Operational flood forecasting for Chao Phraya river Delta

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ABSTRACT: *The flood forecasting model was developed and improved to be used as operational model for Chao Phraya delta. This study applies AIT River Network model to forecast the flood by input the forecasted upstream boundary, which is the daily discharge at the tail of Chao Phraya Dam, and downstream boundary, which is tidal level at Fort Chula. Not only the model that will provide flood forecast but also both boundaries should be good forecasted. At the upstream boundary, the non-dimensional shape of unique flood hydrograph was formulated and proposed. The three empirical formulae for forecasting peak discharge, time base and dimensionless shape of hydrograph were derived. Good agreements between observed and forecasted daily discharge were obtained with the error $\pm$10% or $\pm$300 cms. For the downstream boundary, the conventional harmonic analysis was applied. The optimum length of tidal record and number of tidal constituents were found to be 30 days with 4 constituents which provide the least root meant square with the error $\pm$20% or $\pm$0.20-0.30 m. Finally the model was applied to forecast the daily maximum water levels of 1980, 1983 and 1995 flood with one month in advance. The results of flood forecasting show the acceptable agreements between the observed and forecasted water levels with the average errors of about $\pm$20 cm. in the river and $\pm$15 cm. in the flood plain.*

1 Introduction

The Chao Phraya Delta is one of the most important deltas in the Central Part of Thailand. Many times in the past the delta have been flooded and these floods result in extensive damage to economic and social condition, especially at the lower reach of the Chao Phraya river. Natural flooding in this area is mainly due to high tide in the Gulf of Thailand, high discharge from the north, local rainfall and inflow from the surrounding area. The tide in the Chao Phraya River is highest from November to December while peak flow in the Chao Phraya River from the north normally passes the Chao Phraya Dam in Mid-October and reaches Bangkok in November. Therefore, water levels in the lower reach of the Chao Phraya River due to the combined effect of tide and river flow from the north are highest at the beginning of November. To reduce the damage and protect the city from flooding, flood forecasting is one of the important tools used for this purpose.

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Mathematical models of Chao Phraya River basin flood forecasting were developed by Tingsanchali and Arbhabhirama in 1978 and the models were improved to study the flooding conditions and the effect of the Chao Phraya 2 division channel by Tingsanchali and Vongvisessomjai in 1986. In 1999, JICA carried out the Master plan study on integrated plan for flood mitigation in Chao Phraya River basin using Mike11 model. However none of the model is used in operational level due to lack of real time boundary condition.

The Asian Institute of Technology (AIT) River Network Model, a combination of the River Model and Cell-Link Model developed by Suppataratarn (1990), was used to simulate flow in both the river and the floodplain. This model is appropriate for simulating flow in detaic areas such as the Chao Phraya delta in Thailand. In this study the model is applied for operational flood forecasting in the Chao Phraya delta.

2 Study area

The study area is the Chao Phraya River basin, covered an area of 151,757 km^2 as shown in Figure 1. The basin is divided into ten subbasin as shown in Table 1 which subbasins 1 to 9 are used as the input data for the upstream discharge forecasting and subbasin 10 is the Chao Phraya delta. The delta is characterized by a flat and low lying broad deposited surface. The major drainage systems of the plain are the Chao Phraya River and its tributaries, i.e. the Thachin, the Noi, and the Lopburi rivers. The plain also receives water from the Pasak River in the northeast, the Bangpakong River in the east and the Maeklong River in the west. In Chainat Province, which is the apex of the delta, waters of the Chao Phraya River can be diverted by the Chao Phraya dam into a number of main water courses, consisting of regulated natural rivers and manmade irrigation canals. Figure 2 shows the detail of the Chao Phraya delta.

Table 1 List of names and area of the subbasin

SubBasin	Name of Sub-basin	Area (km^2)
1	Bhumibol Dam Basin	26,386
2	Wang River Basin	11,708
3	Ping River Residual Basin	9,632
4	Yom River Basin	24,720
5	Sirikit Dam Basin	13,130
6	Nan River Residual Basin	20,227
7	Chainat Residual Basin	5,084
8	Pasak River Basin	15,206
9	Some Parts of Chao Phraya River Basin	6,664
10	Chao Phraya Delta	19,000
	Total	**151,757**

3 Theoretical considerations

3.1 Flood forecasting model

The River Network Model is applied to use for flood forecasting in the Chao Phraya delta by input the forecasted upstream and downstream boundary. The model was a combination of the River model and the Cell-Link model (quasi two-dimensional model) which represent the characteristic of flow over riverbank in the floodplain. The River model for describing flow in the river channel was formulated using one-dimensional unsteady flow of de SAINT VENANT equations. The Cell-Link model describing the flow in floodplains was based on the diffusion model as proposed by ZANOBETTI and LORGERE (1970). The detail of governing equations and the numerical formulations is in SUPPATARATARN (1990).

3.1.1 Physical layout and schematization of model

River reaches are subdivided into small reaches while the flood plains are subdivided into cells. Flows between cell and cell or cell and river reach are through links, which represent canals, weirs or siphons. The physical layout of the model is shown in Figure 3 while the schematization is shown in Figure 4. There are 126 grids in the River model and 139 cells in the Cell and Link model. The maximum, average and minimum values of lengths between grids are 17.0, 9.3 and 2.0 km while those of cell are 470, 137 and 13 km^2 respectively

3.1.2 Data

- *Observed data*: The observed data are topographic data and some of hydrologic data. The topographic data are the main river cross-section and berm section data, ground elevations, canal sections and dike levels. The hydrologic data are initial water levels in cell, initial water levels and initial discharges at grids, rainfall and evapotranspirations.

- *Forecasted boundaries*: The forecasted boundaries are discharges at upstream boundary at Chao Phraya dam (Station C13) and tidal level at downstream boundary at Fort Chula as shown in Figure 4.

3.2 Forecasting of discharge hydrograph at the tail of Chao Phraya Dam (Station C13)

Chao Phraya Dam is a large barrage dam, locates on the Chao Phraya River at Chainat Province. The upper part of Chao Phraya Dam, the Chao Phraya River system consist of four principle tributaries; Ping, Wang, Yom and Nan rivers, all originating in the northern highland. The Wang and Yom rivers join the Ping and Nan rivers in the middle basin, respectively. Then, the Ping and Nan rivers join to from the Chao Phraya River at Nakhon Sawan Province, which flows down to the lower basin through the Chao Phraya Dam.

Due to the complicate characteristics of upstream river system, the hydrograph in the upstream catchment of Chao Phraya dam can be formulated using hydrograph characteristics and hydrological parameters. However, it may not suitable to apply for flood forecasting since the rainfall is unknown in advance. Therefore the simplified model will be studied to use for forecasting.

From the study, it found that the discharge hydrograph at C13 as shown in Figure 5 is related with the volume of waters from upstream catchment area. Therefore the discharge hydrograph forecasting models are formulated by considering simple relationship between previous rainfall data and volume of discharge from reservoirs in the study area & discharge hydrograph at C13.

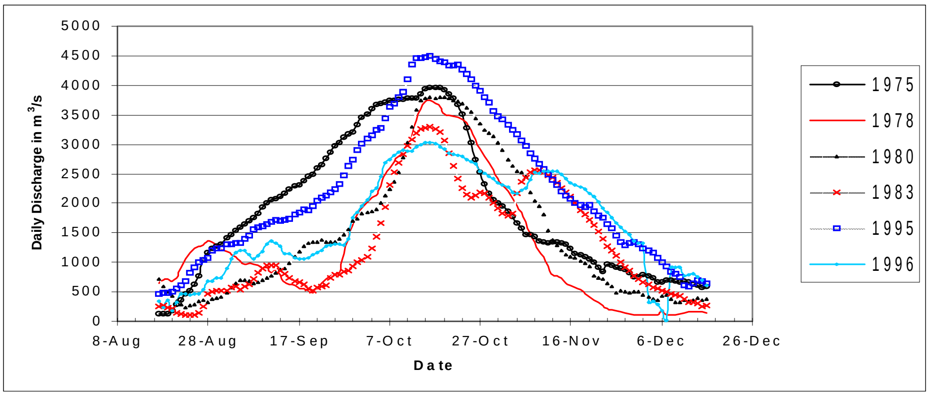


Figure 5. Daily Discharge Hydrograph at C13

The empirical formulae of forecast the upstream discharge hydrograph at the tail of Chao Phraya Dam, station C13 are formulated using multiple regression model by considering relationship between the characteristics of upstream river system and discharge hydrograph at upstream boundary.

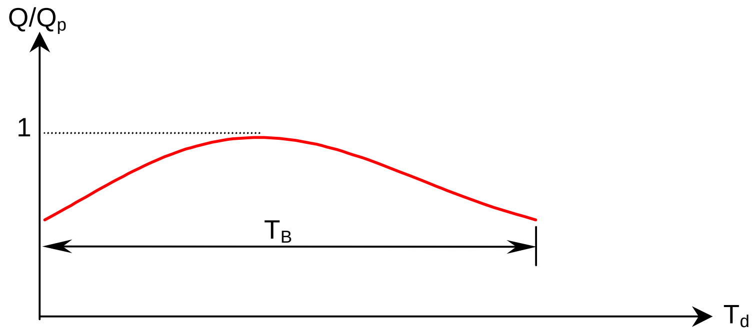
3.3 Required Data

Flooding record that will be used in the study are 9 years which are 1975, 1978, 1980,1983, 1985, 1988, 1994, 1995 and 1996. The peak of all flood were more than 2,500 m^3/s. The required data of each flood events are the following:

Rainfall: Rainfall data that were used in this study are daily rainfall of 76 rainfall stations. The distribution of the selected rainfall stations into various subbasins is done by using Thiessen polygon method.

Reservoir: There are two major dams, which located in the study area; one is Bhumibol Dam and the other is Sirikit Dam. Both of them are storage dams, which are under the operation of Electricity Generating Authority of Thailand. The required data is daily released discharge.

Discharge Hydrograph: The past recorded daily discharges at the tail of Chao Phraya Dam (C13) are used in the study. These data are provided every year by RID in “Thailand Hydrological Yearbook”.



Peak Discharge Forecasting

$$Q_p^{'} = -448 + 0.0989R_{f1A} + 0.0823R_{f1B} + 0.0153R_{f2A} + 0.0863R_{f2B} + 0.1360R_{f3A} \quad (1)$$

where

- $Q_p^{'}$ = peak discharge forecasted at station C13 (m^3/s)
- R_{f1A} = cumulative volume of rainfall and released discharge from reservoirs during 1July to 15 July (mcm)
- R_{f1B} = cumulative volume of rainfall and released discharge from reservoirs during 16 July to 31 July (mcm)
- R_{f2A} = cumulative volume of rainfall and released discharge from reservoirs during 1 August to 15 August (mcm)
- R_{f2B} = cumulative volume of rainfall and released discharge from reservoirs during 16 August to 31 August (mcm)
- R_{f3A} = cumulative volume of rainfall and released discharge from reservoirs during 1 September to 15 September (mcm)

Time Base Forecasting

$$T_B^{'} = 960 - 0.0305R_{f1} - 0.0639R_{f2} - 0.0131R_{f3} + 7.8052E\text{-}07(R_{f1})^2 + 1.6657E\text{-}06(R_{f2})^2 + 6.4996E\text{-}07(R_{f3})^2 \quad (2)$$

where

- $T_B^{'}$ = time base forecasted of hydrograph at station C13
- R_{f1} = cumulative volume of rainfall and released discharge from reservoirs during 1 July to 31 July
- R_{f2} = cumulative volume of rainfall and released discharge from reservoirs during 1 August to 31 August
- R_{f3} = cumulative volume of rainfall and released discharge from reservoirs during 1 September to 15 September

Normalized Hydrograph

$$Q/Q_p = -15.698(T^{'})^6 + 33.311(T^{'})^5 - 7.391(T^{'})^4 - 25.144(T^{'})^3 + 16.433(T^{'})^2 - 1.5206(T^{'}) + 0.4609 \quad (3)$$

where

- $T^{'}$ = T_d/T_B
- T_d = Time of Discharge Forecasting by the model (d = 1, 2, …, T_B days)
- T_B = Time Base of hydrograph (days)
- Q/Q_p = Shape of Hydrograph at day *d*

Figure 6. Non-Dimensional Discharge Hydrograph

3.4 Model formulation

There are three parts for discharge hydrograph forecasting. Those are peak discharge (Q_p), time base of hydrograph (T_B) and shape of hydrograph (Q/Q_p) as shown in Figure 6. The combination of upstream rainfall and released discharge from dam are combined in different ways in order to obtain the best fit of non-dimensional discharge hydrograph. Finally equations (1), (2) and (3) using 15 days interval rainfall and water volume released from Bhumipol and Sirikit dam are found to be the best for discharge hydrograph forecasting at station C13. Details of other equations can be found in THAMMASITTIRONG (2000).

3.5 Result of discharge hydrograph forecasting at C13

By substitute $Q_p^{'}$ from Eq.(1) and $T_B^{'}$ from Eq. (2) into Eq. (3), the forecasted discharge at station C13 can be determined. The comparisons of the forecasted and observed discharge hydrograph at station C13 in 1975, 1978, 1980, 1983 , 1988, 1994, 1995 and 1996 are shown Figure 7. It was found that the accuracy of forecasting is about 90% or ± 300 m^3/s. and it can forecast the date of peak discharge occurring within 9 to 26 days in advance with an error of ± 5 days. This procedure can be used to forecast the maximum discharge at C13 which is useful to assess the possible worse flood condition.

3.6 Forecasting of water level at downstream boundary

The water level fluctuation in the Gulf of Thailand depends on the astronomical factor and physiography of the region, while the meteorological factor is considered to produce only minor effects.

The characteristics of the water level variation at Fort Chula is analyzed from previous records of hourly tides at Fort Chula by using harmonic analysis and are then incorporated into the Harmonic Model to generate the water level fluctuation at any desired period of time to be used as the downstream boundary condition of the River Network Model.

The harmonic model is used to forecast the downstream water level at Fort Chula and the suitable number of constituents and the tidal record length that used as input of the model are determined to obtain the best tidal forecasting in the next 7 days.

3.7 Harmonic model

The relative motion of the earth, moon and sun causes periodic tide producing forces. The period of each constituent can be determined form astronomical studies. The harmonic analysis expresses the tide as a composition of a number of simple harmonic constituents. The tidal variation, denoted by $\eta_r(t)$, at a particular location and time, t, can be expressed as the sum of the effects of various constituents as

$$\eta_r(t) = a_0 + \sum_{i=1}^{N} a_i \sin\left[\frac{2\pi\ t}{T_i} + \delta_i\right] \qquad (4)$$

In Eq. 4, a_0 is the mean sea level, N is the total number of constituents, while a_i, δ_i and T_i are the amplitude, phase and period of the i^{th} constituent. The values of a_0, a_i, δ_i can be determined for each corresponding values of T_i using the information obtained from tidal records at Fort Chula.

Applying known values of a_0, a_i, δ_i, and T_i, the hourly sea level fluctuation at Fort Chula can be generated at any future time. The detailed description of harmonic analysis is given by AIT (1978).

3.8 Result of Analysis

There are three types of methods that used to measure the efficiency of the model, the first is Maximum Error, the second is Mean Absolute Deviation (MAD) and the last is Root Mean Square Error (RMSE).

In this section, the number of constituents and the tidal record length will be determined to obtain the best tidal forecasting in the next 7 days. The number of harmonic constituents varies from 4 to 8 constituents and the record length varies from 7 to 60 days. Figure 8 shows the comparison of root mean square error of harmonic analysis vary with various sets of record length and number of constituents in September 1995.

From the study, it is found that the suitable record length of data is 30 days and the suitable number of constituents is 4 constituents (M_2, S_2, K_1 and O_1 with periods of 12.4206, 12.0000, 23.9346 and 25.1894 hr, respectively). This model can forecast hourly tidal level for next 7 to 30 days ahead with an error of $\pm$0.20-0.30 m

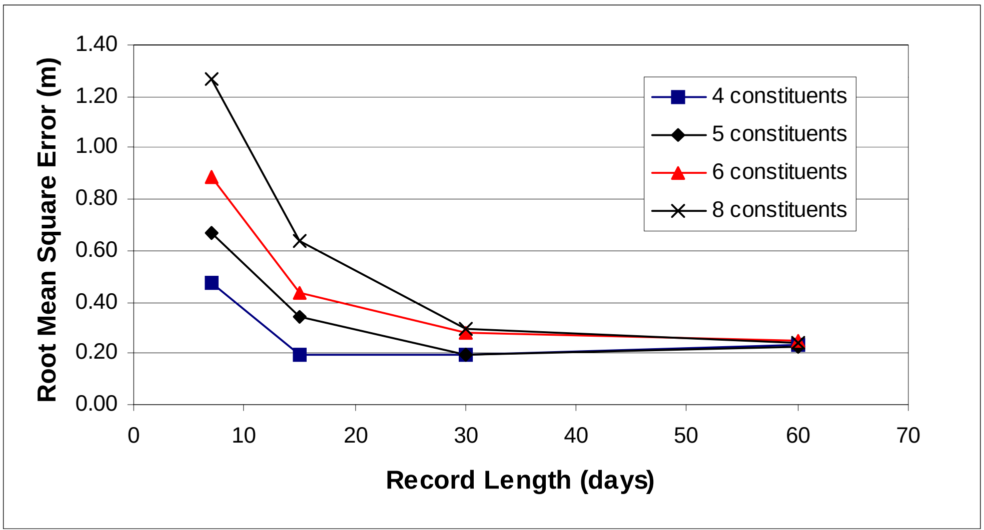


Figure 8. Comparison of the Root Mean Square Error of Harmonic Analysis at Fort Chula in September 1995

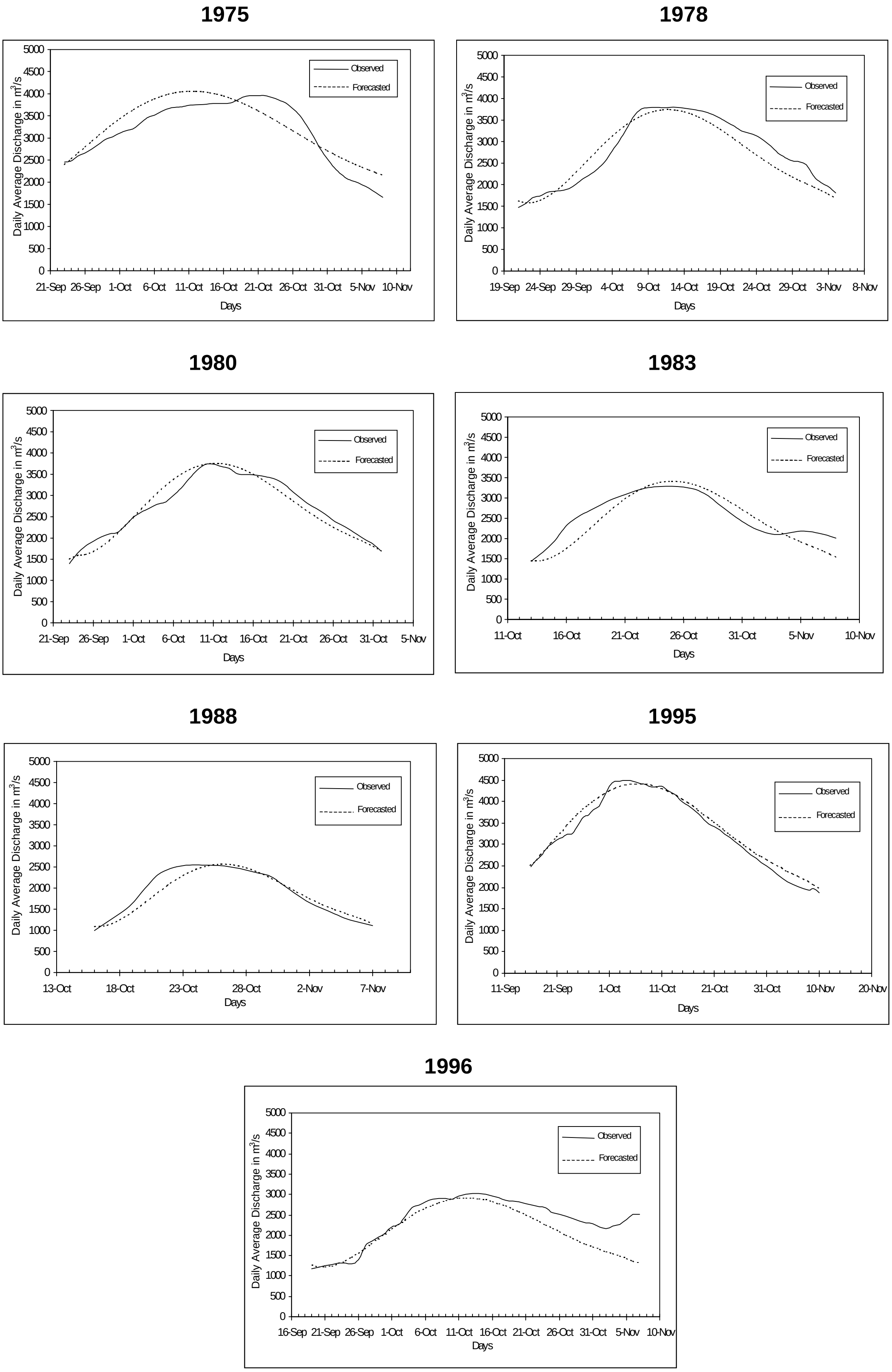


Figure 7. Comparison of Observed and Forecasted Discharge Hydrograph at C13

4 Application and results

Flood Forecasting in the Chao Phraya River Delta

The River Network Model is applied to use for flood forecasting in the Chao Phraya River Delta by input the forecasted upstream and downstream boundary condition.The upstream boundary is the released discharge hydrograph at the tail of Chao Phraya Dam and the downstream boundary is the water level at Fort Chula. The model is used to forecast three severe flood events in 1980, 1983 and 1995.

Result of Forecasting

The results of forecasting will be compared with the observed data. The daily maximum water level hydrographs in three area namely, the river stations, the eastern floodplain stations and the western floodplain stations is used to examine the capability of flood forecasting model. In each flood events, the results of forecasting for 7 days ahead are considered in order to prepare flood protection measures.

Table 2. Root Mean Square Error between the observed and forecasted maximum water level at various stations.

Station Names	**Root Mean Square Error (m)**		
	1980 Flood	**1983 Flood**	**1995 Flood**
River Stations			
Bangkok Port	0.15	0.14	0.23
Memorial Bridge, C4	0.23	0.10	0.18
RID Pak Kret, C22	0.18	0.15	0.08
Bang Sai	0.12	0.06	0.09
Ayutthaya, S5	0.08	0.06	0.10
Bangban, C15	0.33	0.35	-
Angthong, C7A	0.30	0.27	0.56
Lopburi, L2A	0.12	0.09	0.09
Singburi, C3	0.19	0.33	0.55
West Bank Floodplain Stations			
Bang Yai-Chimpli	0.05	0.08	0.30
Tail of Tawee Wattana	0.04	0.17	0.33
East Bank Floodplain Stations			
Chula Longkorn	0.05	0.04	0.03
Samwa	0.02	0.04	0.05
Ladprao	0.06	0.04	-

The comparison of the observed maximum water level and the forecasted result of some selected station of 1995 flood are showed in Figure 9 and Table 2. shows the root mean square error between the observed water level and the forecasted result at some selected locations in river and floodplain stations of 1980, 1983 and 1995 flood.

Figures 10 to 12 show the comparison of travel time of the observed and forecasted maximum water level from Chao Phraya Dam to different stations along the Chao Phraya River in 1980, 1983 and 1995 Flood respectively. It was found that floods in 1980 and 1995 show overestimate (faster) of travel time while that in 1983 shows underestimate (slower). It is difficult to have precise forecasting of flood travel time using maximum water level since its peak is rather flat for 1-2 weeks as shown in Figure 9.

5 Conclusions

1. The upstream discharge forecasting model could forecast discharge hydrograph at the Tail of Chao Phraya Dam (Station C13) with the error of ±10% or ±300 cms. by input the record rainfall and released discharge from reservoirs. The harmonic model could forecast the tidal level at downstream boundary (Fort Chula) with the error ±20% or ± 0.20-0.30 m. by input the record water level using 30 days record length and 4 constituents. The combined results of both could be used for flood warning and flood control for cites along the Chao Phraya River, especially Bangkok which the full capacity of the water receiving is about 2,500 m^3/s and is high effected from tide at the river mouth.

2. The AIT River Network Model could be used for flood forecasting by input the forecasted upstream and downstream boundary. The formulated model for the Chao Phraya delta area could well forecast the flood flow conditions in 1980, 1983 and 1995 using almost the same parameters except the topographic conditions and gate operations which were based on the actual conditions. The forecasting results are generally good enough. The average error of forecasting is about ±20 cm. in the river and ±15 cm. in the flood plain. However, in 1995 flood the error of forecasting is quite high when compared with the 1980 and 1983 flood and should be adjusted for further study.

3. The results of this study could be used for optimizing the effectiveness of flood control measured to protect the city from flooding and minimizing the damage as the following:

    - Forecast the upstream discharge hydrograph at the Tail of Chao Phraya Dam: To estimate peak discharge and date of occurrence and used them for operating the barrage height along the river and operating the reservoirs.

    - Forecast the downstream tidal level at Fort Chula: To estimate tidal effect and avoided the combined effect of tide and river flow from the upstream by controlling the released discharge from reservoirs and operating gates.

    - Flood forecasting: To use the results of water level forecasting for flood warning and flood control in the cites.

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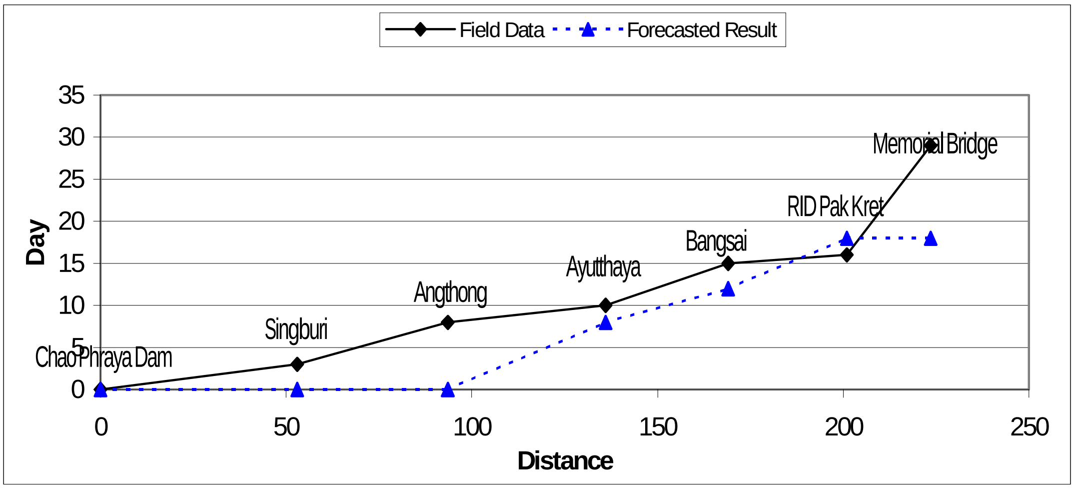

Figure 10. Comparison of Travel Time of Maximum Water Level from Chao Phraya Dam to Different Stations along River in 1980 Flood

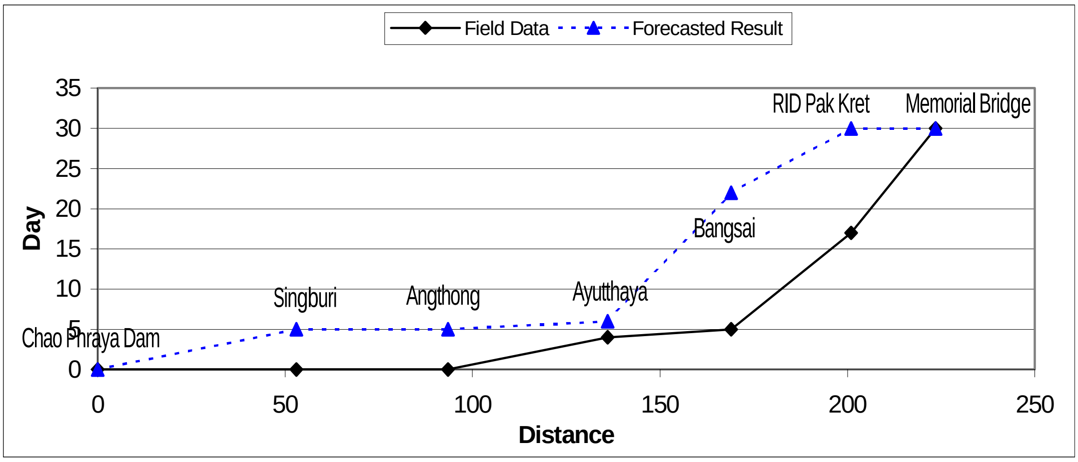

Figure 11. Comparison of Travel Time of Maximum Water Level from Chao Phraya Dam to Different Stations along River in 1983 Flood

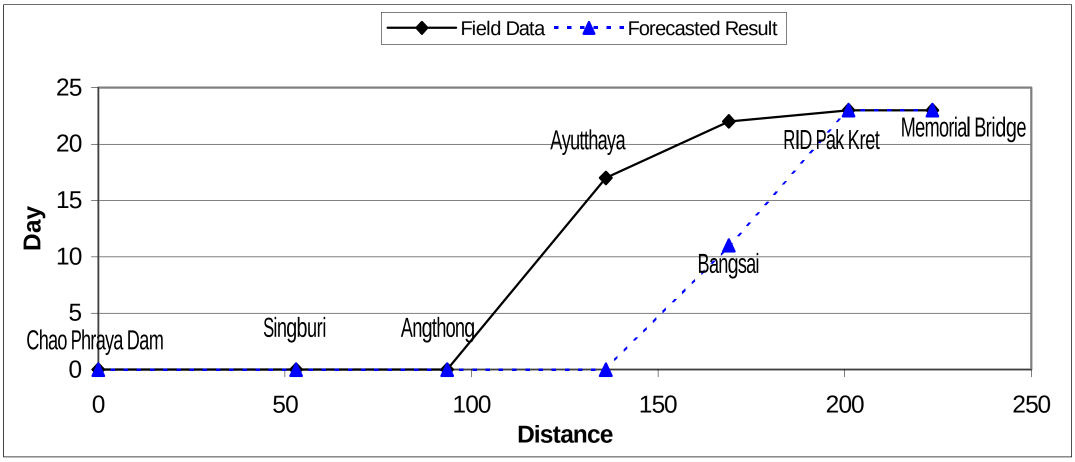

Figure 12. Comparison of Travel Time of Maximum Water Level from Chao Phraya Dam to Different Stations along River in 1995 Flood