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Evaluating Hydroelectricity Production Re-operating with Adapted Rule Curve Under Climate Change Scenarios: Case Study of Bhumibol Dam in Thailand

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Abstract

Hydroelectricity production is being impacted by climate change due to the considerable changes in water availability of reservoir system and dam release. This study aims at evaluating the response of energy production of the Bhumibol dam through the reservoir re–operation system with non–engineering adaptation measures due to climate change. Re–operating the Bhumibol (BB) dam with adapted rule curve and modelling exercise with MIKE11 to predict series of reservoir inflow were conducted under RCP4.5 and RCP8.5 climate change scenarios. The adapted rule curves of BB dam were established by either increasing or lowering the upper and lower rule levels of 0.5 meters from the rule curves which were developed by EGAT in 2012. In addition, the standard operation policy was applied to specify the amount of water release corresponding to the adapted rule curves established. The water balance–based reservoir re–operation model was developed using MATLAB Simulink Toolbox for short–term simulation from 2012 to 2018. Influence of climate change on the seasonal and yearly reservoir inflows were considerably investigated. In addition, the relation of current and projected inflows, and the response of dam release and hydroelectric production of BB dam were then evaluated. The results of the short–term simulation from 2012 to 2018 show that dam release is likely to be increased corresponding to the high variability of projected inflows. Therefore, the seasonal and yearly hydroelectricity production are accordingly increased when re–operating dam under RCP4.5 and RCP8.5 inflows. It is found that the yearly hydroelectricity production with RCP4.5 and RCP8 inflows are about 52% and 30% respectively higher than the current inflow. It is also revealed that re–operating dam with the different types of adapted rule curves does not alter the volume of released water and energy production generated from the reservoir radically because the standard operating rules were adopted for all adapted rule curves. Importantly, the study on the adaptation measures to climate change would help increase understanding of necessity of new operational rules for dam and reservoir re–operation to cope well with instability of reservoir water supply for sustainable hydropower production in future.

Keywords: Adapted Rule Curve, Climate Change, Hydroelectricity, Water Balance–based Simulation Model.

1. INTRODUCTION

Great attention has been paid to climate change for few decades as it has caused serious impact on water resources management and responses to the natural disasters. The climate change has drastically altered the frequency and intensity of extreme rainfall creating large uncertainty of water availability in hydrologic cycle and occurrences of unprecedented huge floods and prolonged droughts (Kundzewicz et al., 2014). Moreover, the changes in rainfall patterns and streamflow discharges may adversely impact the efficiency of hydropower generation (ASEAN Development Bank, 2012; Goyal & Surampalli, 2018). Therefore, the dam and reservoir operation practices have to be re–examined and efficiently improved through adaptation measures based upon the rational and up–to–date information. For hydroelectric dam, the non–engineering adaptation measures such as re–operating reservoir with the new operating rules, improving the predictability of hydrological data, and developing the localized regional climate model to suggest the operational changes in reservoir management, can be very useful and need to be more explored for applications (Jia, 2016).

Most of the reservoirs in Thailand have been designed to serve multiple water uses such as irrigation, municipality, ecology, and hydropower generation. As the demand for electricity has become more competitive due to a massive increase in population and human being, a large number of small to large hydropower plant development projects has been established by aiming to effectively support the electricity requirement and to manage the renewable energy sources (Aroonrat & Wongwises, 2015; Punarai et al., 2015). Therefore, the attempt to re–operate the dam and reservoir system under climate change and to evaluate the response to energy production was made in this study by selecting Bhumibol dam as the study area.

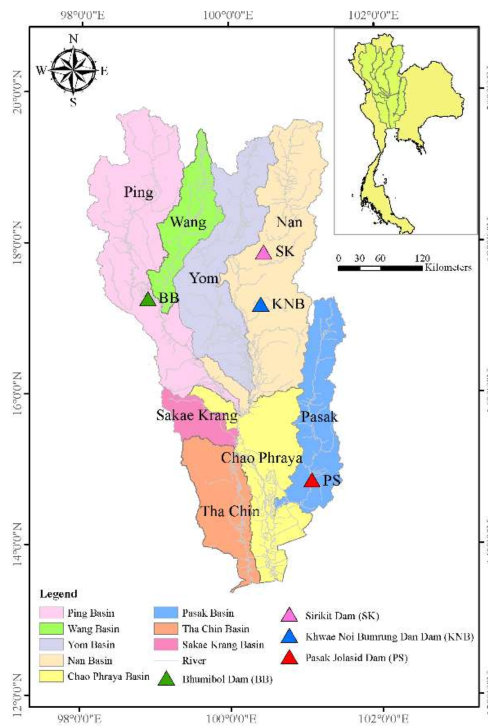

Figure 1 Bhumibol dam in the Greater Chao Phraya River Basin (GCPYRB)

The Bhumibol (BB) dam is a multipurpose dam built across the Ping River in the northern elevated plain of Thailand as shown in Fig.1. It is the major source of water supply in the Greater Chao Phraya River Basin (GCPYRB). GCPYRB is termed for this study to describe the principal river basin cluster for cooperative management of water resources in the central region of Thailand covering Ping, Wang, Yom, Nan, Pasak, Sakae Krang, and Tha Chin River basins with the total area of 138,977 km^2. The Bhumibol dam has been jointly operated with Sirikit (SK) and Khwae Noi Bumrung Dan (KNB) dams not only to supply water for national domestic, agricultural, industrial uses, as well as the ecological needs downstream, but also for hydropower production to supply electric power in the nearby region. The hydropower plant of Bhumibol dam has been built since 1961 and enlarged to the total installed capacity of 779.2 MW in 1991 with the average energy of 1,037 GWHr/yr (Thongthamchart & Raphitphan, 2016). The Electricity Generating Authority of Thailand (EGAT) is a key institutional operator responsible for dam and reservoir operation and hydroelectricity production.

In this study, the relation of reservoir inflow, dam release and hydroelectric production of BB dam which is altered by the climate change impact and the consequences of reservoir operation policy undertaken, are considerably investigated through the development of reservoir re–operation model using the adapted rule curves. The adapted rule curves were generated by increasing and lowering the levels of upper rule curve (URC) and lower rule curve (LRC) of ±0.5 m from existing rule curve established by EGAT in 2012 (Kyaw et al., 2022). The long–term response of energy production among the current and future climate change scenarios were examined and tested using statistical procedure to exhibit the statistical differences of obtained energy as the results of reservoir re–operations and climate change.

2. METHODOLOGY

In this study, the projection of reservoir inflow of BB dam was carried out through the platform of MIKE11 Zero. MIKE11 RR NAM Model and MIKE11 HD, the physically–lumped model, were adopted for rainfall–runoff simulation into Ping River Basin. Prediction of rainfall and evaporation under climate change scenarios was implemented based on the simulation of EC–EARTH under RCP4.5 and RCP8.5 scenarios regionally downscaled by RegCM4 with 25 km x 25 km grid size over the study area (Tabucanon et al., 2021). The projected inflow of BB dam was then generated for five periods namely, 2000–2020 (baseline), 2021–2040, 2041–2060, 2061–2080 and 2081–2099. However, the baseline period was only used for this study due to time duration of the available historical record. The water balance–based reservoir re–operation model was then developed using MATLAB Simulink Toolbox, as typically shown in Fig.2.

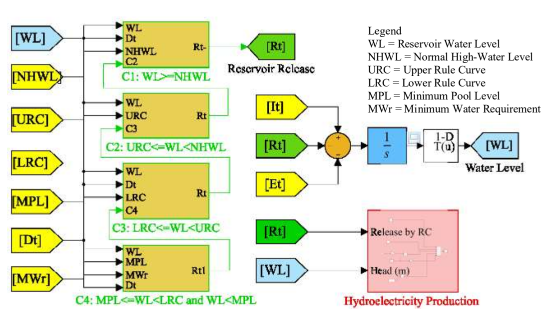

Figure 2 Water balance–based reservoir re–operation model using adapted rule curve

To emphasize the response of energy production when altering the reservoir operating policy under impact of climate changes, the adapted rule curves of BB dam which were modified from the rule curve established by EGAT in 2012, were used. The daily short–term simulation based upon the associated reservoir data were then performed from 2012 to 2018 under current and projected inflows. Identifying the water demand for BB dam was referred to yearly water allocation plan to reach all the water use sectors in GCPYRB. Water supplied to the target demand nodes was shared by BB and SK dams in the proportion of 0.44:0.56 (Tabucanon et al., 2021).

In the final step, the potential hydropower energy under current and future RCP 4.5 and RCP8.5 inflows were investigated to envisage the statistical difference of obtained energy by using ANOVA statistical procedure (St & Wold, 1989).

2.1 Adapted Rule Curve–Based Reservoir Re–operation Model

The reservoir rule curve is regarded as the common tool to provide useful guidance in the decision–making process of dam release. In this study, the adapted rule curve–based reservoir re–operation model for BB dam was established based on the existing rule curve developed in 2012 by EGAT. To accomplish the modelling practice for reservoir re–operation, four main scenarios of adapted rule curve were generated by increasing and lowering the water storage levels of upper rule curves (URC) and lower rule curves (LRC) of ±0.5 meters from the existing rule curve. The reservoir operating policies were set up in accordance with the standard operating policy (SOP) (Neelakantan & Sasireka, 2013; Kangrang et al., 2018) aiming to reduce the risk of unmanageability of reservoir operation system to handle with water deficit and flood while maximizing potential hydroelectricity production over the specific time periods. The water release from the reservoir is specified as the same amount of target demand when the reservoir storage is between LRC and URC. However, the water can only be released with the minimum water requirement of 5 million cubic meter per day (MCM/day) when the reservoir storage is lower than LRC. In case of reservoir storage is higher than URC, the reservoir water release is accordingly based on the conditions of excessive water and maximum turbine discharge of the hydropower system. The total amount of the water storage above normal high–water level (NHWL) is specified as a spilled water when the water level is above NHWL. Moreover, the reservoir water could not be released in case of the reservoir storage is lower than minimum pool level (MPL) as shown in Fig.3.

2.2 Estimation of Hydroelectricity Production

To simulate hydroelectricity production as a result of water release when re–operating with adapted rule curve, the water balance–based approach (Carvajal et al., 2017). was applied in accordance with the current and projected inflows as shown in Eq. (1).

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

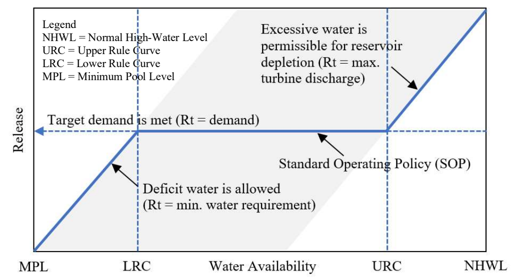

Figure 3 Application of standard reservoir operating policy with rule curves

where S_{t+1} represents the water storage of the reservoir at time step t+1; S_t is the initial storage of the reservoir at time step t; I_t is the reservoir inflow volume at time step t; E_t is the evaporation loss from the reservoir at time step t; and R_t is the water release volume or the reservoir outflow discharging into the hydropower turbines. S_t is constrained by the maximum water storage (S_{max}) and minimum water storage (S_{min}), which dynamically changes due to the associated reservoir data and amount of water release specified by adapted rule curves. The relationship between water storage and water level can be found using reservoir water level–area–capacity curve. R_t is determined by the water balance–based reservoir operation model developed using MATLAB Simulink Toolbox. Finally, daily hydropower electricity output of Bhumibol dam can be computed using Eq. (2).

$$E = \eta \rho g Q H t \tag{2}$$

where, E is the daily electricity output in kilowatts hour (KWHr). η is the overall efficiency of the hydropower plant in percentage, ρ is the water density (1,000 kg/m^3), g is the acceleration of gravity which is 9.81 m/s^2. Q represents the reservoir outflow discharging through the hydropower turbines (m^3/s). H is the hydraulic head (m) which can be calculated by the difference in height between the headwater level in the reservoir and tail water level downstream of the dam. t is the number of working hours for power generation over the specified time periods.

2.3 Statistical Analysis of Hydroelectricity Production Using ANOVA–Test

The energy production performed by the existing and adapted rule curves under the current and projected inflows were tested using one–way analysis of variance (ANOVA) test to determine whether there is a significant difference between the means of two energy dataset (Davis & Mukamal, 2006; Raftery et al., 1995; Labovitz, 1970). In the other words, ANOVA–test, which is a parametric test of difference, was used to describe whether impact of climate change has an effect on the potential energy production at level of significance (α) of 0.05.

3. Results and Discussion

3.1 Influence of Climate Change on the Seasonal and Yearly Reservoir Inflows

To emphasize on the influence of climate change on the seasonal and yearly inflows of Bhumibol dam, the long–term recorded inflow and projected inflow performed by MIKE11 were investigated and compared. It is found from recorded inflow that the average yearly inflow of the BB reservoir from 1969 to 2018 is approximately 5,694 MCM/yr. More than 80% of the total inflow is contributed to BB dam in wet season (May–Oct, WS) and the remaining is occurred in dry season (Nov–Apr, DS). Table 1 and Fig.4 also indicate that the long–term projected yearly inflow into BB dam under RCP4.5 and RCP8.5 tends to be decreased predominantly for all the specific time periods except in 2041–2060. In comparison with the baseline period (2000–2020), RCP4.5 scenario exhibits the increase in inflow in dry season (Nov–Apr) by +0.07%, +10.00%, +15.42% and +6.25% in 2021–2040, 2041–2060, 2061–2080 and 2081–2099, respectively. However, the opposite results are obviously found in wet season (May–Oct) as the change are expected to be –10.44%, +9.60%, –13.01% and –2.63%. For RCP8.5 case, the potential increase in inflow in dry season (Nov–Apr) is +8.14%, +8.15% and +22.71% in 2041–2060, 2061–2080 and 2081–2099, respectively except in 2021–2040 period showing the decrease in inflow by –5.03% deviated from the baseline period. Similarly, the percentage change in projected inflow in wet season (May–Oct) is fluctuated around the baseline by –4.68%, +20.17%, –10.13% and +18.04% in 2041–2060, 2061–2080 and 2081–2099, respectively. The results indicate considerable variations in the seasonal and yearly patterns of reservoir inflow which are key factor influencing the complexity and effectiveness of reservoir management in both the current and future operations.

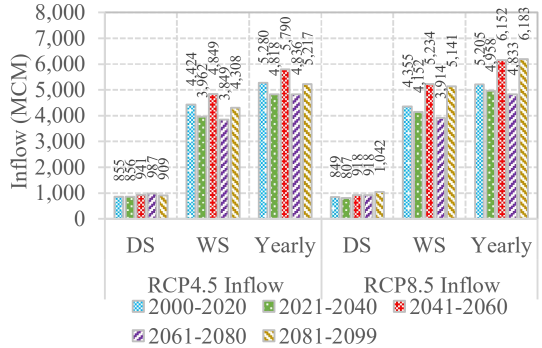

Figure 4 Projected changes in average seasonal and yearly reservoir inflows of Bhumibol dam

3.2 Response of Reservoir Water Release When Re–operating with Adapted Rule Curves under Climate Change Scenarios

As aforementioned, the average long–term yearly inflow of the Bhumibol dam is projected to significantly decrease under climate change scenarios (RCP4.5 and RCP8.5). However, in this study the simulation run of reservoir re–operation model was implemented using the short–term dataset from 2012 to 2018 since the rule curves has been established in 2012 by EGAT. It is noticeable that the average values of projected inflows from 2012 to 2018 are 6,358 and 5,168 MCM/yr for RCP4.5 and RCP8.5, respectively which are much higher than the current inflow of 4,269 MCM/yr as shown in Fig.5. These average values of projected inflows from 2012 to 2018 appear largely inconsistent with the average values of 5,280 and 5,205 MCM for RCP4.5 and RCP8.5 from 2000 to 2020, and 5,694 MCM from historical record from 1969 to 2018 due to the occurrences of extreme flow events in two consecutive years in this region creating severe flood in 2011 and handling flood risk in 2012. This reflects that climate change has significantly created the serious impact on the large variation of reservoir inflow for both short– and long–term data. The increase in projected inflows from 2012 to 2018 could lead to the increase in the seasonal and yearly release volumes from reservoir as expressed in Table 2 since determination of amount of reservoir release is substantially subject to the total inflow. The Fig.5 and Fig. 6 show strong correlation between the reservoir inflow and water releases when existing rule curve and 4 scenarios of adapted rule curves were employed. It exhibits that releasing water from BB dam is not only based on the conditions of available water storage and target water demand but also significantly subject to the extent of incoming inflows. Therefore, for the RCP4.5 and RCP8.5 inflow cases, the seasonal and yearly releases are relatively higher than water release for the current inflow case. It is also found that the released water in dry season is higher than in wet season for all scenarios. However, altering the operating rule curves by increasing and lowering the levels of ±0.5 meters while the same standard rules were applied, shows the slight differences in terms of seasonal and yearly release volumes from the reservoir system. Moreover, monthly water shortage is not existed for the current and projected inflows scenarios when re–operating with adapted rule curves from 2012 to 2018. Importantly, even the huge amount of water release in wet season obtained from RCP4.5 and RCP8.5 inflow scenarios is profoundly noticed, however, the maximum values of dam releases in wet season are 3,018 and 2,234 MCM for RCP4.5 and RCP8.5 inflow scenarios, respectively which are definitely associated with the water allocation plan specified in normal operation periods.

Table 1 The recorded and projected reservoir inflows of Bhumibol dam for the specified time periods

Month	**Recorded Inflow (MCM)**	**Projected Inflow under RCP4.5 (MCM)**					**Projected Inflow under RCP8.5 (MCM)**				
Periods	1969–2018	2000–2020[1/]	2021–2040	2041–2060	2061–2080	2081–2099	2000–2020[1/]	2021–2040	2041–2060	2061–2080	2081–2099
Jan	132.20	117.25	116.49	125.56	127.85	130.11	118.11	112.31	132.20	136.68	133.59
Feb	59.08	71.31	69.96	75.19	72.42	73.30	71.08	69.09	80.57	77.40	82.20
Mar	38.02	60.30	55.07	65.30	140.95	55.70	57.73	52.50	61.79	58.17	62.97
Apr	48.12	56.24	81.80	72.12	76.07	65.92	65.53	46.95	54.80	47.89	105.81
May	247.46	227.58	328.21	403.26	281.83	264.96	243.73	240.15	264.25	106.10	339.54
Jun	317.08	425.75	288.30	657.90	356.29	465.86	403.38	355.65	429.98	251.00	444.47
Jul	379.35	428.09	378.96	414.31	342.98	428.75	440.60	278.99	455.13	299.64	548.93
Aug	923.49	726.06	584.56	707.69	672.31	651.17	563.78	576.64	1,302.83	662.55	994.77
Sep	1,504.04	1,351.93	1,185.17	1,420.61	1,061.18	1,342.31	1,418.73	1,207.00	1,461.26	1,243.92	1,438.88
Oct	1,209.42	1,264.98	1,197.26	1,245.40	1,134.31	1,154.85	1,285.25	1,493.23	1,320.32	1,351.16	1,374.54
Nov	590.14	352.97	348.38	398.26	359.56	385.30	345.57	332.92	382.38	397.67	420.61
Dec	245.24	197.31	184.27	204.51	210.40	198.50	191.29	192.82	206.67	200.65	236.97
Yearly	5,693.64	5,279.77	4,818.43	5,790.10	4,836.15	5,216.72	5,204.77	4,958.25	6,152.17	4,832.84	6,183.27
Δ%			(–8.74)	(+9.67)	(–8.40)	(–1.19)		(–4.74)	(+18.20)	(–7.15)	(+18.80)
DS	1,112.80	855.37	855.99	940.93	987.26	908.83	849.30	806.59	918.40	918.47	1,042.14
Δ%			(+0.07)	(+10.00)	(+15.42)	(+6.25)		(–5.03)	(+8.14)	(+8.15)	(+22.71)
WS	4,580.84	4,424.40	3,962.44	4,849.17	3,848.89	4,307.89	4,355.47	4,151.66	5,233.77	3,914.36	5,141.13
Δ%			(–10.44)	(+9.60)	(–13.01)	(–2.63)		(–4.68)	(+20.17)	(–10.13)	(+18.04)

Remark: [1/] baseline period

Table 2 Seasonal and yearly water release when re–operating with adapted rule curves from 2012 to 2018

Types of Inflow	**Reservoir Water Release (MCM)**														
	Existing Rule Curve			**(+0.5 m) URC**			**(–0.5 m) URC**			**(+0.5 m) LRC**			**(+0.5 m) LRC**		
	DS	**WS**	**Yearly**	**DS**	**WS**	**Yearly**	**DS**	**WS**	**Yearly**	**DS**	**WS**	**Yearly**	**DS**	**WS**	**Yearly**
Current	2,632	1,702	4,334	2,632	1,702	4,334	2,632	1,700	4,332	2,632	1,700	4,332	2,632	1,703	4,335
RCP 4.5	3,008	3,019	6,027	3,018	2,985	6,003	3,000	3,049	6,048	3,009	3,018	6,027	3,021	3,006	6,027
Δ%	(+14)	(+77)	(+39)	(+15)	(+75)	(+39)	(+14)	(+79)	(+40)	(+14)	(+77)	(+39)	(+15)	(+77)	(+39)
RCP 8.5	2,869	2,224	5,093	2,859	2,222	5,082	2,851	2,261	5,111	2,861	2,234	5,094	2,861	2,234	5,094
Δ%	(+9)	(+31)	(+18)	(+9)	(+31)	(+17)	(+8)	(+33)	(+18)	(+9)	(+31)	(+18)	(+9)	(+31)	(+18)

Remark: [1/] the different values compared with the current inflow case

Table 3 Seasonal and yearly hydroelectricity production when re–operating with adapted rule curves from 2012 to 2018

Types of Inflow	Hydroelectricity Production (GWhr)														
	Existing Rule Curve			(+0.5 m) URC			(–0.5 m) URC			(+0.5 m) LRC			(+0.5 m) LRC		
	DS	WS	Yearly	DS	WS	Yearly	DS	WS	Yearly	DS	WS	Yearly	DS	WS	Yearly
Current	660	377	1,037	660	377	1,037	659	376	1,035	660	377	1,036	660	377	1,037
RCP 4.5	788	789	1,577	793	782	1,575	784	794	1,578	788	789	1,577	791	786	1,577
Δ%	(+19)	(+109)	(+52)	(+20)	(+108)	(+52)	(+19)	(+111)	(+52)	(+19)	(+109)	(+52)	(+20)	(+109)	(+52)
RCP 8.5	781	568	1,349	780	569	1,349	775	576	1,351	779	571	1,349	778	570	1,348
Δ%	(+18)	(+51)	(+30)	(+18)	(+51)	(+30)	(+17)	(+53)	(+30)	(+18)	(+52)	(+30)	(+18)	(+51)	(+30)

Remark: [1/] the different values compared with the current inflow case

Table 4 Results of ANOVA test for the daily energy performed various reservoir re–operation models

Re–operation	Diff.	Source of Variation	Sum of Square	Degree of Freedom	Mean Squared	F	p–value	F critical
Existing Rule Curve	$\Delta E^{1/}$	Between Groups	2798714108	1	2.799E+09	151.8326	2.11E–34	3.8433
		Within Groups	94228936748	5112	18432891			
		Total	97027650856	5113				
	$\Delta E^{2/}$	Between Groups	936810177.7	1	936810178	79.3998	6.94E–19	3.8433
		Within Groups	60314713786	5112	11798653			
		Total	61251523963	5113				
(+0.5 m) URC	$\Delta E^{1/}$	Between Groups	2776119189	1	2.776E+09	150.2820	4.51E–34	3.8433
		Within Groups	94432634805	5112	18472738			
		Total	97208753994	5113				
	$\Delta E^{2/}$	Between Groups	935875162.3	1	935875162	79.3168	7.23E–19	3.8433
		Within Groups	60317542813	5112	11799206			
		Total	61253417975	5113				
(–0.5 m) URC	$\Delta E^{1/}$	Between Groups	2824975555	1	2.825E+09	153.5799	9E–35	3.8433
		Within Groups	94031007217	5112	18394172			
		Total	96855982772	5113				
	$\Delta E^{2/}$	Between Groups	954884620.2	1	954884620	80.6869	3.65E–19	3.8433
		Within Groups	60497651904	5112	11834439			
		Total	61452536524	5113				
(+0.5 m) LRC	$\Delta E^{1/}$	Between Groups	2800368148	1	2.8E+09	151.9171	2.03E–34	3.8433
		Within Groups	94232199964	5112	18433529			
		Total	97032568113	5113				
	$\Delta E^{2/}$	Between Groups	938147770.1	1	938147770	79.5401	6.47E–19	3.8433
		Within Groups	60294268970	5112	11794654			
		Total	61232416740	5113				
(–0.5 m) LRC	$\Delta E^{1/}$	Between Groups	2799519087	1	2.8E+09	151.9133	2.03E–34	3.8433
		Within Groups	94205960025	5112	18428396			
		Total	97005479113	5113				
	$\Delta E^{2/}$	Between Groups	927441951.2	1	927441951	78.9799	8.55E–19	3.8433
		Within Groups	60029006055	5112	11742763			
		Total	60956448006	5113				

Remark: $\Delta E^{1/}$ = the difference between current inflow and projected RCP4.5 case
$\Delta E^{2/}$ = the difference between current inflow and projected RCP8.5 case
F = F–statistic value representing how much the variability among the means exceeds that expected one
F critical = value of the F–statistic at the threshold probability α of mistakenly rejecting a true null hypothesis

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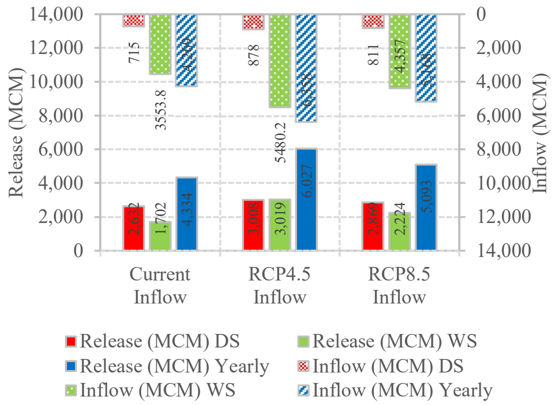

Figure 5 Relation of average reservoir water release with the current and projected inflows from 2012 to 2018 when existing rule curve was employed

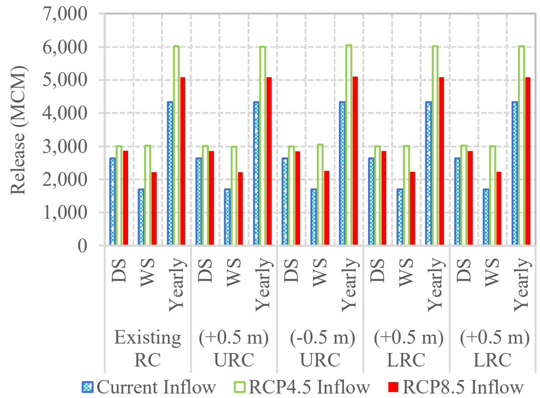

Figure 6 Average seasonal and yearly water releases when re–operating with adapted rule curve under RCP4.5 and RCP8.5 inflows from 2012 to 2018

3.3 Response of Hydroelectricity Production When Re–operating with Adapted Rule Curves under Climate Change Scenarios

In principle, the potential hydroelectricity production is relatively subject to the volumetric released water, hydraulic heads and overall efficiency of hydropower plant. As the dam release from 2012 to 2018 is likely to be increased due to the high variability of projected inflow, therefore, the seasonal and yearly hydroelectricity production are obviously increased when re–operating dam under RCP4.5 and RCP8.5 inflows. The yearly energy amounts to 1,037 GWhr for the current inflow when re–operating reservoir with the existing rule curve. By comparing with the current inflow case, the yearly energy is expected to increase of 52% and 30% under RCP4.5 and RCP8.5 scenarios when the existing rule curve is employed. However, there is no significant differences when changing the operating policy by the adapted rule curve as expressed in Table 3 and Fig. 7. The response of hydraulic head for hydropower generation was also investigated in this study as shown the results in Fig.8. It is revealed that the average values of monthly hydraulic head under RCP4.5 and RCP8.5 scenarios are higher than the current inflow case, leading to the increasing in energy production over the simulation time periods.

3.4 ANOVA Test for Hydroelectricity Production under Climate Change Scenario

The impact of climate change on the potential energy production of BB dam was re–diagnosed through the analysis of ANOVA–test to compare the means of energy when re–operating reservoir under the current and projected inflows. The results in Table 4 obviously show a significant difference between the means of two energy dataset at level of significance (α) of 0.05 when existing and adapted rule curves were employed. This implies that the changes in the extent of reservoir inflow and volume of released water due to impact of climate change would influence to the potential energy production in future.

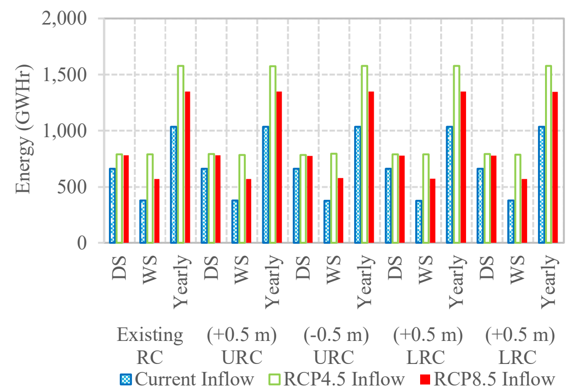

Figure 7 Average seasonal and yearly hydropower generation when re–operating with adapted rule curve under climate change scenarios

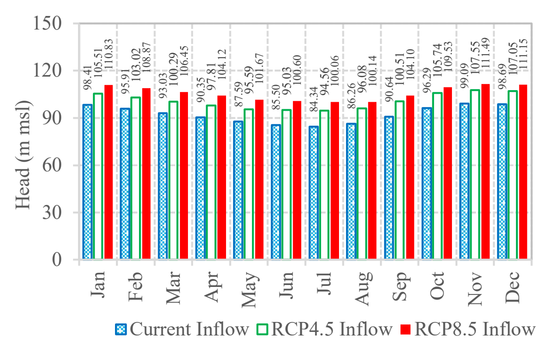

Figure 8 Response of average hydraulic head for hydropower generation under climate change scenarios

4. Conclusion

Hydroelectric generation is sensitively affected by the changes in water availability of the reservoir system and dam release. Based on the short–term simulation of BB dam from 2012 to 2018, dam release is likely to be increased corresponding to the high variability of projected inflow. Therefore, the seasonal and yearly hydroelectricity production are significantly increased when re–operating dam under RCP4.5 and RCP8.5 inflows. It is also revealed that re–operating dam with the different types of adapted rule curves does not alter the volume of released water and energy production generated from the reservoir radically because the standard operating rules were adopted for all adapted rule curves. However, the further study on the adaptation measures to climate change would help increase understanding of necessity of new operational rules for dam and reservoir re–operation to cope well with instability of reservoir water supply in future.

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