Investigating the effect of initial soil moisture on river discharge using pseudo-discharge data generated by a distributed hydrologic model

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***Abstract*—The initial condition of soil moisture for river discharge simulation is neglected for river planning or management. In this study, the effect of initial soil moisture on river discharge was investigated. The target of this study was the upper part of Bhumibol dam catchment in Thailand. Throughout statistical correlation test for JRA-55 atmospheric reanalysis data and CHIRPS satellite-based rainfall data, it was assumed that monthly atmospheric fields in rainy season didn't have significant autocorrelation. Therefore, a log-term atmospheric data was generated by recombining atmospheric data between August and September. And then, a long-term pseudo-discharge data was generated utilizing a distributed hydrologic model using recombination atmospheric data. Annual maximum daily river discharge from a pseudo-discharge data was evaluated by comparing the river discharge data generated by original atmospheric data and a distributed hydrologic model. It was found that significant difference was not detected with 10% level between a CDF from the former data and that from the latter data. Annual maximum daily river discharge from a pseudo-discharge data could be categorized into two groups. First one was the data using same rainfall, another one was the data using same initial soil moisture. Analyzing each data, it was estimated that the effect of rainfall on river discharge was 718 cubic meter per second and the effect of initial soil moisture was 127 cubic meter per second.**

Keywords—river discharge, soil moisture, distributed hydrologic model

I. Introduction

For river planning and basin water resources management, it is necessary to determine the design water level which has long term return period. In general, observation record is shorter than that. Therefore, pseudo-discharge data is generated much enough to determine design level. There are many methods for generating pseudo-discharge data. The typical one is to prepare various spatial and temporal patterns of rainfall and calculate discharge by them utilizing rainfall-runoff simulation model. In this method, it is assumed that the initial condition has no impact on that peak discharge. However, some papers mentioned that initial soil moisture may affect flood [1] [2].

For considering the effect of initial soil moisture on discharge explicitly, it is better to utilize a distributed hydrologic model. Yorozu and Tachikawa have developed a distributed hydrologic model which consists of land surface model SiBUC and flow routing model 1K-FRM [3]. In their model, runoff is calculated according to soil moisture content which is updated based on the diurnal cycle of atmospheric condition. In this sense, a distributed hydrologic model must be utilized for much longer period to consider soil moisture impact on discharge.

In previous study, some method has been developed for generating pseudo-discharge data of Bhumibol dam inflow utilizing a distributed hydrologic model [4]. In that study, numerous atmospheric data was created by recombining both atmospheric reanalysis data and satellite based observed rainfall data as a data could be happened in actual situation. And then, Bhumibol dam inflow was calculated utilizing a distributed hydrologic model by those data. Unfortunately, in that paper, the effect of initial soil moisture on discharge wasn't analyzed well because of precipitation data accuracy. Therefore, the objective of this paper is to investigate the effect of initial soil moisture on discharge updating preparation of precipitation data on previous paper.

II. Methodology

A. Target catchment

In this study, Bhumibol dam inflow is set as target discharge for analyzing the effect of initial soil moisture. Bhumibol dam is one of the biggest dam in Thailand and located in upper part of Ping river basin, northern east part of Thailand. To simulate Bhumibol dam inflow, upper part of Bhumibol dam is a target catchment of this study.

B. Distributed Hydrologic Model

Yorozu and Tachikawa [3] have developed a distributed hydrologic model which consists of land surface model SiBUC and flow routing model 1K-FRM. A land surface model SiBUC is originally from the Simple Biosphere model. SiBUC uses a mosaic approach to incorporate the effects of land surface heterogeneity on land surface fluxes. A flow routing model 1K-FRM is based on one-dimensional kinematic wave theory (http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/1K-DHM.html).

SiBUC provides surface and sub-surface runoff, and irrigation water withdrawal with 1K-FRM as lateral inflow. On the other hand, 1K-FRM provides the river discharge rate as the irrigation water source for the irrigation scheme in SiBUC.

This distributed hydrologic model was tested for 2011 Thailand large flood. As a result, simulated peak inflow is 3410 $m^3 s^{-1}$, which error is 57 $m^3 s^{-1}$ (1.7%), and peak timing is same as observation. The Nash-Sutcliffe coefficient for daily inflow is 0.79. Those result could conclude our model has enough ability to reproduce flood discharge.

C. Generating Atmospheric Data

In this study, JRA-55 atmospheric reanalysis data [5] and CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) [6] rainfall data are utilized for implementing a distributed hydrologic model. Yorozu *et al.* [4] checked whether monthly atmospheric data have auto-correlation with one-month time-lag on upper part of Bhumibol dam catchment. Through their analysis, they concluded atmospheric data between August and September could be assumed to be not related. Then, numerous atmospheric data ware generated by recombining atmospheric data between August and September.

D. Simulation

Following previous study [4], two kinds of simulations were carried out in this study. One of the simulations is done by actual time series of atmospheric data. Another is done by recombined atmospheric data. Hereafter, the former one is called as CONT simulation and the latter one is called as RECOM simulation.

In previous study, monthly precipitation amount by JRA-55 was corrected by that by CHIRPS. In this study, daily precipitation amount by JRA-55 was corrected for more precise analysis. The CONT simulation covers from 1983 to 2016, total 34 years. According to the previous study, time series of atmospheric data was recombined between August and September. For example, atmospheric data from January to August in 1983 was combined with atmospheric data from September to December in 1985. This means that the combination of data from January to August is 34 years and the combination of data from September to December is also 34 years. Then, the RECOM simulation consists of 1156 years which means 34 years multiplied by 34 years. While the RECOM simulation actually includes the CONT simulation, all the simulation data is analyzed as it is because this paper doesn't focus on comparison of them.

Each 1156 years result in RECOM simulation can be divided two groups. One is different atmospheric data after September is used but same atmospheric data before August. Another one is vice versa. The first group is expected to show the impact of rainfall pattern on discharge because there is same soil moisture at the end of August but different rainfall pattern after September. The second group is the result by using different atmospheric data before August is used but same atmospheric data after September. This group is expected to show the impact of soil moisture before flood event on discharge because there is different soil moisture at the end of August but same rainfall pattern after September which usually causes flood in upper part of Bhumibol dam catchment.

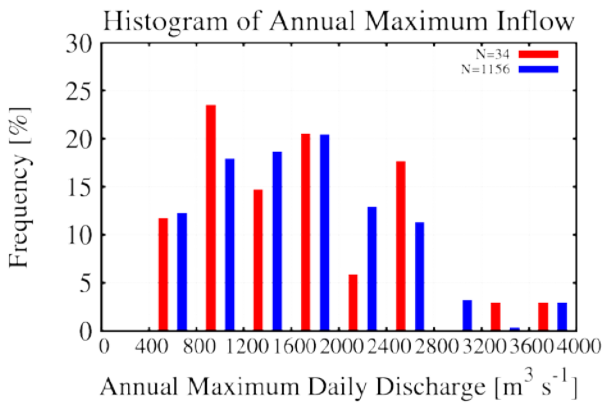

Fig. 1 Histogram of annual maximum inflow estimated by CONT simulation (red) and RECOM simulation (blue).

III. Result

A. Annual Maximum Daily Discharge

A distributed hydrologic model carried out for 34 years in case of CONT simulation which uses actual time series of atmospheric data and for 1156 years in case of RECOM simulation which uses recombined atmospheric data. Therefore, 34 of annual maximum daily discharge can be derived from the result of CONT simulation and 1156 of that from RECOM simulation.

The histogram of annual maximum daily discharge for both simulations is shown in Fig. 1. In that figure, red bar shows the histogram by CONT simulation and blue bar shows that by RECOM simulation. It can be seen that both histograms look similar. Two sample Kolmogorov-Smirnov test, generally utilized, was implemented for identifying the difference of those distributions. As a result, null hypothesis, which is that populations of both data follow different distributions, was rejected with 10% significant level. It concluded that the difference between the distribution of annual maximum daily discharge for CONT simulation and that by RECOM simulation is not detected. It is assumed that the annual maximum daily discharge by RECOM simulation is reasonable.

Then, let's focusing on maximum value of annual maximum daily discharge in each simulation. In CONT simulation, maximum value is 3676 $m^3 s^{-1}$. However, maximum value in RECOM simulation is 4002 $m^3 s^{-1}$. This difference may be caused by the difference of soil moisture at the end of August.

B. Effect of Rainfall Pattern

It is possible to investigate the effect of rainfall pattern on discharge analyzing result which was used different

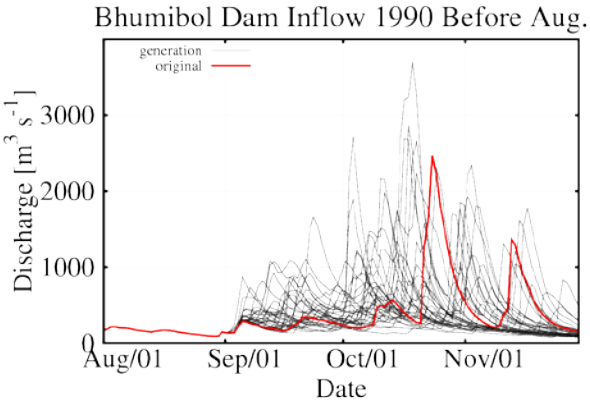

Fig. 2 Hydrographs for Bhumibol dam inflow by CONT simulation in 1990 (red) and RECOM simulation in which atmospheric data in 1990 is used from January to August (grey).

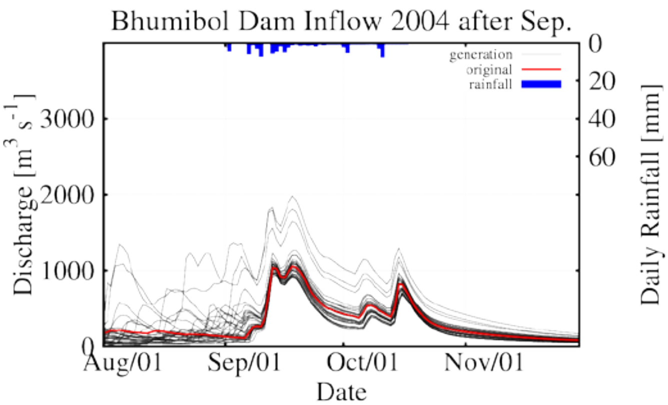

Fig. 4 Hydrographs for Bhumibol dam inflow by CONT simulation in 2004 (red) and RECOM simulation in which atmospheric data in 2004 is used from September to December (grey). The blue bar is hyetograph in 2004.

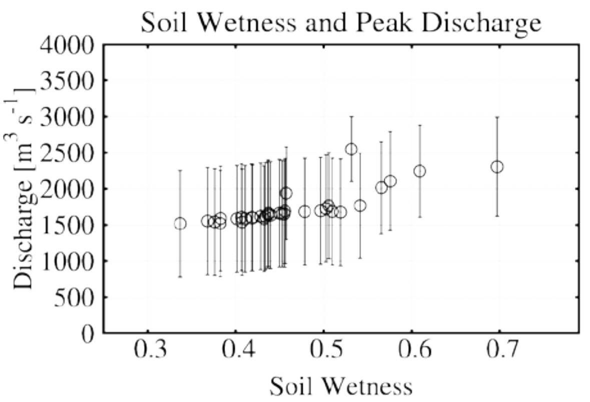

Fig. 3 Averaged annual maximum daily discharge (circle) and standard deviation (bar) by RECOM simulation in which same atmospheric data is used from January to August. Horizontal axis is catchment averaged soil moisture at the end of August.

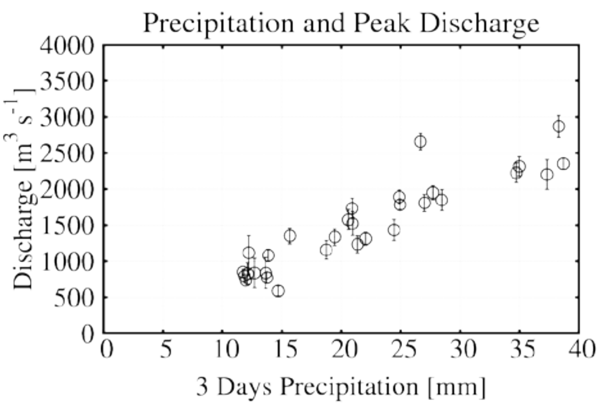

Fig. 5 Averaged annual maximum daily discharge (circle) and standard deviation (bar) by RECOM simulation in which same atmospheric data is used from September to December. Horizontal axis is catchment averaged three days rainfall after September.

atmospheric data after September and same atmospheric data before August. Because there is same soil moisture at the end of August but different rainfall pattern after September. Fig. 2 shows hydrographs in which atmospheric data in 1990 is used from January to August because this case shows highest variation of annual maximum river discharge. From that figure, it can be seen that there is no different time series of discharge until the end of August because atmospheric data is same and different pattern after September because atmospheric data is different among simulations.

Annual maximum daily discharge is 2467 m^3 s^{-1} by CONT simulation. On the other hand, in RECOM simulation maximum value of annual maximum daily discharge is 3696 m^3 s^{-1}, minimum value is 623 m^3 s^{-1}, average value is 1662 m^3 s^{-1} and standard deviation is 743 m^3 s^{-1}. This result shows that simulated peak discharge could vary about 45%, maximum case is 5.9-fold, if there is difference of rainfall pattern.

Fig. 3 shows the relationship between soil moisture and annual maximum daily discharge. In that figure, for RECOM simulation in which same atmospheric data is used from January to August, averaged annual maximum daily discharge is shown as circle and standard deviation is shown by bar. From that figure, it can be seen that positive relation between soil moisture at the end of August and averaged annual maximum daily discharge. The standard deviation, which is indicated by bar in that figure, could be assumed to show the effect of rainfall pattern on discharge estimation. From the result, it is calculated by 718 m^3 s^{-1}.

C. *Effect of Initial Soil Moisture*

It is possible to investigate the effect of soil moisture before flood event on discharge analyzing result which was used different atmospheric data before August and same atmospheric data after September. Because there is different soil moisture at the end of August but same rainfall pattern after September which usually causes flood in upper part of Bhumibol dam catchment. Fig. 4 shows hydrographs in which atmospheric data in 2004 is used from September to December and hyetograph in 2004 because this case shows highest variation of annual maximum river discharge. From that figure, it can be seen that there is different time series of discharge until early September because atmospheric data is different and similar pattern after rainfall event in early September because atmospheric data is same among simulations.

Annual maximum daily discharge is 1053 $m^3 s^{-1}$ by CONT simulation. On the other hand, in RECOM simulation maximum value of annual maximum daily discharge is 1982 $m^3 s^{-1}$, minimum value is 931 $m^3 s^{-1}$, average value is 1117 $m^3 s^{-1}$ and standard deviation is 237 $m^3 s^{-1}$. This result shows that simulated peak discharge could vary about 21%, maximum case is 2.1-fold, if there is difference of soil moisture at the end of August.

Fig. 5 shows the relationship between maximum three days rainfall after September and annual maximum daily discharge. In that figure, for RECOM simulation in which same atmospheric data is used from September to December, averaged annual maximum daily discharge is shown as circle and standard deviation is shown by bar. From that figure, it can be seen that positive relation between three days rainfall after September and averaged annual maximum daily discharge. The standard deviation could be assumed to show the effect of soil moisture before flood event on discharge estimation. From the result, it is calculated by 127 $m^3 s^{-1}$ which is one third of the effect of rainfall pattern on discharge.

IV. SAMMARY

Following precious study [4], numerous atmospheric data was generated by recombining atmospheric data and huge amount of pseudo-discharge data was created utilizing a distributed hydrologic model for the upper part of Bhumibol dam catchment. By using generated pseudo-discharge data, the effect of rainfall pattern on discharge and that of initial soil moisture on discharge were analyzed. As a result, the former one is calculated by 718 $m^3 s^{-1}$ and the latter one is calculated by 127 $m^3 s^{-1}$. From this study, it is seemed that the effect of initial soil moisture on discharge is not negligible.

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