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Projection of River Discharge in Thailand under Climate Change and its Impact on Water Resources

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The impact of climate change on river flow in Thailand is analyzed by feeding future climate projection data into a distributed rainfall-runoff model. The projection data used consists of daily hydrologic data downscaled by hourly precipitation for the present climate (1979-2003), the near future climate (2015-2039), and the future climate (2075-2099), which were simulated by a 20km spatial resolution general circulation model (MRI-AM20km) developed by the Meteorological Research Institute, Japan Meteorological Agency. It is found that a change of river flow appears at the tributaries of the Chao Phraya River. The change pattern differs according to location, and it is expected to decrease of water resources at the Pasak River basin. Thus, we develop a water resources assessment model at the Pasak River basin, which includes a distributed hydrologic model, a dam reservoir water storage prediction model, and a plant growth model for rice production assessment.

Key Words : *Thailand, Chao Phraya River, Pasak River, water resources, climate change, river flow, rice production*

1. INTRODUCTION

Global warming will give us a serious impact on our life. Frequencies and magnitudes of floods and sedimentation disasters are predicted to increase due to the change of precipitation extremes. The IPCC, the Intergovernmental Panel on Climate Change, 4th assessment report (WG1, WG2; 2007) describes increase of global average surface temperatures, and potential increase of frequency of heavy rainfall, and so on based on long term observations. The report also shows the projections of climate change according to several greenhouse gas emission scenarios and the impacts of climate change on water-related disasters and water resources.

To cope with water-related disasters induced by climate change, both mitigation measures and adaptation measures are essential. For adaptation measures, prediction of future water resources is a key issue. In this paper, a distributed hydrologic model of the Chao Phraya River basin is developed. Then, future river discharge is projected using the latest GCM output to detect the hotspots of river discharge change. It is found a change of flow characteristics at the tributaries of the Chao Phraya River, and water resource at the Pasak River basin is decreased. Thus, we develop a water resources assessment model at the Pasak River basin, which includes a distributed hydrologic model, a dam reservoir water storage prediction model, and a plant growth model for rice production assessment.

2. DISTRIBUTED HYDROLOGIC MODEL

(1) Watershed model

The topography of the catchment is modeled using the eight direction method which assumes the flow direction one-dimensionally to the steepest gradient direction illustrated in Fig. 1. Each slope element determined by the flow direction is represented by a rectangle formed by the two adjacent nodes of grid cells. The watershed model is developed using a digital elevation model, DEM, included in HydroSHED, which cover the globe with about 100m spatial resolution. Figure 2 shows the delineated catchments of the Chao Phraya River basin (160,400km^2), Thailand using the DEM. The area, length, and gradient of each rectangular slope element used for runoff and channel routing are calculated according to the watershed model.

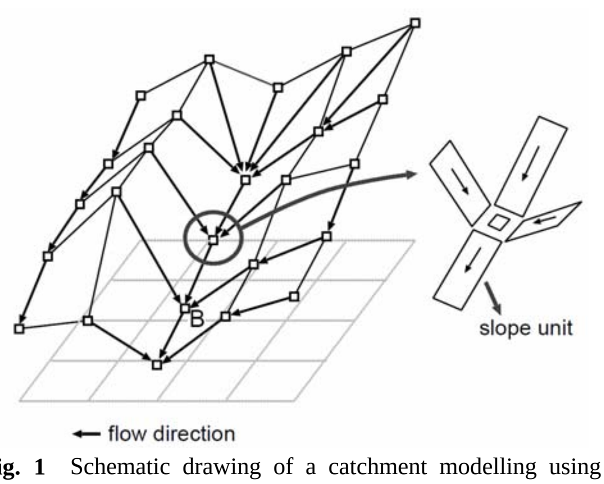

Fig. 1 Schematic drawing of a catchment modelling using DEMs.

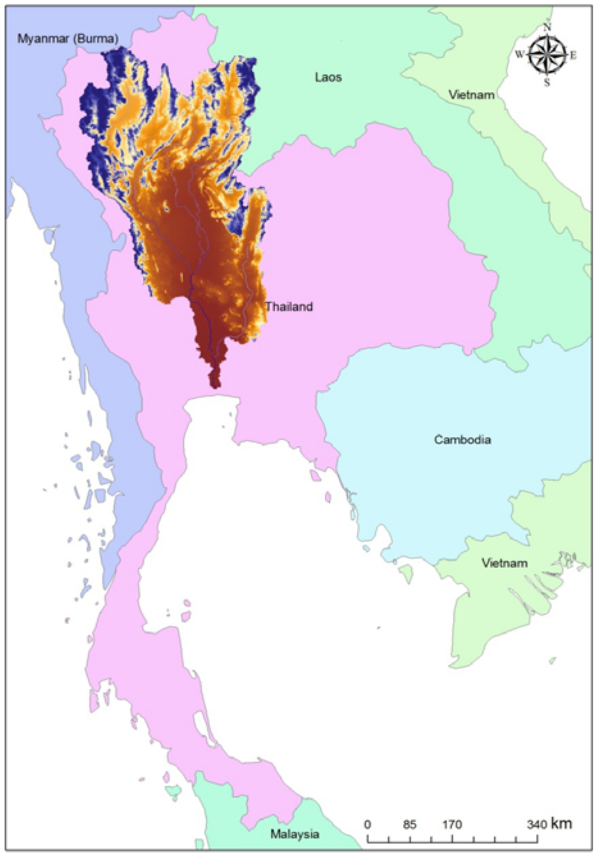

Fig. 2 Chao Phraya River basin in Thailand derived from DEM.

(2) Flow model

The kinematic wave model is applied to all rectangular slope elements to route the water to downstream according to the derived watershed model. The continuity equation for each rectangular slope element is:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q(t) \tag{1}$$

where t is time; x is distance; A is cross-sectional area; Q is discharge; and $q(t)$ is the lateral inflow per unit length of slope or channel given as runoff generation provided by MRI-AM20km. The Manning type relation of the discharge and the cross-sectional area:

$$Q = \alpha A^m, \quad \alpha = \frac{\sqrt{i_0}}{n}\left(\frac{1}{B}\right)^{m-1}, \quad m = 5/3 \tag{2}$$

is combined with the continuity equation to route the water, where i_0 is slope; n is roughness coefficient; and B is width of the flow. The slope i_0 is determined according to the watershed model. The model parameters of the flow model are B and n. The value of B is determined using the regression relationship $B=aS^c$, where S is the catchment area, and a and c is constant parameters. The value of n is determined to 0.03m$^{-1/3}$s when the size of the catchment is larger than 250km^2 and 11.0m$^{-1/3}$s when smaller than 250km^2. These values were tuned to reproduce the observed data at two different catchments and applied to all basins.

The flow model was applied to all catchments and 75 years runoff simulations were conducted. The simulated river discharge data of daily maximum and daily mean were stored for each day with about 1km spatial resolution.

3. GCM DATA USED FOR RIVER FLOW PROJECTION

The projection data used here is simulated by the general circulation model (MRI-AM20km) developed by the Meteorological Research Institute in Japan. MRI-AM20km realizes 1920×960 of grid cells of about 20 km spatial resolutions (Kitoh *et al.*, 2009). The products of MRI-AM20km consists of various atmospheric and hydrologic variables of the present climate experiment (1979-2003), the near future climate experiment (2015-2039), and the future climate experiment (2075-2099), which were simulated under the SRES A1B scenario.

The river discharge for the Chao Phraya River basins is predicted by feeding the future climate projection data into the 1km-spatial resolution distributed hydrologic model. The hydrologic projection variables related to river discharge is shown in Figure 3. The inputted data to the distributed hydrologic model is daily surface runoff generation and daily sub-surface runoff generation data, which are simulated by the land-surface process model embedded in the MRI-AM20km.

The time-scale of daily runoff generation data is insufficient to reproduce the hourly flood peak discharge, thus it was downscaled using the time-series of hourly precipitation data of MRI-AM20km to add the same hourly distribution pattern into the daily surface runoff generation data. We confirmed that river discharge simulation with the timely downscaled surface runoff generation and daily subsurface runoff generation data successfully reproduced almost similar river discharge simulated by using hourly precipitation, daily snowmelt, daily evaporation and daily transpiraion (Takino *et al.*, 2010). Thus, the timely downscaled surface runoff generation data and daily subsurface runoff generation data were used as inputted data to the distributed hydrologic model.

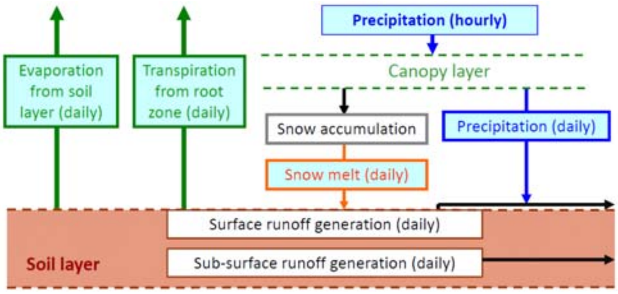

Fig. 3 Hydrologic projection data provided by MRI-AM20km used for river discharge simulation.

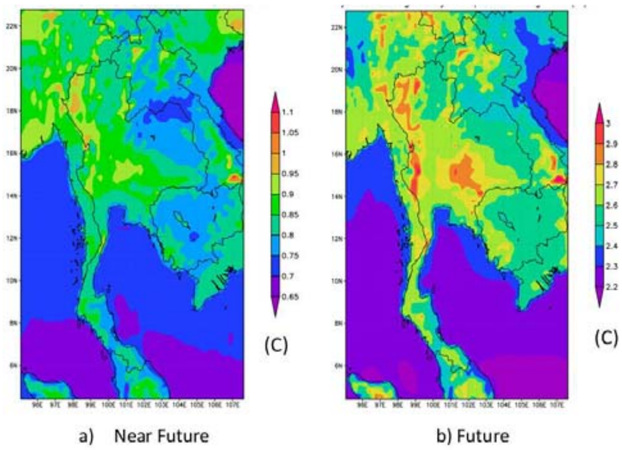

Fig. 4 Change of the difference of the mean of the annual average daily temperature in near future and future climate with respect to the present climate.

4. CHANGE OF BASIC METEOROLOGI -CAL PARAMETERS

According to the MRI-AM20km projection data for the near future climate experiment, the surface temperature found to increase roughly by 0.5 to 1 degree from the present temperature whereas the temperature increased by about 2.5 to 3 degrees in the future climate. Figure 4 shows a spatial pattern of the change of the difference of the mean of the annual average daily temperature in the near future and the future climate experiment with respect to the present climate experiment.

Figure 5 shows a spatial pattern of the change of the percentage difference of the mean annual rainfall in the near future and the future climate experiment with respect to the present climate experiment. The percentage difference *PD* is obtained as

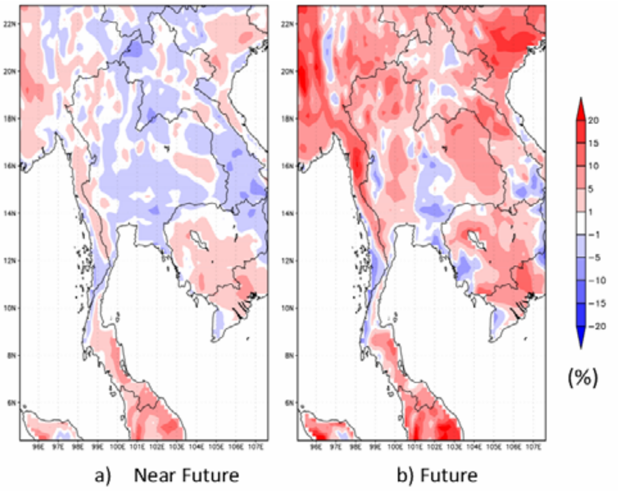

Fig. 5 Change of the percentage difference of the mean annual precipitation in the near future and the future climate experiment with respect to the present climate experiment.

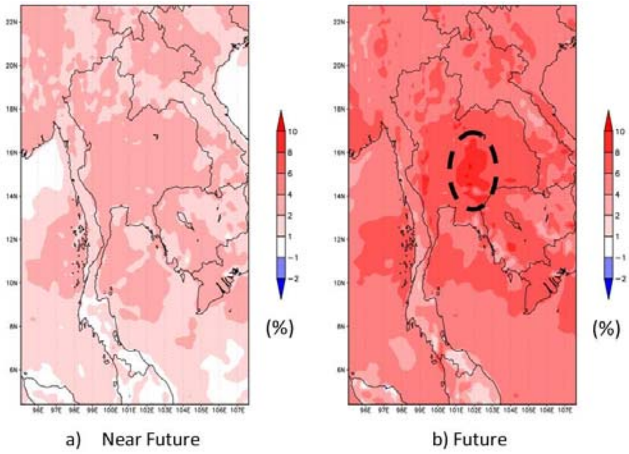

Fig. 7 Change of the percentage difference of the mean annual daily potential evapotranspiration in the near future and the future climate experiment with respect to the present climate.

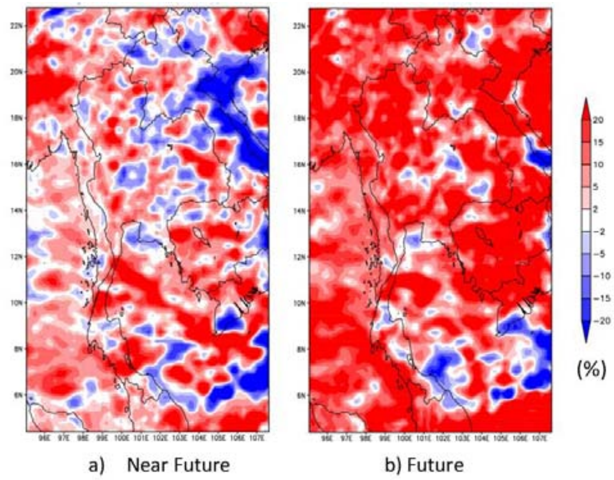

Fig. 6 Change of the percentage difference of the mean annual maximum hourly rainfall in the near future and the future climate experiment with respect to the present climate experiment.

$$PD = 100 \times \frac{r_f - r_p}{r_p} \quad (3)$$

where r_f is the annual mean precipitation in the near future or the future climate experiment and r_p is the annual mean precipitation in the present climate experiment. 1% to 5% decreases of annual precipitation is observed in the central region of Thailand and 1% to 10% of increase in annual precipitation is observed in the southern region in the near future climate experiment. In the future climate conditions, it is expected to have 1% to 10% of increase in annual precipitation in the north mountainous region and 5% to 10% increase in the northeast region.

Figure 6 shows a spatial pattern of the change of the percentage difference of the annual maximum hourly rainfall in the near future and the future climate experiment with respect to the present climate experiment. It is observed that a clear increasing trend of the annual maximum hourly rainfall over Thailand for both time periods of the climate experiments. Notably, in the future climate experiment, about 20% increase of the annual maximum hourly rainfall in many parts of the region.

Figure 7 shows a spatial pattern of the change of the percentage difference of the mean annual daily potential evapotranspiration in the near future and the future climate experiment with respect to the present climate experiment. It is noticed that the potential evappotranspiration increase by 4% to 6% in the near future climate experiment and 4% to 10% in the future climate experiment.

5. IMPACT OF CLIMATE CHANGE ON RIVER FLOW REGIME

Runoff simulations of 75 years for the present climate experiment (1979-2003), the near future climate experiment (2015-2039), and the future climate experiment (2075-2099) were conducted. Runoff simulation data of hourly maximum and daily mean are stored for each day with about 1km spatial resolution. The simulated discharge data were analyzed to discuss the change of the flood risk and water resources.

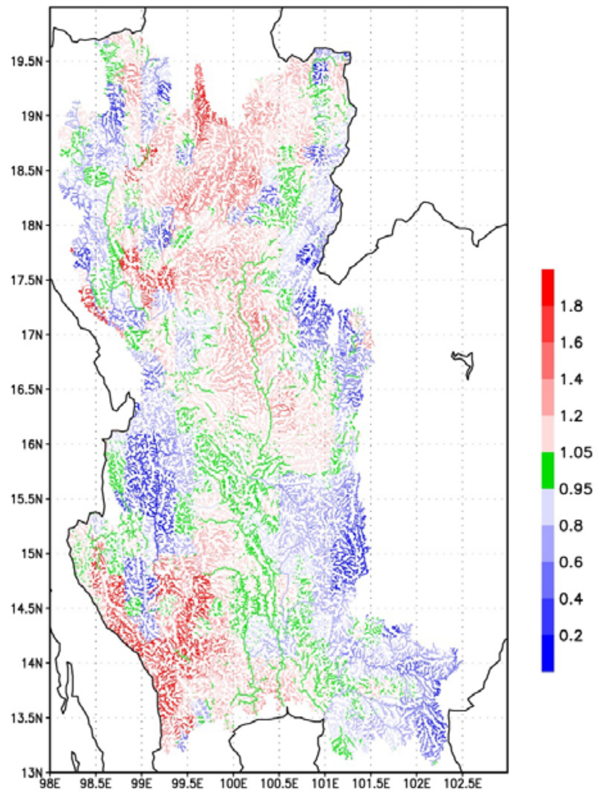

Fig. 8 Change of the ratio of the mean of the annual maximum hourly discharge in the future climate experiment with respect to the present climate experiment.

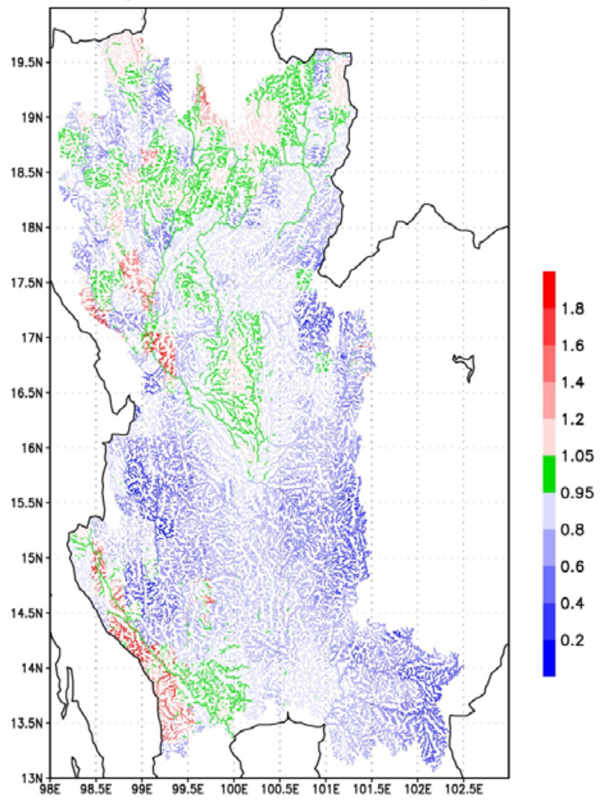

Fig. 10 Change of the ratio of the mean October river discharge in the future climate experiment with respect to the present climate experiment.

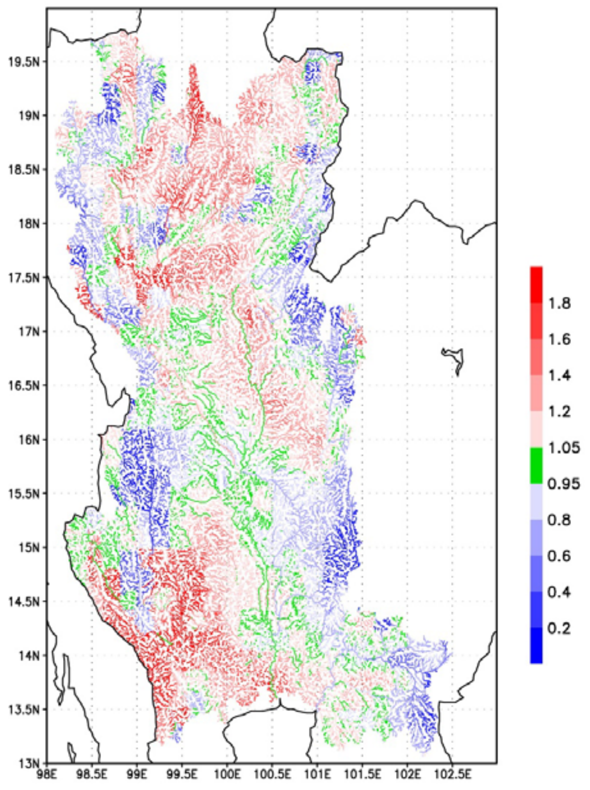

Fig. 9 Change of the ratio of the 10-years return period river discharge in the future climate experiment with respect to the present climate experiment.

(1) Change of flood

Annual maximum hourly discharge data was compiled and the statistical characteristics were analyzed. Figure 8 shows the change ratio of the mean of the annual maximum hourly discharge for the present climate experiment and the near future climate experiment. Generally, the annual maximum discharge of the main stream of the Chao Phraya River does not change, however the one of the tributaries changes location to location.

Figure 9 shows the change ratio of the 10-year return period river discharge in the future climate experiment with respect to the future climate experiment using the Gumbel distribution. The spatial pattern is similar to the change of the mean of the annual maximum river discharge. It is important to recognize that the change of the discharge would appear especially at the tributaries.

(2) Change of water resources

Figure 10 shows the change ratio of the mean October discharge in the future climate experiment with respect to the present climate experiment. Generally, the monthly discharge on October decreases in the middle and lower part of the Chao Phraya River basin.

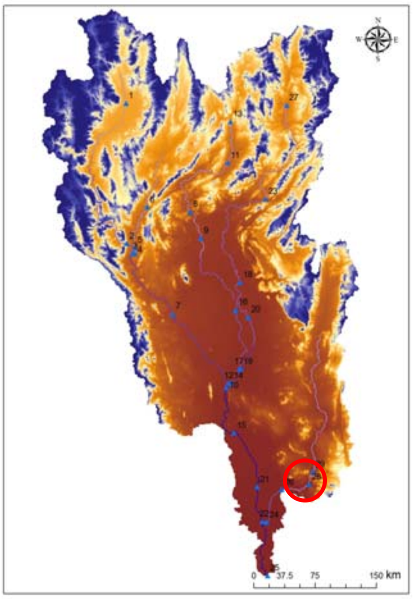

Fig. 11 The location of the Pasak Dam reservoir which is located at the Pasak River, a tributary of the Chao Phraya River.

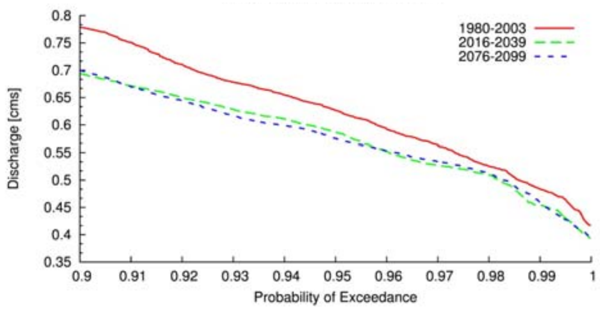

Fig. 12 Change of the ratio of the mean October river discharge in the future climate experiment with respect to the present climate experiment.

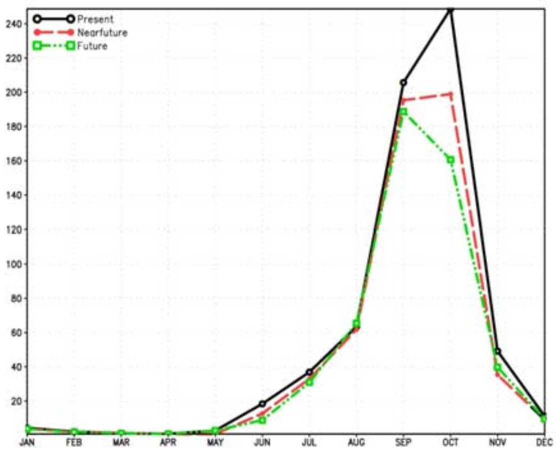

Fig. 13 Change of the monthly discharge at the lower reach of the Pasak River.

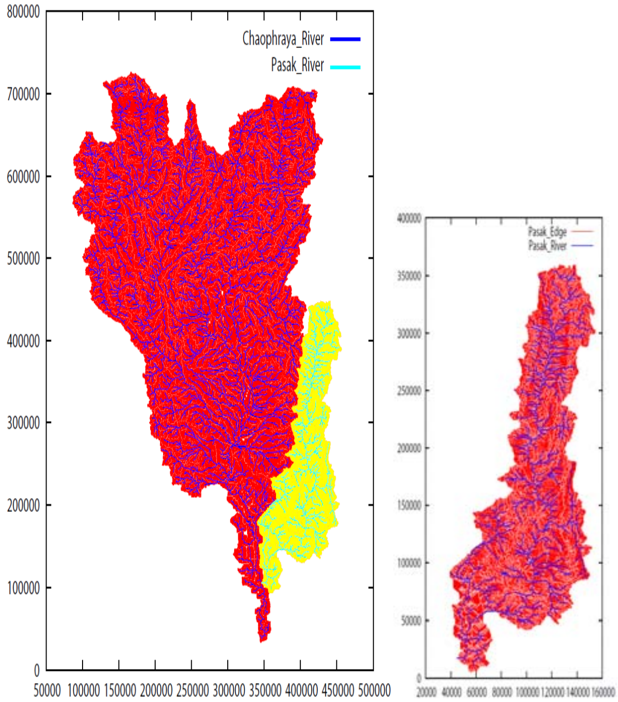

Fig. 14 Detail topographic modeling using HydroSHED for a distributed hydrologic model. Left shows the entire Chao Phraya River basin and Right shows the Pasak River basin.

Figure 12 shows the last 10% daily flow duration curve for each 25 years climate experiment at the lower reach of the Pasak River shown in Figure 11 in the red circle. The figure shows the decrease tendency of the low discharge at the area. Figure 13 shows the projected monthly discharge at the lower reach of the Pasak River. The figure shows the clear pattern of the decrease of the October discharge.

6. WATER RESOURSES ASSESSMENT MODEL AT THE PASAK RIVER BASIN

Through the river discharge projection research of the entire Chao Phraya River, it was revealed that the Pasak River basin would be one of the hotspot basins for the river discharge change. Thus, we focus the catchment and develop a water resources assessment model to analyze the change of hydrologic cycle, water resources, and its impact on rice production (Tachikawa and Yorozu, 2009). Figure 14 shows the detail topographic modeling using HydroSHED. Left figure shows the entire Chao Phraya River basin and right figure shows the Pasak River basin. The topography data is used for a detail distributed hydrologic model.

Fig. 15 Irrigated area extended over the lower part of the Pasak dam reservoir.

Fig. 16 A hydro-meteorological observation instrument installed at the Rama VI office, RID.

Figure 15 shows the irrigated area at the lower part of the Pasak Dam, where water is taken from the lower reach of the Pasak River for paddy fields extended over the lower part of the Pasak River basin. To predict a potential rice crop yield for the irrigated area, a development of a crop production model combined with a distributed hydrologic model and a dam storage prediction model is in progress. We have installed a hydro-meteorological observation instrument at the Rama VI office, RID to develop a crop yield model (Fig. 16).

7. SUMARRY

The impact of climate change on river flow regimes in the Chao Phraya River basin was analyzed. A possible change of water resources are indicated in the near future climate experiment and it becomes clearer in the future climate experiment. We found the Pasak River basin would be one of hotspots of river discharge change. Thus, the following researches are in progress at the Pasak River basin:

- Development of a detailed distributed hydrologic model at the Pasak River basin,
- Development of the Pasak Dam storage prediction model,
- In-situ observation of crop production cycle at the irrigation area of the Pasak dam reservoir,
- Development of crop production model, and
- Hydro-meteorological observation at the study area.

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