



## An Improved Multi-Reservoir Operation using Gridline Operating Rule for Water Management in Chao Phraya River Basin

Assada Kijpayoong<sup>1</sup> and Panuwat Pinthong<sup>1\*</sup>

<sup>1</sup> Faculty of Technical Education, King Mongkut's University of Technology North Bangkok, THAILAND.

\*Corresponding Author (Email: [panuwat.pinthong@gmail.com](mailto:panuwat.pinthong@gmail.com))

Paper ID: 12A10D

Volume 12 Issue 10

Received 14 June 2021

Received in revised form 10  
July 2021

Accepted 20 July 2021

Available online 23 July  
2021

### Keywords:

Reservoir Operation;  
Harmony Search (HS);  
Genetic Algorithm;  
Optimization; Gridline  
Operating Rule (GOR);  
Water peak discharge;  
Water resource  
management.

### Abstract

The release of water from the multi-reservoir system in the Chao Phraya River Basin (CPRB) is extremely important since this basin has the largest irrigation area in Thailand with a large volume of water use. There are four main reservoirs, consist of Bhumibol, Sirikit, Khwae Noi Bumrungdan, and Pasak Jolasid reservoirs. The operators have to decide when and how to release water from the reservoirs for the water allocations in the CPRB. The development of a decision-making model for optimal multi-reservoir release in the CPRB based on the Gridline Operating Rule concept will be useful for the decision-makers to release water properly. The objectives of the model are reducing peak discharge at control point C4 and reducing water shortages in the irrigation areas. The performance of water allocation was also evaluated by using reliability, vulnerability, and resiliency indices. The result indicates that the calibration period, Gridline Operating Rule With Harmony Search (GOR-HS) with three indices values of 74%, 452 million cubic meters (MCM), and 46%, respectively. In addition, it could reduce floods in 2011 by 16 days; the volume of water is 819 MCM and peak discharge is 192 cubic meters per second which may affect the area.

**Disciplinary:** Civil Engineering & Technology (Hydrology), Computer Application.

©2021 INT TRANS J ENG MANAG SCI TECH.

### Cite This Article:

Kijpayoong, A., Pinthong, P. (2021). An Improved Multi-Reservoir Operation using Gridline Operating Rule for Water Management in Chao Phraya River Basin. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies*, 12(10), 12A10D, 1-14. <http://TUENGR.COM/V12/12A10D.pdf> DOI: 10.14456/ITJEMAST.2021.193

## 1 Introduction

The area of Thailand is 51.31 million hectares, with an irrigation area of 5.25 million hectares. The Chao Phraya River Basin area is an important river basin that has an irrigation area of 2.08 million hectares or approximately 39.62 percent of the entire irrigation area of the country. It

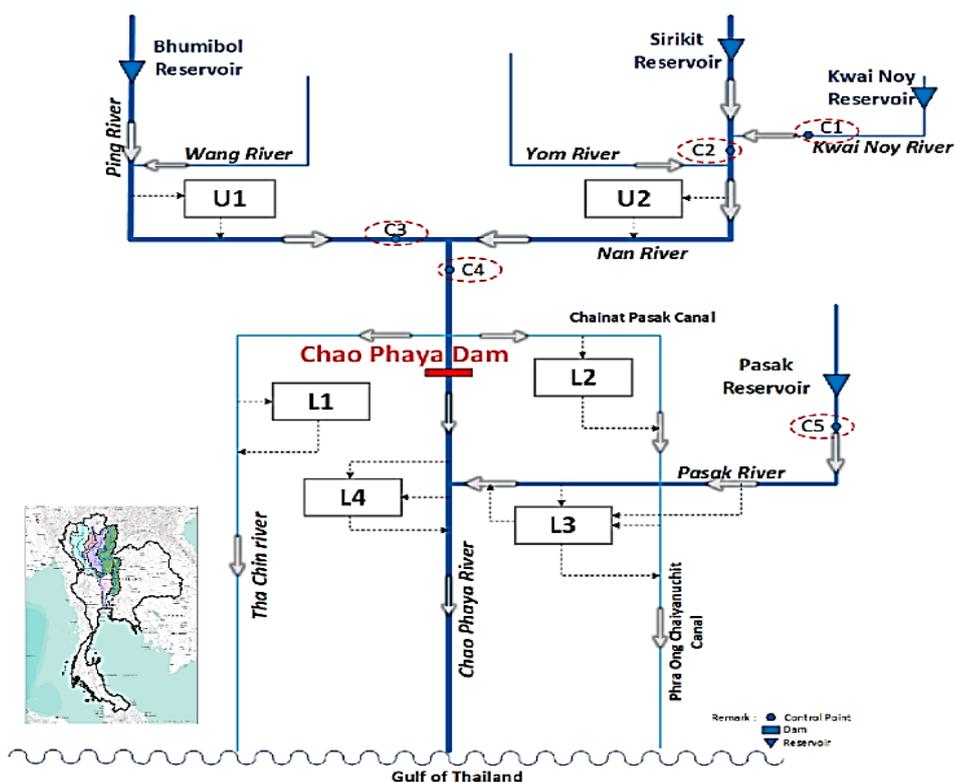
relies for its water source on 4 main reservoirs, namely Bhumibol, Sirikit, Khwae Noi Bumrungdan (Khwae Noi), and Pasak Jolasid (Pasak) reservoirs with capacities of 13,462 9,510 939 and 960 million cubic meters (MCM), respectively.

The water is released to the Chao Phraya River Basin area, consisting of 22 provinces, via 38 irrigation projects. Water allocation can be divided into 6 areas according to Figure 1 consisting of two upper Chao Phraya areas U1 and U2 and four lower Chao Phraya areas L1, L2, L3, and L4. The narrowest point of the river was designated as a control point is shown in Table 1. Also, water demand areas in the Chao Phraya River Basin, according to various groups, are shown in Table 2.

Water management in the Chao Phraya River Basin is a multi-purpose water supply and the rule curves of all reservoirs were used for the decision of water release. However, it is difficult to manage the water according to the rule curves because there are many variations of rainfall and inflow each year. The Pasak Reservoir often suffers from overflowing water due to a large volume of reservoir inflow during the rainy season.

Because its location is close to an important economic area, the reservoir operation for reducing the flooding in the downstream area is more complex and difficult. In 2011, the heavy rainfall is concentrated over the upstream and downstream of the Chao Phraya River Basin; hence, flooding occurs in a vast area of the river basin. Furthermore, during 2014 - 2016, there were water shortages due to less rainfall.

This paper presents The Gridline Operating Rule (GOR), together with an appropriate technique by using Genetic Algorithm (GA) and Harmony Search (HS) methods to find the appropriate value of variables that were used in the grid techniques to develop a model of suitable water release for the reservoir system in the Chao Phraya River Basin in Thailand.



**Figure 1:** Grouping of water allocation and control points in the river basin.

**Table 1: Control Points in the Chao Phraya River Basin**

Control Point	Discharge Max	
	m <sup>3</sup> /s	MCM
C1	476	41
C2	1,120	97
C3	1,815	157
C4	3,590	310
C5	1,175	102

**Table 2: The Average Water Demand in Chao Phraya River Basin (2010-2018)**

Month	Avg. Demand (MCM)	Month	Avg. Demand (MCM)
Jan	2,218	Jul	2,240
Feb	2,245	Aug	1,907
Mar	2,066	Sep	1,222
Apr	1,282	Oct	975
May	1,159	Nov	1,138
Jun	1,907	Dec	1,665

## 2 Literature Review

There are many methods to determine reservoir rule curves, such as a statistical rule curve [1], a probability base rule curve [2], and a vacancy rule curve [3],[4]. However, many researchers have proposed various techniques to solve the problem of planning and operating a reservoir appropriately.

In the past, mathematical techniques were applied. Azamathulla, H. Md. et al. [5] applied Linear Programming (LP) with the real-time Chiller Reservoir operating system in the Madhya State, India, to allocate suitable irrigation water for plants at the farm level at different times, for different plants and to effectively reduced water shortages. However, the LP method has limitations for applying nonlinear [6, 7] problems. In summary, the LP method is suitable for solving problems where the relationship between the variables of the objective equations and conditional equations are linear.

The Dynamic Programming (DP) method divides the problem into stages and finds the answer for each stage until receiving an appropriate answer in the final stage. In Thailand, The DP methods were used to study the criteria for releasing water from Bhumibol Dam and Sirikit Dam by Chaleeraktragoon C. et al. [8]. The result of this study indicates that the DP method was successful in increasing the efficiency of the management of both reservoirs, which could reduce the period that the storage capacity exceeded the capacity and reduced the water shortage period to the lowest.

The development of a solution of the LP and the DP led to the development of Nonlinear Programming (NLP), but the complexity of solving the problem was higher than the LP method, it took a long time to find the answer than the original method [9], [10].

Previous studies have explored the solution of planning and operation of the reservoir was implemented by using optimization techniques to solve the problem of water release, which was a

nonlinear and non-convergence model, such as the Genetic Algorithm (GA), which was the first technique used to solve problems of finding the appropriate value for reservoir operation.

The GA method, Holland [11] was the initiator of such a technique which had the concept of problem-solving by using the principle of natural selection to find the most suitable value. It could solve problems in linear and non-linear forms. Wardlaw and Sharif [12] applied the GA to solve problems of networks of four reservoirs and ten reservoirs, and the result of this study found that GA obtained higher potential than using the DP method.

The application of many hybrid techniques, such as Pinthong [13], Genetic and Neurofuzzy Algorithm (Neuro-Fuzzy-GA) techniques to determine the water release criteria of the Pasak Reservoir, the study showed that Neuro-Fuzzy-GA could more reduce water shortage and reduce the volume of spill compared with the actual reservoir operation; Nevertheless, this method could solve the problem well, but it required complicated steps.

Lee and Geem [14] employed the Harmony Search (HS) technique, which was inspired by the composition of an orchestra by the musical instrument and applying it to solve problems that needed to find appropriate values. Determining musical notes was like a decision variable used to find the most suitable value of an objective function.

The HS workflow begins with a random number of notes based on the length of the song, which determines the harmony memory size (HMS). Then, it starts the memory consideration process by creating and analyzing a new set of notes from the existing HM through the harmony memory considering rate (HMCR) and entering the pitch adjustment process, which requires the pitch adjusting rate (PAR) and the random selection of notes to be changed.

After that, it makes the best comparison according to the objective function. The worst song set in HMS is replaced by song sets that have been modified in past processes, and this process is continued repeatedly until the population in the specified model gets the most appropriate value according to the specified objective function.

This study presents an application of the GA and HS methods to determine the appropriate parameters of the GOR techniques for operating four main reservoirs by considering reducing the water shortage in the Chao Phraya basin as much as possible under flood protection restrictions, the physical limitations of the river and the limit of minimum water demand.

## **3 The Development of a Decision-Making Modeling for Optimal Multi-Reservoir Release in the Chao Phraya River Basin by Using the Gridline Operation Rule Technique**

### **3.1 Concept of Gridline Operation Rule**

The process of releasing water by the Gridline Operation Rule (GOR) technique has the following variables:

- 1) The volume of water is used to divide the line at the horizontal axis of the various reservoirs ( $Line_i$ ).

2) The number of days that the reservoir has to release water in advance to prevent the reservoir overflow at  $i$  ( $nDay_i$ ).

3) The parameters of water release proportion in the horizontal axis of the reservoir at  $i$  under Line<sub>1</sub> ( $CL_{i,1}$ ).

4) The parameters of water release proportion in the vertical axis of the reservoir at  $i$  in month  $m$  ( $CM_{i,m}$ ).

For the formulation of the gridline, the horizontal gridline used the GOR technique to determine the appropriate value to randomly select the water grid at the reservoir in the horizontal axis of line1 to linen and randomly select the appropriate water release proportion under the horizontal axis  $CL_1$  to  $CL_n$ . The vertical grid designation specified that on the 1st day of each month the reservoir was divided into the gridline in the vertical axis and used the technique to find the appropriate value to randomly calculate the suitable water release proportion of the vertical axis  $CM_1$  to  $CM_{12}$  as shown in Figure 2.

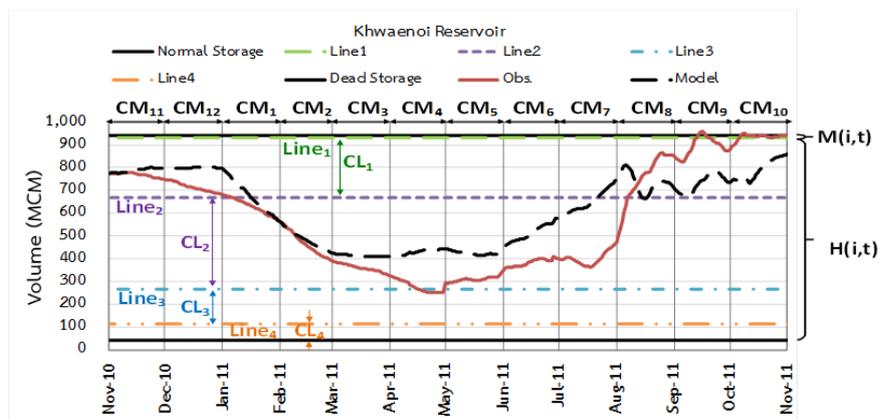


Figure 2: Example of gridding and vertical and horizontal efficiency.

In this study, the release of water was proportional to the available water volume of each reservoir compared to the total volume of available water in the four reservoirs, with the volume of water demand of the watershed and the water release proportion of the gridline as

$$Re(i, t) = \frac{AS_{i,t} \times TD_t \times Cgrid_{i,l,m}}{\sum_{i=1}^4 AS_{i,t}} \quad (1),$$

$$Cgrid_{i,l,m} = CL_{i,l} \times CM_{i,m} \quad (2),$$

where

$Re(i, t)$  = Water release function of reservoir  $i$  at the time  $t$  (MCM)

$AS_{i,t}$  = Available water of reservoir  $i$  at the time  $t$  (MCM)

$TD_t$  = Total water demand at the time  $t$  (MCM)

$Cgrid_{i,l,m}$  = Proportion of water release gridline of reservoir  $i$  under line  $l$  in the month  $m$

$CL_{i,l}$  = Proportion of water release at the horizontal axis of reservoir  $i$  under line  $l$

$CM_{i,m}$  = Proportion of water release at vertical axis of reservoir  $i$  in the month  $m$

### 3.2 Water Release Criteria from the Four Reservoirs

The release of water from all four reservoirs had a process, as shown in Figure 3. The first step was to anticipate the volume of inflow water to the reservoirs in advance, as the number of nDay days, by considering releasing the water from the reservoirs in advance to reduce the outflow and control of the volume of water release which was not to exceed downstream river capacity including side flow of each reservoir.

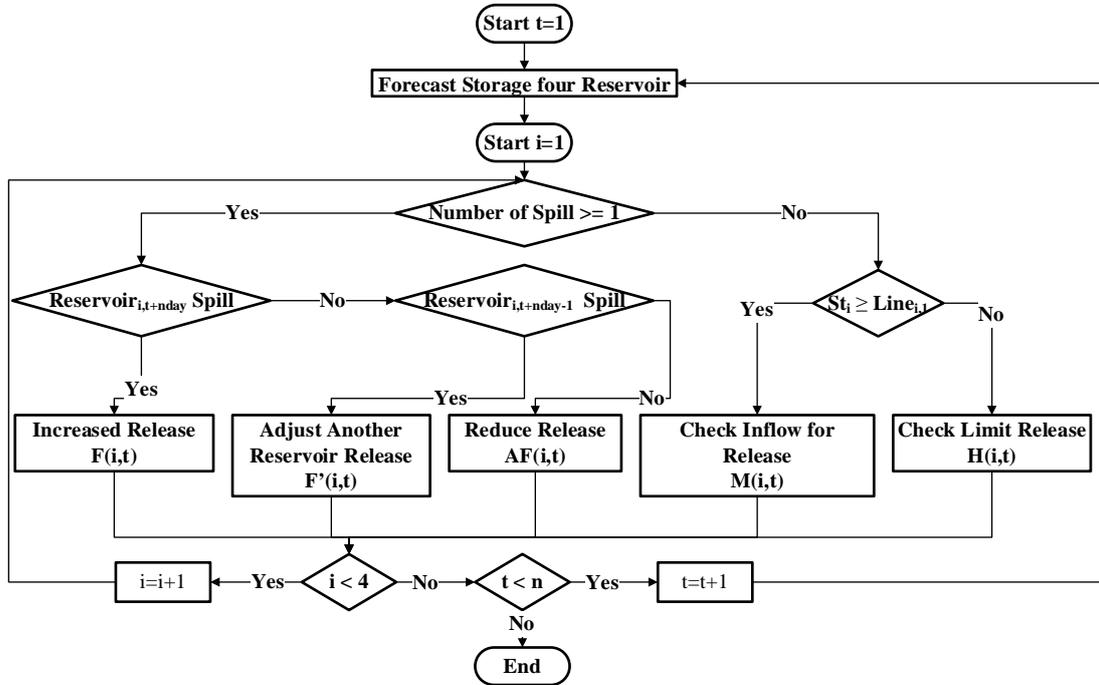


Figure 3: Workflow of the four reservoir model of water release GOR

So that the reservoir storage did not exceed the normal storage, as shown in Equation 3, which would increase the water release rate by 20% of the maximum release capacity of the reservoir, as shown in Equation (4) until the volume of water release was equal to maximum water release. If the anticipated volume of inflow water did not cause an overflow of the reservoir as in Equation 5 After reducing the water release by 20% until the volume of water released was close to the volume of water demand as Equation (6). While other reservoirs would reduce water release proportionally according to Equation (7).

$$S_{i,t} + \sum_{d=1}^{nDay_i} (IF_{i,t+d} - D_{i,t+d}) \geq NS_i \quad (3).$$

$$F(i, t) = \begin{cases} O_{i,t} = O_{i,t-1} + 0.2 \times R_{max\ i} & \text{for } O_{i,t-1} + 0.2 \times R_{max\ i} < R_{max\ i} \\ O_{i,t} = R_{max\ i} & \text{for } O_{i,t-1} + 0.2 \times R_{max\ i} < R_{max\ i} \end{cases} \quad (4).$$

$$S_{i,t} + \sum_{d=1}^{nDay_i} (IF_{i,t+d} - D_{i,t+d}) < NS_i \quad (5).$$

$$AF(i, t) = \begin{cases} O_{i,t} = O_{i,t-1} - 0.2 \times R_{max\ i} & \text{for } Re(i, t) > O_{i,t-1} - 0.2 \times R_{max\ i} \\ O_{i,t} = Re(i, t) & \text{for } O_{i,t-1} - 0.2 \times R_{max\ i} > Re(i, t) > R_{min\ i} \\ O_{i,t} = R_{min\ i} & \text{for } O_{i,t-1} - 0.2 \times R_{max\ i} > R_{min\ i} > Re(i, t) \end{cases} \quad (6).$$

$$F'(i, t) = \frac{P_i \times AS_{i,t} \times (TD_t - F(i,t)) \times Cgrid_{i,l,m}}{\sum_{i=1}^4 P_i \times AS_{i,t}} \quad (7).$$

Whereas

- $S_{i,t}$  = The volume of water in the reservoir  $i$  at the time interval  $t$  (MCM)  
 $nDay_i$  = Number of forecasted days of inflow water to the reservoir  $i$  (day)  
 $NS_i$  = The volume of water at a normal level of reservoir  $i$  (MCM)  
 $IF_{i,t+d}$  = The volume of anticipated inflow water to the reservoir  $i$  at the time of  $t + d$  (MCM)  
 $D_{i,t+d}$  = The volume of water demand of reservoir  $i$  at the time of  $t+d$  (MCM)  
 $F(i,t)$  = Water release function to prevent flooding  
 $AF(i,t)$  = Function to reduce water release after returning to normal  
 $F'(i,t)$  = Water release function of other reservoirs  
 $P_i$  = Coefficient of function  $F'(i,t)$  with a value of 0 for reservoirs that release water according to function  $F(i,t)$  and equal to 1 for reservoirs that release water according to function  $F'(i,t)$   
 $O_{i,t}$  = Volume of water release from the reservoir  $i$  at the time of  $t$  (MCM)  
 $R_{max\ i}$  = Maximum water release of reservoir  $i$   
 $R_{min\ i}$  = Minimum water release of reservoir  $i$

However, when the anticipated inflow of water to the reservoir did not cause outflow in any reservoir, they would consider if the water level was above line 1, if so, the reservoir would release water according to  $M(i,t)$  function. The volume of water release would be equal to or greater than the water demand as Equation 8, but if the volume of water in the reservoir were lower than the specified level of line 1, the reservoir would release water according to the  $H(i,t)$  function.

This would release less water than the water demand as Equation 9. In the rainy season, the maximum water release from the reservoir when combining the side flow must not exceed the river capacity, and the minimum release when combined with effective rainfall and the side flow is equal to the water demand. In the dry season, the minimum release is 18 MCM/day, according to Kongjun [15].

$$M(i, t) = \begin{cases} O_{i,t} = R_{max\ i} + Sp_{i,t} & \text{for } IF_{i,t} \text{ or } Re(i, t) > R_{max\ i} \\ O_{i,t} = IF_{i,t} + Sp_{i,t} & \text{for } R_{max\ i} > IF_{i,t} > Re(i, t) \\ O_{i,t} = Re(i, t) + Sp_{i,t} & \text{for } R_{max\ i} > Re(i, t) > IF_{i,t} \end{cases} \quad (8)$$

$$H(i, t) = \begin{cases} O_{i,t} = R_{max\ i} & \text{for } Re(i, t) > R_{max\ i} > R_{min\ i} \\ O_{i,t} = Re(i, t) & \text{for } R_{max\ i} > Re(i, t) > R_{min\ i} \\ O_{i,t} = R_{min\ i} & \text{for } R_{max\ i} > R_{min\ i} > Re(i, t) \end{cases} \quad (9)$$

### 3.3 Reservoir Performance Indices

The performance of analysis indices all four-reservoir is used to evaluate the efficiency of the system, including reliability, vulnerability, and resiliency. The reliability indices are the indicator of reliability in which the reservoir release system can meet demand targets within the period considered according. Vulnerability Indices are indices to measure the severity of average shortage magnitude of failure duration during the entire system failure according. Resiliency Indices are Indices that represent the capability of the system that can recover from a failure state according.

## 4 Development of the GOR Model for Reservoir Operation the Chao Phraya River Basin

### 4.1 Determination of Appropriate Parameters of GOR Model

The process of finding the appropriate parameters using GA and HS techniques is to perceive the water release coefficient, which will test the number of lines that divide the grid horizontally, starting at 2 lines up to 6 lines, as there were 6 lines in the 5 groups cases.

In each line number, the number of water release days was randomly calculated in advance to prevent flooding. The water release coefficient in the horizontal grids was obtained by dividing the line, and the release coefficient in the vertical grids was obtained by dividing the months from Jan to Dec. Then calculate the volume of water released by considering where the water volume exists in any grid. The water release would be according to the release coefficient in that zone grid. Then the best fitness value for all five groups cases of line division was calculated.

In this study, a total of 30 sets of variables was used in both techniques, considering the water demand from the Royal Irrigation Department (RID), water management plan data in the Chao Phraya River Basin, from Nov 2009 to the end of October 2016, as summarized in Table 1. The data were used for developing the model consist of the quantity of runoff, rainfall, evaporation, physical characteristics of reservoirs, water demand, and downstream conditions. The reliability, vulnerability, and resiliency indices were used to evaluate the efficiency of reservoir management that minimizes water shortage.

The GA techniques consist of selection, crossover, and mutation procedures were tournament selection, uniform crossover, and non-uniform mutation, respectively. The HS procedures determined parameters PAR between 0.65-0.95 and HMCR equals 0.95. Both techniques determined the number of variable sets was 30 and determined the number of calculation cycles to find the best fitness value equals 20,000 cycles.

### 4.2 Objective Equation of GOR Model

Many large reservoirs in Thailand normally were operated for multiple objectives such as irrigation and flood prevention. Therefore multiple-objective management which consists of hard constraint and soft constraint was applied in order to avoid Pareto events or a group of many possible answers. The objective equation 10 was used for a hard constraint.

$$\text{Min } Z_1 = \sum_{t=1}^T \begin{cases} (DC4_t - 3,500)^2 & \text{for } DC4_t > 3,500 \\ 0 & \text{for } DC4_t \leq 3,500 \end{cases} \quad (10).$$

Equation (10) illustrates how much water releases from the reservoir at any time  $t$ , can reduce the Discharge rate at the control point C4 ( $DC4_t$ ) not exceed the threshold.

Objective equations as shown in Equations (11) and (12) were used for soft constraint,

$$\text{Min } Z_2 = \frac{\sum_{t=1}^T Sp_t}{\sum_{t=1}^T \sum_{i=1}^4 R_{i,t}} \quad (11),$$

$$\text{Min } Z_3 = \frac{\sum_{t=1}^T Sh_t}{\sum_{t=1}^T \sum_{i=1}^4 R_{i,t}} \quad (12).$$

Equations (11) and 12 provide the indicators for controlling the volume of water released from the reservoirs to reduce water spills ( $Sp_t$ ) and water shortages ( $Sh_t$ ).

Equation (13) was used for calculating the constraint of the water balance scenario in the reservoir throughout the scenario time  $T$ .

$$S_{i,t+1} = S_{i,t} + I_{i,t} - O_{i,t} - E_{i,t} \quad (13).$$

The constraint equation in terms of the volume of water released from the reservoir is

$$R_{min i} < O_{i,t} < R_{max i} \quad (14).$$

## 5 Results and Discussion

The results of this study consist of three parts, model calibration, model validation, and model application which can be explained as follows.

### 5.1 Model Calibration

The calibrated model, for the period 1 Nov 2010 – 31 Oct 2013, considered the horizontal water distribution lines at line 2 to line 6, as show result in Table 3. It found that GOR-HS is high performance at line 4, with parameters that are the best, as in Table 4. while GOR-GA is high performance at line 3 with parameters that are the best, as in Table 5.

**Table 3:** Summary of the test for the suitable line number of years 2010-2013 by HS and GA technique.

Line	Water Shortage (MCM)			Reliability %		Number of Spills (Day)	
	Obs.	HS	GA	HS	GA	HS	GA
2	10,169	4,896	4,861	69	68	0	0
3		4,190	4,455	70	72	0	0
4		5,480	5,239	74	68	0	0
5		4,493	5,179	73	67	0	0
6		5,315	4,913	65	66	0	0

**Table 4: Best decision variables from HS technique**

Reservoir (i)		Bhumibol (i=1)	Sirikit (i=2)	Khwae Noi (i=3)	Pasak (i=4)
nDay		18	29	15	17
Storage (MCM, %AS)	Line 1	13,269 (99%)	8,178 (86%)	930 (99%)	941 (98%)
	Line 2	7,761 (58%)	4,848 (51%)	670 (71%)	453 (47%)
	Line 3	5,346 (40%)	4,648 (49%)	267 (28%)	214 (22%)
	Line 4	4,186 (31%)	2,917 (31%)	115 (12%)	80 (8%)
CL <sub>i,1</sub>	CL <sub>i,1</sub>	0.80	0.94	0.96	0.96
	CL <sub>i,2</sub>	0.78	0.9	0.73	0.83
	CL <sub>i,3</sub>	0.69	0.89	0.69	0.48
	CL <sub>i,4</sub>	0.37	0.13	0.24	0.23
CM <sub>i,m</sub>	Jan	0.71	1.11	1.46	1.71
	Feb	0.90	1.09	1.40	1.99
	Mar	0.92	1.10	1.57	1.88
	Apr	1.09	1.25	0.55	1.50
	May	1.39	1.95	0.19	1.62
	Jun	0.88	0.47	1.93	0.63
	Jul	0.42	0.91	0.77	1.81
	Aug	0.43	1.40	0.47	0.18
	Sep	0.29	0.91	0.63	0.21
	Oct	0.36	0.12	1.65	1.51
	Nov	1.32	1.09	1.28	1.07
	Dec	0.45	0.65	0.38	1.04

**Table 5: Best decision variables from GA technique**

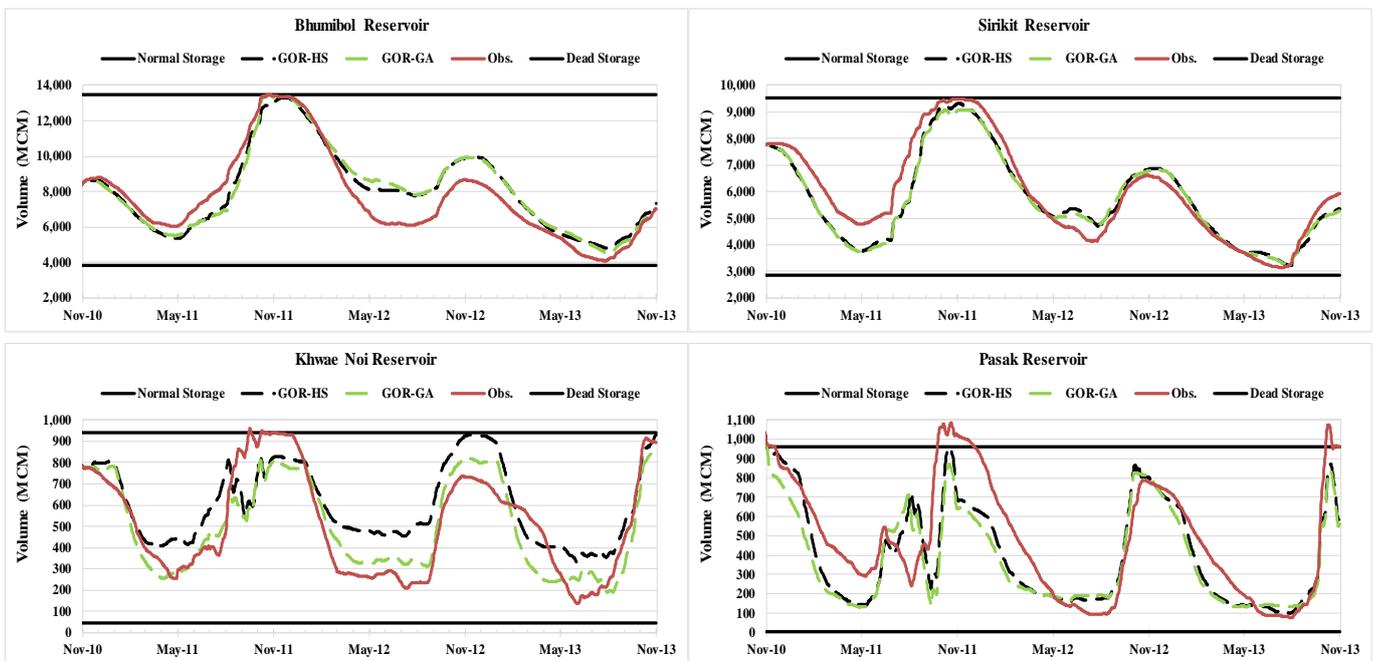
Reservoir (i)		Bhumibol (i=1)	Sirikit (i=2)	Khwae Noi (i=3)	Pasak (i=4)
nDay		12	25	14	17
Storage (MCM, %AS)	Line 1	13,365 (99%)	9,443 (99%)	840 (89%)	807 (84%)
	Line 2	7,472 (38%)	4,781 (29%)	330 (32%)	261 (27%)
	Line 3	4,573 (8%)	3,316 (7%)	276 (26%)	137 (14%)
CL <sub>i,1</sub>	CL <sub>i,1</sub>	0.90	0.94	0.98	0.99
	CL <sub>i,2</sub>	0.87	0.84	0.77	0.65
	CL <sub>i,3</sub>	0.62	0.8	0.75	0.22
CM <sub>i,m</sub>	Jan	0.71	1.11	1.46	1.71
	Feb	0.75	1.08	1.65	1.70
	Mar	0.89	1.44	1.50	1.13
	Apr	0.79	1.82	0.57	1.27
	May	1.12	1.57	1.42	0.29
	Jun	0.64	0.75	0.95	0.55
	Jul	0.48	1.20	1.18	0.20
	Aug	0.20	0.42	1.35	1.40
	Sep	0.40	0.93	0.27	1.58
	Oct	1.20	1.38	1.88	0.13
	Nov	0.55	0.55	0.72	1.17
	Dec	0.91	1.20	0.22	1.00

When comparing the results of GOR-HS, GOR-GA, and actual operation. It was found that the water shortage from GOR-HS was less than the actual operation evaluated to be 5,480 MCM

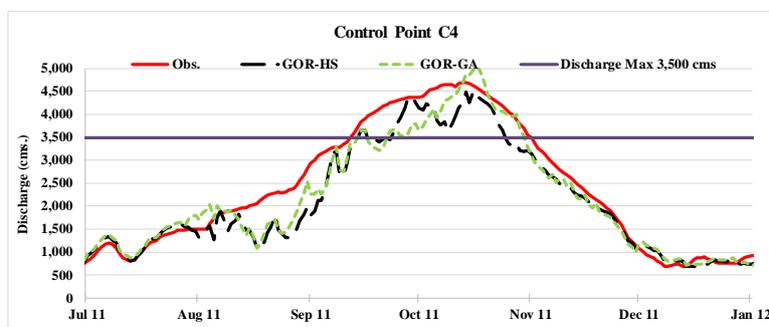
with the reliability, vulnerability, and resiliency indices of 74%, 452 MCM, and 46%, respectively, without the occurrence of overflow. GOR-GA is less than the actual operation evaluated to be 4,455 MCM with the reliability, vulnerability, and resiliency indices of 72%, 598 MCM, and 45%, respectively, without the occurrence of overflow. While, the actual operation had water shortages, reliability, vulnerability, resiliency, and the number of overflow days of 10,169 MCM, 52%, 679 MCM, 29%, and 131 days, respectively, as shown in Table 6.

**Table 6:** Reservoir operation with the actual data, GOR-HS and GOR-GA technique from the calibrated model

	Observe	GOR-HS	GOR-GA
Demand (MCM)	62,699		
Release (MCM)	57,023	58,750	59,218
Water Shortage (MCM)	10,169	5,480	4,455
Reliability	52%	74%	72%
Vulnerability	679	452	598
Resiliency	29%	46%	45%
Spill (Day)	131	0	0



**Figure 4:** Simulation of the volume of water in the four reservoirs during the model calibration



**Figure 5:** Simulation results of water discharge at Control Point C4 year 2011

The volume of water in the reservoirs at that time is shown in Figure 4. The result of GOR-HS and GOR-GA, water release from the three reservoirs during the 2011 flood at the control point

C4 were 819 and 1,059 MCM, the number of overflow days was reduced from 49 days to 33 days and 40 days respectively. However, GOR-HS was able to reduce the peak discharge at control point C4 in the year 2011 from 4,689 m<sup>3</sup>/s to 4,497 m<sup>3</sup>/s. While GOR-GA has a peak discharge higher than the actual operation from 4,689 m<sup>3</sup>/s to 5,070 m<sup>3</sup>/s, as shown in Figure 5.

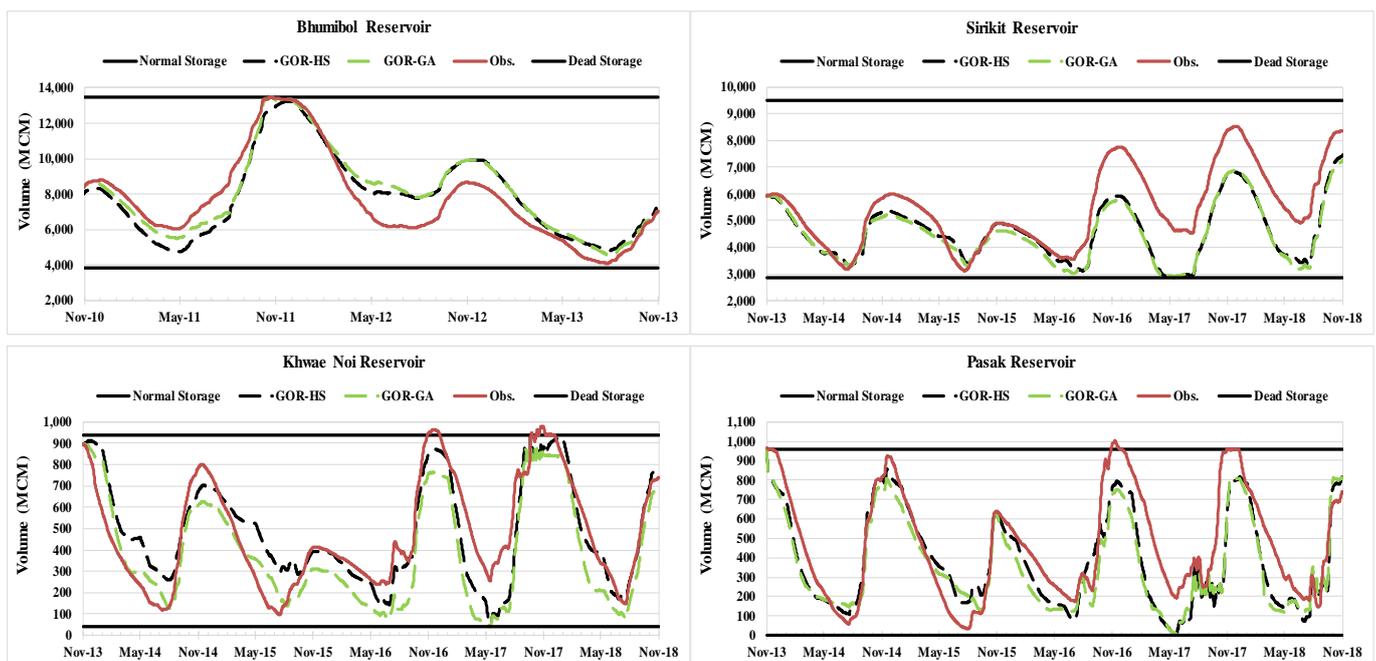
## 5.2 Model Validation

According to the validation results for the period from 1 Nov 2013 to 31 Oct 2018. It was found that GOR-GA was best effective in reducing water shortages, with reliability index values of 8,022 MCM and 83%, respectively. However, the vulnerability and resilience index was lower than the other methods with 798 and 31% respectively.

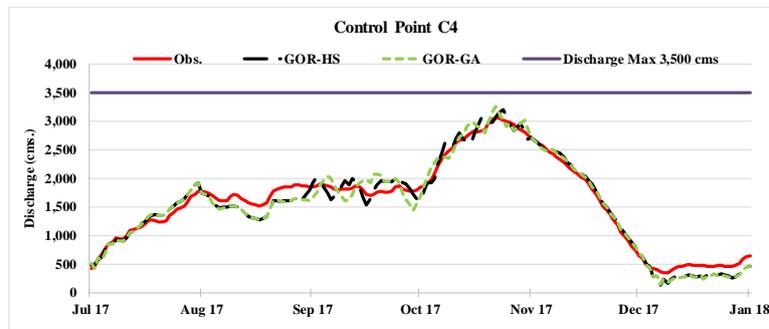
GOR-HS was the 2nd efficient in all aspects with Water Shortage, Reliability, Vulnerability, and Resiliency with values of 8,764 MCM, 80%, 632 MCM, and 33% respectively, as shown in Table 7. The reservoir water volumes are shown in Figure 6. In 2017, the Chao Phraya River Basin floods. However, Discharge at control point C4 does not exceed the maximum discharge, as shown in Figure 7.

**Table 7:** Reservoir operation with the actual data, GOR-HS and GOR-GA technique from the validated model

	Observe	GOR-HS	GOR-GA
Demand (MCM)		71,832	
Release (MCM)	56,678	59,974	61,505
Water Shortage (MCM)	14,187	8,764	8,022
Reliability	63%	80%	83%
Vulnerability	562	632	798
Resiliency	39%	33%	31%
Spill (Day)	127	0	0



**Figure 6:** Volume of water in the reservoirs during the model validation



**Figure 7:** Simulation results of water discharge at Control Point C4 year 2017

## 6 Conclusion

This study involved the development of a decision model using the GOR technique. GOR was performed by a Gridline divided into horizontal lines from the reservoir water volume division. The vertical line uses the 1st day of each month as a separator. Finally, the appropriate water discharge coefficient for each grid was determined.

GOR performance assessments using performance indicators such as reliability, vulnerability, and resiliency. Results showed that the model performed well in both calibration and validation.

Specifically, modeling results indicate that the use of decision criteria for releasing water obtained from the GOR-HS and GOR-GA could effectively provide the water release criteria of all four reservoirs.

Especially in years with heavy rainfall. GOR-HS is able to reduce water scarcity and provide better indices of reliability, vulnerability, and resilience of the Chao Phraya River Basin compared with actual performance. Whereas GOR-GA was most effective in years with moderate to low rainfall. It has the best water shortage reduction and reliability index.

The newly developed modeling technique is based on GOR-HS and GOR-GA. It can be applied with a multi-purpose reservoir for reduced water shortage in the dry season, peak discharge, and duration of floods. Which could be very beneficial to many sectors and stakeholders, especially decision-makers.

## 7 Availability of Data and Material

Data can be made available by contacting the corresponding author.

## 8 Acknowledgement

The author wishes to thank the Center for Water Engineering and Infrastructures Research, King Mongkut's University of Technology North Bangkok for all supports as well as the Royal Irrigation Department and personnel for supporting data.

## 9 References

- [1] Chaleeraktragoon, C., Chaipuriphat, A., & YingKrainkrai, P. (2001). Management of Available Water at the Bhumiphol and Sirikit Dams Base on Rule Curves. *the 7th National Conference on Civil Engineering*, (pp. 83-86). Thailand.

- [2] Vudhivanich, V. (2000). Simulation Criteria for Probability Based Rule Curves reservoir operation. In V. Vudhivanich, *Research Techniques in Irrigation Engineering* (pp. 50-62). Thailand.
- [3] Rittima, A. (2003). Development of Reservoir Operating Rules for Mun Bon-Lam Chae Reservoirs. Proceedings of the 40th Kasetsart University Annual Conference (pp. 156-165). Thailand: Kasetsart University.
- [4] Putrawutichai, S. (2017). *Optimal Operation of a Multipurpose Multi-Reservoir System in The Upper Chao Phraya River Basin*. Thailand: Kasetsart University.
- [5] Azamathulla, H., Ab Ghani, A., Zakaria, N., & Chun Kiat, C. (2009). Linear Programming Approach for Irrigation Scheduling - A case Study. *14th MANCID Annual Conference (14th MANCO)*, (pp. 1-11). Malaysia.
- [6] Needham, J., Watkins, D., Lund, J., & Nanda, S. (2000). Linear Programming for Flood Control in the Iowa and Des Moines Rivers. *Journal of Water Resources Planning and Management*, 118-127.
- [7] Abrishamchi, A., Dashti, M., & Tajrishy, M. (2011). Development of a Multi-Reservoir Flood Control Optimization Model; Application to the Karkheh River Basin, Iran. *World Environmental and Water Resources Congress 2011*, 3048-3057.
- [8] Chaleeraktragoon, C., & Kangrang, A. (2007). Dynamic programming with the principle of progressive optimality for searching rule curves. *Canadian Journal of Civil Engineering*, 170-176.
- [9] Labadie, J. W. (2004). Optimal operation of multireservoir systems: state-of-the-art review. *Journal of Water Resources Planning and Management*, 93-111.
- [10] Yeh, W. G. (1985). Reservoir Management and Operations Models: A State-of-the-Art Review. *Water Resources Research*, 1797-1818.
- [11] Holland, J. H. (1992). *Adaptation in Natural and Artificial Systems*. University of Michigan Press.
- [12] Wardlaw, R., & Sharif, M. (1999). Evaluation of genetic algorithms for optimal reservoir system operation. *Journal of Water Resources Planning and Management*, 25-33.
- [13] Pinthong, P., & Weesakul, S. (2008). A hybrid genetic-neurofuzzy system based decision modeling for real-time reservoir operation. *proceeding of the 13th National Conference on Civil Engineering*, (pp. 257-262). Thailand.
- [14] Geem, Z. W. (2007). Optimal Scheduling of Multiple Dam System Using Harmony Search Algorithm. *International Work-Conference on Artificial Neural Networks* (pp. 316-323). Springer.
- [15] Kongjun, T. (2018). Water Management in The Chao Phraya River Basin during Drought Crisis. *The National Defence College of Thailand Journal*, 8-34.



**Assada Kijpayoong** is a student at the Department of Teacher Training in Civil Engineering, King Mongkut's University of Technology North Bangkok, Thailand. He got a Bachelor's degree in Irrigation Engineering from Kasetsart University, Thailand. His researches are Water Resource Management and Computer Application Development.



**Dr. Panuwat Pinthong** is a Faculty member at the Department of Teacher Training in Civil Engineering, and Head of Center for Water Engineering and Infrastructures Research King Mongkut's University of Technology North Bangkok. He got a Ph.D. (Water Engineering and Management) from the Asian Institute of Technology, Thailand.

**Note:** The origin of this article was reviewed, accepted, and presented at The 8th International Conference on Technical Education (ICTechEd8), jointly held by the Faculty of Technical Education, King Mongkut's University of Technology North Bangkok (KMUTNB), Thailand, and the Association of Industrial Education (AIE) during 8-9 July 2021.