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The Study of Flood Peak Analysis at Khlong Tha Taphao and Khlong Chumphon Basins by Hydrologic Model

Wisuwat Taesombut and Viraphol Taesombut

ABSTRACT

Khlong Tha Taphao and Khlong Chumphon Basins are subbasins of Peninsula East Coast Basin. The catchment areas of these subbasins are 2,227 and 521 square kilometers, respectively. Chumphon city which is located in the downstream portion of these subbasins has always faced up with several flood problems each year because of heavy rains from both moonsoon and tropical storm. Two severe floods which caused serious disaster were Gay Typhoon Storm at the beginning of November, 1989 and Zita Tropical Storm at the end of August, 1997.

Two hydrologic models namely NAM model developed by the Danish Hydraulic Institute (DHI), Denmark, and Hydrologic Flood model using Unit Hydrograph technique to calculate flood runoff from rainfall were used in this study. In calibration and verification of NAM model, the relevant data for the period 1998-2001 were evaluated. These two Hydrologic models were then applied for flood forecasting from Zita Tropical Storm occurred during 22-27 August, 1997 and Depression Storm occurred during 10-15 March, 2001. The performance of these two hydrologic models was investigated by comparing the obtained results with observed data at stations X.46, X.64, X.158 and X.53A.

It was found that both NAM and Hydrologic Flood models could be used for flood analysis in the studied subbasins with certain accuracy. Both models could be applied to estimate flood peak from storm rainfall to be used for making decision in flood management. However, NAM model is more reliable in determining flood estimation than using Hydrologic Flood model.

Key words: flood peak analysis, Khlong Tha Taphao and Khlong Chumphon basins, hydrologic model, NAM model

INTRODUCTION

Natural disasters can cause inevitable loss of human lives and extensive damage to properties of residents living in low-lying areas which are susceptible to floods. However, we can slow down, or alleviate the damage if we can accurately estimate the size of the flood and predict the time of occurrence. Some countries developed a computer model to simulate the impact of heavy rain storms and resulting heavy floods on low-lying areas to establish suitable flood prevention/mitigation measures. This is considered an example of effective water resources management.

The accuracy and complexity of such flood forecasting models varies from simple to complex models. Complex flood forecasting models require more data input to produce accurate forecasts, and

Department of Water Resources Engineering, Faculty of Engineering, Kasetsart University, Bangkok 10900, Thailand.

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may not be suitable in some situation where extensive data is not available. In such case, a less complex forecasting model may be more appropriate.

Based on the review of the natural disaster occurred in Thailand river basins, Khlong Tha Tapao and Khlong Chumphon Basins were hit by the typhoon "Gay" at the beginning of November 1989, the tropical storm "Zita" at the end of August 1997, and the low pressure through induced storm at the beginning of March 2001 (RID, 2002a). Due to the inadequate data on the Gay typhoon natural disaster, this research will select the remaining two natural disasters for conducting this research.

The hydrologic model, namely, NAM model developed by the Danish Hydraulic Institute (2002b), Denmark, and the Hydrologic Flood model developed by Taesombut (1999) were used to analyze the flood peak from the rainfall data obtained from the two selected rain storms for comparisons with data recorded by the index runoff stations.

MATERIALS AND METHODS

Study area

Chumphon city is located in the downstream portion of the Khlong Tha Taphao and Khlong Chumphon Basins, which are subbasins of Peninsula East Coast Basin. The catchment areas of these subbasins are 2,227 and 521 square kilometers, respectively. These subbasins have always faced up with many flood problems each year because of heavy rains from both moonsoon and tropical storm. The severe floods which caused the most serious disaster were Gay Typoon Storm at the beginning of November, 1989 and Zita Tropical Storm at the end of August, 1997. The location of the Khlong Tha Taphao and Khlong Chumphon Basins and their tributaries are shown in Figure 1.

The application of NAM model

NAM is the abbreviation of the Danish "Nedbør-Afstrømnings-Model", meaning precipitation-runoff-model. The model structure is shown in Figure 2. It is an imitation of the land phase of the hydrological cycle. NAM simulates the rainfall-runoff process by continuously accounting for the water content in four different and mutually interrelated storages that represent different physical elements of the catchment. These storages are snow storage (not use in Thailand), surface storage, lower zone storage (root zone) and groundwater storage.

Basic model components

1. *Surface storage*: Moisture intercepted on the vegetation, water trapped in depressions and in the upper part of the ground are represented as surface storage. The amount of water (U) in the surface storage is continuously diminished by evaporative consumption and horizontal leakage, interflow (QIF). U_{max} is the upper limit of the amount of water in the surface storage. When there is maximum surface storage, some of the excess water (P_N) will run off to the streams as overland flow, while the remainder is diverted as infiltration into the lower zone and groundwater storage.

2. *Lower zone or root zone storage*: The soil moisture in the root zone below the surface storage, can transpire the water. L_{max} is the upper limit of the amount of water in the lower zone storage. This storage controls the amount of water that run off to the groundwater storage as recharge and the interflow and overland flow components.

3. *Evapotranspiration*: Evapotranspiration demands are the potential rate from the surface storage. If the surface storage is less than these demands ($U < E_p$), the remaining fraction is assumed to be withdrawn by root activity from the lower zone storage at an actual rate (E_a). E_a is proportional to the potential evapotranspiration and varies linearly with the relative soil moisture content (L/L_{max}) of the lower zone storage.

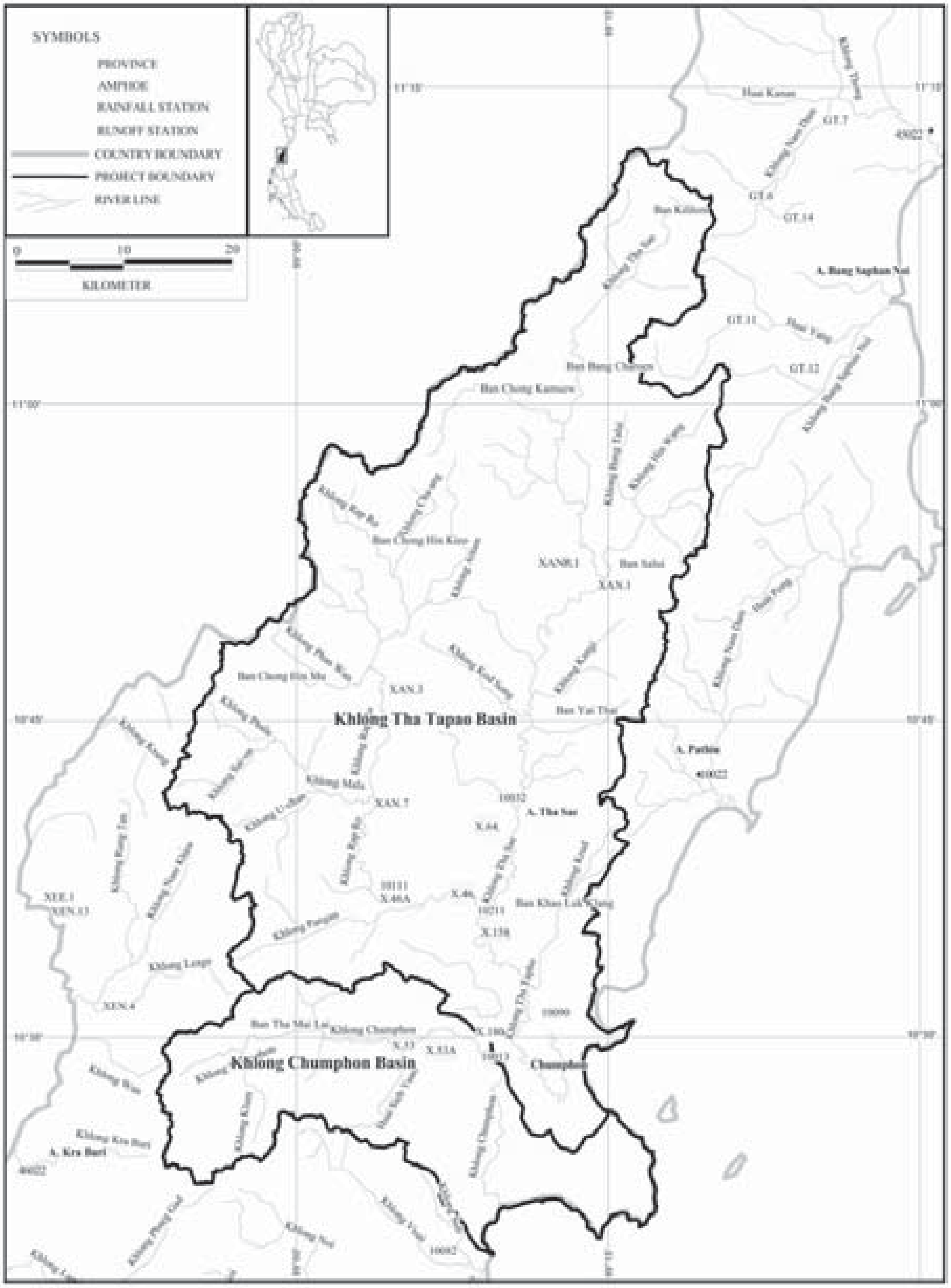


Figure 1 The location of Khlong Tha Tapao and Khlong Chumphon Basins and their tributaries.

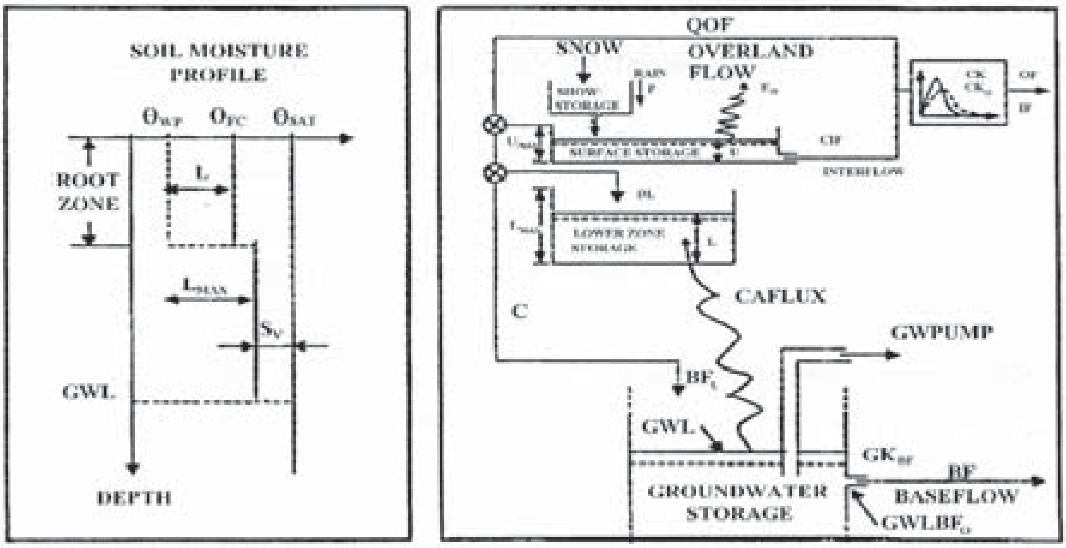


Figure 2 Structure of the NAM model (Danish Hydravlic Institue, 2001a).

$$E_A = E_P \times L/L_{\max} \quad (1)$$

4. *Overland flow*: When the surface storage spills ($U > U_{max}$), the excess water P_N gives rise to overland flow as well as to infiltration. QOF is the part of P_N that contributes to overland flow. It is assumed to be proportional to P_N and to vary linearly with the relative soil moisture content (L/L_{max}) of the lower zone storage.

$$QOF = \begin{cases} CQOF \dfrac{L/L_{max} - TOF}{1 - TOF} P_N & for\ L/L_{max} \rangle TOF \\ 0 & for\ L/L_{max} \le TOF \end{cases} \quad (2)$$

where CQOF is the overland flow runoff coefficient ($0 \le CQOF \le 1$)

TOF is the threshold value for overland flow ($0 \le TOF \le 1$).

The proportion of the excess water (P_N) that does not run off as overland flow infiltrates into the lower zone storage. The water available for infiltration (DL) is assumed to increase the lower zone storage (L). The remaining amount of infiltration (G) is assumed to percolate deeper and recharge the groundwater storage.

5. *Soil moisture content*: After dividing the excess water between overland flow and infiltration to groundwater, the remainder of the excess water increases the moisture content (L) within the lower zone storage (DL).

$$DL = (P_N - QOF) - G \quad (3)$$

6. *Interflow*: The interflow (QIF) is assumed to be proportional to the surface storage (U) and to vary linearly with the relative moisture content of the lower zone storage.

$$QIF = \begin{cases} (CKIF)^{-1} \dfrac{L/L_{max} - TIF}{1 - TIF} U & for\ L/L_{max} \rangle TIF \\ 0 & for\ L/L_{max} \le TIF \end{cases} \quad (4)$$

where CKIF is the time constant for interflow

TIF is the root zone threshold value for interflow ($0 \le TIF \le 1$)

7. *Interflow and overland flow routing*: The interflow is routed through two linear reservoirs in series with the same time constant (CK_{12}). The overland flow routing is also based on the linear reservoir concept but with a variable time constant as follows:-

If $OF < OF_{min}$: CK_{12}

If $OF > OF_{min}$: $CK_{12}^{OF} = CK_{12} \times (OF/OF_{min})^{-b}$ (5)

where OF is the overland flow (mm/hour)
OF_{min} is the upper limit for linear routing (= 0.4 mm/hour)
b = 0.4 (constant)

8. *Groundwater recharge*: The amount of infiltrating water (G) recharging the groundwater storage depends on the moisture content in the root zone.

$$G = \begin{cases} (P_N - QOF)\dfrac{L/L_{max} - TG}{1 - TG} & for\ L/L_{max} \rangle TG \\ 0 & for\ L/L_{max} \le TG \end{cases} \quad (6)$$

where TG is the root zone threshold value for groundwater recharge ($0 \le TG \le 1$)

9. *Baseflow*: The baseflow BF from the groundwater storage is calculated as the outflow from a linear reservoir with time constant CKBF.

The basic input requirements for the NAM model consist of model parameters, initial conditions, meteorological data, runoff data for model calibration and verification. The basic meteorological data requirements are rainfall and potential evapotranspiration.

The calibration and verification of NAM model

The researchers chose daily rainfall data in the year of 1998-1999 and 2000-2001 for the calibration and verification, respectively. The calibration process consisted of adjusting various parameters in the NAM model to minimize the difference between observed and computed hydrograph during these periods. The verification process was used to approve the calibrated parameters by applying the model with different data.

An application of Hydrologic Flood model

The Hydrologic Flood model is a hydrologic model developed for calculation of flood peak hydrograph from daily rainfall at different flood events using Unit Hydrograph technique. The steps of analysis are shown as follows:-

1. Unit hydrograph analysis for representative basin by using modified Snyder technique

1) Watershed parameters were collected from representative basin, then the time of concentration were calculated and used as the duration of rainfall that derived as follows:-

$$T_C = (0.87\ L^3/H)^{0.385} \quad (7)$$

where L = Lengths of longest watercourse in kilometer
H = Elevation difference between divide and outlet in meter

Then unit hydrograph parameters for each subbasin including peak discharge (q_p) was calculated as well as basin lag (t_p), and the rainfall duration (t_r) by using formulated equations that derived from the correlation of the watershed parameters of runoff station in Khlong Tha Tapao and Khlong Chumphon basins.

$$t_p = 1.728\ (LL_c/S^{1/2})^{\ 0.2248}\ (r = 0.8805) \quad (8)$$

$$q_p/A = 0.7333\ (t_p)^{\ -0.6778}\ (r = 0.8910) \quad (9)$$

2) The unit hydrograph of each subbasin was calculated by using the unit hydrograph parameters from 1) and the dimensionless unit hydrograph of the subbasins in Khlong Tha Tapao and Khlong Chumphon basins.

2. Flood peak hydrograph analysis at different flood events

1) Subbasin rainfall duration was divided into increments equally to the unit hydrograph duration at different flood events and reduced excess rainfall depth with areal rainfall reduction factor, then rearrange rainfall sequence which has duration the same as a unit hydrograph from each subbasin.

2) The flood hydrographs for each subbasin were computed from the excess rainfall and unit hydrograph. Base flow was determined from the correlation of base flow (Q_B) and flood peak (Q_P) in regression equation (Royal Irrigation

Department, 2002b).

3) The flood hydrographs at each control point in Khlong Tha Tapao and Khlong Chumphon basins were routed and combined from upstream to downstream by using Time of Storage method (Taesombut, 1990).

Criteria for evaluating model performance

Model performance can be evaluated by comparing the computed and the observed discharge at different runoff stations. In this research, three statistical measures are used. They are a difference of average and standard deviation of discharge data, and correlation coefficient (r).

1. Difference of average discharge data is shown as follows:-

$$\overline{Q}_o = \sum_{i=1}^{N} \frac{Q_{oi}}{N} \quad (10)$$

$$\overline{Q}_c = \sum_{i=1}^{N} \frac{Q_{ci}}{N} \quad (11)$$

Difference of average discharge =

$$\frac{\left(\overline{Q}_o - \overline{Q}_c\right)}{\overline{Q}_o} \times 100 \quad (12)$$

where $\overline{Q}_o$ is the average observed discharge data

$\overline{Q}_c$ is the average computed discharge data

N is the number of data

2. Difference of standard deviation of discharge data is shown as follows:-

$$STD\ Q_o = \left(\frac{1}{N} \times \sum_{i=1}^{N} \left(Q_{oi} - \overline{Q}_o\right)^2\right)^{0.5} \quad (13)$$

$$STD\ Q_c = \left(\frac{1}{N} \times \sum_{i=1}^{N} \left(Q_{ci} - \overline{Q}_c\right)^2\right)^{0.5} \quad (14)$$

Difference of standard deviation of discharge =

$$\frac{\left(STD\ Q_o - STD\ Q_c\right)}{STD\ Q_o} \times 100 \quad (15)$$

where $STD\,Qo$ is the standard deviation of observed discharge data

$STD\,Qc$ is the standard deviation of computed discharge data

3. Correlation coefficient (r) between the computed and the observed discharge data is shown as follows:-

$$r = \frac{\sum_{i=1}^{N} \left(Q_{oi} - \overline{Q}_o\right) \times \left(Q_{ci} - \overline{Q}_c\right)}{\left[\sum_{i=1}^{N} \left(Q_{oi} - \overline{Q}_o\right)^2 \times \left(\sum_{i=1}^{N} \left(Q_{ci} - \overline{Q}_c\right)^2\right)\right]^{0.5}} \quad (16)$$

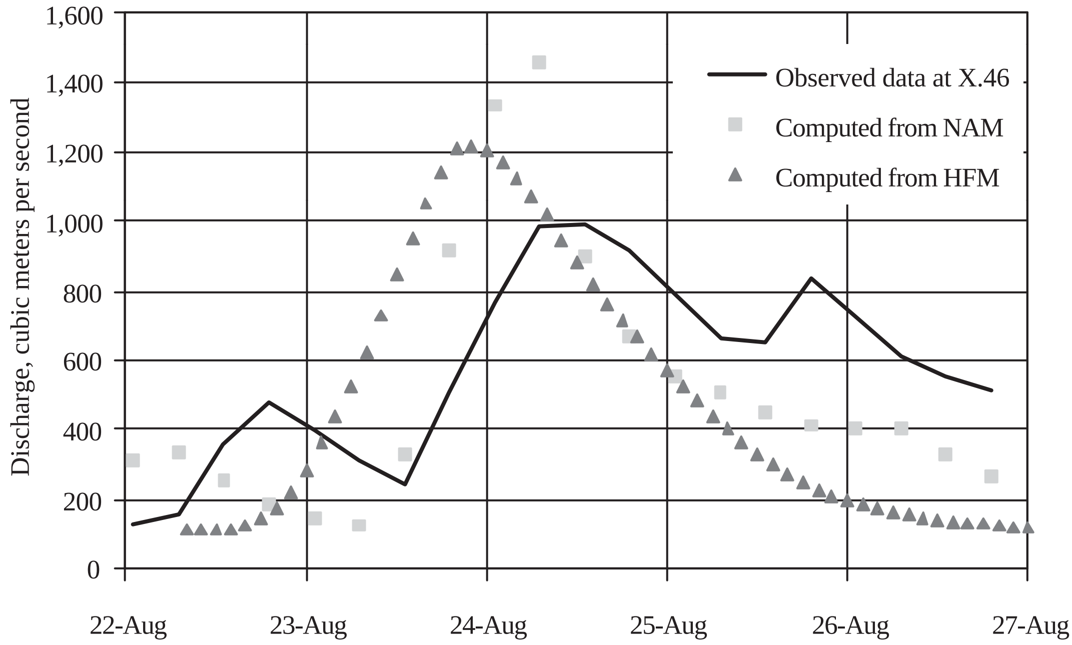
RESULTS

The results of the flood peak hydrograph as recorded by the 5 days rainfall brought by the Zita rainstorm in 1997 and the low pressure storm of 2001 calculated from the hydrologic models (NAM model, Hydrologic Flood model), and the runoff measurement of X.46, X.64, X.158 and X.53A are shown in Figures 3, 4, 5 and 6, respectively.

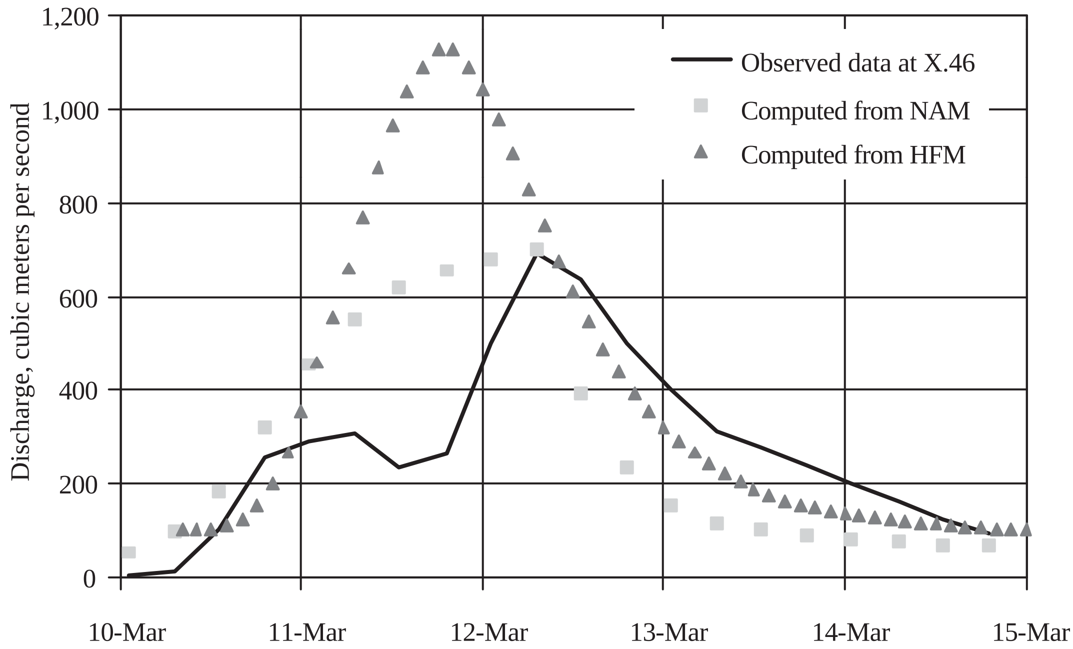
From the NAM model calibration and verification, the researchers discovered that the suitable period (time step) was 6 hours so that the discharge computation results and the actual measurement were in line with each other for both time and size of occurrence.

Using NAM model to find the flood peak hydrograph at various runoff stations, the researchers discovered that the flood peak hydrograph at X.64 runoff station was most in line, and was within acceptable range for other stations.

As for Hydrologic Flood model, the flood peak hydrograph at X.158 runoff station was found to be most in line, and was within acceptable range for other stations.

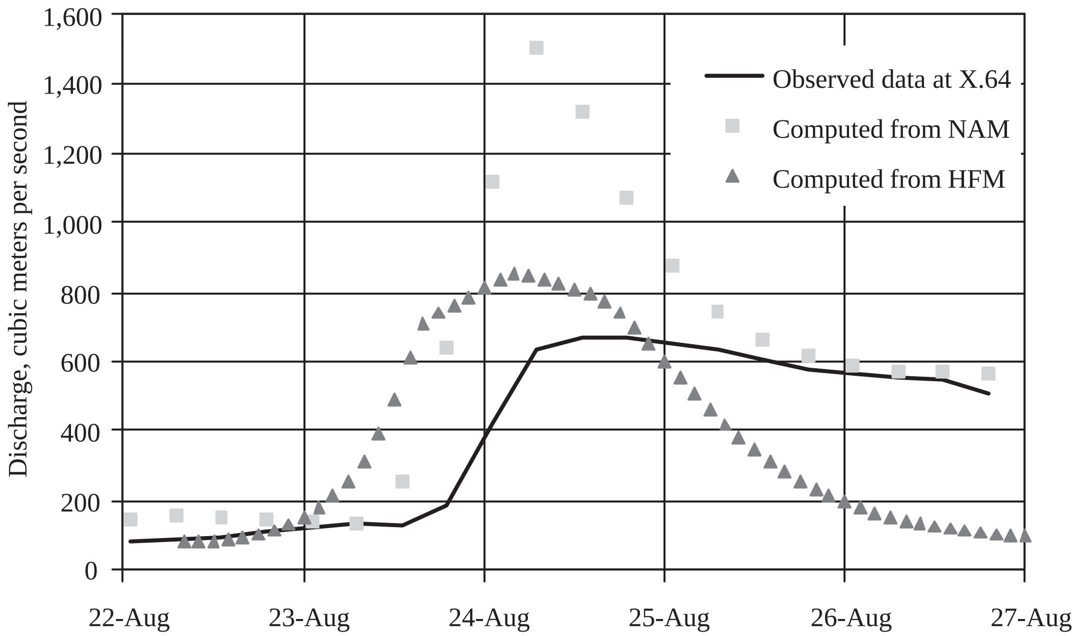


(a) Flood peak hydrograph during 22-27 August 1997

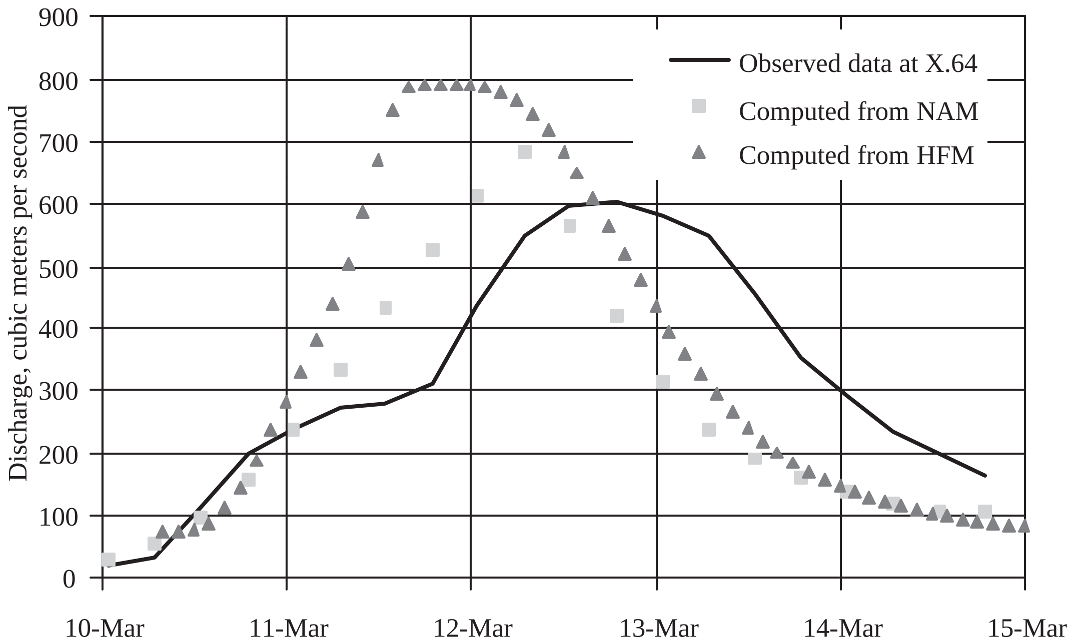


(b) Flood peak hydrograph during 10-15 March 2001

Figure 3 Flood peak hydrograph comparison between the NAM and Hydrologic Flood models at X.46 station.

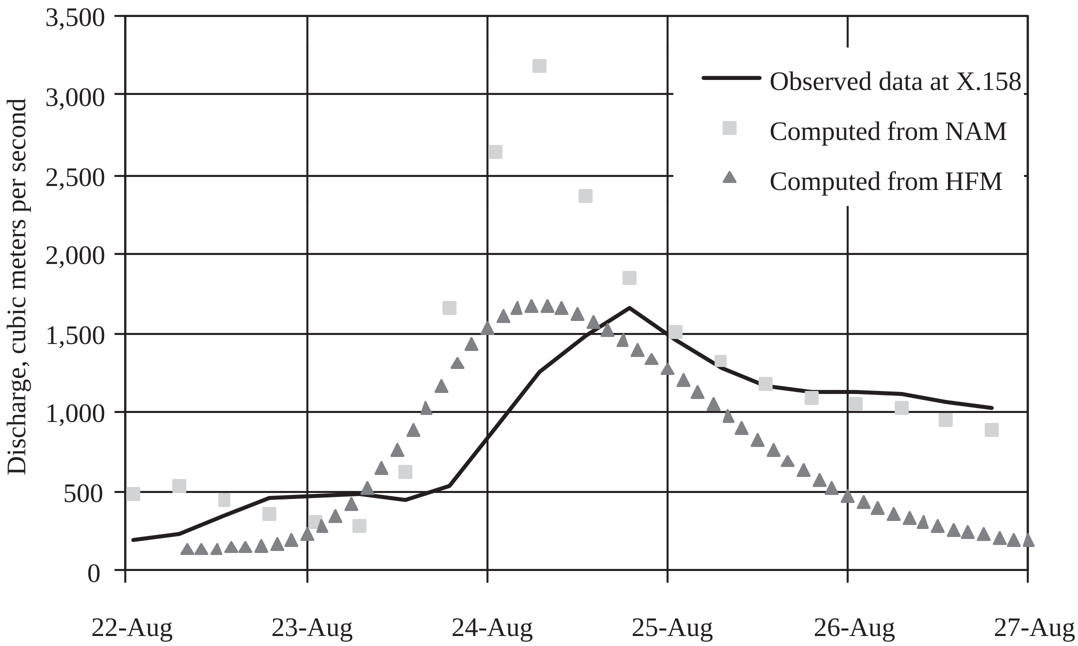


(a) Flood peak hydrograph during 22-27 August 1997

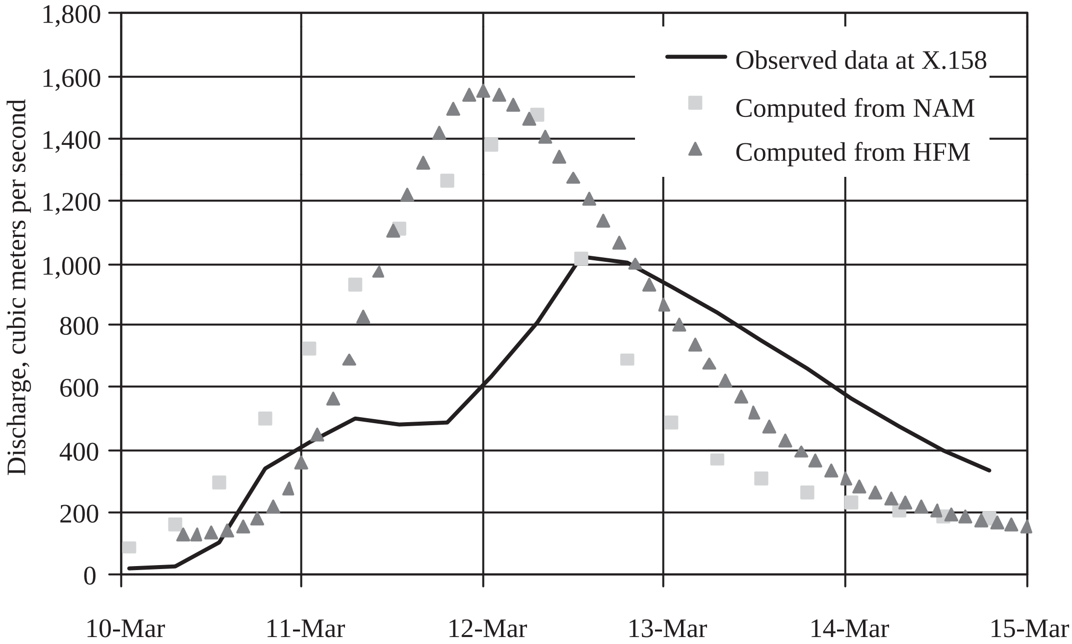


(b) Flood peak hydrograph during 10-15 March 2001

Figure 4 Flood peak hydrograph comparison between the NAM and Hydrologic Flood models at X.64 station.

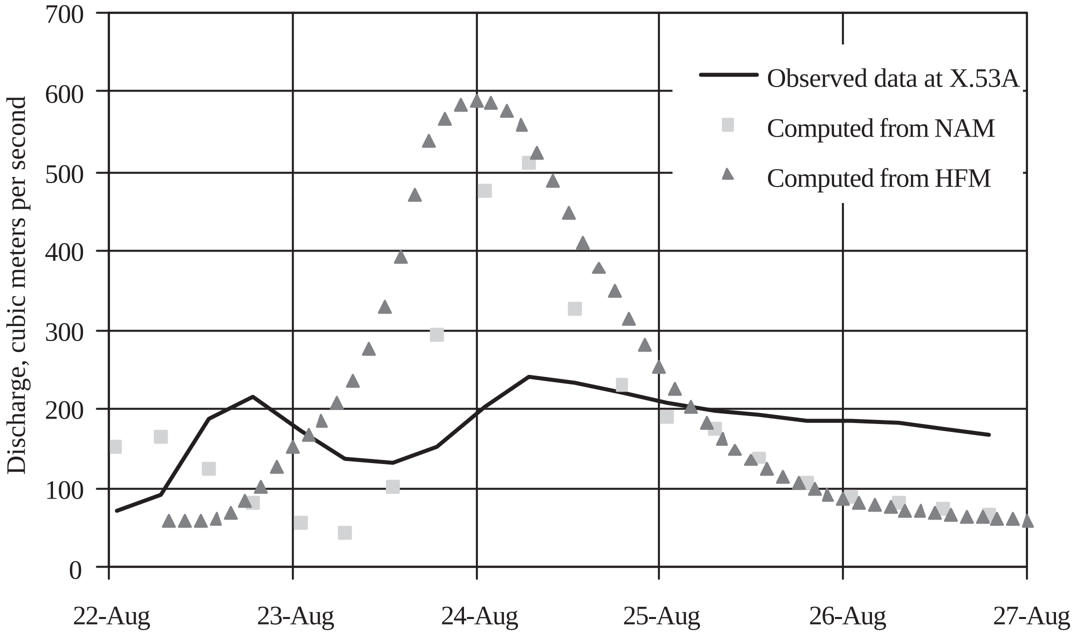


(a) Flood peak hydrograph during 22-27 August 1997

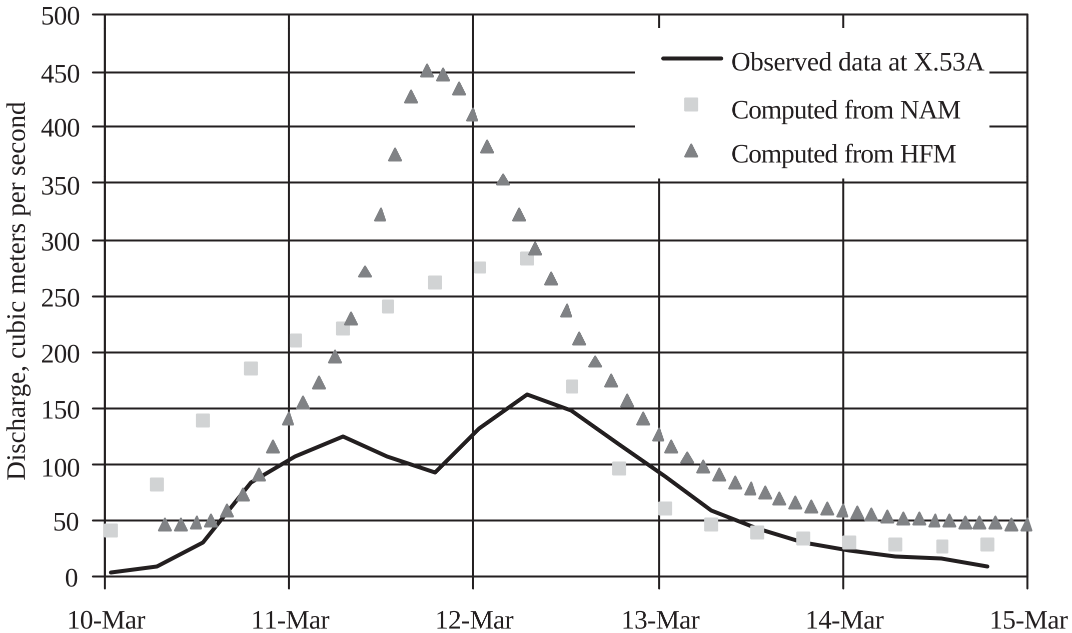


(b) Flood peak hydrograph during 10-15 March 2001

Figure 5 Flood peak hydrograph comparison between the NAM and Hydrologic Flood models at X.158 station.



(a) Flood peak hydrograph during 22-27 August 1997



(b) Flood peak hydrograph during 10-15 March 2001

Figure 6 Flood peak hydrograph comparison between the NAM and Hydrologic Flood models at X.53A station.

DISCUSSION

Although there are 15 parameters for the NAM model, only 3 significant parameters were used in the calibration. The 3 parameters are the maximum contents of surface storage (U_{max}), maximum contents of root zone storage (L_{max}), and the overland flow coefficient (CQOF). After adjusting these parameters, the flood peak volume changed significantly. The other important parameter is the time constant for routing overland flow (CK_{12}) used to revise the shape of the hydrographs with no change in the result of the flood peak volume and the initial condition, especially the relative moisture content (L/L_{max}). As for the remaining parameters which revised will not significantly change the result of the flood peak volume, are usually constant/fixed figures as recommended by specialist for use with various types of river basins.

Flood peak hydrograph calculated from the rain storm via Unit Hydrograph technique in the Hydrologic Flood model results in considerable deviation with the data recorded at various runoff stations due to lack of data from rainfall measurement station which is similar to the data used in the NAM model. As for the limitation of the Hydrologic Flood model, the direct runoff hydrograph derived from excess rainfall (more than one rain storm event) by the Unit Hydrograph technique is the combined result of each rainstorm according to a particular time period. The rainfall volume of each rain storm has no impact on each other despite the continuation of the rainfall. When considering this criteria, it is obviously different from reality/actual situation, because the rainfall amount of the previous rain will affect the soil infiltration rate and the soil moisture. This caused the direct runoff amount arising from the following rainstorm to change. In any case, this research technique did offer acceptable results and was generally suitable for calculating the flood peak hydrograph from 5-7 days of accumulated rainstorms.

All flood peak hydrographs derived from the Hydrologic Flood model have bell-shaped graphs because due to the rain storms sequence arrangement to allow for equal time increments to that of the unit hydrograph. The goal of the sequence arrangement is to maximize the runoff which may not be the same as the volume figure of the actual rainfall.

When comparing the flood peak hydrograph computed by the NAM and Hydrologic Flood models to the data recorded at each runoff station, most of the NAM calculation results are higher and with little variation. The difference in the computation of the flood peak hydrograph of the NAM and Hydrologic Flood models to that of the actual records, may be due to the inability to analyze over-bank flow and spreading to the floodplain with regards to the movement of the flood peak hydrograph of various control points.

The rainfall data used in the computation of the flood peak hydrograph in the NAM and Hydrologic Flood models are daily data. Moreover, some rainfall stations have recorded rainfall data for only 6 months each year, contributing to the limitation of the data obtained. Hence, the model calibration and verification may result in specific area parameters which are not quite acceptable. However, since October 2002, the Khlong Tha Tapao basin has a telemetering system comprising of 12 automatic rainfall measurement stations, which provide rainfall data at 15-minutes interval at continuous basis. Thus, in the future it is necessary to revise some of the parameters for suitability by studying the 15-minutes interval rainfall data of this telemetering system.

In measuring the flow velocity to develop rating curves for each runoff station, the flow rate figure at the high level, or flow rate of major floods is very important to flood analysis. It is necessary to conduct all possible measurements. Usually, the rating curves of the runoff stations in certain year does not cover high flow period. This leads to extrapolation problem when the water level is converted into flow rate for a particular station during high flow period. Thus, the flow rate obtained is not quite accurate.

The hydrologic model is the lump model type which is based on average figures of the study area, covering only changes during certain time period. The result of the hydrologic model is the hydrograph which is used to compute water volume according to rain storms changes. Thus, it is suitable for use as input data, as boundary condition, or as lateral flow. As for the hydraulic model for analyzing the river network, hydraulic structures in river and the hydraulic routing which considered the changes in space and time via simultaneous calculation of the discharge and water level rather than segregated computation as in the lump model, will result in higher accuracy to the actual condition (for major floods) than the lump model.

The longitudinal river profile is generally concave upward. The river bed slope is vary from steep to flat and has extensive floodplain at the downstream portion. The catchment characteristics of Khlong Tha Tapao basin at X.46 and X.64 stations are narrow-long catchments. The location of the runoff station generally selected at the river site that never have over-bank flow. Thus some locations with flat bed slope may be caused the storage effect. This research does not consider the storage effect in the computation of the flood peak hydrograph from the two hydrologic models.

The observed flood peak in 1997 at X.46 station was higher than the observed flood peak in 2001 because of the higher storage effect. The observed flood peak in 2001 at X.64 and X.158 gave also higher storage effect than the flood peak computation derived from the two Hydrologic models.

The topography condition of the river basin is the most influence affecting the shape of the flood hydrograph. Moreover, the development of urbanization in the large river basin with particular narrow-long shape such as the Khlong Tha Tapao basin, might give a higher storage effect. Hence, the ground truth survey is used to derive approximately the storage elevation curve to adjust the accuracy of the computation results.

CONCLUSION

Result of this research is an application of hydrologic models, such as the NAM model (calibrated and verified) and the Hydrologic Flood model to compute flood peak hydrograph for each control point of the subbasins of Khlong Tha Tapao and Khlong Chumphon basins. The daily rainfall data during the rainstorm showed the flood peak hydrograph and the time of occurrence for each control point. When compared to the capacity of the river and the rating curves, we can estimate the chance of a natural disaster (flood), or over-bank flow, flooding of residential areas and can prepare relocation/evacuation in time before the flood hit the area, thereby minimizing potential damage. However, we must consider the accuracy of the computation results derived from the hydrologic model as well as making decision in flood management.

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