_n = ordinate of discharge of direct runoff hydrograph, P_m = ordinate of rainfall excess depth and U_{n-m+1} = ordinate of discharge of unit hydrograph M = order number of time interval

Number of ordinates of Q_n, P_m and U_{n-m+1} are computed by dividing the hydrograph duration of each variable with the same time interval $\Delta t = 2$ minutes.

Assumptions for the unit hydrograph ; (a) Shape of unit hydrograph depends on time interval (t_R) of rainfall excess hyetograph (b) Rainfall excess is distributed uniformly in each time interval (Δt) and over the watershed (c) Unit hydrograph should be applied to small watersheds having an area less than 25 km^2 [2] (d) Time duration (t_R) of unit hydrograph must be equal to time interval (Δt) of rainfall.

2.1.2 Santa Barbara Urban Hydrograph (SBUH) computes a hydrograph directly without deriving the unit hydrograph from data. SBUH uses the principle that routes the rainfall excess (computed loss rate by NRCS method) hyetograph through the imaginary linear reservoir to determine an outflow hydrograph. The method is explained in [1].

2.1.3 Rational method is the direct runoff hydrograph method that defines the hydrograph shape as shown in Fig.2. The parameters used for constructing the hydrograph shape are determined as follows : time to peak is equal to t_c ,time base of direct runoff hydrograph is computed from t_c and rainfall duration (D) and peak discharge is computed from Q_p = CiA, C = runoff coefficient, i = average rainfall intensity over t_c and A = watershed area. Time of concentration (t_c) is the time interval from the end of rainfall excess to the inflection point (change of slope) on the recession curve.

2.1.4 Clark unit hydrograph uses a two – step procedure for development of a unit hydrograph. The first step is to create a time area (TA) curve based on dividing watershed into sub - areas. This curve is then routed through a linear reservoir to produce the final unit hydrograph. The method is explained in [1].

2.1.5 Dimensionless unit hydrograph (DUH), combines average unit hydrographs in each sub-drainage basin to develop DUH for general area by following steps:

(a) Divide each discharge ordinate of unit hydrograph by the peak discharge (Q_p). Divide each time ordinate by time to peak (t_p). Then a dimensionless unit hydrograph for each area is obtained.

(b) Average dimensionless unit hydrograph for every area as shown in Fig.3.

(c) Determine the relation between Q_p, t_p, i and drainage physical characteristics as shown in the (2) and (3) which are applicable for general area.

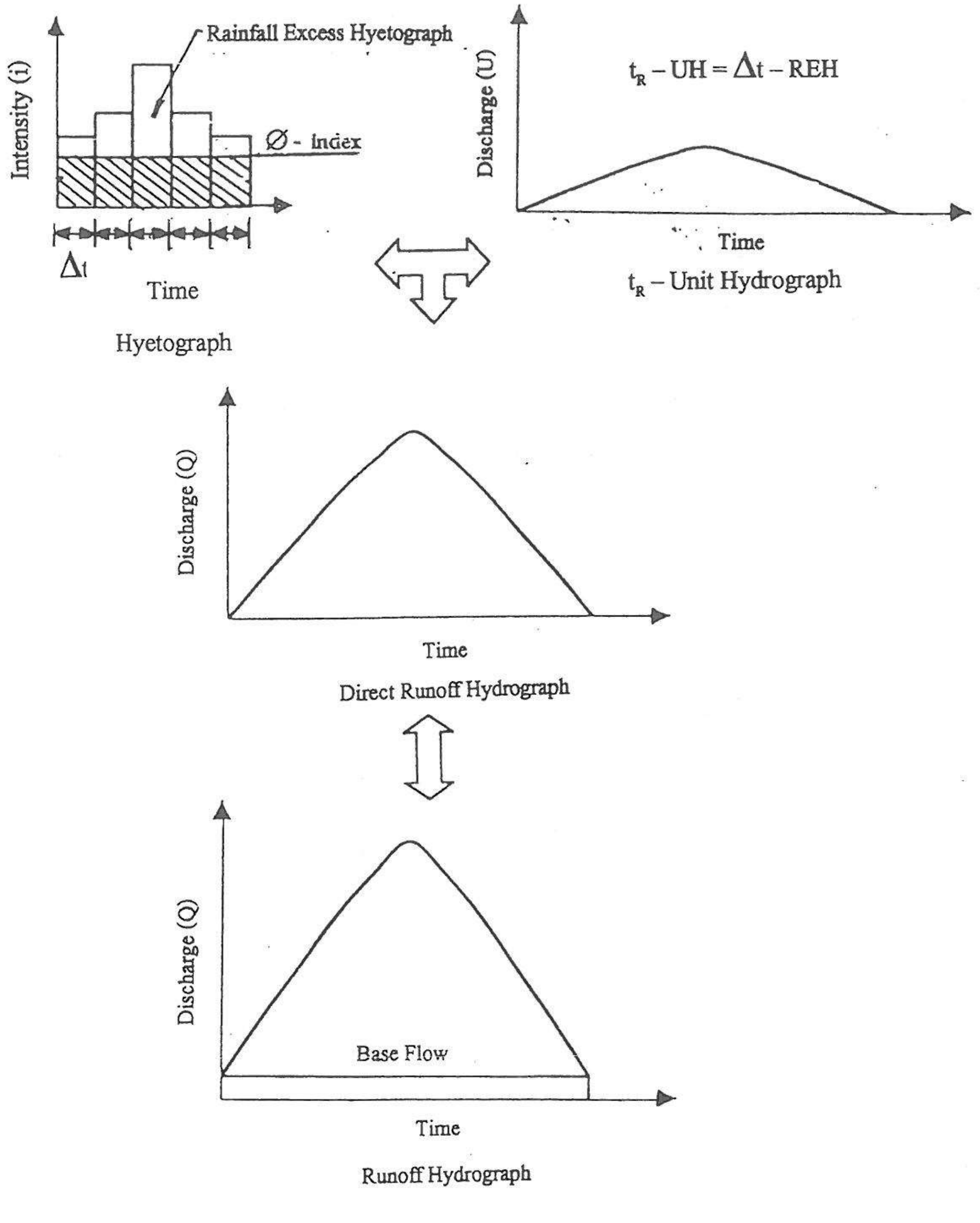


Figure 1 Relation between direct runoff hydrograph – rainfall excess hyetograph and unit hydrograph

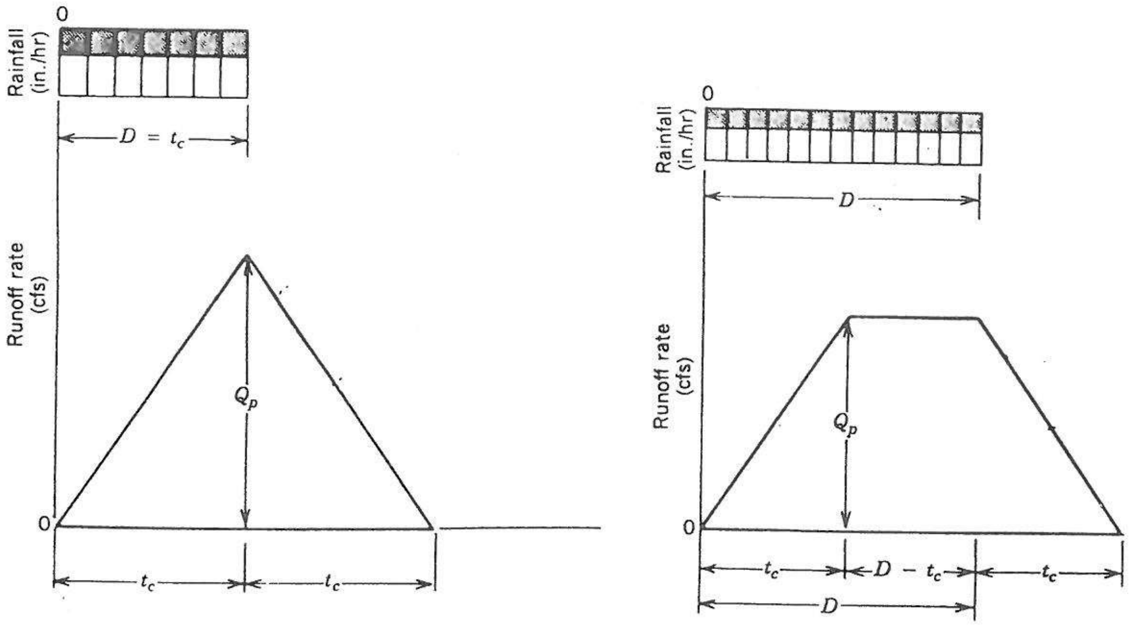


Figure 2 Direct runoff hydrograph by rational method

$$t_p = 425.241+0.00013A-258.185ESPF-248931i_{tp}-0.054L_L-0.063L_M-19824S_L \quad (2)$$

$$Q_p = -387.669+0.000166A-0.094L_L+0.00909L_M-0.221t_p+370.507ESPF-161.682S_M \quad (3)$$

where t_p = time to peak (minute), Q_p = peak discharge (liter/second), A = drainage area ($metre^2$), ESPF = ESPEY factor [1], i_{tp} = average rainfall intensity over t_p (metre/second), L_L = longest channel distance (metre), L_M = main channel distance (metre), S_L = the longest channel slope and S_M = the main channel slope

This DUH method is applicable to determine a unit hydrograph for any area by calculating Q_p and t_p and then combine with the dimensionless unit hydrograph in order to obtain the unit hydrograph.

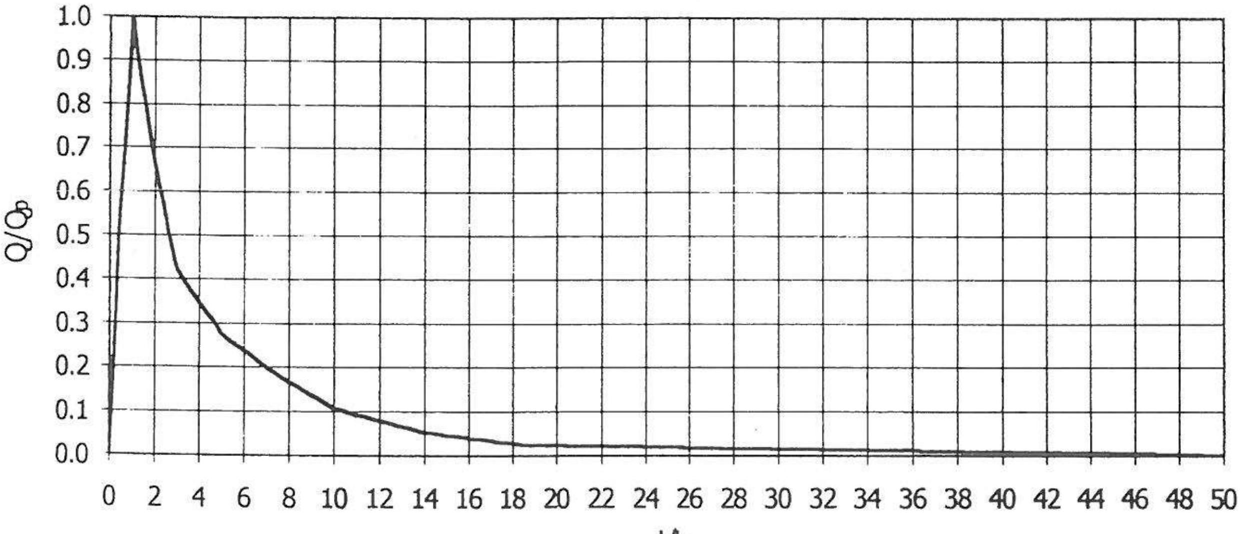


Figure 3 Dimensionless Unit Hydrograph

2.2 Adjustment methods of direct runoff hydrographs

The direct runoff hydrograph computed by some methods may have hydrograph shape and runoff volume different from the observed data significantly. Therefore it is necessary to set up correction methods to adjust the hydrograph shape until the runoff volume to be equal to the observed data.

SBUH method

$$\text{Adjusted } Q_n = \frac{\text{observed runoff volume x computed } Q_n}{\text{computed runoff volume}}$$

where Q_n = ordinate of discharge of direct runoff hydrograph

Rational method

$$0.5xQ_px(t_p + t_r) = \text{observed runoff volume}$$

$$t_r = \frac{\text{2xobserved runoff volume}}{Q_p} - t_p$$

where t_r = recession time, t_p = time to peak and Q_p = peak discharge

3. Data Used

The rainfall – runoff data are measured in 5 areas, all located in Bangkok. The data are measured continuously in every 2 minutes from August to October 2000. The data used are concluded as shown in Table1.

Table 1 Data used in this study [*].

District	Sub-Drainage Area No.	Area (m^2)	Curve Number (SCS)	Number of Event	Rainfall duration (minute)**	Rainfall depth (mm.)
Bangkapi	5	870,000	84	6	40 – 66	20 – 58
	7-8	270,000	84	6	62 – 116	25 – 99
Bungkum	5	40440	86	5	64 – 118	42 – 99
Nongkam	1	74,420	84	8	34 – 48	15 – 37
	2	51,065	81	5	34 – 48	15 – 37
	3	54,556	86	5	36 – 84	17 – 51
CU.		47,875	85	6	25 – 95	8 – 26
Kannayao		38,720	81	5	25 – 115	13 - 27

Remark : * refer to [3]

** To derive a unit hydrograph (see Eq.1 and Fig.1), every rainfall duration in every area is divided into the same time interval (Δt) of 2 minutes. This leads to obtain a 2 minute – unit hydrograph for each area.

4. Study Results

4.1 Comparison of direct runoff hydrograph computations

Two examples of computed direct runoff hydrographs compared with the observed data in Bungkum and Nongkam are shown in Fig.4. The computed results of each method are discussed as follows

1. Average unit hydrograph : AUH gives the computed direct runoff hydrograph most closely fit to the observed data, both hydrograph shape and peak discharge.
2. Santa Barbara Urban Hydrograph : SBUH gives the computed hydrograph larger than the observed data both peak discharge and runoff volume. This deviation is found to occur particularly in large area having detention storage and non-runoff contributing area, including the very flat slope of the area. However, in the small area this method gives quite good computation.
3. Rational method : This method gives the computed peak discharge close to the observed data. However the computed hydrograph shape having time to peak equal to time of recession, is different from the observed data having the time of recession much longer than the time to peak. Also, the computed runoff volume is much less than the observed data. This deviation is occurred in the almost all areas, except in small paved area with steep slope.
4. Clark unit hydrograph : This method gives the computation different from the observed data in that the peak discharge is higher and time of recession is shorter, however giving the same runoff volume. This deviation is found to occur evidently in large area. However, in the small area this method gives the computed result close to the observed data.
5. Dimensionless unit hydrograph : DUH gives the computed direct runoff hydrograph closely fit to the observed data less than the average unit hydrograph method, but better than the other three methods.

4.2 Adjustment of direct runoff hydrographs

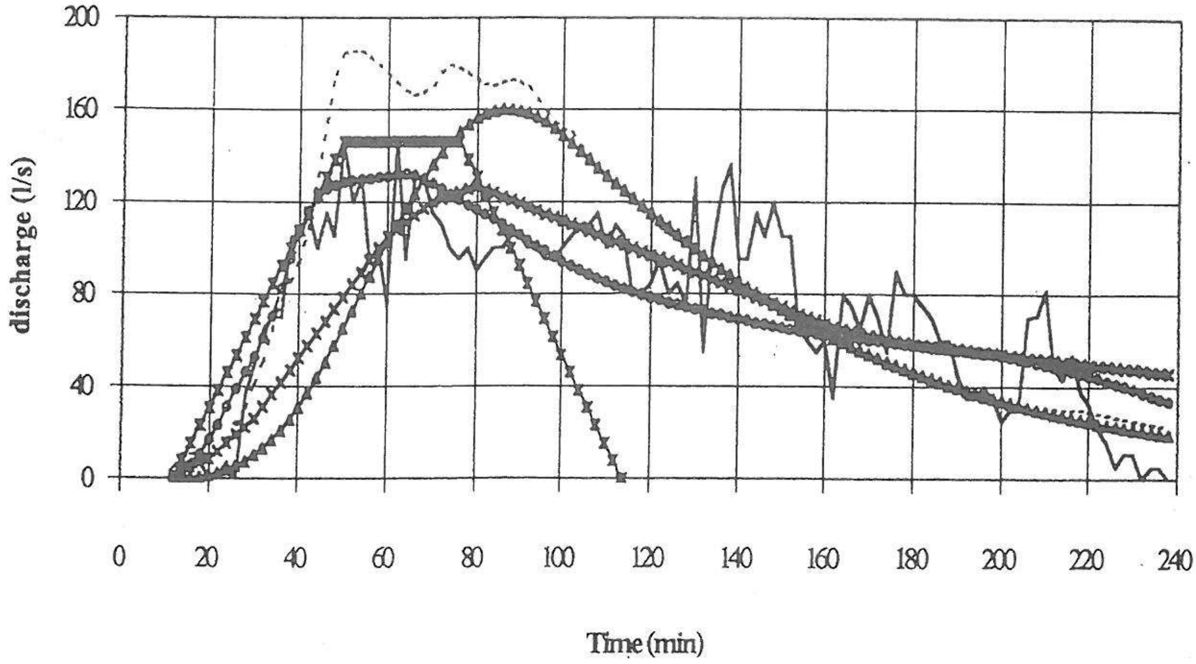
The adjusted direct runoff hydrographs by SBUH and Rational method are shown in the Fig.5, showing the improvement of hydrograph computation.

5. Conclusions

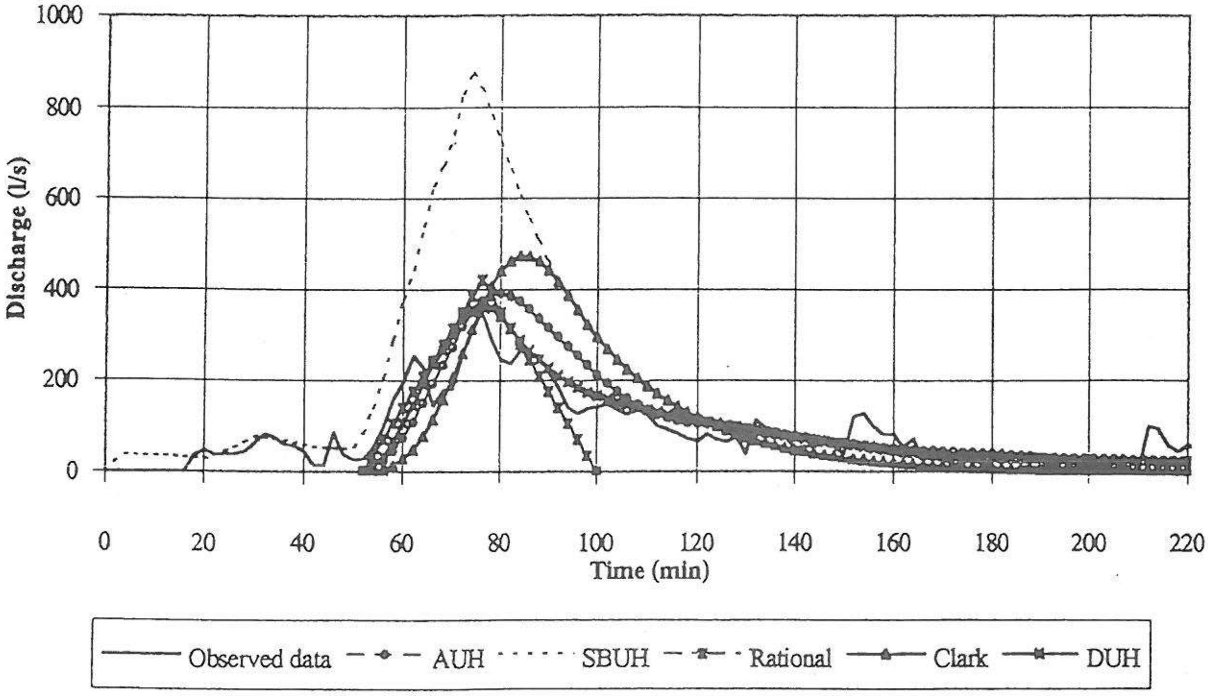
1. There are 3 methods developed from rainfall – runoff data, i.e., average unit hydrograph, rational method and dimensionless unit hydrograph. Other two methods i.e., SBUH and Clark methods are developed not using rainfall – runoff data, but using physical characteristic of drainage area.
2. The average unit hydrograph gives the best computation of direct runoff hydrograph to closely fit with the observed data.
3. SBUH, Rational and Clark methods can give good hydrograph computation in small areas but poor results in large areas.
4. The hydrograph adjustment for SBUH and Rational method by using water balance principle between observed runoff volume and computed runoff volume can improve the computed hydrograph to more fit to the observed data.
5. The measurement of rainfall and runoff data shown the contribution to the direct runoff hydrograph computation as seen from the application in hydrograph comparison and adjustment.

6. Recommendation

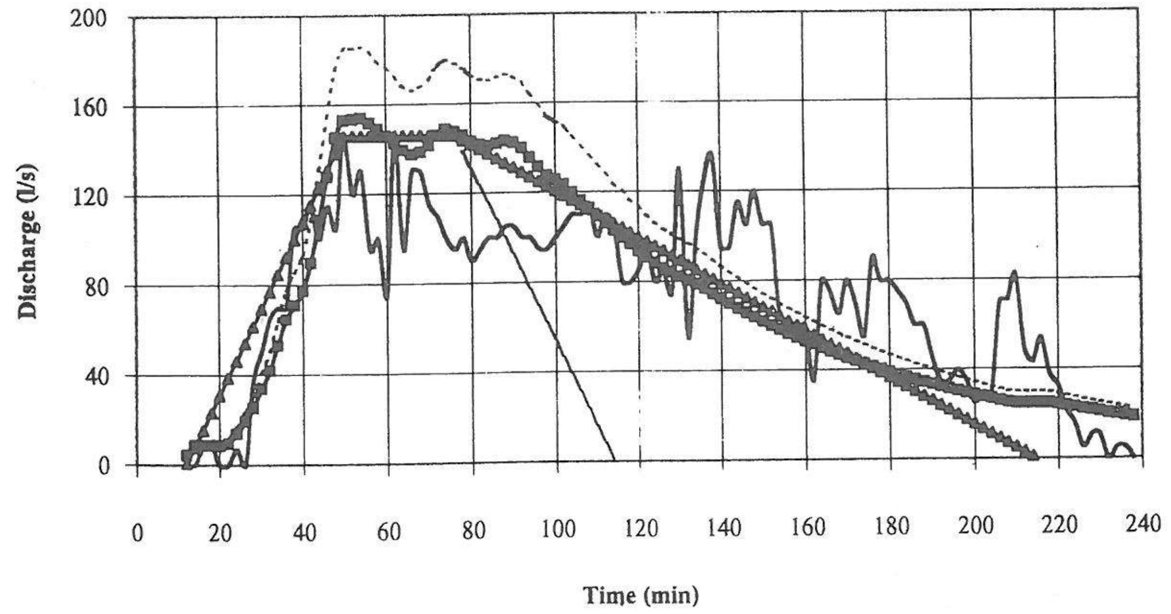
1. The measurement of rainfall – runoff data should be performed continuously for longer period.
2. The physical characteristics of drainage area located in urban area like Bangkok is very complicated and subject to continuous change of land use. Therefore the survey data should be updated.
3. The adjustment of direct runoff hydrograph needs further investigation on the methods in addition to the principle of



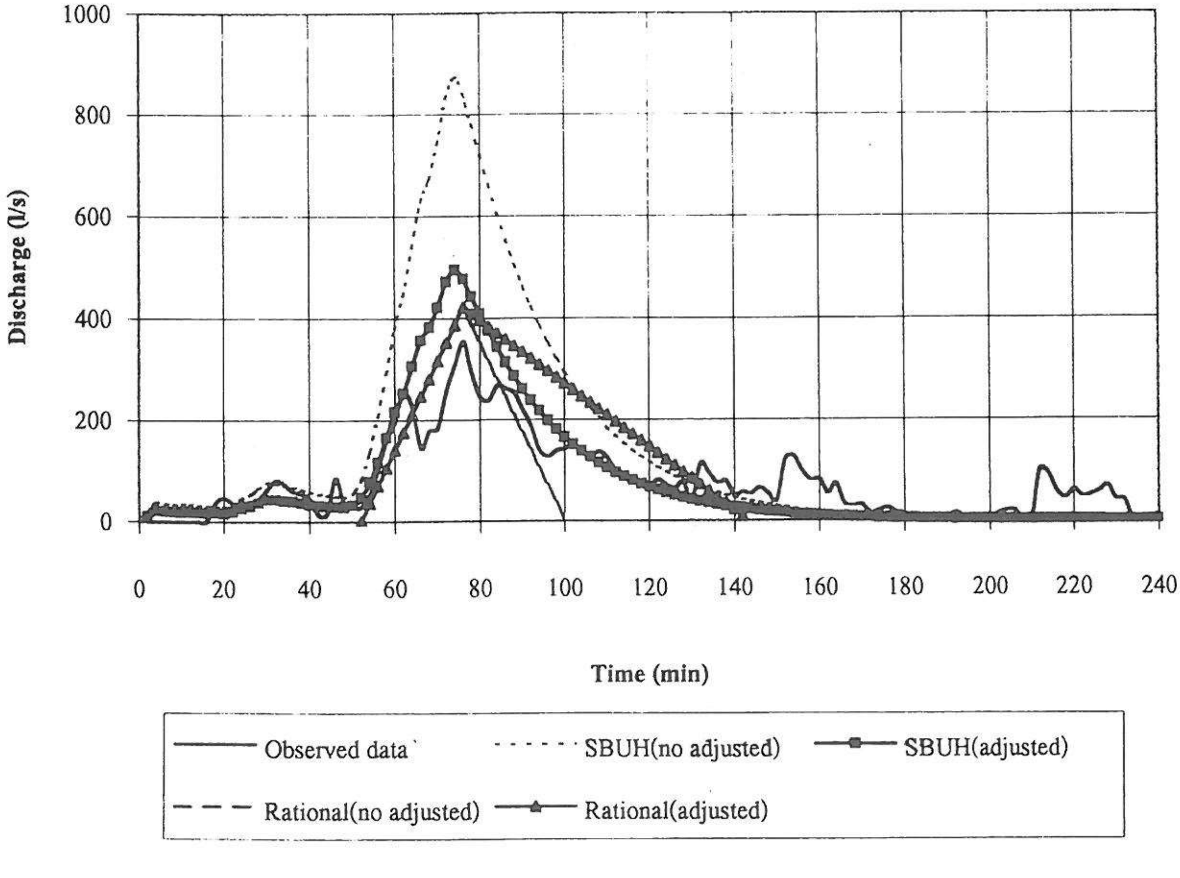
(a) August 19, 2000 on site 5 at Bungkum district



(b) October 1, 2000 on site 3 at Nongkham district
Figure 4 Comparison of computed direct runoff hydrographs with the observed data (no hydrograph modification)



(a) August 19, 2000 on site 5 at Bungkum district



(b) October 1, 2000 on site 3 at Nongkham district

Figure 5 Comparison of adjusted direct runoff hydrographs with the observed data (hydrograph adjustment) water balance between observed and computed runoff volumes.

7. Acknowledgement

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