EFFECT OF CLIMATE CHANGE ON WATER MANAGEMENT IN LOWER CHAO PHRAYA RIVER

Sanit Wongsa*
dept. Civil Technology Education, FIET
King Mongkut's University of Technology Thonburi
Bangkok, Thailand
sanit.won@kmutt.ac.th

SunareeSueathung
dept. Civil Technology Education, FIET
King Mongkut's University of Technology Thonburi
Bangkok, Thailand
kungsunaree@hotmail.co.th

***Abstract*—Climate change causes serious risks to the well-being of nature and people all over the world. Within the estuaries, sea water can be the important controls of water level, salinity and coastal erosion. The objective of this study is to evaluate the effect of climate and sea level changes on water management in lower part of Chao Phraya River, by using MIKE11 model. The study covered the area from Chao Phraya Dam (barrage), Chai Nat Province to the river estuary at the Gulf of Thailand, SamutPrakan Province. The model was divided into two parts, hydrodynamic (HD) module and advection-dispersion (AD) module. Calibration of each part was done by adjusting its important coefficients. It was observed that the Manning's coefficient (n) and coefficient dispersion of mass were in the range of 0.025-0.040 and 800-1,600 m2/s, respectively. The results of comparison between models and observation data revealed order of forecasting error (R2) in the range of 0.70-0.99 for water level and 0.73-0.86 for salinity. For model application, the RCP2.6 and 8.5 scenario from IPCC report were simulated, sea water level rising in were 0.76 and 1.06 m (in the year of 2100), respectively. Maximum salinity at Samlae Station were 0.63-0.67 g/l, the value of 0.25 g/l exceeding standard and the pointed tip of salinity was at Ko rain sub-district, Ayutthaya Province. Results of this study can be used as guidelines for the management of water resources and agriculture of the Chao Phraya River Basin.**

***Keywords*—global warming;sea water level change; Chao Phraya river;mike11 model**

I. INTRODUCTION

Climate change has been observed have local and global effects. Most of the effects were negative. The notable phenomena effected by extreme weather events, are heavy rains, heat waves, and draught. Climate change causes serious risks to the well-being of nature and people all over the world. Within the estuaries, sea water can be the important controls of water level, salinity and coastal erosion. Although the precise effect of climate change on estuaries dynamics and its processes in the alluvial river system is still not clear, there seems to be no doubt that it influences sea water level and salinity intrusion. Recently, numerical modelling has been shown to answer some of these problems. A number of works have used numerical models attempting to simulate river catchment hydrological processes of rainfall-runoff, sediment transport, salinity intrusion and coastal erosion processes as well as to study the impact of climate change. In addition, the numerical model has been applied to predict hill slopes and river channels ([1], [2], [3], [4], [5]). Thus, it is clear that the numerical models appear to have considerable potential as tools for investigating hydrodynamic, sediment transport and water quality over long period simulation. [6] have predicted that sea water level affected rice production in Mekong Delta, Vietnam, during the flood season. However, there are a few application studies in Thailand. [7], [8], [9], [10], [11] have exploited MIKE11 model to predict sea level affecting salinity intrusion and agricultural production in Tha Chin, Mae Klong and Chao Phraya rivers. Metropolitan Waterworks Authority (MWA) reported that salinity intrusion, raw water supply and agriculturalproductivity in Chao Phraya River was affected by climate change.

Fig. 1. Study area of the Lower Chao Phraya River.

This paper addresses these issues by using a proposed MIKE11 numerical modelling to simulate the effects on sea water level change and salinity intrusion. Performance of the numerical model was applied to simulate flow events in 2100, which are water level change and salinity intrusion on agricultural and raw water supply in the Lower Chao Phraya River, Thailand. (*Fig. 1*)

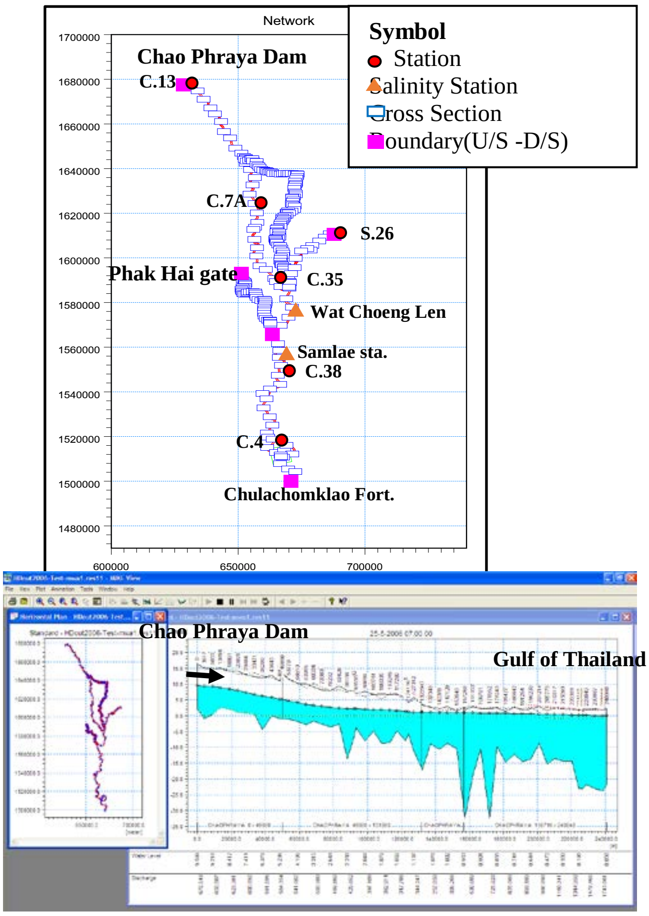


Fig. 2. Model setup.

II. DESCRIPTION OF THE SYSTEM

Chao Phraya River is the most important and largest river flowing fromNakhonSawan Province to estuary at the Gulf of Thailand in SamutPrakan Province, located at central part of Thailand. The climate of the Chao Phraya River has a tropical wet and dry or savanna climate, which generates wet and dry seasons of more or less equal length. The monsoon season is usually from May until late September and/or early October. In the wet season, averagely 1-2 tropical depressions occur over much of the area from August to October of the year. The average annual discharge is 718 m^3/s and rainfall varied between 1,122 to 1,511 mm, depending on monsoon direction and elevation.

The proposed model was applied to Lower Chao Phraya River catchment. Chao Phraya River is the most important and largest river flowing from Chai Nat Province to estuary at the Gulf of Thailand in SamutPrakan Province, located at central part of Thailand. Cities along the Chao Phraya include Chai Nat, Singburi, Ang Thong, Ayutthaya, Pathum Thani, Nonthaburi, Bangkok and SamutPrakan, listing from north to south.

However, some parts of the catchment continue to suffer from drought problems due to the uneven distribution of rainfall. Some areas experience both flooding and drought conditions in a single year, due to temporal and spatial uncertainties in the monthly rainfall or the poor management of the conveyance infrastructure. The Chao Phraya River also imports water from Mae Klong River (right bank) and Pasak River (left bank) to boost water supply, which can also multiply the risk of flooding in the downstream and Bangkok metropolitan areas. The common practice in Thailand is to manage the risks after considering which areas are likely to be vulnerable to either flood or drought. Failure to manage risk by addressing one aspect at a time can lead to adverse results. Therefore, climate change and an association with managing flood and drought risks are new challenge in Thailand and becoming increasingly important.

III. MIKE11 SOFTWARE AND MODEL SETUP

A. MIKE11 Software

The MIKE11 model has been used. This numerical model simulates water flow and salinity as a consequence of low flow conditions. The shallow water equation was used for simulation of 1-D unsteady water flow and transportation of mass was used for salinity. To modelling the river network of the Lower Chao Phraya, a digital elevation map (DEM) was applied. The model input data were cross-section, flow discharge, water level, side flow and salinity. The MIKE11 program, 6-points Abbott's finite difference scheme was used to solve governing equations, consisting of separate modules each representing a different procedure in calculation process. A first module calculated hydrodynamics of river flow (HD module), and the next module of transportation of mass (salinity intrusion; AD module). To assess the influence of the water flow and salinity impacts on climate change of the Lower Chao Phraya River catchment, the MIKE11 model has been used. This numerical model simulates water flow and salinity as a consequence of low flow conditions. The shallow-water equation for one-dimensional unsteady flow can be expressed as following,

Continuity equation:

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

Momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{M^2 A R^{4/3}} = 0 \tag{2}$$

where, Q = flow discharge (m^3/s), A = flow section area (m^2), q = side flow discharge (m^2/s), h = flow depth (m), R = hydraulic radius (m), g = acceleration (m/s^2), α = momentum correction factor, M = Strickler's Number ($M = 1/n$; n = Manning's roughness coefficient), x and t = flow direction and time, respectively.

For transportation of mass, such as, salinity can be obtained from, Advection-Dispersion equation:

$$\frac{\partial AC}{\partial t}+\frac{\partial QC}{\partial x}-\frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x}\right)=-AKC+qC_2 \qquad (3)$$

where, C = salinity concentration (mass/volume), D = dispersion coefficient (m^2/s), K = consumption rate (s^{-1}) and C_2 = Source/Sink Concentration (mass/volume).

B. Model Setup

To modelling the river network of the Lower Chao Phraya, a digital elevation map (DEM) has been used. The model input data were cross-section, flow discharge, water level, side flow and salinity. The MIKE11 program, 6-points Abbott's finite difference scheme was used to solve governing equations, consisting of separate modules each representing a different procedure in calculation process. A first module calculated hydrodynamics of river flow (HD module), and the next module of transportation of mass (salinity intrusion; AD module). The model setup of plan view and longitudinal profile of the Lower Chao Phraya are shown in *Fig. 2*.

C. Field measurements

Field measurements have been carried out at the mouth of the Chao Phraya River in Thailand. The study was conducted at the field level, saline water and temperature by using handheld multi-parameter instrument. The measurement was done between May - September, 2018 at different intervals (*Fig.3*).

Fig. 3. Chao Phraya River Field measurements.

IV. Results and Discussion

The Lower Chao Phraya River was used for calibration and verification of the proposed model. The calibration and validation have focused on the applicability of water flow and salinity intrusion by using flow conditions in the year of 2010 and 2012, respectively. Performance of the foregoing numerical model was applied to simulate scenario from IPCC SRES[12], consisting of RCP2.6 and RCP8.5, the predicted global average sea level rising from 1990 to 2100 for the SRES scenarios by using GCMs. RCP2.6 and RCP8.5are consistent with a wide range of possible changes in future anthropogenicgreenhouse gasemissions, andaim to represent their atmospheric concentrations. For model simulation, flow discharge at station C.13 (Chao Phraya Dam) and water level at Chao Phraya River Estuary (Marine Department) were adopted for upstream and downstream boundaries. Before the water flow and salinity calculation was carried out, the model was run to provide the steady state of necessary flow variables.

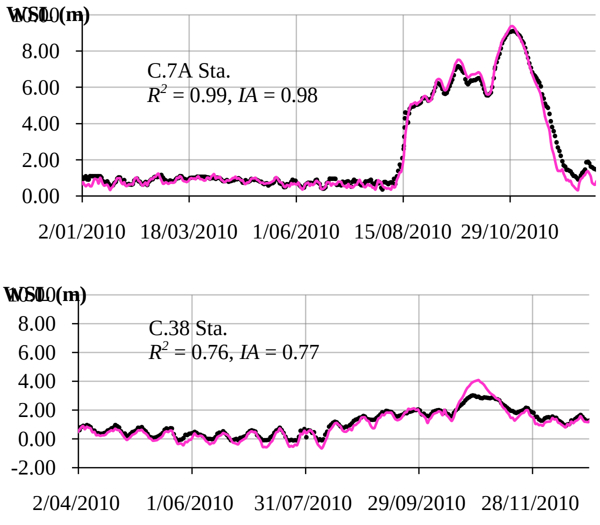


Fig. 4. Comparison of time series of stage hydrograph between simulated results (smoothed-line) and measured data (dotted) at the major gauge stations (model calibration).

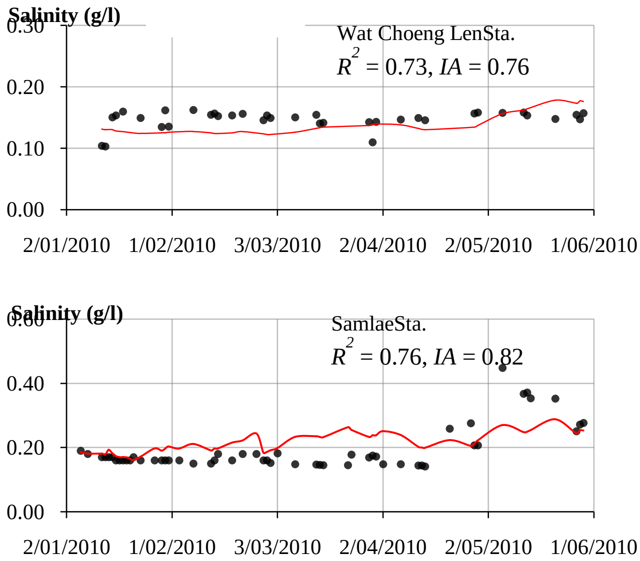


Fig. 5. Comparison of time series of salinity between simulated results (smoothed-line) and measured data (dotted) at the major gauge stations (model calibration).

A. Model Calibration

The comparison of time series of measured and simulated water surface level and salinity at two major gauge stations in 2010 and Manning's roughness coefficient (n) are shown in *Fig*. 4-5. Good agreement between the simulated and measured hydrographs for the low flow events was achieved by considering side flow and pumps in the areas. The coefficient of determinant (R^2) and Index of agreement (IA) have been used as the main criteria to judge whether the data fitted between measurement and simulation. The comparison model was followed by adjusting important coefficient for two parts. The study results, manning (n), global dispersion factor, global exponent and K_{mix} were in the range of 0.03, 800-1,600 m^2/s, 0.1-1.0 and 800-1,600, respectively. The results of comparison between models and observation data revealed order of forecasting error, R^2 and *IA* were in the range of 0.76-0.99, 0.77-0.98 for water level and 0.73-0.76, 0.76-0.82 for salinity. These indicate well fitted between measured data and this proposed model.

B. Model Verification

The comparison of time series of measured and simulated water surface level and salinity at two major gauge stations in 2012 are shown in *Fig.* 5-6. Good agreement between the simulated and measured water surface level was achieved by considering side flow and pumps in the areas. It was observed that the values of R^2 and *IA* for two major gauge stations in verification period were between 0.93-0.94, 0.97-0.98 for water level and 0.71-0.91, 0.72-0.87 for salinity, indicating well fitted between measured data and this proposed model. Good performance of simulated results was observed in both water flow and salinity intrusion characteristics, therefore, indicating that model simulation is reasonable. (*Fig.6*-7).

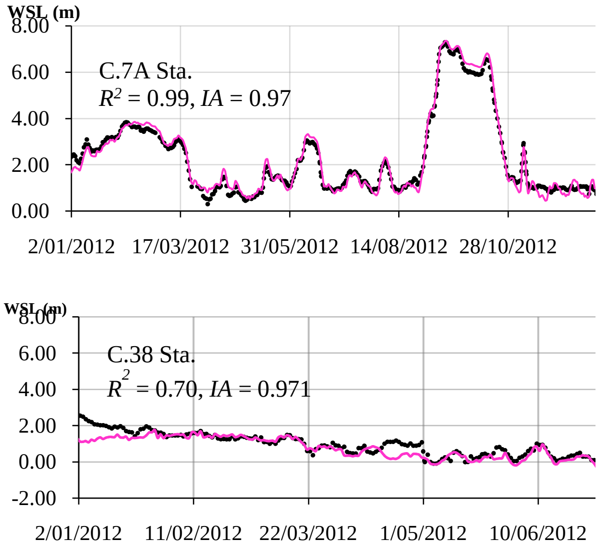
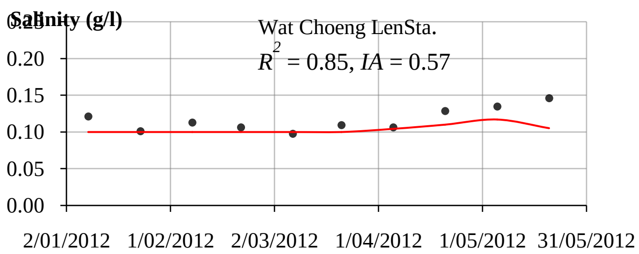


Fig. 6. Comparison of time series of stage hydrograph between simulated results (smoothed-line) and measured data (dotted) at the major gauge stations (model verification).



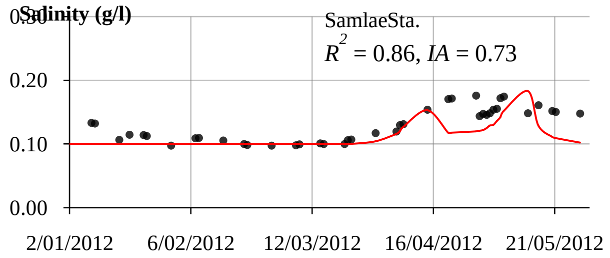


Fig. 7. Comparison of time series of salinity between simulated results (smoothed-line) and measured data (dotted) at the major gauge stations (model verification).

C. Model Application

For model application, a scenario RCP2.6 and RCP8.5from IPCC report were simulated, sea water level rising in was 0.40 and 0.70 m in the year of 2100. The comparison of time series of measured and simulated flow discharge at the major gauge stations are shown in Fig. 7-8. It was found that sea water level at the Chao Phraya estuary had rising and betaking tendency to intrusion of sea water level. Salinity was shown to be in the same tendency. For IPCC SRES in the year of 2100, sea water level rising in RCP2.6 and RCP8.5 scenario was 0.40 and 0.70 m, and salinity values and intrusion distant were in the range of 0.38-0.45 g/l and 142.0-157.0 km (from Chao Phraya Dam), and salinity at Samlae Station were 0.29-0.37 g/l. The value of 0.25 g/l exceeding standard and the pointed tip of salinity was at Bang Sai District, Ayutthaya Province. The worst case scenario, a constant value of salinity of 30 g/l was adopted at the Gulf of Thailand. It was found that salinity at Samlae Station was 0.63-0.67 g/l, the value of 0.25 g/l was at Pratuchai Sub-district, Ayutthaya Province, 133.0 km from Chao Phraya Dam. We could also observe these effects gained a more conspicuous large against higher sea water level rising (*Fig.*8-9).

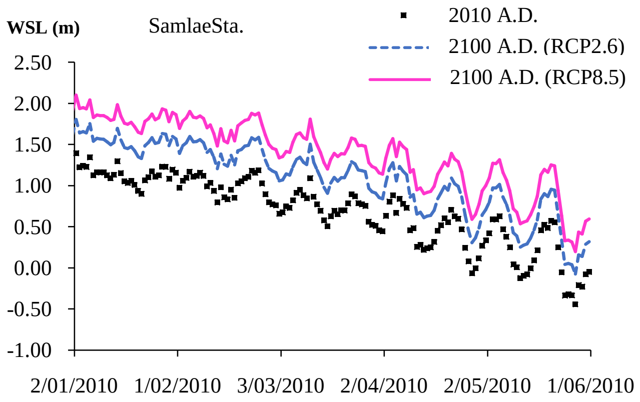


Fig. 8. Water Level in the year of 2100 (IPCC AR5), with 0.40 m and 0.70 m sea water level rising in RCP2.6 and RCP8.5 scenario

However, Metropolitan Waterworks Authority (MWA, 2011) reported that climate change affected salinity intrusion and raw water supply in Lower Chao Phraya River. The observed effects demonstrated that Samlae Pumping Station will not be available when salinity is over 0.25 and/or 0.50 g/l, and water supply shortage. The mitigation plan has suggested that the diversion from Mae Klong River and construction of new pump station for short-term and long-term, respectively. The proposed locations of a new raw water pump station along the Chao Phraya River from Ayutthaya to Singburi Province. It was found that the most suitable sites when evaluation by multi-criteria analysis (MCA) is the proposed site at KlongPongpheng, Ayutthaya Province.

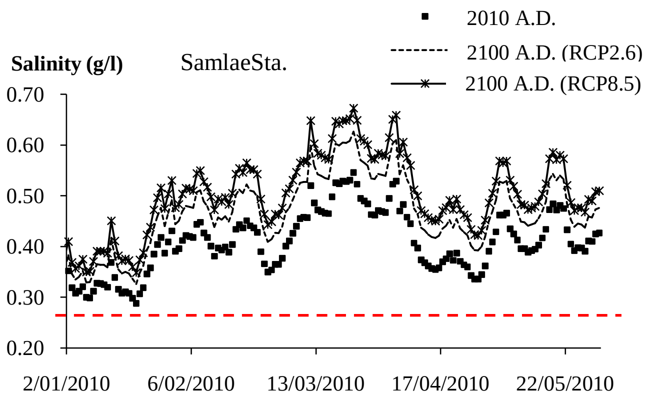


Fig. 9. Salinity in the year of 2100 (IPCC SRES), with 0.40 m and 0.70 m sea water level rising in RCP2.6 and RCP8.5 scenario and salinity 30 g/l at downstream (Gulf of Thailand).

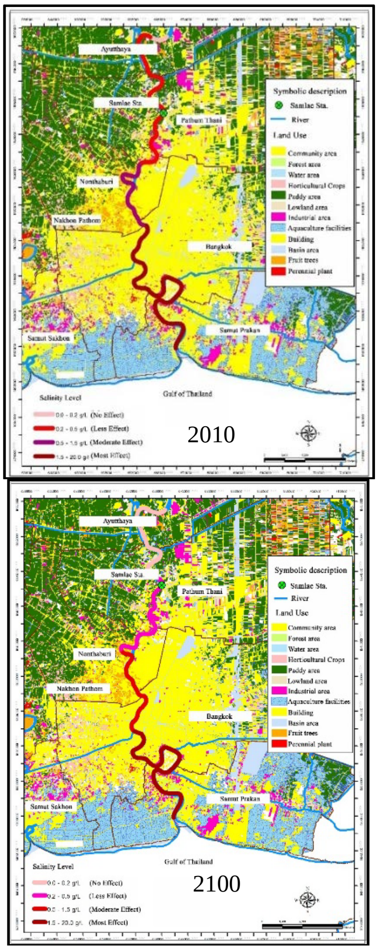


Fig. 10. Salinity profile in the year of 2010 and 2100 (IPCC SRES).

For impact analysis on the urban and agricultural areas, it was found that in the Lower Chao Phraya River sea water level change will affected the water supply in urban, and agricultural areas. Salinity level less than 0.2 g/l was not impacted; it can use irrigation for any planting. Salinity level from 0.2 had little impact, while salinity level from 0.5, and salinity level more than 1.5 g/l were highly impacted (*Fig*. 10). For agricultural sectors, the value of 0.20 g/l exceeding standard and the pointed tip of salinity was at Ban Mai District, Ayutthaya Province (123 km. from Chao Phraya Dam).

V. CONCLUSIONS

In this study, the MIKE11 model was exploited to simulate the effects of climate and sea level changes on the raw water supply of MWA and agricultural areas in the lower part of Chao Phraya River in the year 2100. The study covered the area from Chao Phraya Dam, Chai Nat Province to the Gulf of Thailand at SamutPrakan Province. IPCC SRES predicted that in the year 2100, sea water level rising in RCP8.5 scenario was 0.70 m. Based on this information, the simulation showed that salinity at Samlae will be exceeded 0.25 g/l. Therefore, it suggested to add pump station at Samlae to site at KlongPongpheng, borderline of Ayutthaya and Ang Thong Province. This will help to balance level of salinity in river not over 0.25 g/l. For agricultural sectors, the value of 0.20 g/l exceeding standard and the pointed tip of salinity was at Ban Mai District, Ayutthaya Province (123 km. from Chao Phraya Dam). Results obtained from this study will give guideline in raw water resources management for water supply and agricultural in Chao Phraya River Basin.

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REFERENCES

[1] DHI Water and Environment. MIKE11: A modeling system for rivers and channels - User Guide, Denmark, 2000.

[2] M.J.Kirby,"Modelling some influences of soil erosion, landslides and valley gradient on drainage density and hollow development". Catena Supplement, vol. 10, pp. 1-11, 1987.

[3] Metropolitan Waterworks Authority. "Potential and solution for raw water crisis: Final report", Bangkok, 2011.

[4] R., Wassmann,N.X. Hein, C.T.Hoanh, andT.P.Tuong, "Sea level affecting Vietnamese Mekong Delta: water elevation in the flood season and implications for rice production", Climate Change 66: 89-107, 2004.

[5] J.M. Wicks, and J.C. Bathurst,"SHESED: A physical based, distributed erosion and sediment yield component for the SHE hydrological modelling system", J. Hydrology, vol. 175, pp. 213-238, 1996.

[6] S. Wongsa, and Y. Shimizu,"Modelling artificial channel and landuse changes and their impact on floods and sediment yield to the Ishikari basin."Hydrological processes vol.18, pp. 1837-1852, 2004.

[7] S.Wongsa, "Distributed model for catchment scale simulation of runoff and sediment transport", Ph.D. Thesis, Hokkaido University, Japan, 2004.

[8] S. Wongsa, andC.Ekkawatapanit, "Effect of sea water level change on the management in the Lower Thachin River", report for ESS Program, King Mongkut's University of Technology Thonburi, Thailand, 2009.

[9] S. Wongsa, C. Ekkawatapanit, and K. Treerittiwitaya, “Effect of sea water level change on the management in the Lower Thachin River”, Proc. the International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies, 2010.

[10] S. Wongsa, and P. Kamolsin, and K. Inkliang “Effect of Sea Water Level Change on the Estuaries Management in the Lower Thachin and Mae Klong Rivers”, Proc. of GMSTEC 2010: International Conference for a Sustain-able Greater Mekong Subregion, 2010.

[11] IPCC, http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/412.htm

[12] S. Wongsa“Impact of Climate Change on Water Resources Management in the Lower Chao Phraya Basin, Thailand”, J. Geoscience and Environment Protection, vol.3, no.10, pp.53-58, 2015.