

Linear Programming for Optimal Reservoir Operation of Chao Phraya River Basin

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ABSTRACT: This paper presents the optimization of reservoirs operation in Chao Phraya basin of Thailand. Linear Programming was applied to calculate the optimal volumes of water released and water storage of Bhumibol and Sirikit reservoirs. The results are the optimal solutions that compare with the actual volume in year 2011 and 2012. It helps decrease the volume of downstream flood peak, if applying the results controls the reservoirs operation.

KEYWORDS: Optimization, Reservoir Operation, Linear Programming, Water Released, Water Storage, Chao Phraya basin.

I. INTRODUCTION

Severe flooding occurred during 2011 in Thailand that was a long period since the beginning until the end of the year and resulted in heavy damage of agriculture, of industrial, of social, and so on. The provinces of Northern and Central Thailand along Chao Phraya river basin were affected by the severe flooding including the Metropolitan area of Thailand. This flooding disaster occurred due to several causes. The important causes were the rain season coming in that year and the cumulative rainfall in the country higher than the average 35%. The factors of these causes were as follows:

- La Niña phenomenon occurred in the first half and the end of 2011.
- The influence of monsoon, Thailand has been affected directly and indirectly by the storms which moving in the South China Sea. There were five tropical storms that were Hai Ma, Nock Ten, Hai Tang, Ne Sat and Nal Kae Tropical Storms.
- Monsoon trough and local wind, from May to October 2011, the monsoon trough continued to prevail over Thailand especially the upper and middle of country. These resulted in the heavy rains and flooding cover many areas of Thailand.

Moreover, Bhumibol and Sirikit reservoir's accumulated inflow had the highest volumes in the past several years. There were also limitations on the drains due to flooding in the areas from the downstream of the reservoirs.

The reservoirs management in flood season from May to October each year, the water in reservoirs is released to prepare for upcoming rainy season since the beginning of rainy season. However, if it is necessary to drain the large volume of water from reservoirs, the impact of downstream flooding areas problems should be considered as well. Therefore, it is required to determine the reservoirs operating rules which are the operation criteria to be adopted to control the volume of water in the reservoirs according to the desired objectives. These rules are scenario planning for water storage and released from the reservoirs in each period and each situation and be able to actually operating. The scenarios are set up from trends or the past and the recent information together with the uncertainties that may occur in the future such as the rainfall over the catchments affect water inflows of reservoirs. Therefore, there can be many situations depending on these trends and uncertainty occurrences. These scenarios should cover all potential circumstances that may occur in the future as much as possible. Thus, the reservoir operating rules are a useful tool to operate the reservoir. There are several scenarios, each of which is the water release from the reservoir or the required water storage volumes of reservoir in each period of the year.

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The principle of the reservoir operating rule is to plan the water released volume of each reservoir during the given period. This is to provide adequate storage for inflow and protect overflow causing flood disaster in downstream areas. However, if the water flows over the spillway, the overflow rate should be a minimum volume. Meanwhile, to maintain sufficient water volume in the reservoir for use in the dry season, the adequate water meets demand. The upper rule curve is the maximum water storage volume or water level in reservoir that are not overflowed and used to be the reservoir operating criteria. During the dry season, the water should also be determined and maintained volume in the reservoir within each given period. It helps reduce the risk of water shortages. The lower rule curve is the water volume or the water level that should be maintained lower and not caused drought in the future and used to be the reservoir operating criteria. One way to develop operational rules of the reservoir can develop an implementation plan by the optimization model.

Optimization is a procedure of finding the best values of objective functions given a set of constraints which lead to highest levels of system performance. This process will be applied to the reservoir management for the purpose of flood control in the downstream areas of the basins. Considering the normal retention level and volume of water released from the reservoir to meet the demand for irrigation water. Linear Programming is applied to improve efficiency of reservoirs for the reservoir management. This mathematical model is as follow:

$$\text{Min. } \sum_{r \in R} c_r f_r$$

Paper is organized as follows. Section II describes the Chao Phraya river basin structure and Linear Programming in background. Linear Programming is applied to operate the reservoirs in Chao Phraya basin that is given in Section III. Section IV presents experimental results showing results and conclusion. Finally, Section V presents discussion and future work.

II. BACKGROUND

In order to manage the reservoir with the goal of achieving the maximum efficiency, the reservoir optimization is applied to determine the reservoir operation rules.

1. The Chao Phraya basin

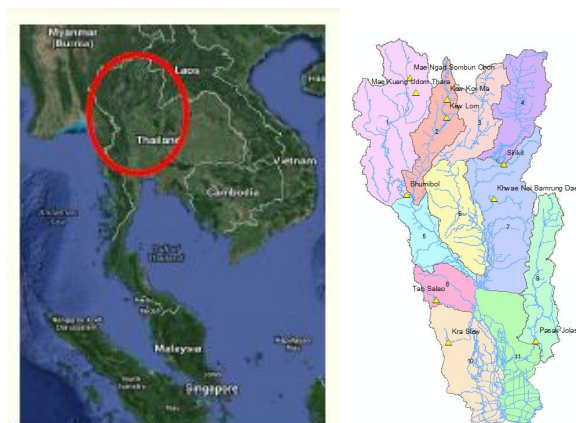


Fig.1 The Chao Phraya basin of Thailand

The study area for the implementation of this optimization is on the Chao Phraya Basin. The Chao Phraya river is the main river of Thailand. Therefore, the Chao Phraya basin is the most important basin in Thailand as shown in Fig. 1. It covers the central area of Thailand. The Basin can be divided into eight sub-basins. The headwaters of the Chao Phraya River originate in mountainous terrain in the northern part of the country and consist of four large rivers, the Ping, Wang, Yom and Nan. The main river system passes through many of the major population areas of the country

International Journal of Innovative Research in Science, Engineering and Technology

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including the capital, Bangkok, which is located at its downstream end [6]. These four rivers in the northern part join together to become the Chao Phraya river at NakornSawan province.

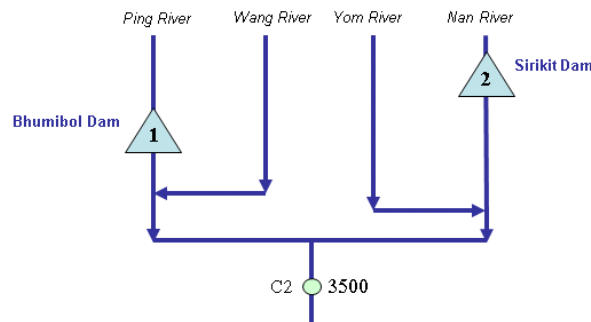


Fig. 2 Chao Phraya river basin flow and Bhumibol and Sirikit dam diagram.

There are two largest dams to control the most of the major stream flow in this basin that are Bhumibol dam is on the Ping river and Sirikit dam is on the Nan river. Both were built to supply the purposes of water storage, hydroelectric power production, irrigation, and agriculture water use. Fig. 2 illustrates the Chao Phraya Basin stream flows. The monthly optimization draining management of the reservoirs is the plan that applies the volume of water flowing from areas as follows:

- 1.1 The first zone is the volume of water flowing of Ping River, Wang River, and the volume of water released from the Bhumibol reservoir.
- 1.2 The second zone is the volume of water flowing of Yom River, Nan River, and the volume of water released from the Sirikit reservoir.

The condition is that the water released volume of each month must not be less than the demand of water in downstream areas and must reduce the volume of water at C.2 and it must not exceed 3500 million cubic meters per second.

III. LINEAR PROGRAMMING

Linear programming theory is applied to this reservoirs operating optimization with the objective functions and constraints which are the decision variables in the form of linear functions. The constraints are in form for either equalities or inequalities [4].

$$\text{Min. } \sum_{r \in R} c_r f_r$$

where R is a set of reservoirs in the area, f_r is the water flow in each reservoir, $r \in R$, and c is a penalty for the volume of water released from the reservoir.

IV. METHODOLOGY

In this work, Linear Programming technique is applied to improve the Bhumibol and Sirikit reservoirs operations in the water management of the upper Chao Phraya Basin. The objective function of this reservoir operating optimization is reducing the water flow rate in downstream areas (From Fig. 1, it is at C2 position. The water volume at C2 must not exceed 3500 million cubic meters per second.) by the water released volume from the reservoir controlling and increasing the water storage volume in the reservoirs. The conditions of this optimization are two followings.

1. The volume of water released from the reservoir must have no less than the water demand in each irrigation area.
2. The volume of water storage in reservoirs must not exceed the upper rule curve of each reservoir.

The optimal solution of this problem is applied with Linear Programming model. It has the objective function which is the linear function and all the conditions are as the linear forms. The mathematical model is

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$$\text{Min: } \sum_{r \in R} c_r f_r$$

where R is a set of reservoirs in the area, f_r is the water flow in each reservoir, $r \in R$, and c is a penalty for the volume of water released from the reservoir. The conditions are as follows:

1. The reservoirs have the condition mathematical model that is

$$S_{t+1} = S_t + I_t - R_t$$

where S_t is the water storage volume in the reservoir at time t , I_t is the water inflow volume of the reservoir during time t , R_t is the water released volume of the reservoir during time t .

2. The water released from reservoir has enough volume for demand of water use. Then, $D \leq R$ where D is the demand of downstream water.
3. The penalty of water supply that the water storage is not exceed the upper rule curve and not lower than the lower rule curve of reservoir, $S_t^{lower} \leq S_t \leq S_t^{upper}$. There are conditions as follows:

$$\begin{aligned} 0 \leq R - D \leq 100; \quad c = 0, \\ 100 < R - D; \quad c = 1000, \\ R - D < 0; \quad c = 100000 \end{aligned}$$

S_t^{lower} is the lower rule curve of reservoir at time t and S_t^{upper} is the upper rule curve of reservoir at time t .

If the volume of water released from reservoir is more than the demand of downstream water within 1-100 million cubic meters per second, then the penalty is 0. If the volume of water released from reservoir is more than 100 million cubic meters per second of the demand of downstream water, then the penalty is 1,000. If the volume of water released from reservoir is less than the demand of downstream water, then the penalty is 100,000.

In addition, there are more variables of the objective function for the decision where R_b is the volume of water released from Bhumibol reservoir, R_s is the volume of water released from Sirikit reservoir, S_b is the volume of water storage in Bhumibol reservoir, S_s is the volume of water storage in Sirikit reservoir, and $R_b + R_s$ is the volume of water released from Bhumibol reservoir including the volume from Sirikit reservoir.

In this case study area, the mathematical model is in the following form.

$$\text{Min: } \sum_{i=1}^{12} c b_i R_b + \sum_{i=1}^{12} c s_i R_s$$

where

$$3800 \leq S_b \leq 13462 \text{ and } 2850 \leq S_s \leq 9510$$

The objective function of this problem is minimizing downstream flood peak. Therefore, the sum of water released from Bhumibol and Sirikit reservoirs should not exceed 3,500 million cubic meters per second. The total volume of water released from both reservoirs should not exceed the upper rule curve and not less than the lower rule curve in each reservoir. The upper rule curve and lower rule curve of Bhumibol reservoir are 3,800 million cubic meters and 13,462 million cubic meters, respectively. The upper rule curve and lower rule curve of Sirikit reservoir are 2,850 million cubic meters and 9,510 million cubic meters, respectively. $c b_i$ is the penalty for water released from Bhumibol reservoir in i^{th} month. $c s_i$ is the penalty for water released from Sirikit reservoir in i^{th} month.

V. RESULTS AND CONCLUSIONS

1. The year 2011

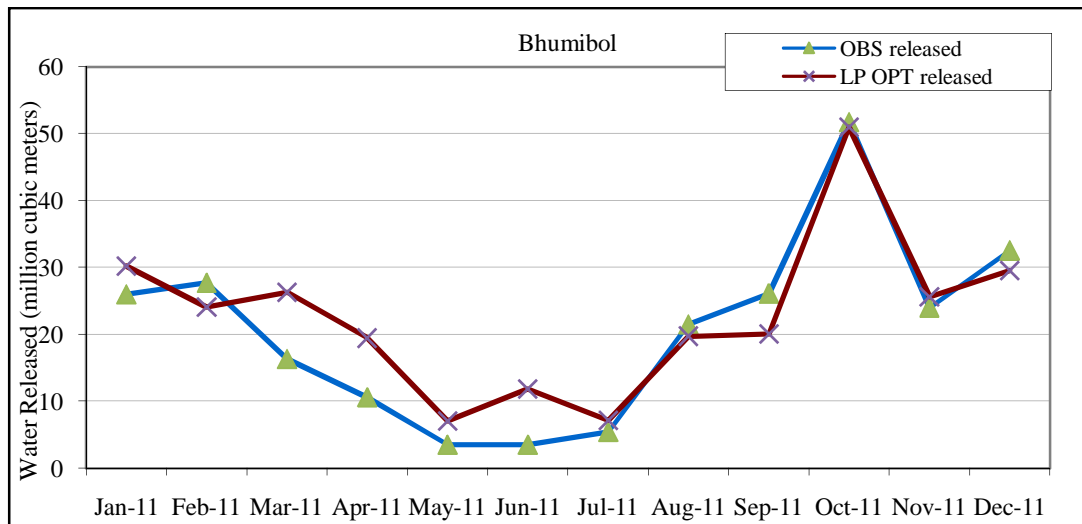


Fig. 3 The graph displaying the average monthly volume of water released from Bhumibol reservoir in 2011.

Fig. 3 is the graph of average monthly volumes of Bhumibol water released in 2011. It shows both the average volumes of the actual data and the optimal volumes from Linear Programming Optimization technique. The graph displays the large volumes of water released from Bhumibol reservoir in Thailand on October when severe flooding occurred in 2011.

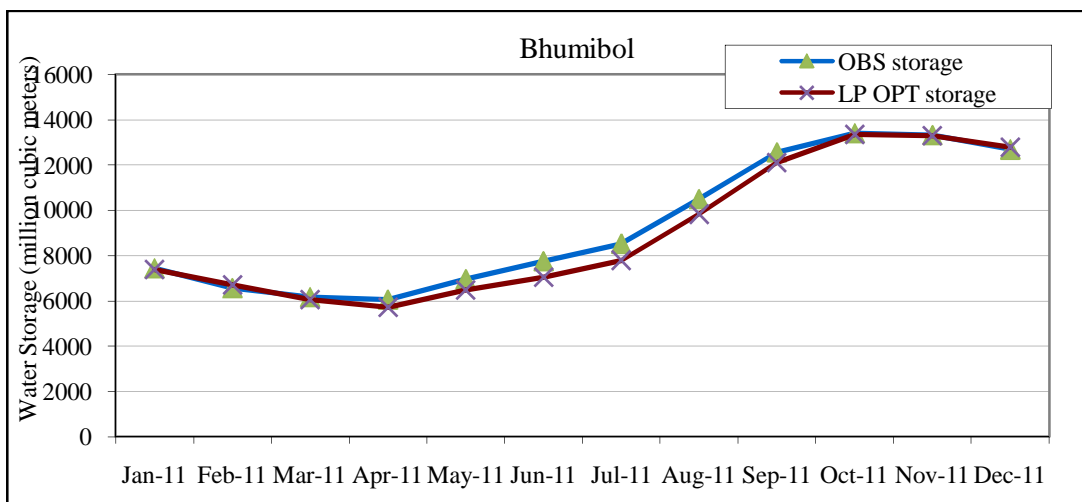


Fig. 4 The graph displaying the average monthly volume of water storage of Bhumibol reservoir in 2011.

Fig. 4 is the graph of average monthly volumes of Bhumibol water storage in 2011. It shows both the average volumes of the actual data and the optimal volumes from Linear Programming Optimization technique. The graph displays the large volumes of water storage of Bhumibol reservoir in Thailand started at the beginning of year.

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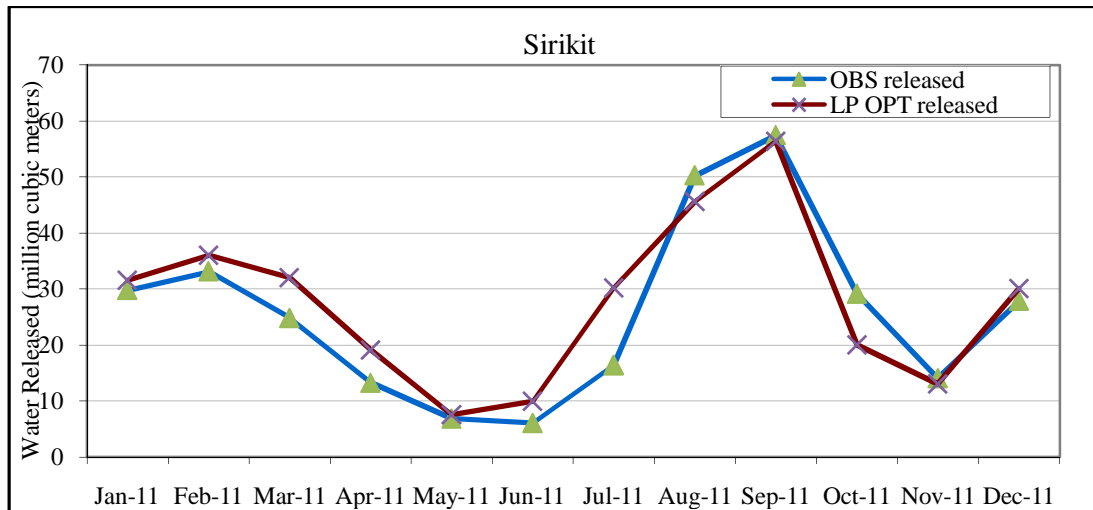


Fig. 5 The graph displaying the average monthly volume of water released from Sirikit reservoir in 2011.

Fig. 5 is the graph of average monthly volumes of Sirikit water released in 2011. It shows both the average volumes of the actual data and the optimal volumes from Linear Programming Optimization technique. The graph displays the large volumes of water released from Sirikit reservoir in Thailand on September when severe flooding occurred in 2011.

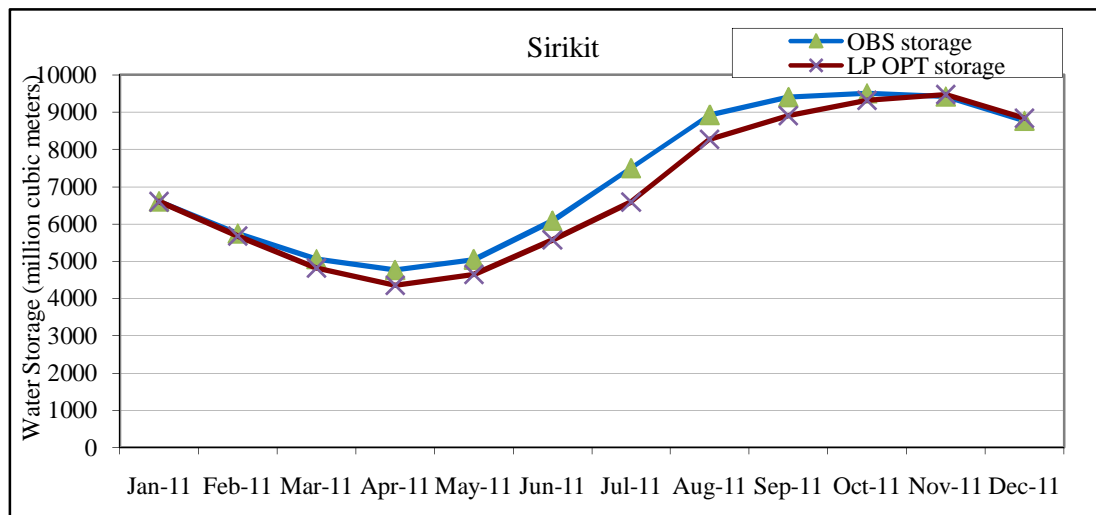


Fig. 6 The graph displaying the average monthly volume of water storage of Sirikit reservoir in 2011.

Fig. 6 is the graph of average monthly volumes of Sirikit water storage in 2011. It shows both the average volumes of the actual data and the optimal volumes from Linear Programming Optimization technique. The graph displays the large volumes of water storage of Sirikit reservoir in Thailand started at the beginning of year.

Due to the influence of many storms, they have severe negative impacts on Thailand. Another cause of flooding in downstream area of Chao Phraya basin is the large volume of water released from upland reservoirs to protect flooding in upstream area. Therefore, to reduce the impact of flooding in the downstream basin areas, the optimization technique was applied to the reservoirs operation and management for finding the optimal solution and improving the efficiency. The conclusion is that the optimal volumes of water released from reservoirs should be more than the actual monthly average volume from January to July, 2011. The consequences were the optimal volumes of water released from

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reservoirs from August to December in 2011 reduced that is the large rainfall volume period, especially the downstream areas. The condition of this experimental was this reducing volume of water released should not increase the volume of water storage exceed the upper rule curve of reservoir.

2. The year 2012

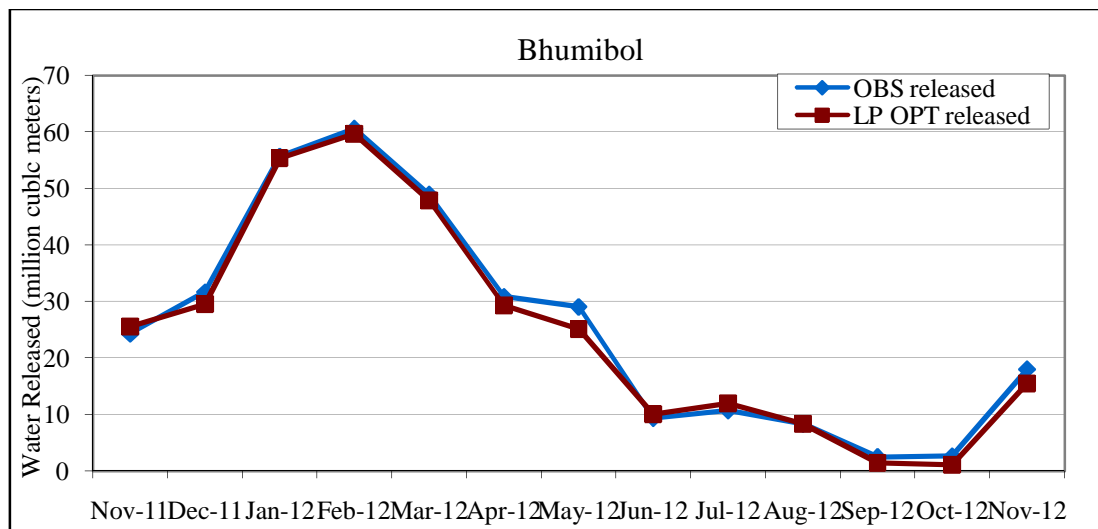


Fig. 7 The graph displaying the average monthly volume of water released from Bhumibol reservoir in 2012.

Fig. 7 is the graph of average monthly volumes of Bhumibol water released in 2012. It shows both the average volumes of the actual data and the optimal volumes from Linear Programming Optimization technique. The graph displays the volumes of water released from Bhumibol reservoir reduced since February until October in 2012.

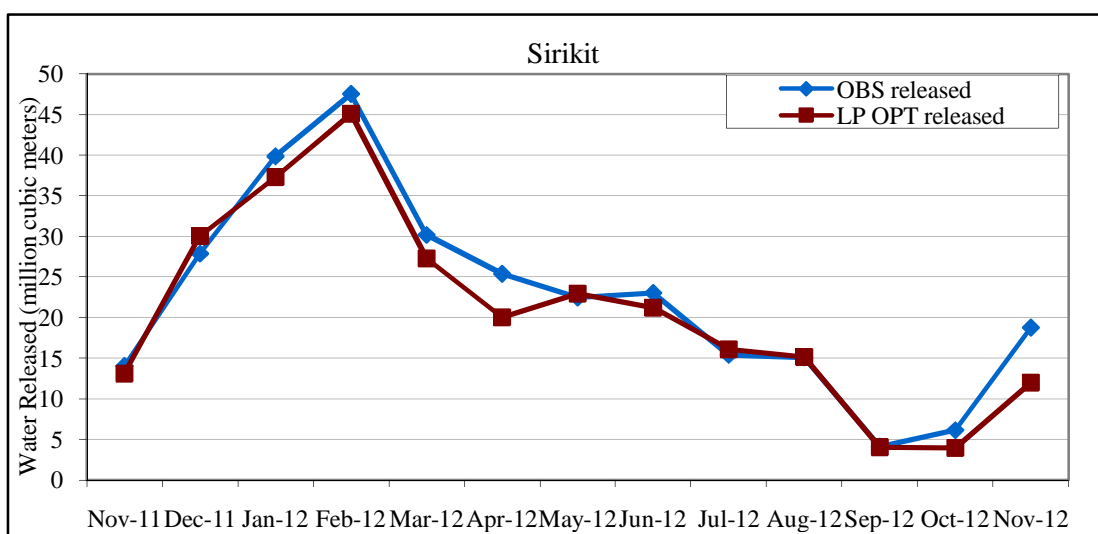


Fig.8 The graph displaying the average monthly volume of water released from Sirikit reservoir in 2012.

Fig.8 is the graph of average monthly volumes of Sirikit water released in 2012. It shows both the average volumes of the actual data and the optimal volumes from Linear Programming Optimization technique. The graph displays the volumes of water released from Sirikit reservoir reduced since February until October in 2012.

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Both reservoirs were controlled the volume of water released to reduce the volume of water demand in downstream areas. If there is a drainage volume control according the reservoirs operation optimization, the reservoirs are able to increase the volume of water storage. However, the volume of water storage should not exceed the maximum threshold of the reservoir.

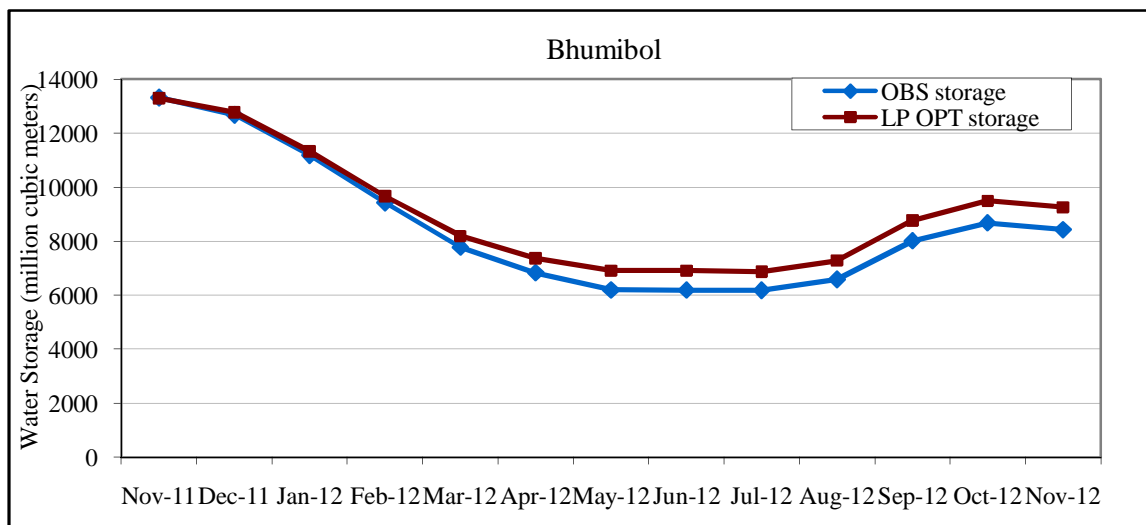


Fig.9 The graph displaying the average monthly volume of water storage of Bhumibol reservoir in 2012.

Fig.9 is the graph of average monthly volumes of Bhumibol water storage in 2012. It shows both the average volumes of the actual data and the optimal volumes from Linear Programming Optimization technique. The graph displays the large volumes of water storage of Bhumibol reservoir in Thailand started at the end of year 2011.

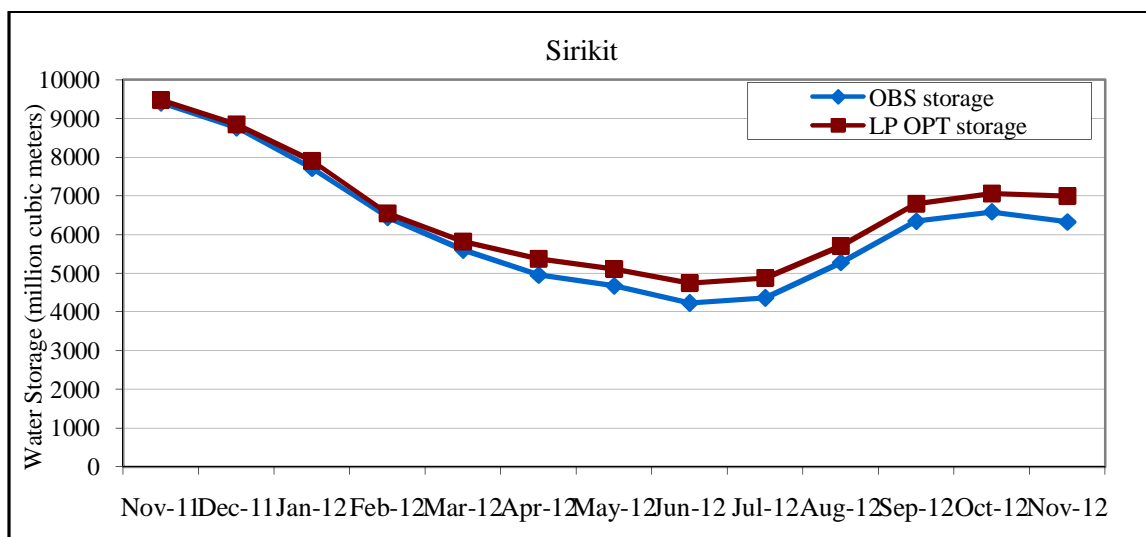


Fig. 10 The graph displaying the average monthly volume of water storage of Sirikit reservoir in 2012.

Fig.10 is the graph of average monthly volumes of Sirikit water storage in 2012. It shows both the average volumes of the actual data and the optimal volumes from Linear Programming Optimization technique. The graph displays the large volumes of water storage of Sirikit reservoir in Thailand started at the end of year 2011.

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From Fig.9 and Fig. 10, the water storage of Bhumibol reservoir can be increased more volume by approximately 11% (Calculated from the maximum volume of the year 2012). The water storage of Sirikit reservoir can be increased more volume by approximately 12% (Calculated from the maximum volume of the year 2012).

VI. DISCUSSION AND FUTURE WORK

From the results in previous section, this work can be further explained as follows:

1. For the water drainage in the year 2011, one approach to increase the volume of water released between January and April, 2011 may be achieved by increasing the demand of water in downstream areas.
2. Reducing the volume of water released from Bhumibol and Sirikit reservoirs is one part of the decrease of water volume that passed through C.2 water gate.
3. Considering the season period, in drought (start from November to April), the water storage is used according to the needs of water use in the basin. This helps drain the water volume to prepare for the rainy season (start from May to October). In the rainy period, the water volumes in reservoirs are prepared to meet the demand of water in the drought period. At present, the reservoirs in the Chao Phraya basin have been operated as previously mentioned.

In the year 2011, there was a lot of volume of precipitation in Thailand. The optimal solution was able to conclude that the water released from Bhumibol and Sirikit reservoirs should be increased the volume in the beginning of year or the drought period. It helps both reservoirs to be able to get more storage during the rainy season. Furthermore, to reduce the volume of water storage in both reservoirs in early 2012, the water was released from both reservoirs in the large volume. However, the optimal solution can decrease the volume of water released from both reservoirs in drought period.

This work is being planned to consider other concerning parameters such as uncertainties in precipitation, catchment areas in basin, other water body, and so on. In order to enhance water management for flood monitoring as process flow in Fig. 11, a dynamic optimization has been developed to track and analyze events rapidly and timely. This functionality can be linked to the flood forecast information from the hydrological models. The flood forecasting estimates the water inflow volume of the reservoir with using uncertainties data from rainfall forecasts. These are the outputs from the climate models and the demand of reservoirs water.

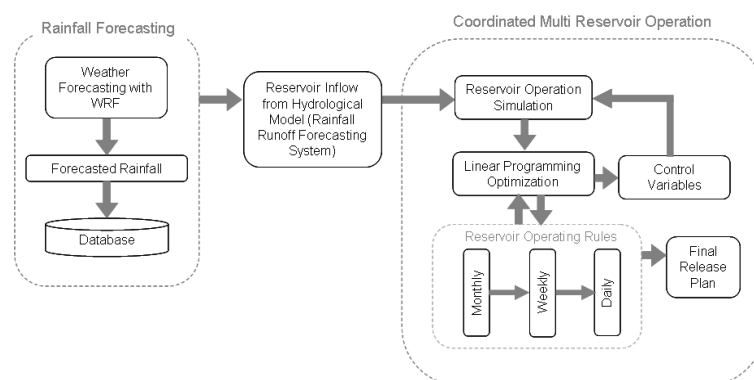


Fig. 11 The process flow of the dynamic reservoirs operation optimization system.

Therefore, the optimization operations to manage the reservoirs user rainfall forecasting data to calculate the reservoirs inflow with the hydrological model and then the results of models can be created as the sets of data. In order to find the best values or optimal values of water released volume and water storage volume, the rules and operation plans will be adjusted as a result of finding the best values depended on the situation. The results will be used to support the decision for water resource management.

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REFERENCES

- [1] D.Raje and P.P. Mujumdar, "Reservoir performance under uncertainty in hydrologic impacts of climate change", *Advances in Water Resources*, Elsevier, 33:312–326, 2010.
- [2] D.J. Jones, "Application of Mixed-Integer Programming for Flood Control in the Sacramento Valley: Insights & Limitations", Master of Science Thesis, University of California, 1999.
- [3] E.T. Alemu, R.N. Palmer, A.Polebitski, and B.Meaker, "Decision Support System for Optimizing Reservoir Operations Using Ensemble Streamflow Predictions", *Journal of Water Resources Planning and Management*, ASCE, pages 72-82, 2011.
- [4] G.Cornuejols and M. Trick, "Quantitative Methods for the Management Sciences: Modeling with Linear Programming (Chapter 5)", Course Notes, Graduate School of Industrial Administration, Carnegie Mellon University, Pittsburgh, 1998.
- [5] J.T. Needham, D.W. Watkins Jr., and J.R. Lund, "Linear Programming for Flood Control on the Iowa and Des Moines Rivers", *Journal of Water Resources Planning and Management*, pages 118-127, 2000.
- [6] The Working Group of the Office of Natural Water Resources Committee (ONWRC) of Thailand, "Chao Phraya River Basin, Thailand", UNESCO Natural Sciences.
- [7] X. Li, S.Guo, P. Liu, and G. Chen, "Dynamic control of flood limited water level for reservoir operation by considering inflow uncertainty", *Journal of Hydrology*, Elsevier, 391:124–132, 2010.