JICA/FRICS FLOOD FORECASTING SYSTEM OF THE CHAO PHRAYA RIVER BASIN

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Abstract

On the request of the Thai government (May 2012), JICA contracted with FRICS for developing a flood forecasting system of the Chao Phraya River, which is a big issue after the 2011 flood in the river. A prototype was developed in September 2012, and information was provided to the registered monitors during the 2012 flood season. Through discussions with the related persons of the Thai government for practical application, necessary improvements were added, and, by January 2013, it became a system that could be made open to the general public widely.

Water-level/flow-rate and inundation areas are forecast, with RRI model simulation based on the observed data (rainfall, water-level, and flow-rate) and meteorological forecast data. Highly accurate inundation area is forecast by using detailed geographic data obtained by LiDAR data, and by calibrating with satellite images of inundation situations.

This paper presents the features of JICA/FRICS flood forecasting system of the Chao Phraya River Basin along with improvement possibilities of the system in the future.

1. BACKGROUND

Thailand experienced an exceptional flood when record breaking rains hit the country one after another between June and October 2011. It brought an unprecedented flood inundation in the Chao Phraya River Basin, and caused loss and damage to wide areas of the country. A project of JICA (Japan International Cooperation Agency) for flood management of the Chao Phraya River was formulated in late December 2011 to early January 2012. It was a holistic project which consisted of the following components,

(i) Component 1: Comprehensive flood management plan considering the effect of the climate change and land development

- Subcomponent 1-1: Preparation of a detailed map
- Subcomponent 1-2: Formulation and evaluation of the Master Plan for Water Resources Management prepared by Strategic Committee for Water Resources Management (SCWRM)

(ii) Component 2: Outline design for Japanese grant aid for disaster prevention and reconstruction.

The progress of the study conducted under the project showed the necessity of the improvement of flood management and flood forecasting system. The Royal Irrigation Department (RID), the Department of Water Resources (DWR), the National Economic and Social Development Board (NESDB), and JICA thus agreed to implement a technical cooperation additionally on the improvement of flood management system. Thus Component 3, Improvement of a Flood Management System and its operation capacity for the Chao Phraya River Basin, commenced in May 2012. JICA contracted with FRICS for conducting a study for Component 3 in July 2012.

The activities of the Component 3 included establishment of flood data analysis/flood forecasting system for the flood season of 2012. This paper describes the development and features of the system.

2. THE 2011 FLOOD

In 2011, the dyke of the Chao Phraya River broke at eight places over the maximum length of 1,300 m, and flood water ran out of the river for the duration of two weeks to one month. Inundation water traveled from the levee break point near the Chao Phraya Dam at Chainat to Ayutthaya in two weeks. Therefore, forecasting the movement of floodwater would have been possible, if proper inundation calculation model had been prepared. Such forecast information on inundation must have been valuable for decision making on evacuation. Inundation began around 23 August near Nakhon Sawan. By end October the flood water in the east side of the Chao Phraya River reached close to the sea. It took two more weeks for the flood water in the west side of the river to reach close to the sea. The alert situation lasted more than two months.

During 2011 flood time, the following web sites were available for people to know the flood situation[1)].

(i) The picture from radars updated hourly for the rain over the whole country in the past 24 hours (data of Thai Meteorological Department (TMD) collected by Hydro and Agro Informatics Institute (HAII), and the Naval Research Lab USA);

(ii) Flood monitoring website (Geo-Informatics and Space Technology Development Agency (GISTDA));

(iii) Water level of main rivers and main dams in the country, discharge into the Gulf of Thailand (RID, HAII, and Department of Drainage and Sewerage (DDS) of Bangkok Metropolitan Administration (BMA));

(iv) Water level on main roads and canals in Bangkok (DDS);

(v) Sea water level forecast at the river mouth of the Chao Phraya River (Samut Prakarn Provincial Government) and sea water level report (Hydrographic Department of Royal Thai Navy, HAII); and

(vi) Three days rainfall forecast image (HAII cooperated by TMD).

It can be pointed out that, during the 2011 flood time, while the forecast on rainfall (upper most) and on the sea water level (lower most) were made public over internet by government agencies, forecast on water level of rivers, discharge, or inundation situation (middle part) was not available. Short-term forecast of the direction of floodwater was most wanted after the capacity of a river section was exceeded. RID had hydrological models to calculate and forecast river and inundation situations of the Chao Phraya River. However, the operational use of such calculations was not possible for disaster preventive actions by the decision makers, government organizations, and the general public, probably because there was not a proper mechanism of systematically utilizing the outcome of such calculations.

Private and academic sectors and volunteers had important role to provide real-time information via TV broadcasting, websites, social networks, and Short Message Service (SMS). Because the government's operation was limited, relevant private sector and academics took a part of roles by providing flood monitoring data, flood maps and flood forecasting analysis to warn people in advance in order to prevent damage, and prepare evacuation in case of serious situation, along with providing flood protecting and relief methods. People also shared their information through social networks (Facebook, Twitter, etc.) and uploading their video record on YouTube to report the real-time situation. They, however, were not necessarily responsible for the quality/accuracy of the information

During and after the flood in 2011, there were outcries for the government to provide more accurate flood information; some claimed that inaccurate and even contradictory information was disseminated by different government agencies[2)]. People wanted information on the broader situation, both in space and time, rather than knowing only the present level of flood water in front of them or nearby.

If there were forecast information, following damage alleviation action could have been taken;

(i) Preparation for inundation (evacuation, sandbagging, moving cars);

(ii) Cropping (even prematurely) before damaged; and

(iii) Evacuation of products.

Flood defense organizations would be able to undertake the following;

(i) Effective countermeasures by emergency sandbagging and pumping;

(ii) Effective operation of water gates and dams; and

(iii) Damage estimate of a levee break (in some cases selection of a break point).

3. FLOOD FORECASTING SYSTEM DEVELOPMENT

A prototype of flood forecasting system (referred to as “the Flood Risk Information System”) was developed within two months after commencement of the study in July 2012.

3.1 Approaches From Information Needs

The system aimed at indicating short-term risks of inundation over the whole area of the Chao Phraya River Basin by collecting various observation data of different organizations and introducing them into analysis models suited for the characteristics of the river. The information sent by the system should not be “sender-oriented”, in which the administrative side decides the contents based on the availability and capacity, but rather be “receiver-oriented” approached from the necessity of actions/judgment of users (various individuals and groups). Considering the above, a series of questions were examined, starting from (i) “what is their actions necessary for damage alleviation?”; considering (ii) “what kind of information they require for that?”; then studying (iii) “what kind of processing or simulation is required?” to get the information properly and constructing analysis system; and finally decide input/output data based on (iv) “what are the required data for that?”.

3.2 Information To Be Provided

Based on the experience in the 2011 flood, the Thai Government was improving information system on present status of water level, flow rate and inundation area[3)4)5)]. To work collectively with the present status information for alleviating damages in Thailand, the system was designed to forecast water level, flow rate and inundation area. Features were,

(i) Forecast water level and flow rate at major points of the Chao Phraya River of 1-7 day(s) after today, and their observed values of past 7 days;

(ii) Forecast inundation area of 1-7 day(s) after today; and

(iii) Simple website structure requiring no manual to use the system.

3.3 Characteristics of The Chao Phraya River

Forecasting flow rate of a river requires consideration of the characteristics of the river. Figure 1 shows the flow rate at Nakhon Sawan and the daily average rainfall over the upstream basin during the 2011 flood season (June - November). Small circles in the figure are observed flow rate values (daily): The graph indicates the flood duration of a few months.

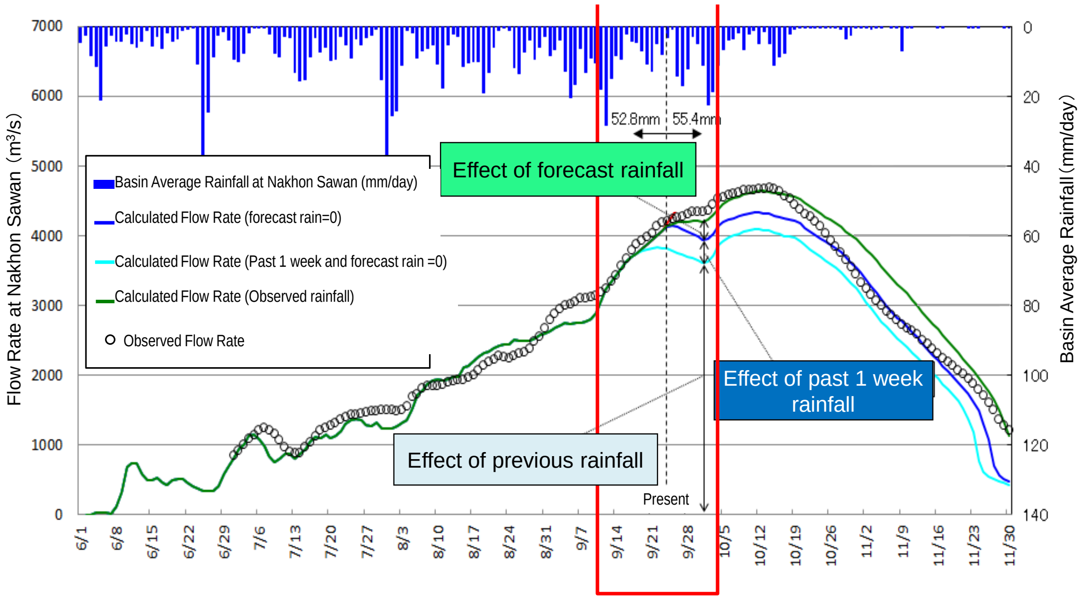

Fig. 1 Flow Rate at Nakhon Sawan and Daily Average Rainfall (2011 Flood Season)

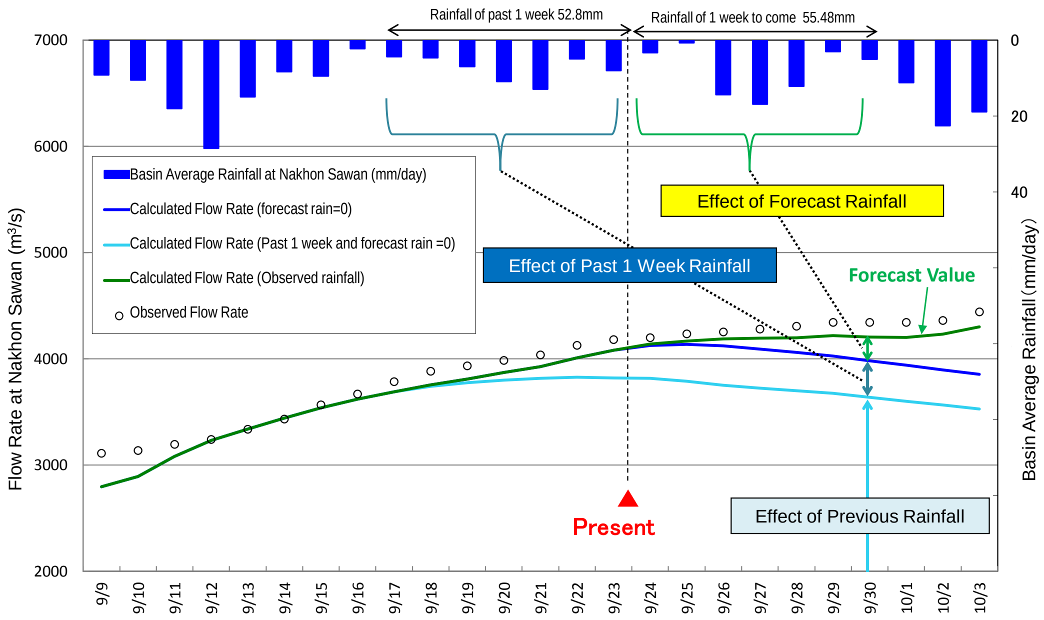

Fig. 2 Flow Rate at Nakhon Sawan and Daily Average Rainfall (9 September - 3 October, 2011)

A part of Figure 1 around 23 September, 2011 is enlarged to get Figure 2. When the flow rate of 30 September (1 week later) is to be forecast on 23 September, the value could be divided into the following three components; (i) the effect of rainfall between 23 and 29 September (forecast rainfall), (ii) the effect of rainfall between 16 and 22 September (observed rainfall), and (iii) the effect of rainfall before 16 September (observed upstream flow rate). The magnitude of three components has the general relationships of (i) >< (ii) < (iii) in the Chao Phraya River (at Nakhon Sawan), with the long-term discharge from large upstream basin dominating the flow rate at Nakhon Sawan. On the other hand, from the viewpoint of the certainty, the magnitude of certainty could be (i) forecast rainfall with meteorological analysis < (ii) forecast flow rate based on observed rainfall < (iii) forecast flow rate from observed upstream flow rate. This would indicate that relatively stable flow rate forecasting would be possible in the Chao Phraya River.

The hydrograph at Nakhon Sawan consists of a big wave with a length of 2 - 6 months and small waves that relatively quickly rise in a few days. The latter corresponds to rainfall concentrated near Nakhon Sawan. For risk management, it would be particularly important to detect the quick rise in water level properly, and to deliver/share the information with users.

3.4 Uncertainty of Natural Disaster Information

Forecast information regarding natural disasters involves uncertainties arising from uncertainties of natural phenomena, as well as insufficient simulation techniques. While simulation uncertainties may decrease through technology development, the uncertainty originally accompanied by natural phenomena would be difficult to decrease technically.

Uncertainty involved in simulation output is a big issue in prediction, forecast, and warning based on model calculation of any phenomena and in any parts of the world. In Japan, many trials and errors were repeated experiencing so called “boy who cried wolf” issues before implementing flood forecasting and warning, debris flow disaster warning information, earthquake early warning, and volcanic eruption caution information. Today in Japan, while the necessity of making efforts for increasing the accuracy of information is a matter of course, we seldom hear an opinion that information should not be released or used unless a forecast value completely coincide with an observed value. The majority agrees to use the information understanding the accuracy of forecast information as it is, and bearing the nature of forecasting in mind. As structural measures alone cannot deal with all the disasters, for reducing damages as much as possible, non-structural measures of information utilization including forecasting is particularly important.

4. FLOOD RISK INFORMATION SYSTEM

A prototype of Flood Risk Information System was developed in two months (July-August, 2012). A prototype, by definition, is “a rudimentary working model built for demonstration purposes and as part of the development process”. Therefore limited functions for providing information given in Table 1 were programmed.

Table 1 Information Provided by the Flood Risk Information System (Prototype)

<table>
<tr><th>Time</th><th>Information</th><th>Expressed in</th><th>Note</th></tr>
<tr><td rowspan="2">Past</td><td>Flow Rate</td><td rowspan="2">Graph</td><td rowspan="5">RID data</td></tr>
<tr><td>Water Level</td></tr>
<tr><td rowspan="3">Present</td><td rowspan="2">Flow Rate</td><td>Pop-up figure over a schematic diagram</td></tr>
<tr><td rowspan="2">Graph</td></tr>
<tr><td>Water Level</td></tr>
<tr><td rowspan="3">Forecast</td><td>Flow Rate</td><td rowspan="2">Graph</td><td rowspan="2">Max. and Min. expressed with two lines</td></tr>
<tr><td>Water Level</td></tr>
<tr><td>Inundation Area</td><td>Color-coded Map</td><td>“High Risk” area and “Risk” area expressed with the difference of colors</td></tr>
</table>

The system was opened to registered monitors in September 2012. Even after the opening of the system to the monitors, the prototype system was continuously improved including;

(i) Error corrections in the name of stations and thresholds of caution/warning levels;

(ii) Inundation extent calibration procedure using satellite images; and

(iii) Detailed ground level data incorporation.

4.1 Input Data

Considering the characteristics of hydrograph at Nakhon Sawan, runoff forecast was to be carried out daily: This required daily data of hydrological observation. The following input data were used,

(i) Observed daily rainfall on the ground;

(ii) Observed water level (at 6 am) of major points of the rivers;

(iii) Daily average dam discharge (Bhumibol, Sirikit, and Pasak dams).

In the Chao Phraya River, it normally takes long time for rainfall to run into the river. However, past events indicate the possibilities of discharge relatively rapidly increases being influenced by short-term rainfall events. Therefore, meteorological rainfall forecast was to be included in the input data of the system. Quantitative Precipitation Estimate (QPE) (global coverage with 0.5 degree grid) based on the meteorological data internationally exchanged under the framework of the World Meteorological

Organization (WMO) was used. In the Chao Phraya River Basin 60 grid points of QPE exist. The uncertainty in daily QPE was reflected in the output of the system by providing it with the maximum values and minimum values of forecast rainfall.

4.2 Forecasting Model

For managing flood risk in the Chao Phraya River using the flood forecasting model, inundation events should be properly reproduced in real-time, based on detailed topographical data. Since the Chao Phraya River has a huge flood plain, the model should reproduce the inundation events efficiently and accurately. Considering the above, Rainfall-Runoff-Inundation Model (RRI Model) developed by the ICHARM of the Public Works Research Institute, Japan (PWRI) was selected. The RRI model was considered suitable for analyzing the Chao Phraya River basin, as it analyzed runoff into the river and inundation in the flood plain as a whole, dividing the basin into meshes.

The RRI model consists of two-dimensional runoff analysis (runoff and inundation analyzed simultaneously) model, and one-dimensional river routing model. Both models use the momentum equation with diffusion wave approximation as a basic equation. To express the rainfall runoff process properly, vertical and lateral infiltration flows are considered underground. Exchange of water between runoff model and routing model is calculated by an overflow formula[6)].

The accuracy of the RRI model was validated based on 2011 and 2006 flood data. As boundary conditions on the model, dam discharge record, observed tidal level, barrage discharge recorded (May-November, 2006, and June-December, 2012) were collected and reflected in the model. The parameters of the model were calibrated for flow rate and water level at main points including Nakhon Sawan, Chainat, and Ayutthaya, and downstream inundation situations.

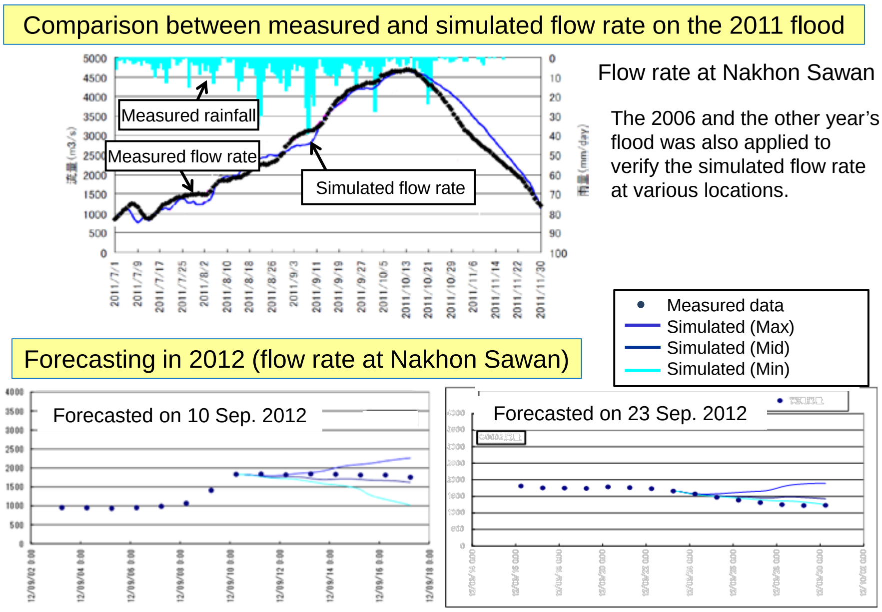

Fig. 3 Forecasting Accuracy (Flow Rate at Nakhon Sawan)

In order to reflect the actual flooding situation, GISTDA satellite images indicating inundation area were applied to the simulation by the RRI model as the initial condition. Satellite images were converted to numerical grid data for determining inundation area. Because the satellite images did not give information on inundation depth, the depth estimated from latest simulation on the same day were used. If results showed that there was disagreement between satellite images and simulated inundation area, approximate water depth values were given to the grid. By linking satellite observation data with inundation simulation model, i) inundation depth information was seemingly added to the satellite image (Fig. 4); and ii) forecast information was added to the today's satellite image.

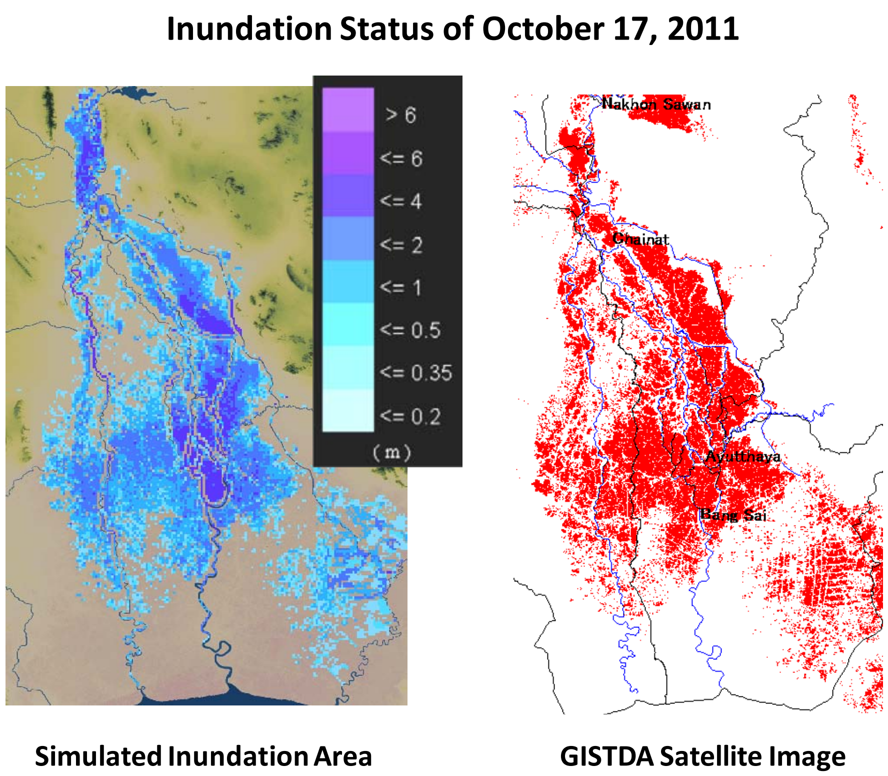

Fig. 4 Satellite Image with Inundation Depth Information?

Forecast inundation area was calculated for 1-7 days, and categorized into two risk areas; "High Risk" area, and "Risk" area. "High Risk" area was the area with the possibility of inundation of more than 1.0 m. "Risk" area was the area with the possibility of inundation of between 0.2 m and 1.0 m.

4.3 Information Display System

An eye-catching, easy-to-use website of the Flood Risk Information system was constructed. The top page had two big buttons only; one for the Schematic Diagram display of flow rate and water level, and the other for Flood Area display. The system provided the forecast status of events; flow rate, water level, and inundation extent together with accurate present situation both in English and Thai.

The Schematic Diagram display (forecast flow rate and water level) had three layers of screens as indicated below.

(i) Layer 1 - Plane view and Bird's-eye view of the Chao Phraya River containing,

- Symbol marks representing stations and dams;
- Symbol of station was color-coded for normal (green), caution (yellow), and warning (red), indicated the magnitude of water level on the current day; and
- Information update time and guide chart indicating displayed screen.

(ii) Layer 2 - Pop-up display of flow rate at a station selected.

(iii) Layer 3 - Additional screen of graphs of forecast flow rate and water level at the station.

Comparison of forecast values with caution level and warning level would help understanding the timing of flooding. The graphs showed,

- Warning level indicating the magnitude above which flooding from the river may occur;
- Caution level indicating the magnitude on which attention was required;
- Center was present (updated) time, left was past and right was future; and
- Two lines of forecast indicating, one (pink) for maximum (with maximum expected rainfall), and the other (green) for minimum (with minimum expected rainfall)

The Flood Area display showed forecast inundation (of 20 cm or more) extent with colored mesh overwrapped on Google Map. Forecast inundation area of 1-day through 7-day can be selected with buttons on the top. The screen contained,

- "High Risk" area (dark-blue), and "Risk" area (light-blue);
- Switching between "All Watershed" and "Downstream Region";
- Scale up/down button (on iPad touch screen operation is possible as well); and
- Information update time and guide chart indicating displayed screen.

Checking daily changes in forecast "High Risk" and "Risk" areas helped understanding the inundation possibility and its timing at the locations of interest.

4.4 System Pages

The structure of Flood Risk Information System is schematically shown blow.

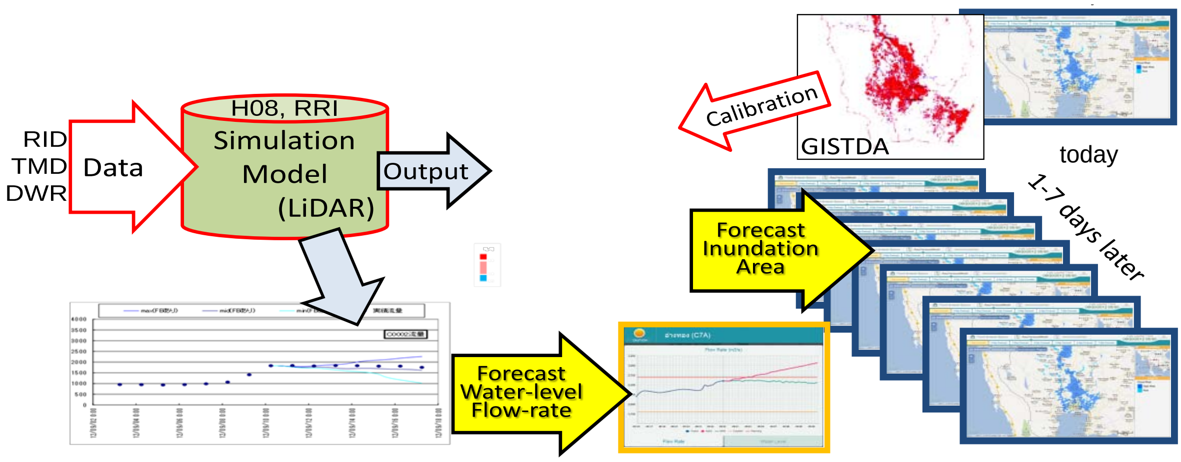

Fig. 5 Structure of Flood Risk Information System

Through discussions with the related persons of the Thai government for practical application, necessary improvements were added, and, by January 2013, the system became the one that could be made open to the general public widely. The website pages of JICA/FRICS Flood Forecasting System of the Chao Phraya River Basin are presented in Figures 6-9 (as of January 2013).

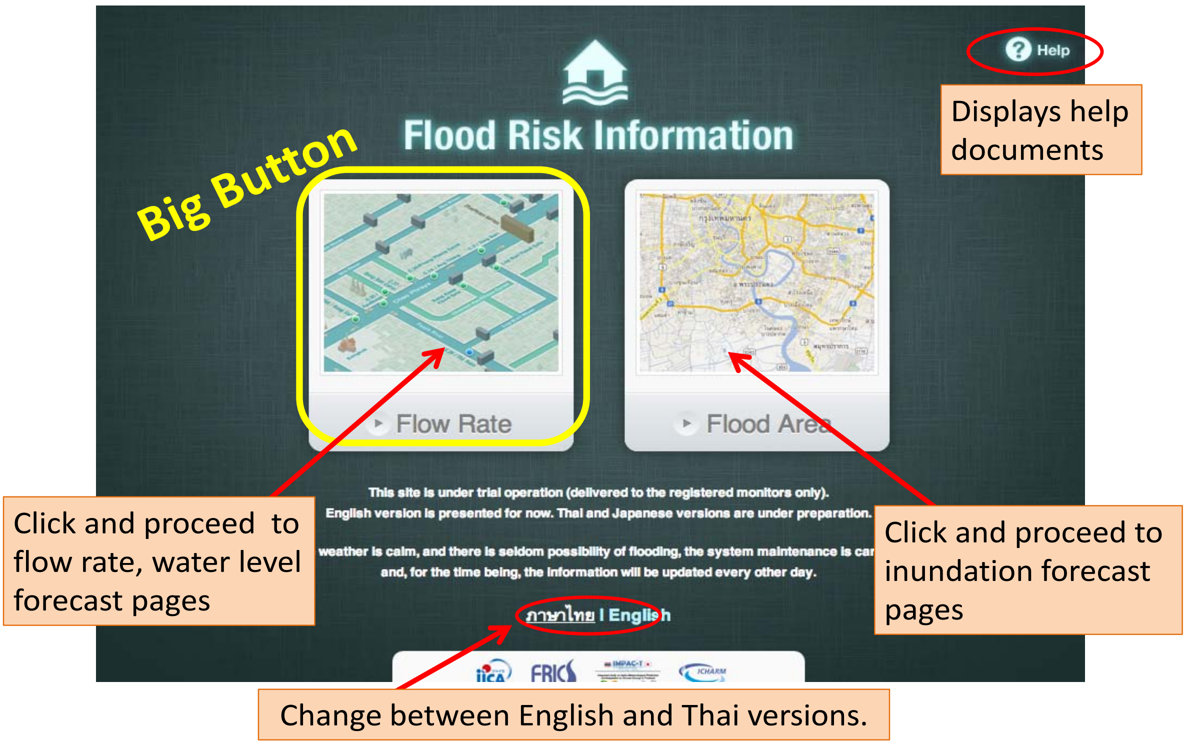

Fig. 6 Top Page

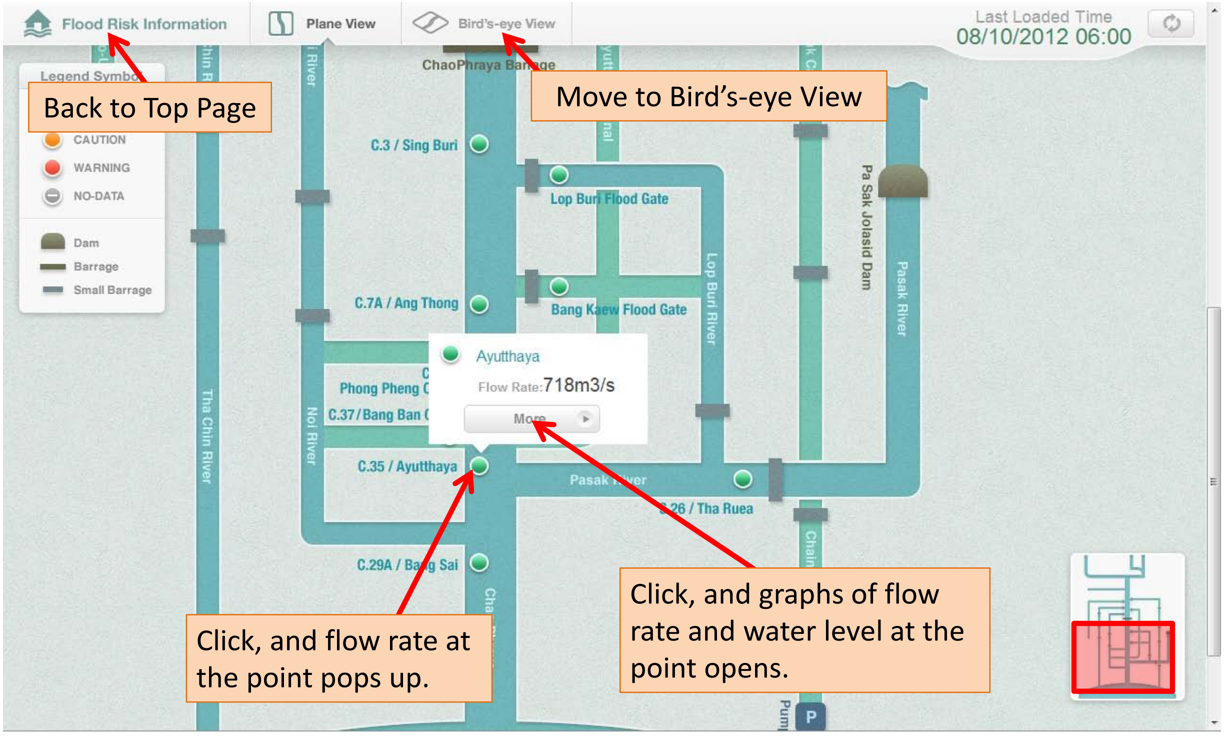

Fig. 7 Schematic Diagram

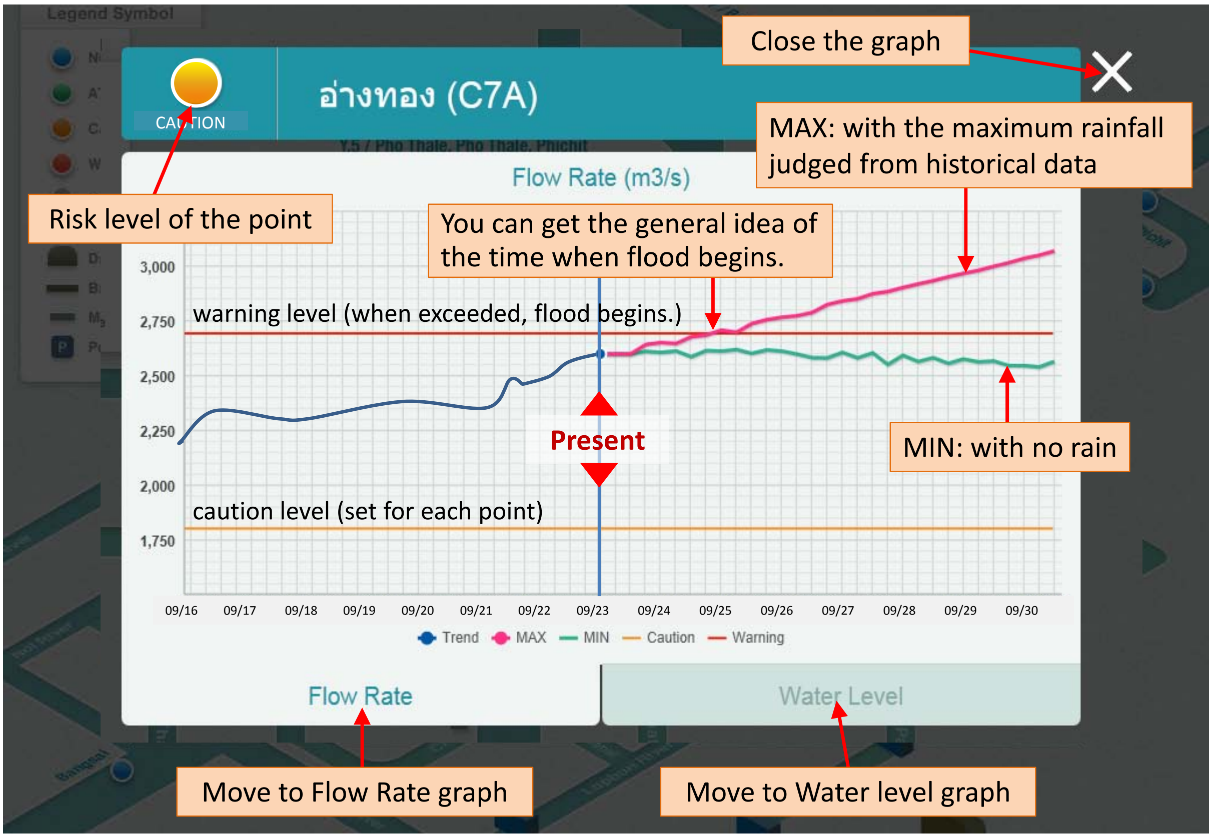

Fig. 8 River Flow Rate Transition and Forecast Graph

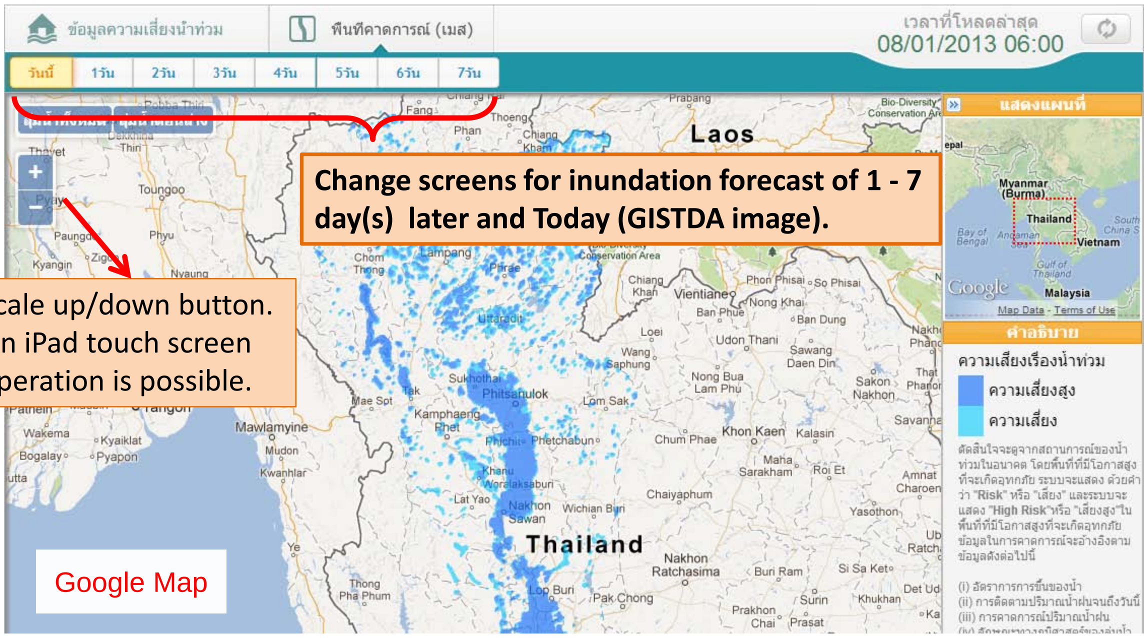

Fig. 9 Inundation Extent Overwrapped on Google Map

4.5 Further Development

The following functions are planned to be added to the system before 2013 flood season.

(i) Government utilization functions such as facility operation/emergency countermeasures scenario consideration functions (Figure 10);

(ii) Operation and management functions (including management/input terminals and printers); and

(iii) Data online functions, system back-up functions.

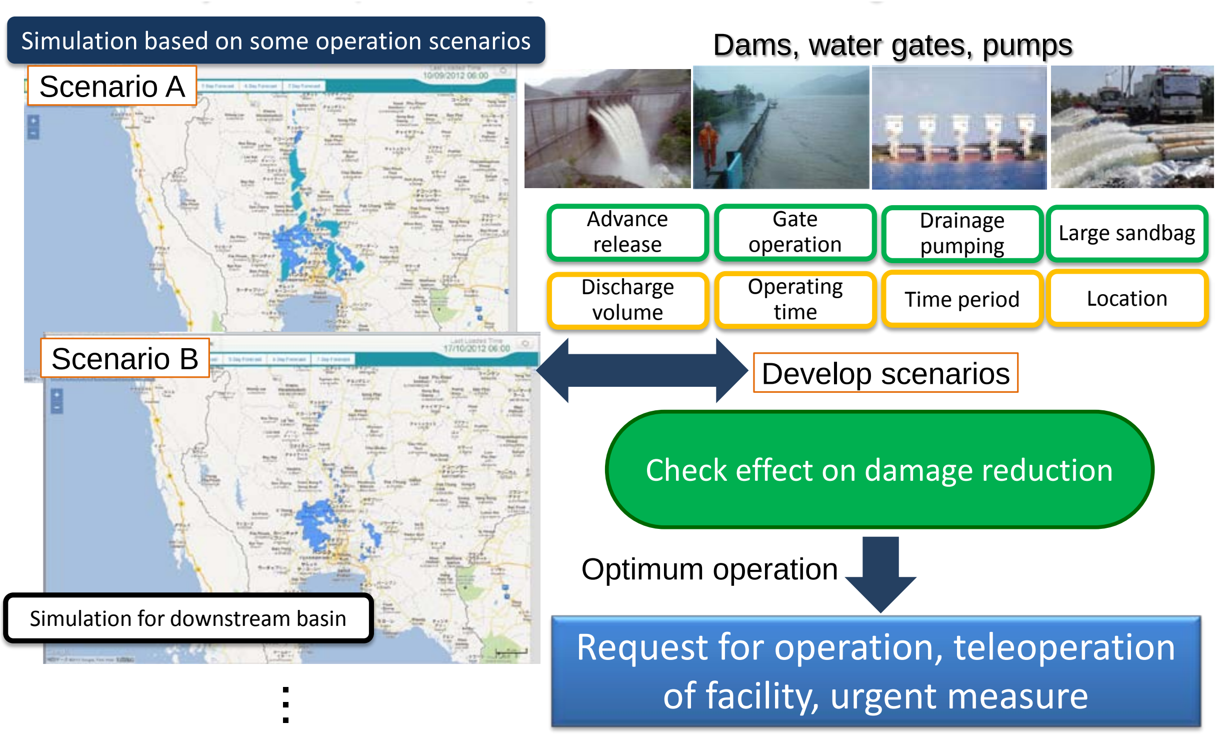

Fig. 10 Simulation for Optimum Operation

5. SUMMARY

An operational flood forecasting system was developed for the Chao Phraya River Basin. The system provides daily updated extent of inundation risks and timing for the entire flood plain of the basin.

As the needs for prediction/forecast of floods were considered high, it was a natural course of actions to promote development of technologies of operational flood forecasting in Thailand, seeking comprehensive disaster prevention combining structural and non-structural measures. However, close examination on the issues involved in forecast information should be made before introducing the flood forecasting system in the Chao Phraya River Basin for achieving the original purpose of reducing flood damage. In particular, uncertainties involved in the natural phenomena, observations, and simulation should be well-understood. Therefore, the flood forecasting system should not simply display the calculation outputs, but be designed to furnish the users with necessary and not-misleading information effectively.

It is hoped that the system would help Thai people as well as industries located in Thailand to be prepared for reducing damages caused by floods in the future.

ACKNOWLEDGEMENTS

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