Flood Warning System over Spatially Predicted Flood Spreading Area

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Abstract—**Flooding has become a catastrophic disaster recently in many cities. Flood model based the satellite images, fuzzy logic evaluation, and water capacity sensors in river were studied while GIS has been applied to various applications. We proposed a flood warning system based on our proposed hydrological river flow model and spatially predicted flood spreading model over Google map. We ran our predicted river flow model over water gates along north section of Chao Phraya River, Thailand, and compared with the actual data collected by Royal Irrigation Department. The comparison shows that the accuracy of our hydrological river flow model is over 90% during flood peak time of raining season.**

Index Terms—**flood warning system, hydrological river flow model, spatial flood spreading model, and earth science data**

I. Introduction

While water is cycling in atmosphere as its nature, human have changed the landscape on the ground where the water mostly remains. Land and water in-land plays the important role of river flood. Hydrological cycle describes the continuous movement of water on the surface, under the ground and above the surface of the earth. The in-land hydrological cycle composes of rain, freshwater storage, stream-flow, surface runoff, ground-water discharge, and evaporation.

Hydrological cycle also includes condensing of water storage in atmosphere before raining into the ground, freezing of water storage in form of ice and snow before melting as snowmelt runoff to streams and oceans, and assembling of water storage in oceans before vaporizing back to atmosphere. Last two parts of cycle are not the major impacts of the inland flooding model. However, they would be major impacts for coastal flood model considering greenhouse effect and integrated flood model considering all possibility of water impact.

The water storage in the atmosphere of hydrological model is the major impact of water flow in the flood model. It creates three major sources of water flow into a single position of the river.

River flows from one position to another. It is the direct source of flood model computation due to the flow velocity. Satellite Synthetic Aperture Radar, SAR, image analysis was proposed by [1] in order to map the images in the spatiotemporal characteristics for flooding from river flow or as remote sensing for hydraulics flood model prediction [2]. SAR-based flood mapping has been extended in different approaches such as a near-real time flood detection called TerraSAR-X services [3] and an algorithm to clarify unclear SAR images [4] and camera images [5] from severe weather.

Streams of water and canals gather into river. Original source of water streams and canal are waterfall, creek, and lake. Ref. [6] developed a risk index system for potential flash flood disaster risk assessment by applying fuzzy synthetic evaluation and spatial analysis to the river drainage networks with other earth science data such as soil moisture, vegetation, height deviation, and rainfall.

Rain drops as a diverse type of sources of water. It should be included in the river model. Three locations of rain drop that increases the water level of the river are dropping into the river, dropping into the wet ground and dropping into the dry ground as shown in Fig. 1. Rain drop into the river increase the water level directly. Rain drop into the wet ground becomes the surface runoff which is more impact to flooding than rain drop into the river due to the larger area of land comparing with the area of river. Rain drop into the dry ground is much less impact to flooding because it remains into the ground for days before it becomes ground-water discharge. Ref. [7] considered the rainfall and discharged water to improve the flood monitoring while [8] considered rainfall runoff to obtain a storm flood model for urban rain pipe network.

In order to ensure the safety of citizen of communities, we need to have flood early warning systems for public [9]. The warning system must be bureaucracy collaborative among emergency agencies [10] for flood analysis with a real-time crisis feeding by citizens via social media [11] so that the evacuation can be handle in time [12].

Therefore, the section 2 of this paper demonstrates the flood model into two parts; river flood model and flood spreading model while the necessary gathering data from various data sources are shown in section 3. We propose a flood warning system with three subsystem according to our models; flood monitoring system, flood analysis, and community flood warning system in section 4. We

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tested our river flood model with data from Royal Irrigation Department of Thailand. The results are shown in section 5 while conclusion and discussion are in section 6.

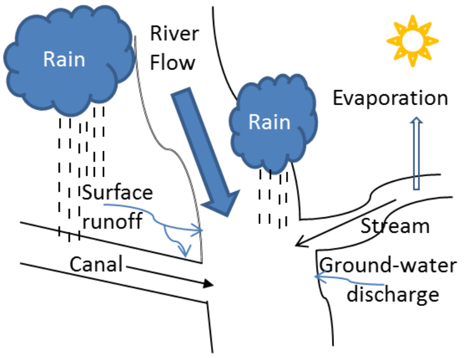

Figure 1. Water flow into a single position of the river

II. Flood Model

Flood model composes of four major factors; river flow model, water gathering model, rain model and flood spreading model. River flow model and flood spreading model are two major factors. Water gathering could be considered as incremental of river flow model while rain is considered as the secondary water level for flood model. According to the limitation of collection from data sources, we consider two major factors in this paper.

A. River Flow Model

River flow model is used to hydraulically determine the amount of time when a capacity of water flow from one location of river to another. The river flow model can be computed as the following:

$$V = Q / A \tag{1}$$

where Q is the capacity or flow rate of water stream in m^3/sec from one water station to another station, V is the velocity of water stream in m/sec, and A is cross-sectional area of river in m^2.

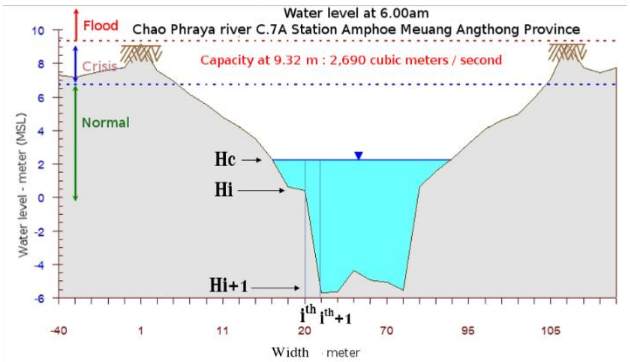

Figure 2. Cross-sectional area at a gate station [13]

However, the cross-sectional area is irregular polygon as an example in Fig. 2. A is divided into many small trapezoids of water above the bottom of the river. Thus, A is the summation of those water trapezoids inside the polygon together.

$$A = \sum_{i=1}^{n} \left([(H_c - H_i) + (H_c - H_{i+1})] \times (x_{i+1} - x_i) / 2\right) \tag{2}$$

where H_c is the current height of water level, H_i is the height of water level at width i^{th}, x_i is the width at position i^{th}, and n is the width of river.

$$T = S / V \tag{3}$$

where T is the amount of time in seconds of water flow from one water station to another station, and S is the distance in meters between two stations.

Royal Irrigation Department provides the capacity of water and height of water each day of each water station of the river. It also provides the cross-sectional illustration of each station as an example in Fig. 2. We can use it to compute its cross-sectional area.

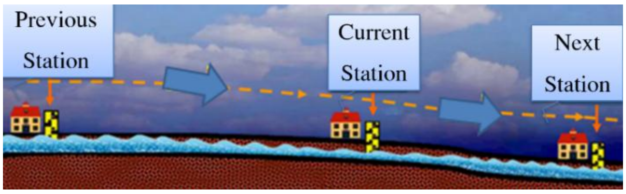

Figure 3. Water capacity in a station

The water capacity in a station must consider both in-coming direction from its previous station and out-going direction to its next station as shown in Fig. 3.

$$Q_{c,\,t+1} = Q_{c,\,t} - Q_{o,\,t+1} + Q_{i,\,t+1} \tag{4}$$

where $Q_{c,\,t}$ is the water capacity of current station at time t, $Q_{o,\,t+1}$ is the water capacity out-going to the next station at time t+1, and $Q_{i,\,t+1}$ is the water capacity in-coming from the previous station at time t+1. This is due to the given water capacity from our data source are specified at each station.

However, the velocity between two adjacent stations is different, due to the differences of cross-section areas of river water at each station. Therefore, the $Q_{o,\,t+1}$ and $Q_{i,\,t+1}$ are deviated by their cross-sectional area. $Q_{o,\,t+1}$ is deviated by the cross-sectional area from current station to the next station, while $Q_{i,\,t+1}$ is deviated from the previous station to the current station.

B. Flood Spreading Model

After river flow model determines the water capacity of a station, flood spreading model determines the distance of water flood into both sides of the river over spatial data. Water capacity will overflow the river bank if the water level is higher than the maximum height of river at the station. Another word, the current water capacity, Q, is more than the maximum capacity of the station.

$$Q > A_{Hmax} \tag{5}$$

The total water capacity is divided into three parts:

Q1 is the capacity of water under the maximum height of the station at the river bank.

Q2 is the capacity of water above the maximum height of the station on top of the river.

Q3 is the capacity of water spreading into land on both sides, Q3' and Q3", of river where Q3 = Q3' + Q3".

Therefore the total water capacity, Q, is Q1 + Q2 + Q3' + Q3". Flood water capacity is Q2 + Q3' + Q3" as shown in Fig. 4.

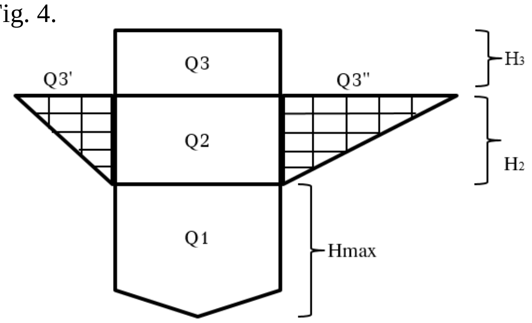

Figure 4. Cross-sectional area of flood spreading into land

However, the elevation of land does not slope smoothly as shown in Fig. 4. Therefore, Q3' and Q3" are divided into grids over the geographic plane, so that we can estimate the water capacity of Q3' and Q3" from summation of water capacity among cubic grids and triangular cubic grids.

With hydraulically flow of water, flood spreading area in land must be continuous along cubical grids. Q3' and Q3" must accumulate only the continuous areas starting from the river bank to the land at the elevation of H_2. However, due to unleveled terrain, a valley below H_2 but surrounded by mountain that is higher than H_2 will not be flooded as shown in Fig. 5.

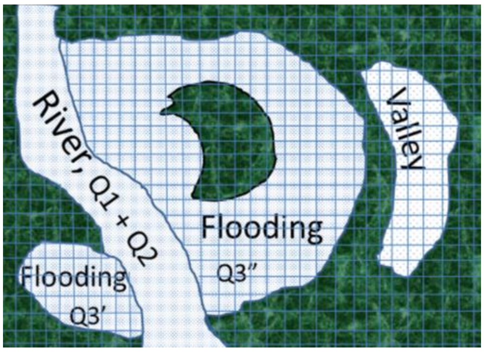

Figure 5. Valley surrounding by mountain without flood

III. Data Sources

According to the three sources of water, data sources of river model can be collected from public service agencies, geographic knowledge, and other predictive agencies.

i) Water levels and flows of water are collected from government agencies that daily measure the water height of each water stream such as river and canal. Royal Irrigation Department has provided water capacity among water gates along various major rivers of Thailand in different views. They collect water capacity from each gate of Chao Phraya River daily at 6 am and publish to public over the internet. We can download the water capacity each day via their water index of Chao Phraya River [13]. They also summarize the water capacity with the weather forecast in a daily report.

ii) Map becomes the major role of the location-based service, LBS, system. In order to notify the emergency situation with any media [14], Google map provides the necessary information such as geographical locations, geography, and land elevation.

iii) Earth Science Data is the rudimentary environment fact that is necessary for the disaster control. It is collected by satellites around the world by various public organizations such as NASA [15], and local organization such as Thai Meteorological Department [16]. The facts for flood model include temperature, rainfall, predicted weather and land elevation, while further knowledge can be discovery from it [17].

Hydro and Agro Informatics Institute is also a Thai public service organization that integrates the water information such as storm tracking, weather, rainfall, and water capacity from various sources in order to support the agriculture community. They also provide the past and current water capacities of each water gate [18].

IV. Flood Warning System

We built a flood warning system from our model. We collect water capacity among water gates along north section of Chao Phraya River. We feed them into our river model. Our model estimates the water level for the next day. Then, we pass the water level of the next day into our flood spreading model. If the water floods over the river bank, we overlay the flooding water over the map. Then, people who live in the flooding area will receive a warning message.

Therefore, we divided the flood warning system in three subsystems; flood monitoring system, flooding analysis and community flood warning system.

A. Flood Monitoring System, FMS

In order to predict the flood at each area, our Flood Monitoring System, FMS, needs water capacity from previous water gates flowing water to the measured water gate. However it does not include the gates beyond the dam due to its unpredicted releasing water for the purpose of water reservation. Royal Irrigation Department has provided water capacity among water gates along various major rivers of Thailand. We download the water capacity each day via their water index of Chao Phraya River [13].

We obtain the cross-sectional area of each water gate from the Royal Irrigation Department into our model so that FMS can determine the amount time and capacity of the water that will flow from one gate down to the next gate.

Since flowing time from one station to another is hydrological varied, the time of water flow could be less or more than one day between two stations. We calibrate the water capacity among sequence of stations.

B. Flooding Analysis, FA

After FMS determines the water capacity, Flood Analysis, FA, will analyze the water capacity with the water volume of surrounding area over the spatial data. We pre-quantified water volume of each square of

100x100 meters for every height of 10 centimeters. We plot them in grids according to our flood spreading model and marked them over the Google map.

Depending on the water capacity at each gate, FA overlays water over flood area on Google map. Administrator can manually analyze the flood area by identifying the water capacity. For examples, FA shows the flood area as shown in Fig. 6 where the water capacities are 100, 500, and 1,000 million m^3.

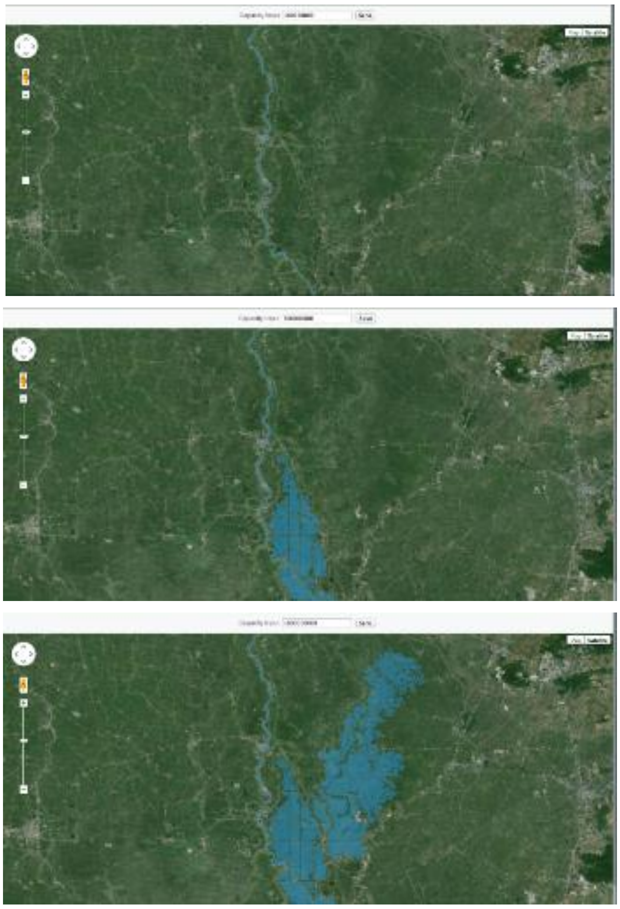

Figure 6. Flood analysis of different water capacities

C. *Community Flood Warning System, CFWS*

Our flooding system allows user to identify their geographical location over the Google map via Community Flood Warning System, CFWS. Their latitude and longitude are saved in a database. User geographical location will be labeled, after our FA analyzes the current water capacity for the flooding area of the next day. CFWS will label the user locations where they overlap with the flooding area as shown in Fig. 7. CFWS will also send a message to the user so that the user will have time to prepare themselves before flooding.

Due to a long period of flooding, CFWS will send only two messages to users for each flood event. The first message is the notification on the day before the flood happening to their location. The second message notifies the users the day before the flood situation resumes no-flood at their location. This is to reduce the unnecessary messages.

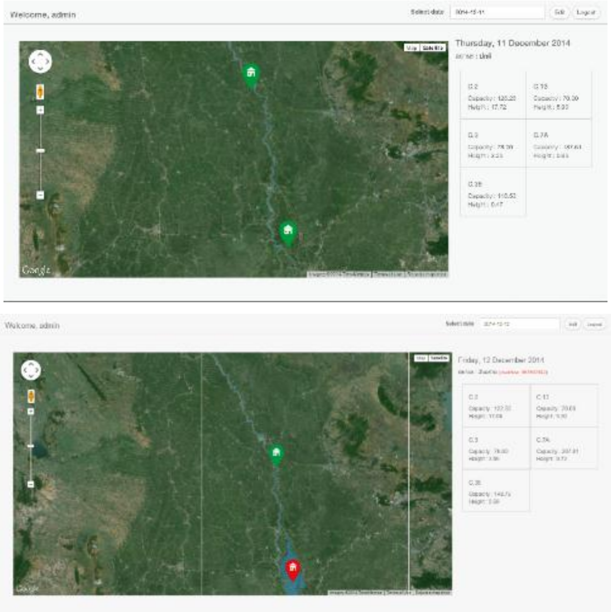

Figure 7. User location labeled before and after flooded

V. TESTING AND RESULTS

We ran our model in comparison with the actual data of water capacity from the Royal Irrigation Department of Thailand that collects the water capacity daily at 6 am at each river gate station. We tested our model with the water capacity at gate C35 of Chao Phraya River which is the central river of Thailand. According to our flood spreading model, we also need the water capacity from prior gates before C35 in order to predict water of gate C35, especially when water flow is fast. Water capacity from gates C2, C13, C3, and C7A were used to predict the water capacity of gate C35 which is below C7A as shown in Fig. 8.

Thailand separates the weather season into three seasons; summer, rainy, and winter seasons. We divided the tests according to Thai seasons. During the summer, water level of Chao Phraya River is quite low as shown in Fig. 9. The rainy season starts around May and June. Chao Phraya River starts to accumulate the water during this time. Due to the dry water during summer, the water at the beginning of rainy season will remain at the part of rivers above the Chao Phraya River until the middle of rainy season around July. The water from the rivers above the Chao Phraya River will be released passing through dams and water gates into Chao Phraya River.

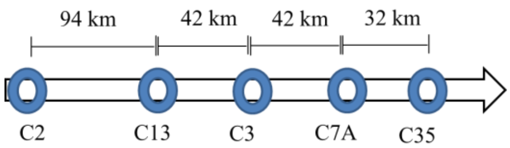

Figure 8. Water gates along north section of Chao Phraya River [14]

The flood will start in some places at the beginning of Chao Phraya River. Area of the tested water gate, C35, will start flooding around September as shown in the rainy season of Fig. 9. Water around gate C35 will resume in the normal level around the end of November which is the beginning of winter season.

For each season in Fig. 9, we compared the water capacity between data collected from the Royal Irrigation Department of Thailand and the results our predicted model. The charts show us that the results of our predicted model are close together with the actual data from the Royal Irrigation Department. We find the average of water capacity each monthly in Table I. The accuracy average of the overall months among twelve months is 78.77%.

The accuracy among months between August and November of the flood period is 90.77%. The precision of the predicted model during the flood period is better than of the dry water period.

TABLE I. ACCURACY OF THE PREDICTED MODEL

Month	Average of Predicted Water Capacity	Average of Actual Water Capacity	Accuracy (%)
Nov	328.01	287.82	86.04%
Dec	50.51	57.60	87.69%
Jan	56.06	56.29	99.58%
Feb	50.08	110.15	45.47%
Mar	42.71	40.59	94.79%
Apr	45.11	61.70	73.11%
May	45.76	76.88	59.53%
June	62.19	118.40	52.52%
July	50.86	73.17	69.51%
Aug	196.20	183.58	93.12%
Sep	716.38	631.36	86.53%
Oct	989.75	964.40	97.37%
Average			78.77%

VI. CONCLUSION AND DISCUSSIONS

Flood is a major disaster that causes loss of lives and assets. Longer time for evacuation, lesser loss for societies. Modern flood warning system must combine flood monitoring, and flood spreading analysis with warning messages directly to citizens in the flood area.

We proposed a hydraulically river flow model and spatially flood spreading model. We applied them to our prototype of flood warning system on flood monitoring system and flood analysis respectively while community flood warning system was implemented. We also tested our river flow model with the actual data collected by Royal Irrigation Department of Thailand.

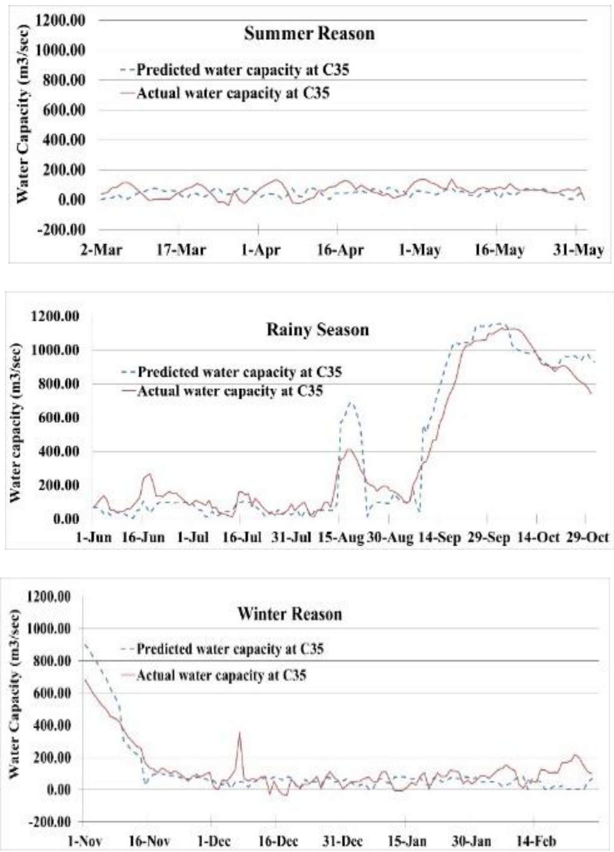

Figure 9. Water capacity comparison between predicted model and actual water collected by Royal Irrigation Department

River flood model should include the river drainage model and recent rainfall in order to increase the accuracy of the flood monitoring system. While global warming has increased the amount of rainfall, the weather forecast on rainfall should be considered for the flood monitoring system and the flood spreading in the flood analysis.

Also the variety of communication over integrated media such as SMS, email, social media, and even the automatic voice recording message over the public telephone network would provide directly and quickly warning to people in the community.

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