Development of a regional hydrological model including inundation effect of the extreme flood in the Chao Phraya River Basin, Thailand

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1. Introduction

The Chao Phraya River Basin is the center of rice production and the economy. An unexpected and devastating flood lasting from July 2011 to the end of the year was caused mainly by continuous intense precipitation in the upper part of the basin that generated a huge amount of surface flow. Agricultural, residential, and industrial areas in the lower part of the basin were flooded by the overbank flow of the Chao Phraya River and its tributaries.

It is therefore critical to develop tools that are applicable to the Chao Phraya River Basin to evaluate the vulnerability of the present and future river system in water-related disasters. Specifically, after the extreme flooding in 2011, we realized that the flow routing in the channel that included in a regional hydrological model alone is not enough to reproduce phenomena of realistic river flow. This paper focused on the development of a regional hydrological model including inundation effect to improve flood movement simulation of the extreme flood event of 2011 for a further study of the future of water resources in a changing climate in the Chao Phraya River Basin. In this study, we focused on runoff generated in upper sub-basins of the CPRB as observed at the C.2 station (15°40′N and 100°06′E).

2. Methodology

Rainfall data were collected from 26 stations throughout the basin. Evapotranspiration data were obtained from reference crop evapotranspiration calculated by the Royal Irrigation Department of Thailand (RID).

We developed a regionally distributed hydrological model comprised of 1) a hydrological model based on the concept of tension water storage variation and aquifer condition proposed -- the Simplified Xinanjiang Model -- and 2) a flow routing model -- 1K-FRM -- based on kinematic wave equation and also including a dam operation model, the Bhumibol (BB) and Sirikit (SK) dams (Wichakul et al, 2013). Apart from that, in this study, we included the inundation effect to improve a discharge prediction at the C.2 station.

Inundation Model

For the purpose of including the effect of inundation in the routing model, we adopt the concept of the diffusive tank model by considering the drainage discrepancy between the main channel and floodplain ponds (Moussa and Bocquillon 2009). Once the water height of the main channel exceeds bank height, water is drained into the adjacent floodplain, and then when the water height of floodplain ponds exceeds bank height and the water level in the main channel, water is drained back into the main channel. The cross-section of the main channel and floodplain is illustrated in Figure 1. Exchange lateral overbank flow between the channel and floodplain area is modeled using a broad crested weir equation for a clear overflow weir, expressed as:

\[ q_{l_l} = C_i(\Delta h)\sqrt{2g(\Delta h)} \]  (1)

where \( q_{l_l} \) is lateral overbank flow per unit width solved by this inundation model, \( C_i \) (i= b, c, … and f) represents a constant value, \( \Delta h \) is the difference in head or water depth exceeding the bank, \( L \) is the channel length, and \( g \) is gravity (9.81 m/s²). \( C_i \) and \( \Delta h \) depend...
Figure. 1 Sketch of a river channel and a floodplain pond defined for each computational grid. $Z_b$ is bank height, $B$ is river width, $h_r$ is water height in the river, $S_i$ is storage volume of the floodplain pond, $h_p$ is water height in the floodplain pond, $W$ is floodplain width, $Elev_p$ is floodplain pond elevation, and $A_p$ is surface area of the floodplain pond.

on flow characteristics and shape. According to the value of $\Delta h$ indicating the lateral flow direction, the lateral inflow can be either positive or negative.

To determine the lateral flow of the recession process back to the channel by infiltration, we identified lateral flow $q_{ll}$ by modifying a concept of Darcy’s law as

$$q_{ll} = C_g (\Delta h)$$

where $C_g$ is the constant value of underground flow in m/s.

There were ten model parameters, i.e., floodplain width $W$, floodplain elevation $Elev_p$, bank height $Z_b$, evaporation loss $Loss$, rise stage constants $C_b$ and $C_r$, equilibrium stage constant $C_d$, recession stage constants $C_e$ and $C_f$, and underground flow constant $C_g$.

3. Results and discussion

Final results best fitting observed and simulated hydrographs are shown in Figures.2, 3 and 4 for the BB and SK dams and the C.2 station, respectively. Because the BB and SK dams are located in the mountainous upper part of the CPRB, simulated flow was not affected by the inundation effect. It is obvious that simulated inflow without considering the inundation effect was similar to the simulated inflow considering the inundation effect for both locations (Figures.2 and 3). When data on simulated inflow including the inundation effect and observed inflow is analyzed, Nash-Sutcliffe efficiency (NSE) was 0.60 and 0.68, coefficient of determination ($R^2$) was 0.61 and 0.73, and root mean square error (RMSE) was 320 m$^3$/s and 275 m$^3$/s at the BB and SK dams, respectively.

4. Reference


Keywords: Flood, regional hydrological model, inundation model, Chao Phraya River Basin.