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# River Discharge Assessment under a Changing Climate in the Chao Phraya River, Thailand by using MRI-AGCM3.2S

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**Abstract** In recent years, General Circulation Model (GCM) has been widely used in climate change impact studies. It is an effective tool for well understanding of a change in climate behavior in a long term. Nowadays, more than twenty GCMs have been developed in many research institutes around the world. We selected the latest version of GCM developed by Meteorological Research Institute (MRI), Japan Meteorology Agency, MRI-AGCM3.2S. The model has a horizontal resolution of triangular truncation 959 (TL959), and the transform grid uses 1920 x 960 grid cells, corresponding to approximately a 20-km grid interval with 64 vertical layers (top at 0.01 hPa).We used a regional distributed hydrologic model based on the concept of the variable infiltration capacity to generate runoff intensity and a kinematic wave model including effects of dam operation and inundation to simulate river discharge. The C.2 gauging station at Nakhon Sawan was selected to monitor changes in the river discharge. Input data of the distributed hydrological model, GCM precipitation and evapotranspiration, were corrected to remove biases using the quantile-quantile bias-correction method for precipitation and the different factor bias-correction method for evapotranspiration. The results of the experiment in projecting discharge of the Chao Phraya River under the near future climate (2015-2043) and the future climate (2075-2103) by using the bias-corrected GCM data set showed that 1) the mean annual discharge tends to increase in both near future and future projection periods, 2) During a dry season the tendency of low flow in the near future period tends to decrease. However, the flood frequency analysis using Generalized Extreme Value distribution (GEV) indicates that flood risk in the future will have more severities and damages to the country as the result of the analysis shows that, in the near future the magnitude of 80-year return period flood is greater than the devastating 2011 Thai flood.  .

**Keywords** *Climate change, Discharge projection, Chao Phraya River, Distributed hydrological model*

## Introduction

Prediction of the Chao Phraya River discharge has been conducted for water resources assessment of the basin by utilizing outputs of the MRI-AGCM3.2S (20 km resolution) without bias correction. The result showed that water availabilities in the CPRB increase all year round, both in the wet and dry seasons in the future climate experiment, and during dry season of the near future climate trends of projected discharge considerably reduced (Wichakul et al., 2014). However, direct usage of hydrological variables of the GCM does not provide reliable information on scales below about 200 km (Maraun et al., 2010). Therefore, for reliable and realistic prediction result of the river discharge situation of the Chao Phraya River, we introduced several bias correction methods to the MRI-AGCM3.2S outputs, precipitation and evapotranspiration. Bias in the GCM precipitation distribution was removed by the empirical distribution and quantile-quantile correction methods. For the GCM evapotranspiration, the multiplicative factor and different factor correction methods were applied.

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The research aims to project discharge of the Chao Phraya River and to evaluate tendency of flood and drought risks under a changing climate by using the bias-corrected GCM precipitation for a reliable result.

## Input data and study area

We used the MRI-AGCM3.2 variables from three (3) different climate experiments: are the present climate experiment (1979–2008), the near future climate experiment (2015–2044), and the future climate experiment (2075–2104). The GCM precipitation is rainfall reaching to soil layer (PRCSL) and the GCM evapotranspiration is a summation of evaporation from bare soil (EVPSL) and transpiration from root zone soil (TRNSL). The GCM variables covering the CPRB were extracted total 1,120 grids resolution 0.1875 (Cols=28 and Rows=40), which is defined as being between Latitude = 12.094 - 19.406 N and Longitude = 98.060 – 103.123 E.

To prepare the input data for the distributed hydrological model, the GCM variables were processed to remove biases by quantile-quantile bias-correction method for precipitation and the different factor bias-correction method for evapotranspiration. In the bias correction process, APHRODITE precipitation and the reference evapotranspiration (ETo) were used to simulate the reference as observed discharge. In our study, we obtained a reference crop evapotranspiration (ETc) calculated by the Royal Irrigation Department of Thailand (RID) using the FAO Penman-Monteith method (Allen et al., 1998) with recorded climatology data for the 30 years from 1981 to 2010 to be the truth reference data. Due to limitation of APHRODITE data which were available for 1979-2007, the bias correction was piloted for only a period of 29 years. Therefore our hydrological simulation was simulated for 1979-2007, 2015-2043, and 2075-2103 periods.

Study area is the Chao Phraya River basin, Thailand. The discharge monitoring is at C.2 located about 5 km downstream of the Ping River and Nan River confluence, beginning of the Chao Phraya River (15°40′N and 100°06′E). The location of the C.2 station can represent the overall situation of the Chao Phraya River.

## Modeling approach

The regional distributed hydrological model composes of rainfall-runoff model and flow routing model including dam operation. The rainfall-runoff named the Simplified Xinanjiang model (SXAJ). It was established based on the concept of the variable infiltration capacity (Wichakul et al., 2013a). 1K-FRM is a 1 kilometer resolution flow routing using a kinematic wave equation. In part of flow routing, the 1K-FRM was additionally developed to include the inundation effect and reservoir operation model to improve predicted discharge for the Chao Phraya River Basin. (Wichakul et al., 2013b). **Fig. 1** shows the framework of model simulation.

The bias-corrected precipitation and evapotranspiration were input to the SXAJ model to generate runoff intensity represented 1120 (28 columns and 40 rows) grid cells covering the CPRB. Then, the runoff intensity was input to the 1K-FRM represented by 288,000 (480 columns and 600 rows) computational grid. The predicted discharge was extracted at the C.2 grid.

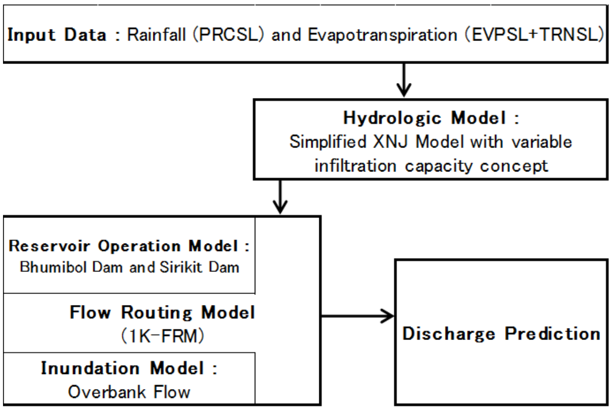


**Fig. 1** Framework of the distributed hydrological model including inundation model by using the GCM output.

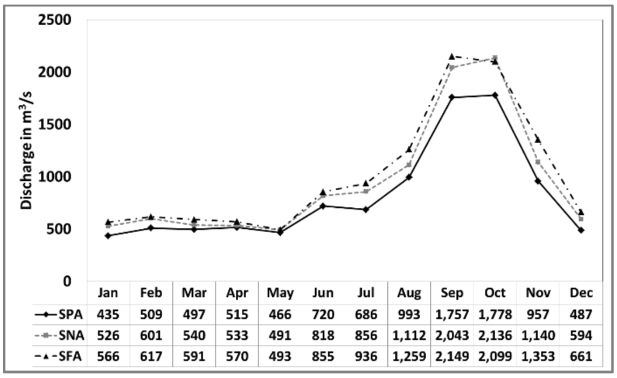
## Result and discussion

### *River discharge assessment under a changing climate*

By using the bias corrected precipitation and evapotranspiration as input to the regional distributed hydrological model, we generated series of daily discharge for twenty night (29) year in each climate experiment period. Mean monthly discharge at the monitoring station, C.2 station, has been calculated to detect trend of stream flow change under a changing climate as plotted in **Fig. 2**. It shows mean monthly discharge at for three climate experiments. For the future climate, comparison of the discharge of the present climate (1979-2007) and the future climate (2075-2103) shows significant increases about 10% to 41% of the mean monthly discharge in the present climate. For the near future, most of the months the mean monthly discharge shows a bit increase about 10% to 25% of the mean monthly discharge in the present climate. On the other hand, the discharge of the near future climate extremely rises up in October at the same rate of increase as the next three decades. Only in May, the mean discharge does not much change. According of the Thailand climatology, May is the end of summer season and beginning of rainy season. That is why effect of changes of temperature (or evapotranspiration) and rainfall intensity have less effect to the mean discharge in this month.
One of important tools to characterize the response of the river to a changing climate is flow duration curve. The

probability of exceedance (P) of mean annual flow magnitude of each climate experiment periods are illustrated in flow duration curves. **Fig. 3** presents mean annual flow duration curves with standard deviations for the three climate experiments. It clearly shows that the magnitudes of river flow considerably rise up for P < 0.6 in both the near future and future climate experiments. The magnitude of river discharge in the future period has a tendency to increase for all occurrence time.

For P > 0.6, there is no a significant signal of changes in mean annual flow for the near future and future period. According to the dam operation model embedded in the flow routing model for generating stream flow, discharge during low flow season was influenced by the dam model (Wichakul et al., 2011). It means that future inflow into dams dose not much change, so the dam operation model still operates and releases flow from storage water to downstream as operating in the current climate. However, to enlarge the low flow section, **Fig. 4** compares the flow duration curves constructed based on daily discharge of a period-of-record of each climate experiment at the low flow section. Therefore, it is clear that the low flow values tend to decrease in the near future experiment which might result in increased drought risk in the CPRB. Conversely, for the 21st century the low flow values tend to increase roughly 15 % of the flow in the present climate period. For the flood risk assessment, the frequency analysis of the extreme events is generally applied to evaluate to risk that we discuss in the next paragraph.



| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SPA | 435 | 509 | 497 | 515 | 466 | 720 | 686 | 993 | 1,757 | 1,778 | 957 | 487 |
| SNA | 526 | 601 | 540 | 533 | 491 | 818 | 856 | 1,112 | 2,043 | 2,136 | 1,140 | 594 |
| SFA | 566 | 617 | 591 | 570 | 493 | 855 | 936 | 1,259 | 2,149 | 2,099 | 1,353 | 661 |

**Fig. 2** Mean monthly discharge at the C.2 station for the present (SPA), near future (SNA) and future climate experiments (SFA).

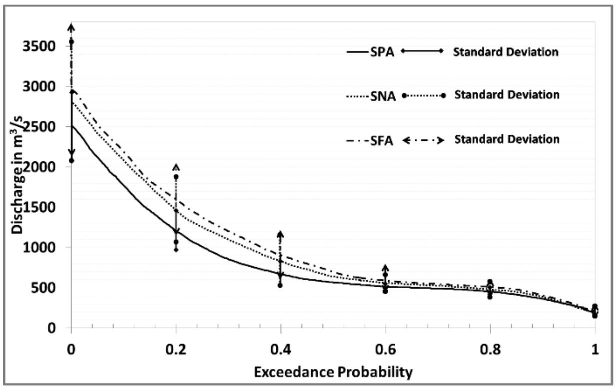


**Fig. 3** Mean annual flow duration curves with standard deviation of the present climate (SPA), near future climate (SNA), and future climate (SFA) experiments.

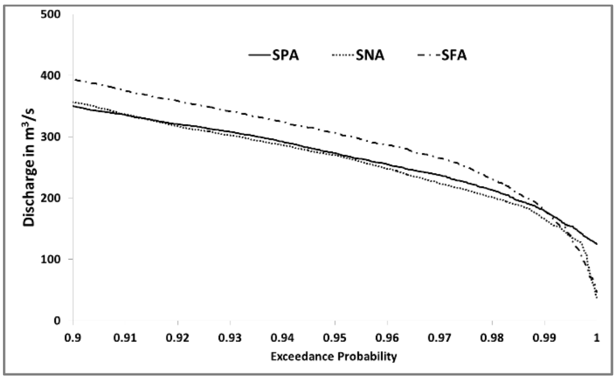


**Fig. 4** Low flow section of the flow duration curves constructed based on daily discharge of a period-of-record of each climate experiment.

## Frequency analysis of extreme events

Frequency of occurrence of the extreme events was analyzed by fitting the probability distribution function (PDF) of extreme values with three families of distribution functions, Square-root exponential type maximum distribution (SqrtET), Generalized extreme value distribution (GEV), and Gumbel distribution. The following are the cumulative distribution functions (CDFs) of each distribution.

The Square-root exponential type maximum distribution's CDF is as:

$$F(x;\ \beta,\lambda) = \begin{cases} -\lambda\{(1+\sqrt{\beta x})\ exp(-\sqrt{\beta x})\} & x \geq 0, \\ 0 & x < 0. \end{cases} \tag{1}$$

In which β is the scale parameter, and λ is the frequency parameter (Etoh et al., 1987). The generalized extreme-value (GEV) distribution has a cumulative distribution function with a parameter k ≠0 as:

$$F(x;c,a) = exp\left[-\left(1-k\frac{x-c}{a}\right)^{1/k}\right] \tag{2}$$

where x is an annual maximum daily discharge; a is a positive scale parameter; c is a location parameter and k is a negative shape parameter. In case of k = 0, the GEV distribution is equivalent to the Extreme Value Type I distribution or the Gumbel distribution. The cumulative distribution function of Gumbel distribution is shown as:

$$F(x;c,a) = exp\left[-exp\left(-\frac{x-c}{a}\right)\right] \qquad (3)$$

For the Gumbel distribution, x is unbounded ($-\infty < x < \infty$) (Takara, 2009).

The annual maximum series of river flow at the C.2 station was extracted from three periods of simulation, to fit with the distribution function as mention above. **Fig. 5, 6,** and **7** illustrate the CDFs of twenty night (29) values of annual maximum river flow fit with different functions for SPA SNA, and SFA, respectively.

Standard least-squares criterion (SLSC) is a criterion we used to evaluate goodness of fit of each distribution to the annual maximum daily discharge. It was proposed by Takara and Takasao (1998). Afterward, Tanaka and Takara (1999) proved that SLSC < 0.04 is acceptable to river discharge frequency analysis in Japan. However, the Chao Phraya River Basin topographic condition is very different to river basins in Japan. Therefore, we evaluated the acceptable SCSC by the smallest value among each probability distribution function. **Table 1** shows comparison of the goodness-of-fit for the annual maximum daily discharge at the C.2, Y.16, N.67 and P.17 stations for present climate (1979-2008) near future climate (2015-2043) and future climate (2075-2013).

The Y.16 is located at 16°45'N and 100°07'E on the Yom river upstream of the N.67 station (15°52'N and 100°15'E). Other monitoring location is at 15°56'N and 99°58'E on the Ping River named P.17 station. From the **Table 1**, it shows that among these probability distribution functions, GEV distribution function provides the best goodness-of-fit to the annual daily maximum discharge of the projection periods for all locations. Therefore, we selected the GEV for evaluating change in extreme floods and assessing flood risk.

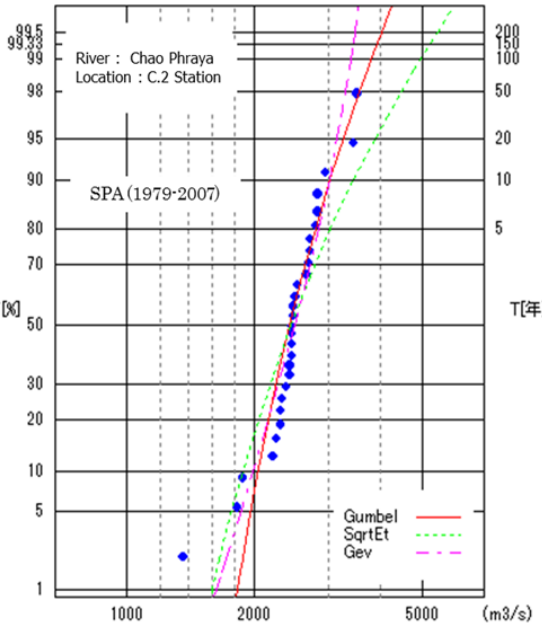


**Fig. 5** Cumulative distribution functions of the annual maximum daily discharge at C.2 station for present climate.

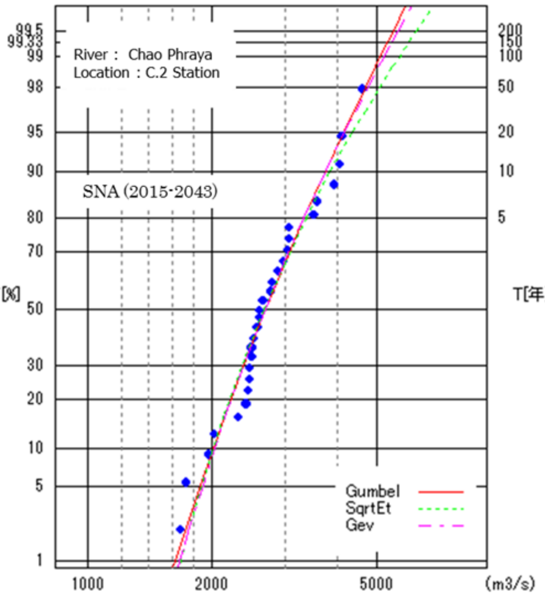


**Fig. 6** Cumulative distribution functions of the annual maximum daily discharge at C.2 station for near future climate.

**Table 1** Goodness-of-fit criteria for each probability distribution function. Standard Least Squares Criterion, SLSC

| Standard Least Squares Criterion, SLSC | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PDF | C.2 | | | Y.16 | | | N.67 | | | P.17 | | |
| | SPA | SNA | SFA | SPA | SNA | SFA | SPA | SNA | SFA | SPA | SNA | SFA |
| Gumbel | 0.071 | 0.036 | 0.043 | 0.035 | 0.056 | 0.058 | 0.047 | 0.031 | 0.054 | 0.036 | 0.087 | 0.120 |
| SqrtEt | 0.090 | 0.038 | 0.067 | 0.046 | 0.051 | 0.059 | 0.059 | 0.043 | 0.073 | 0.054 | 0.098 | 0.122 |
| Gev | 0.092 | 0.037 | 0.029 | 0.035 | 0.050 | 0.058 | 0.034 | 0.030 | 0.040 | 0.020 | 0.060 | 0.078 |

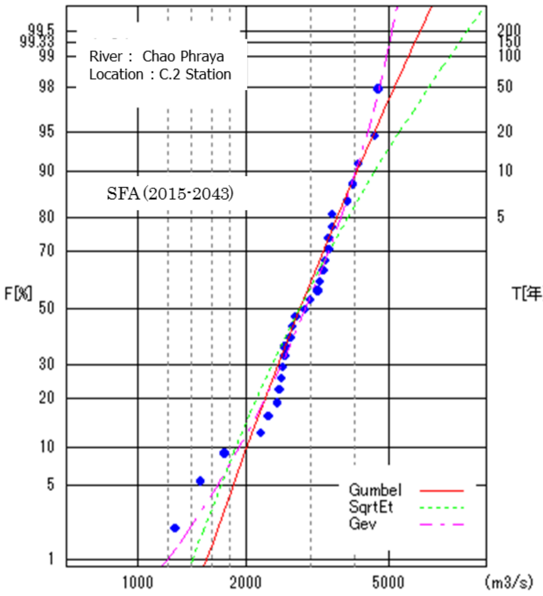


**Fig. 7** Cumulative distribution functions of the annual maximum daily discharge at C.2 station for future climate.

Changes in return period of flood for different periods are illustrated in **Fig. 8** for four different locations; (a) for C.2 station, (b) for Y.16 station, (c) for N.67 station and (d) for P.17 station. The assessment has been conducted by comparing the return period of the 5-year, 10-year, 20-year, 30-year, 50-year, 80-year, 100-year, 150-year, and 200-year. The short return periods (shorter than 50-year return period) are relevant to flood related design structure according the impacts of climate change, such as irrigation structure, urban drainage and bridge. Refer to **Fig. 8a**, in 21st century the magnitude of extreme events at the C.2 station significantly increase for the return period shorter than 50-year and also it is larger than the magnitude of the flood events in the near future climate (2015-2143). For the long return periods (form 80-year return period), the magnitude of discharge is extremely high in the near future climate. That change in the C.2 station mostly corresponds to change in flood magnitude in the P.17 and N.67 stations for both near future and future periods, referring to **Fig. 8c** and **8d.**

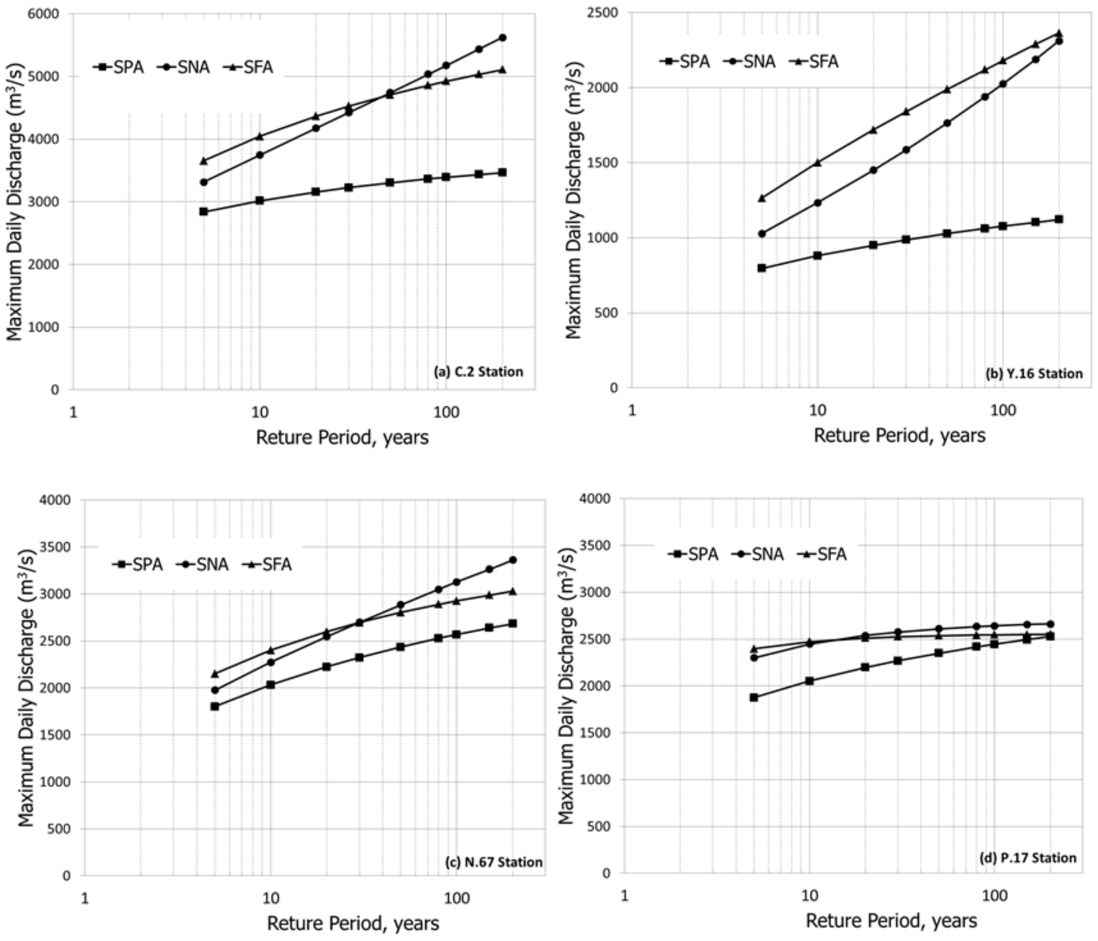


**Fig. 8** Maximum daily discharge corresponding to different return periods for present climate (SPA), near future climate (SNA) and future climate (SFA) for each location.

Flood frequency analysis of the Y.16 station showed different pattern from other location as illustrated in **Fig. 8b** because location of the Y.16 station is far for the location of those another three stations. Flow from the Y.16 station merges with the Nan river at the confluence located upstream of the N.67 station.

The corresponding discharge of the C.2 station (5,034 m$^3$/s) at 80-year return period of the near future is larger than the peak discharge of Thai's flood 2011 (4,686 m$^3$/s). Consequently, overall trend shows the flood risk is increase in the future that will cause more damage to the CPRB.

## Conclusion

Four sets of bias-corrected outputs of the MRI-AGCM3.2S, precipitation and evapotranspiration, were applied to the Chao Phraya River for projection river discharge in the present climate (1979–2007). The regional distributed hydrological model including the effect of dam operation and inundation simulated the river discharge. Simulated long term hydrographs from different sets of the input data were compared with the reference observed hydrograph. Result shows that the hydrograph simulated by using the bias-corrected precipitation by the quantile-quantile method with the bias-corrected evapotranspiration by the different factor achieved a well fit with the reference observed discharge at the C.2 station.

Consequently, the bias-corrected GCM data have been conducted for the near climate future and the future climate experiments. Changes in the projected river discharge at the C.2 station, Nakorn Sawan province can be concluded that 1) the mean annual discharge tends to increase in both near future and future projection periods, 2) during a dry season the tendency of low flow in the near future period leads to decrease. These findings of our study are also compatible with previous studies of Hunukumbura and Tachikawa (2012), and Kure and Tebakari (2012); but it is contradictory with the study result of Champthong et al., (2013). Furthermore, the GEV was applied for flood frequency analysis which indicates that flooding frequency has increased, leading high flood risk in the future. Flood in the basin will have more severity; especially in the near future (2015-2043) the magnitude of 80-year return period flood (5,034 m$^3$/s) is greater than the devastating 2013 Thai flood (4,686 m$^3$/s). Therefore, adaptation measures to protect damages of flood in the country are critical to accomplish.

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