

APPLICATION OF DWCM-AGWU MODEL TO THE MAE KLONG RIVER BASIN WITH LARGE COMPLEX IRRIGATION SCHEME

Jutitthep Vongphet¹ and Takao Masumoto²

ABSTRACT

The DWCM-AgWU (Distributed Water Circulation Model incorporating Agricultural Water Use) was applied to assess the water use in the Mae Klong River basin, especially amount of irrigation water for the Greater Mae Klong Irrigation Project during the years 2008-2015. The result of this application was also used to assess the limitation of the present model on the water requirements and water allocation sub-models for irrigated areas. The Greater Mae Klong Irrigation Project supplies irrigation water from two large reservoirs, the Srinagarind and Vajiralongkorn dams. The water is fed to these irrigated areas is considered a component of the water requirements of various agricultural activities, such as paddies, upland crop fields like sugar cane, as well as fisheries and perennial crop fields. As a result, in the present model, the amount of diverted water was considered as only that used by irrigation rice paddies. From this limitation, the modified model should be expanded to include the calculation of water requirement for other agricultural activities by using a database of crop coefficients of water requirement and cropping patterns. The new model will facilitate the development of adaptation measures against extreme events, especially drought and to evaluate the effectiveness of such measures. Furthermore, it enables us to evaluate and project the effects on water circulation in the basin brought about by various human activities (e.g., changes in agricultural practices) and meteorological changes from global warming.

Keywords: Complex irrigation project, water requirement, water management, drought.

1. INTRODUCTION

Climate change has a strong effect on the natural hydrological cycle (Xu *et al.* 2009; Beniston *et al.* 2012; Strauch *et al.* 2015). It is predicted to increase the frequency and intensity of extreme events such as flood and drought (IPCC 2012). It has become more prevalent globally, and the future availability of resources, especially water resources for human consumption, agricultural production, and manufacturing has become more uncertain. As a risk prevention strategy, countermeasures and/or adaptation measures for extreme events such as floods and droughts must be proposed and evaluated. An integrated distributed hydrological model combining the catchment-scale natural hydrological cycle with the impact of human activities is required to facilitate the development of adaptation measures against extremes and to evaluate the effectiveness of such measures. Moreover, the component of water for agricultural activities which is managed through irrigation facilities should be considered in those measures because irrigation is the most important use of water; as on a global basis about 70% of freshwater use is accounted for in irrigation.

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The Distributed Water Circulation Model Incorporating Agricultural Water Use (DWCM-AgWU) was developed for water use analysis in the Mekong River Basin (Masumoto *et al.* 2009; Taniguchi *et al.* 2009). The original model targeted river basins dominated by paddies over a continuous series of years that included droughts. Kudo *et al.* (2013) modified the model to reproduce the paddy irrigation processes using the large dams in north-eastern Thailand. In the modified model, the management of irrigation systems and dam operations was introduced systematically. In addition, Vongphetet *al.* (2015) developed a Seamless-DIF model, which expands on the DWCM-AgWU by incorporating inundation and flood processes. Assessment of the Seamless-DIF model is carried out through its application in the Chao Phraya River Basin against extreme events such as the flood in 2011. As the first step of a seamless model development, Vongphetet *al.* (2014; 2016) modified the model of Kudo *et al.* (2013) and applied it to the Chao Phraya River Basin to assess water use from 2008–2011, a period that includes both drought and flood years. The modelling emphasized the importance of dams and irrigation systems for agricultural water resource management, especially in the middle and lower reaches of the basin, which was affected by the 2011 flood. However, the amount of irrigation water is determined based on the paddy water requirements, and the model does not consider components of water use for other agricultural lands such as upland and/or perennial crops, for which water is also supplied through irrigation canals.

The Greater Mae Klong Irrigation Project is one of the largest irrigation-service areas in Thailand (480,000 hectares), and is mainly supplied water by two large multi-purpose reservoirs, the Srinagarind and Vajiralongkorn dams, which are located in the upper part of the Mae Klong River Basin (Biltonenet *al.* 2000). The water is fed to these irrigated areas after considering the water requirement for various agricultural activities such as paddies, upland crop fields, especially sugar cane, as well as fisheries and vegetable and perennial crop fields. In addition, these two large dams also release water for domestic use in the western part of Bangkok and surrounding areas, which are located in the lower part of the Chao Phraya River basin, and to protect salt water intrusion in the lower part of the Tha Chin and Mae Klong Rivers.

The objective of this study is to assess water use in the river basin, especially the amount of irrigation water for the Greater Mae Klong Irrigation Project, which is a large complex irrigation area. The result of the application also was used to verify the limitations of the present model on the water management and allocation sub-model as the first step to add components of the water requirements for several agricultural activities.

2. STUDY AREA AND DATA

2.1 Study area and river schematic

The study area consists of three river basins: the Mae Klong (approximately 30,000 km²), Tha chin (13,500 km²) and Phetchaburi river basins (6,500 km²), with a total area of approximately 50,000 km² in the western part of Thailand (Figure 1). The study area was selected based on the irrigated areas of the Greater Mae Klong Irrigation Project, that is, the irrigated areas encompassed by the boundaries of the Mae Klong, Tha Chin and Petchaburi river basins with percentages of irrigation area at 45, 50 and 5 percent, respectively.

Figure 2 shows the schematic of river and drainage system in the study area. The Mae Klong River Basin is fed by two main tributaries, namely the KwaiYai and KwaiNoi Rivers, which are controlled by two large multi-purpose reservoirs, the Srinagarind (storage capacity, 13 billion m³) and Vajiralongkorn Dams (storage capacity, 13 billion m³), respectively. These two dams store water in large, perennial storage type reservoirs, both of which are operated by the Electricity Generation Authority of Thailand (EGAT), the main objectives being irrigation, domestic use in western areas of Bangkok and protection of salt water intrusion in the Mae Klong and Tha Chin rivers, while power generation is a by-product of those releases. Downstream from station K3A, there is a large barrage that has a series of gates as diversion dams, namely the Mae Klong Diversion Dam, and the Royal Irrigation Department (RID) uses this facility to regulate the intake of irrigation water for the Greater Mae Klong Irrigation Project, and water for water supply in Bangkok. Moreover, during dry years, RID conveys water to protect salt water intrusion in the Tha Chin River through the irrigation canal, namely the Chorakae Samphan Canal (Fig. 2).

The Tha Chin River Basin is one of the many sub-river basins of the Chao Phraya River. The main tributary of the basin, the Tha Chin River, originates from the upper part of the basin. However, the Tha Chin River is connected to the Chao Phraya River on the right bank by the intake gate (Pholthep Gate) which is regulated by the Chao Phraya Diversion Dam. The Tha Chin River is used as the main irrigation and drainage canal for the western areas of the Greater Chao Phraya Irrigation Project. The KrangKrajan Dam (storage capacity, 3 million m³) has been constructed on the Phetchaburi River to mainly irrigate water for the Phetchaburi Irrigation Project. On the other hand, excess water in the Mae Klong Irrigation Project is drained to the Tha Chin River through two main drainage canals, namely the Tha San Bang Pla and Tha Ruae Bang Pha Canals, which is the same as the Phetchaburi River, which receives drained water from lower areas of the Greater Mae Klong Irrigation Project (Figure 2).

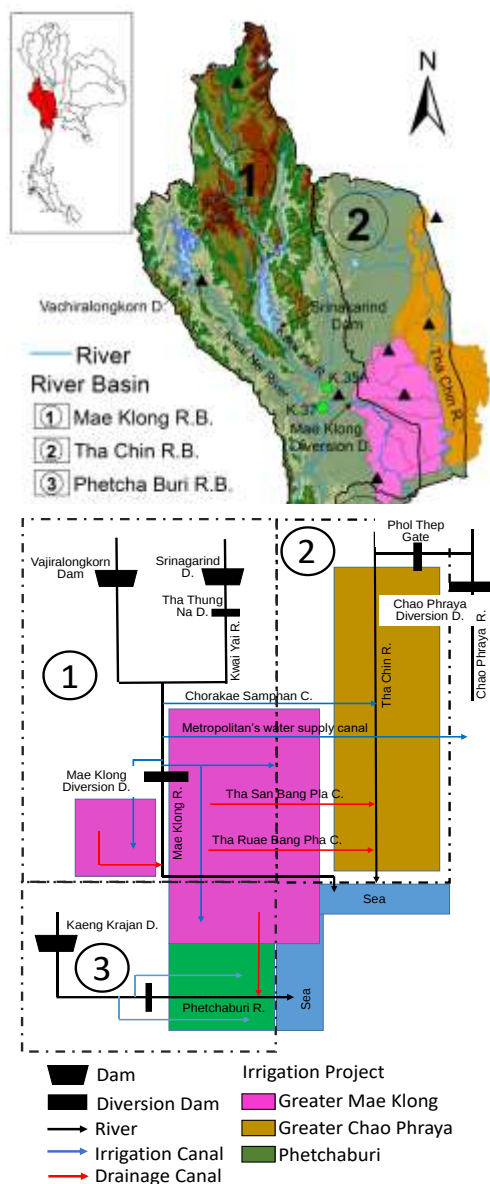


Figure 2. Schematic of river system in the target areas

2.2 Meteorological and hydrological data

Daily rainfall and meteorological data (2007–2015) was collected from the U.S. National Oceanic and Atmospheric Administration for the 11 stations (**Figure 1**). The meteorological data includes rainfall, maximum temperature, minimum temperature, and average temperature, wind speed at 2 meters, visibility and relative humidity. The data was used for calculating evapotranspiration based on the FAO-Penman-Monteith equation. Data for the period of missing records was filled by using normal ratio method which consists of weighting the rainfall value by the ratios of the normal annual rainfall values. Then, the method of using a double-mass curve was used to verify the consistency of the data by comparing the data at target stations with records from a group of other stations in the same area. Finally, the data was interpolated into each cell in the target area by using the inverse distance weighted method, which produced a weighted average of inverse numbers of distances between a cell and station.

For hydrological data, monthly discharge and cross-section data was gathered from RID, while the data of dam management, including inflow, release and storage at the Srinagarind and Vajiralongkorn dams was collected from EGAT. Those were used in the process of model calibration which is explained in **section 4**.

2.3 Land use

Land use data was created in 2010 based on surveys carried out by the Land Development Department, Thailand (LDD). Land use data was mainly classified into five categories: Forest, Agricultural, Water Body, Urban Area, and Others (e.g., mines). Table 1 shows the area size of land use types in the three river basins and each irrigation areas. Concerning sub-categories of agricultural areas, there are several types of agricultural land use, such as paddy fields, upland crop fields, perennial crop fields, fisheries and vegetable fields. The upper areas of these three river basins are almost completely covered by forests in mountainous areas, while the agricultural land, including irrigation and non-irrigation areas, extend over inter-mountainous regions, and low-lying regions are covered with irrigated areas. For agricultural lands in the Greater Mae Klong Irrigation Project, only 40% is covered by paddies, and more than half is covered by other agricultural lands (Table 1). For other irrigation areas, almost all irrigation lands are covered by paddies, at a rate of more than 70%.

2.4 Water allocation and management

The Srinagarind and Vajiralongkorn dams are the main sources of water for several activities in the lower areas of the Mae Klong and Tha Chin river basins. The water required from these two large dams is mostly for irrigation, ecology and domestic use. The water management plan takes into the considerations of water requirement for all water use activities and remaining storage of two large dams. There are four main activities for water use which are allocated by using the Mae Klong Diversion Dam and irrigation canals, as follows:

- (a) To supply irrigation water to the Mae Klong Irrigation Project during both dry and wet seasons.
- (b) To maintain the Mae Klong River by releasing water through the Mae Klong Diversion Dam at least $70 \text{ m}^3\text{s}^{-1}$ or approximately $2,200 \text{ m}^6\text{year}^{-1}$

- (c) To convey water to the Tha Chin River through the Chorakae Samphan and Tha San Bang Pla canals with diversion water of $22 \text{ m}^3\text{s}^{-1}$ or approximately $400 \text{ m}^6\text{year}^{-1}$ and $50 \text{ m}^3\text{s}^{-1}$ or approximately $800 \text{ m}^6\text{year}^{-1}$, respectively.
- (d) To directly distribute water for water supply producing in western areas of Bangkok and nearby with $45 \text{ m}^3\text{s}^{-1}$ or $250 \text{ m}^6\text{year}^{-1}$.

Although agriculture is the main water user, water management plans are set prior to supply of water during drought as 1) Domestic use, 2) Environmental use (such as protection against salt water intrusion), 3) Agricultural water use and 4) Industrial, respectively.

Table 1. Land use in sub-area categories

No	River Basin Name	Area Size (km ²)						
		Agricultural Land					Forest	Urban
		Paddy	Upland crop	Perennial crop	Fishery	Vegetable		
1	Mae Klong	1,028	3,316	1,854	182	223	20,706	966
2	Tha Chin	4,717	3,754	1,042	572	215	1,085	1,305
3	Phetchaburi	839	370	551	173	32	3,295	370
No	Irrigation Project Name							
1	Greater Mae Klong	1,544	840	729	502	252	24	787
2	Greater Chao Phraya	2,853	40	317	156	113	21	874
Note: The Greater Chao Phraya Irrigation project is only irrigation areas in The Thai Chin River Basin								

3. MODELING OF THE DWCM-AGWU MODEL

1.1 Original model

The DWCM-AgWU (Masumoto *et al.* 2009; Taniguchi *et al.* 2009) was originally developed for the Mekong River Basin. The model estimates the water circulation through river basin within 0.1° (lat) $\times$ 0.1° (long) cells by considering the component of agricultural water use via four sub-models: (1) the Reference Evapotranspiration Forecast sub-model estimates the reference evapotranspiration based on the modified Penman-Monteith equation; (2) the Cropping Time and Area Forecast sub-model projects changes in the cropping area; (3) the Paddy Water Use sub-model calculates the amount of irrigation water used for the crops; and (4) the Runoff sub-model forecasts the runoff and changes in soil water content.

1.2 Dam management and its modification on co-operation of reservoir's management

The storage $V_{res}(t)$ [m³] of a reservoir can be calculated from Equation (1), given the storage $V_{res}(t-1)$ in the previous period:

$$V_{res}(t) = V_{res}(t-1) + (Q_{resin}(t) - Q_{resout}(t))\Delta t \quad (1)$$

Where Δt [days] is the duration of a single calculation step. The reservoir inflow $Q_{resin}(t)$ is given by the DWCM-AgWU, and the reservoir outflow $Q_{resout}(t)$ [m³/day] includes releases for irrigation, spillway overflow, domestic use, and hydropower generation. For irrigation, the reservoir releases supplementary water to compensate for the shortage of necessary intake based on a comparison of agriculture water demand and river discharge at the intake point. Furthermore, a co-operation of reservoir's management is one of modification on the DWAM-AgWU to connect two large reservoirs with remoted irrigated areas (Vongphet *et al.* 2016). This modification was modified and used to estimate release for irrigation, that is, the release for irrigation water requirements from each dam was determined by considering the ratio of the remaining storage in each dam to the total remaining storage and water requirement in the irrigation areas.

Irrigation release, Srinagarind or Vajiralongkorn Dam

$$= \sum \text{irr. Req (Mae Klong Irr. Proj)} \times \frac{\text{Storage in Srinagarind or Vajiralongkorn Dam}}{\sum \text{Storage in Srinagarind and Vajiralongkorn Dams}} \quad (2)$$

3.3 Water allocation and management model

This model estimates the actual intake at a specific point and the water supply to paddy fields in irrigated areas (Kudo *et al.* 2013). That is, water to be taken and supplied to the area is the river discharge of the intake cell (Q_{riv}), the water demand of the area (Q_{dmnd}), or the capacity of the facilities (Q_{cap}), whichever is the smallest.

$$Q_{div} = \min(Q_{riv}, Q_{cap}, Q_{dmnd}) \quad (3)$$

The amount at which water is distributed to the cell is the projected gross water requirement, which accounts for the irrigated area of each cell and the irrigation efficiency.

4. APPLICATION OF THE MODEL

We applied the DWCM-AgWU to the study area including three river basins in the western part of Thailand, namely the Mae Klong, Tha Chin, and Petchaburi river basins. The simulation was carried out with a one-day time step during the years 2008-2015. However, the year of 2008 was used as a spin up year, the accuracy of the model calculation was validated by using results during 2009-2015 as the target period.

The model parameters were determined by trial and error such that the simulated daily inflow matches the observed value into the Srinagarind and Vajiralongkorn dams for the target period from 2009 through 2014. Observed releases from the Srinagarind and Vajiralongkorn dams were used as input river discharges, to determine model parameters for the reaches in lower areas, the KwaiYai and KwaiNoi rivers, the accuracy of the model in these areas was validated at the stations K.35 A and K.37, respectively, by comparing the monthly observed and calculated river flow volumes.

A co-operation of reservoir's management model was modified and used to connect both dams with the Greater Mae Klong Irrigation Project to estimate irrigation water which is supplied to paddies in irrigated areas. In this model, water for domestic use is also taken into consideration for the water releases of both dams. However, the reservoir and water allocation and management models consider only water demand of the irrigation areas for paddies, while there is no consideration of water supply for other agricultural activities.

5. RESULT AND DISCUSSION

1.3 Estimated result for river flow

Figures 3(a) and **3(b)** show the comparison between the calculated and observed inflow discharge and river discharge at the Srinagarind Dam and Station K. 37, respectively (**Figure 1**). Model accuracy was validated for data from 2009-2014. Inflow at the Srinagarind and Vajiralongkorn dams was selected to assess the accuracy of the model for the upper parts of the basin which are covered by forest. The relative errors of calculated and observed monthly inflow at the Srinakarind and Vajiralonkorn dams were 25% and 58%, respectively. The relative error of the calculated monthly river flow volumes in relation to observed values at station K.35A and K.37 were 12 % and 11 %, respectively. These value validate model accuracy in the lower reaches with are affected by the management of the Srinagarind and Vajiralongkorn dams. The results indicate that the fluctuations in the discharge during the rainy and dry season are well reproduced by the model in both the sites. However, there remain some discrepancies at the peaks.

5.2 Assessment of performance of model on agricultural water use

To illustrate the effects of applying the water allocation and management sub-model, the amount of irrigation water which is intake to the Greater MaeKlong Irrigation Project was selected to assess the performance of the model. In the model, there are two intake facilities supplied irrigation water to eastern and western areas of the Greater Mae Klong Irrigation Project. The calculated results of intake water were calculated based on irrigation requirements for paddies.

Figures 4(a) and **4(b)** show typical comparison between calculated intake water and observed values for eastern- and western-areas of the Mae Klong Irrigation Project.

As the result, in dry season (Jan.-Jun.), the averaged ratio of the calculated intake water in relation to the observed values for eastern and western irrigation areas were 0.54(0.44-0.64) and 0.87(0.81-0.96), respectively. While, in the rainy season the ratio in eastern and western were 0.69(0.48-0.87) and 0.98(0.8-1.18), respectively. The results in the western areas of the Mae Klong Irrigation Project more closely than the eastern areas because agricultural lands in western are mainly cover by paddies, while, the areas in eastern are cover by several agricultural lands as paddies, perennial crops and upland crops especially for sugar cane. However, from the result, agricultural water for other

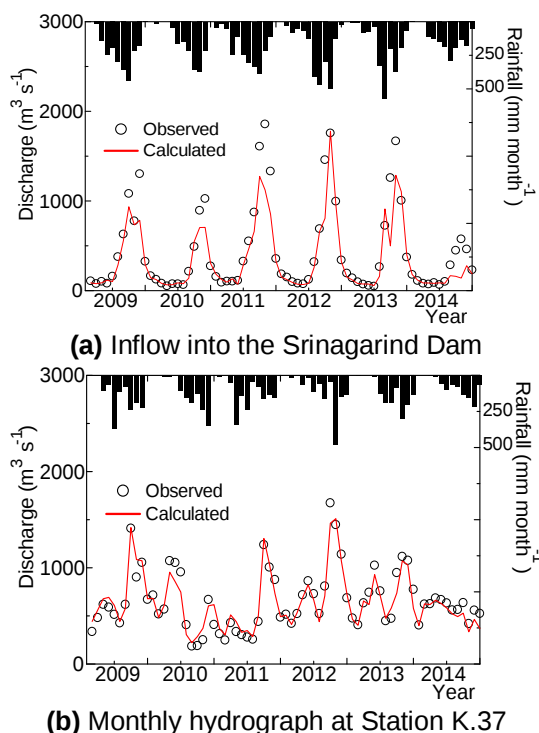


Figure 3. Comparison of obs. And Calc. monthly inflow and hydrograph

activities except rice cultivation are also important for this region especially in the eastern areas.

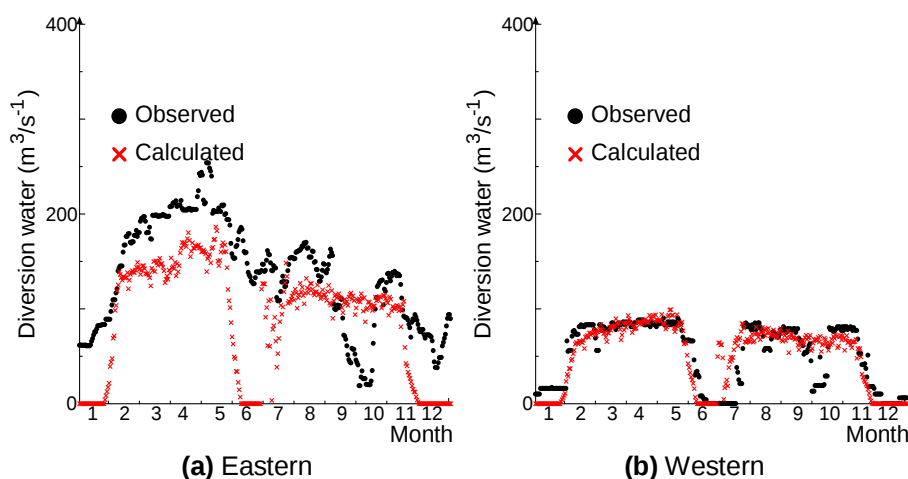


Figure 4. Comparison of observed and calculated diversion water for Eastern- and Western-areas of the Mae Klong Irrigation Project in the 2012

5.3 Remaining problems

The model considers agricultural water use only for rice cultivation. There is no function to estimate water use for other agricultural land such as upland and perennial crops which are main water user in this basin. The Cropping times & areas and Paddy water use sub-models should be improved to consider component of agricultural water use for others activities through the basin. As well as, for the irrigation regions, the Dam management and Water allocation & management sub-models should be adding calculation of water requirement for other agricultural lands in the irrigation releasing. Moreover, water amount for water supply, as water for domestic use, is not considered in the Water allocation & management model even though the dam operation sub-model has a release function for this user. Water supply are also important water user, therefore amount of diversion water for water supply ought to combine in the Water allocation & management model.

6. CONCLUSIONSAND RECOMMENDATION

The DWCM-AgWU was applied to the targeted river basins which mainly emphasize the Mae Klong River Basin. The Srinagarind and Vajiralongkorn dams are the most important facilities with respect to the management of water use in many sectors as agricultural water use in remote irrigation systems, domestic use including water supply for the Bangkok areas and protection against salt water intrusion in the Mae Klong and Tha Chin rivers. Hence, dams and irrigation systems are important for agricultural water resource management. The model allowed us to calculate water circulation integration with water management from human activities, especially water management for agricultural use, which is the principal water use. There are several agricultural activities, such as sugar cane, vegetables, perennial crops and fisheries, for which water is supplied through irrigation canals. However, our model considers only irrigation water use for paddies.

In the future, the DWCM-AgWU will be expanded to include further calculations of irrigation water use, and upland and/or perennial crops and fisheries should be

considered. Water requirements for each agricultural activity should be calculated by using a database on monthly crop coefficients. Moreover, urban areas are also an important consideration in overall water use. However, domestic use from main streams is not considered even though the dam operation sub-model has a release function for domestic use. This type of component would be calculated based on the size of the area or the area population. The results obtained by using this model will be fundamental for expanding the model on the components of irrigation water, which is the main water use. The model will allow the development of adaptive measures to mitigate the effects of extreme weather conditions, especially, drought. Application of this improved model should be helpful in the future management of water resources.

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