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Improvement of water management project by correcting irrigation water requirement in farmer participation and optimization

Anongrit Kangrang[1*], Haris Prasanchum[2], Ratana Hormwichian[1], Rapeepat Techarungruengsakul[1], Ratsuda Ngamsert[1], Nanthawat Phookinghin[1], Jirayut Wangthken[1]

[1]*Mahasarakham University, Faculty of Engineering, Kantarawichai, Mahasarakham, 44150 Thailand*
[2]*Rajamangala University of Technology Isan, Faculty of Engineering, KhonKaen, 40000 Thailand*
[*]*Corresponding author:* anongrit.k@msu.ac.th

Abstract

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This study explored water resource management in an irrigation project in Yasothorn Province, Thailand in order to improve the water resource management system. The Huay Sabag and Huay Ling Jone Irrigation Schemes pilot projects were studied by field observations, interviewing stakeholders and collecting data. Data were collecting about water requirements, allocation and land use and then corrected using farmer participation. The improvement of water resource management was achieved by improving reservoir rule curves that provide decisions concerning release of water following the corrected water requirement. The results revealed that monthly water requirements corrected by farmer participation are less than existing water demand and that the newly obtained rule curves of both reservoirs provided more reserve stored water for irrigation water requirement than the previous rule curves.

Keywords: participation; reservoir; rule curves; genetic algorithms; water requirement; irrigation project

Introduction

Water is essential for human and animal survival. However, flood and draught are still classical water problems. There are many challenges and problems that remain unresolved including poor quality irrigation distribution, lack of incentives for stakeholders and low efficiency in reservoir operation etc. It seems that the above issue of stakeholders in water management is the aspect of prime importance for sustainable development. A review and analysis of participatory irrigation management reflected many problematic aspects, such as the level of stakeholder participation, sources of finance and water requirement estimation. Nowadays, stakeholders' involvement in water resources management is seen as an ongoing process to promote efficiency of water resources management for sustainable development (Cuesta & Rañola, 2009; Molobela & Sinha, 2011). Stakeholders need to participate in water management to effectively integrate the goals of efficiency, sustainability and equity for all sections. Supporting stakeholders in managing their water resources to make choices and to reach a common understanding on sharing water is the basis on which stakeholders should seek a well-informed decision (Chenoweth, et al., 2002). To make the transition to more sustainable water management, most analysts recommend managing water based on river basins and increasing stakeholders' participation in water management (Wester et al., 2003). There are great challenges in a transition to participatory decision-making in water systems management, especially regarding public participation (Song et al., 2011). Effective public participation is the key factor to improve the efficiency of the river basin's water resource management and to provide successful comprehensive management (Jinling et al., 2010; Zaharani et al., 2011; Sivanpheng et al., 2014).

The combination of traditional control techniques and subjective aspects of decision-making promotes effective and efficient management of water systems and can reduce the gap between theories and practice (Castelletti et al., 2008). Participation of stakeholders delivers an approach of optimization that is acceptable to farmers and officers. Reservoir operation is performed to store water and release water for target demands. Generally the target demands for a reservoir are the agricultural sector, water supply, industry, power generation, ecology and environment conservation etc. A reservoir operation that uses rule curves can improve water budgeting, better respond to water requirements, provide positive solutions to flood problems, and achieve long term operation planning (Kangrang et al., 2011).

Reservoir operating rule curves have been found to provide the best all-around budgeting solution. Typically, reservoir operating systems have been large and complex. The searching of the optimum rule curves is a non-linear optimization problem. Years ago, the optimization technique being applied to search the optimal rule curves was performed with a reservoir simulation model (Jain et al., 1998). Later dynamic programming (DP) was applied to solve non-linear problems in water resource areas (Kumar & Baliarsingh, 2003; Chaleeraktrakoon & Kangrang, 2007). Genetic algorithms (GA) have been widely used to solve complex problems (Chao-Hsien, 1997). The best part of the GA approach is that it can handle any type of objective function of the search. GA was applied to the reservoir operation model, studied in this paper, as it has been in several studies (Chang et al., 2003; Chang et al., 2005; Hormwichian et al., 2009).

This paper involved stakeholders in water resources management. The field activities undertaken within the pilot project were field observations, interviewing stakeholders and collecting data about water requirements, allocation and land use. Then, the GA with reservoir simulation was applied to determine the accepted rule curves that provide for release water following the corrected water requirement. This study was applied to the pilot projects of Huay Sabag and Huay Ling Jone Irrigation Schemes in Yasothorn Province, in the Northeast region of Thailand.

Material and Methods

The study area included two irrigation schemes, the Huay Sabag and the Huay Ling Jone Irrigation projects located in Yasothorn province in the Northeast region of Thailand. The study area is shown in Fig. 1. The total area of the Huay Sabag is approximately 52 km^2 and total cumulative annual average runoff

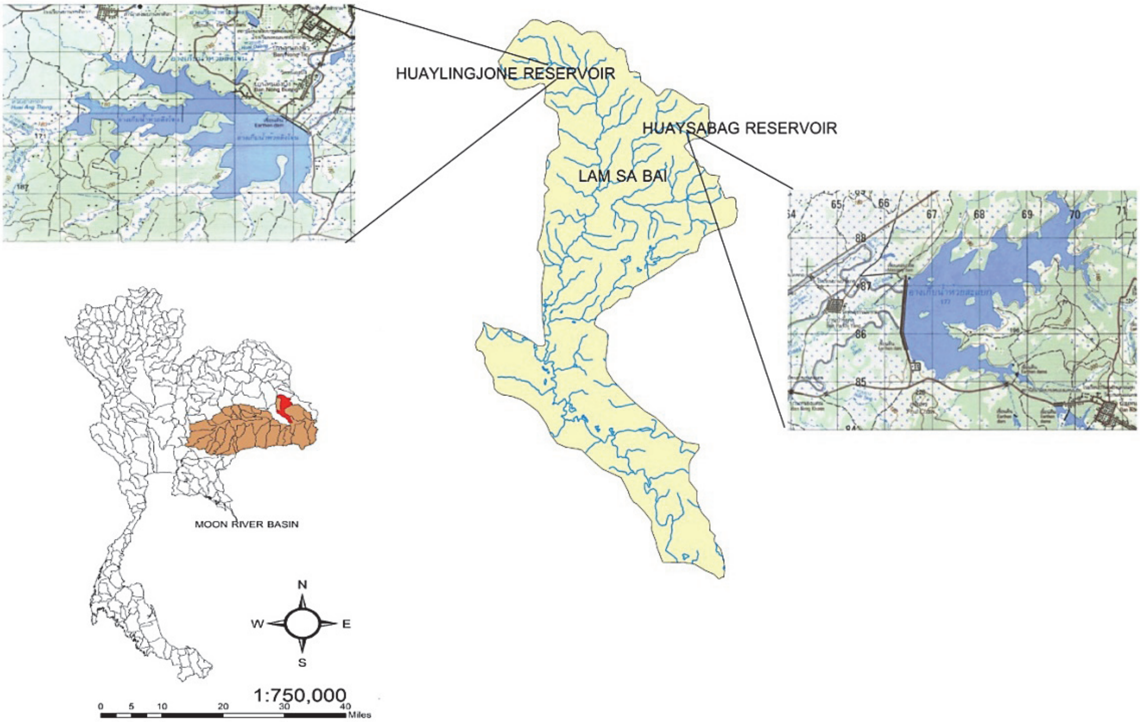

Fig. 1. Location of Huay Sabag and Huay Ling Jone Irrigation Schemes

is about 22.4 million m^3 (MCM). The normal storage capacity is 30.03 MCM and dead storage capacity of 0.6 MCM. The Huay Ling Jone reservoir has an irrigation area of 19.88 km^2, full storage capacity of reservoir is 21.06 MCM and dead storage capacity is 0.4 MCM. The water requirements at downstream sites are irrigation demand, livestock demand, domestic water supply and environmental conservation. A schematic diagram of the reservoirs is presented in Fig. 2.

Collection of data about water requirements and allocation

The actual irrigated areas, cropping patterns and water demand were recorded by the authorities of the irrigation projects and by farmers. The information was crosschecked by field observation. This information included the kinds of crops to be grown and corresponding cultivation areas. The inflows and outflows of the command areas were recorded and measured to establish the water balance. Water discharge in the main, secondary and tertiary canals was measured to identify the flow inside. The water balance concept was used to provide information on all inflows and outflows in a command area and also to determine the water delivery destinations, while taking into account the multiple uses of water within a command area.

Correction of water requirements by farmer participation

The *ETo* was determined first. Then, the second stage in estimating crop water requirements was the selection of the *Kc* according to the cropping pattern during a production season and the growth characteristics of the crop. The *ETc* was then calculated for each period throughout the growing season depending on the chosen budgeting period for the application of water to supplement any rainfall as follows:

$$ETc = ETo \times Kc, \tag{1}$$

where *ETc* is the consumptive use (mm/day), *Kc* is the crop coefficient. The reference crop evapo-transpiration (*ETo*) was calculated using the Modified Penman method (Doorenbos & Pruitt 1977; Allen et al., 1998).

The crop water requirement (*WRc* in mm/day) for each agricultural practice was calculated using the following equations:

$$WRc = ETo \times Kc, \tag{2}$$

where the total scheme crop water requirement (*SWR* in m^3) was calculated based on the requirements for multiple uses of all the above mentioned agricultural activities within the irrigation area including sticky rice, jasmine rice, sweet corn, sticky corn, animal corn, sugarcane, cassava, soil bean, pumpkin, calabash, watermelon, cucumber and para rubber as follows (Allen et al., 1998; Sivanpheng et al., 2014):

$$SWR = \sum_{i=1}^{n} \int_{j=1}^{m} WRc_{ji} \times A_{ji}, \tag{3}$$

where *i* is the type of agricultural activity (e.g. sticky rice, jasmine rice, sweet corn, sticky corn, animal corn, sugarcane, cassava, soil bean, pumpkin, calabash, watermelon, cucumber and para rubber), *j* is the day, *m* is the number of days, *n* is the number of agricultural activities practiced

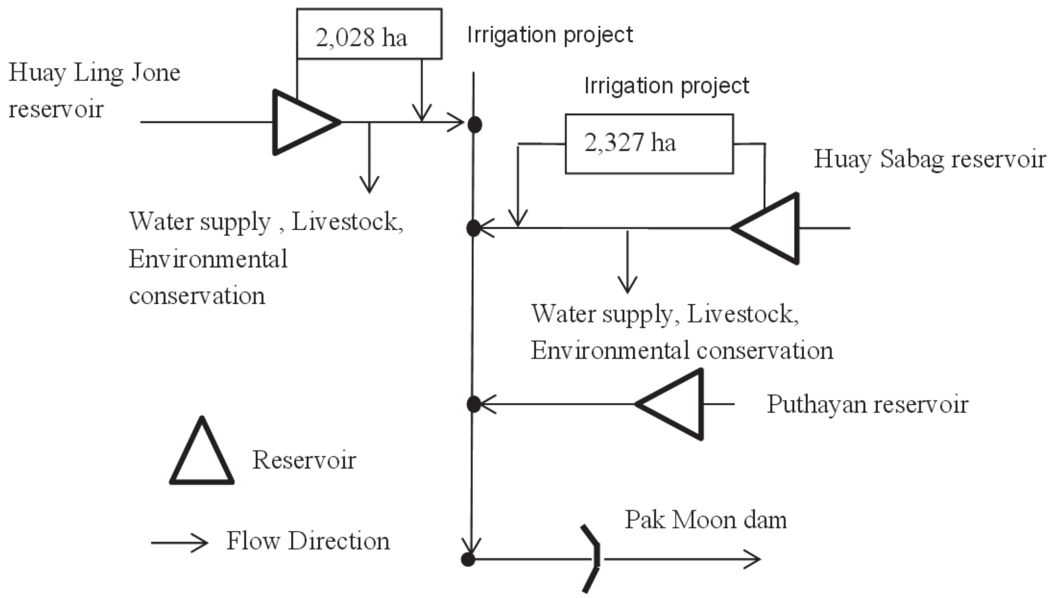

Fig. 2. Schematic diagram of Huay Sabag and Huay Ling Jone reservoir system

within the command area, WRc_{ji} is the crop water requirement (mm/day x 10^{-3}) of crop type (i) at the day (j) and Aji is the actual cultivated area (m^2) of crop type (i) at day (j).

Water supply requirement is calculated as the follow:

$$WRw = P \times Rc, \tag{4}$$

where WRw is the water supply requirement (m^3/month), P is number of people in considering area (person). Rc is water use rate (m^3/person-month).

Livestock requirement is calculated as follows:

$$WRa = Pa \times Ra, \tag{5}$$

where WRa is the livestock water (m^3/month), Pa is number of livestock for animal a in the area considered (number). Ra is water use rate for animal a (m^3/number-month). These livestock are cattle, buffalo, swine, chicken and duck. For environmental conservation water this study used 10% of total inflow.

Reservoir simulation model

Generally, a reservoir system comprises available water that flows into the reservoir with a single or multipurpose downstream service area. The reservoirs usually operate under water usage criteria and reservoir rule curves. The reservoir rule curves have been found to offer the most equitable solution to all operational problems and reservoir operating policies are based on the reservoir rule curves and the principles of a water balance concept.

The release water of the reservoir based on a standard operating rule was used to calculate the situations of water shortage and excess water release, namely, the number of failures in a year, the number of excess water releases, as well as the average annual shortage (Prasanchum & Kangrang, 2018).

Application of genetic algorithm for searching accepted rule curves

The application of a genetic algorithm with reservoir simulation model for searching optimal accepted rule curves is described as follows. The GA requires encoding schemes that transform the decision variables into chromosomes (lower rule curves (x_τ) and upper rule curves (y_τ). Then, the GA operations (reproduction, crossover and mutation) are performed. These GA operations will generate new sets of chromosomes. The most common encoding schemes use bi-

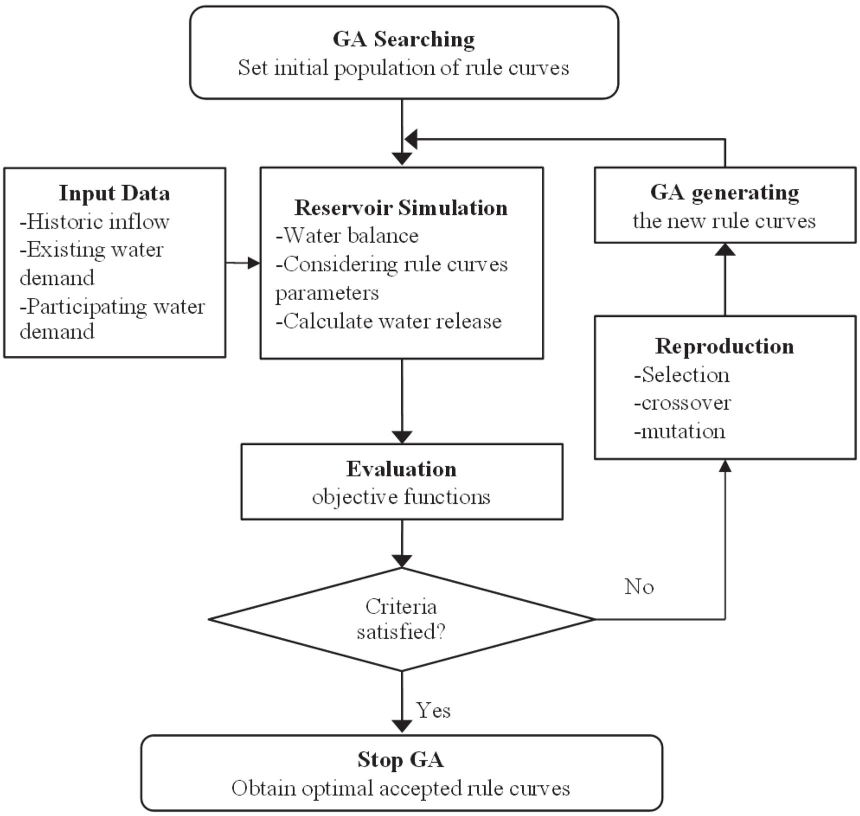

Fig. 3. Integration of genetic algorithm and reservoir simulation model for searching optimal rule curves

nary strings. In this study, each decision variable represents a monthly level of the rule curves of reservoirs that described in the mentioned release with standard operating rule. After the chromosomes of the initial population have been determined, the release water is calculated in a simulation model using these rule curves. Then, the release water is used to calculate the objective function for evaluating GA fitness. Next, the reproduction including selection, crossover and mutation is performed in order to create new rule curves parameters in the next generation. This procedure is repeated until the criterion is satisfied as described in Fig. 3. There are 24 parameters (rule curve levels) which are represented by the chromosomes (Prasanchum & Kangrang, 2018). The objective function of searching the optimal rule curves is the minimum of the average water shortage (MCM/year) for the Huay Ling Jone reservoir and minimum average excess water (MCM/year) for the Huay Sabag reservoir as following.

$$f_i(x_\tau, y_\tau) = \mathrm{Min}\left(\frac{1}{n}\sum_{v=1}^{n} Sh_v\right), \quad (6)$$

$$\text{if } R_\tau < D_\tau\text{; Then } Sh_v = \sum_{\tau=1}^{12}\left(D_\tau - R_\tau\right), \quad (7)$$

Else $Sh_v = 0$

$$f_i(x_\tau, y_\tau) = \mathrm{Min}\left(\frac{1}{n}\sum_{v=1}^{n} Sp_v\right), \quad (8)$$

$$\text{if } R_\tau > D_\tau\text{; Then } Sp_v = \sum_{\tau=1}^{12}\left(R_\tau - D_\tau\right), \quad (9)$$

Else $Sp_v = 0$

where R_τ is the release discharges from the reservoir during year ν and period τ (τ = 1 to 12, representing January to December); D_τ is the water requirement of month τ; x_τ is lower rule curve of month τ; y_τ is upper rule curve of month τ; n is the total number of considered year. Sh_υ is water deficit during year ν, Sp_υ is excess water during year ν and i is iteration number of each generation.

The boundary of the search for each generation is limited in order to reduce the fluctuation of the obtained rule curves. The range of searching for the lower and upper rule curves is fixed on the dead storage and normal high water level respectively (Prasanchum & Kangrang, 2018).

Evaluation accepted rule curves

The optimal accepted rule curves were obtained from GA and were used to run the simulation model for evaluating the efficiency of each rule curve. Then these accepted rule curves were used to run with both historic inflow and 1000 samples of synthetic inflow. For each case the existing water demand and the participating water demand were used in the run for evaluating the accepted optimal rule curves.

Results and Discussion

Water requirement by participation

Water requirement from reservoir are classified into 4 sectors: irrigation demand, water supply demand, livestock demand and environmental conservation demand. Irrigation water demand is the majority sector. Table 1 shows irrigation water requirement from Huay Sabag reservoir by field observation and data collection. The results indicated that nine crops: sticky rice, jasmine rice, sweet corn, sticky corn, animal corn, sugarcane, cassava, soil bean and para rubber were cultivated in downstream area of Huay Sabag. The total irrigation water requirement is 3165.401 m^3/year. The highest irrigation demand is for jasmine rice.

Table 2 also shows irrigation water requirement from Huay Sabag reservoir corrected by farmer participation. The twelve crops are rice, palm, sweet corn, sticky corn, animal corn, sugarcane, cassava, soil bean, para rubber, pumpkin, calabash and watermelon were approved by farmer partici-

Table 1. Irrigation water requirement from Huay Sabag reservoir by field observation and data collection

No.	Plant type	Cultivation period (month)	Irrigation size (ha)	ETo (mm/month)	Kc	ETc (mm/month)	Water requirement (m^3)
1	Sticky rice	May-October	411.20	126.20	1.24	156.50	643.528
2	Jasmine rice	May-October	1207.52	126.20	1.31	165.30	1996.031
3	Sweet corn	May-August	1.60	128.20	0.93	119.20	1.907
4	Sticky corn	May-August	68.00	128.20	0.93	119.20	81.056
5	Animal corn	May-August	18.40	128.20	1.19	152.30	28.023
6	Sugarcane	February-April	65.60	144.50	1.01	145.90	95.710
7	Cassava	April-May	82.56	151.90	0.62	94.20	77.772
8	Soil bean	December-April	95.52	126.50	0.89	112.60	107.556
9	Para rubber	January-December	77.12	124.80	2.33	290.80	224.264
Total			2027.52	–	–	–	3165.401

pation to cultivate in the downstream area. The number of types of crops recorded after correction by famers was larger than before correction. Table 2 also shows current cultivation areas assessed from farmer information. However, the total irrigation water requirement is 1554.065 m^3/year which is less than irrigation requirement before correcting by the participation process. The highest irrigation demand is for sugarcane and the least water requirement is for sweet corn. Therefore, the stored water in the reservoir can provide more water for more irrigation than the existing demand situation.

Table 3 shows irrigation water requirement from Huay Ling Jone reservoir by field observation and data collection. These six crops are sticky rice, jasmine rice, sugarcane, corn, cassava and para rubber and were cultivated in the downstream area of the Huay Long Jone reservoir. The total irrigation water requirement is 3732.731 m^3/year and that is less than the irrigation requirement of the Huay Sabag reservoir. The highest irrigation demand is for jasmine rice and the least water requirement is for corn. Table 4 shows irrigation water requirement from Huay Ling Jone reservoir that has

Table 2. Irrigation water requirement from Huay Sabag reservoir corrected by farmer participation

No.	Plant type	Cultivation period (month)	Irrigation size (ha)	ETo (mm/month)	Kc	ETc (mm/month)	Water requirement (m^3)
1	Rice	May-August	90.88	144.40	1.12	161.70	146.953
2	Palm	May-December	64.00	118.80	2.09	248.30	158.912
3	Sweet corn	May-August	1.60	128.20	0.93	119.20	1.907
4	Sticky corn	May-August	68.00	128.20	0.93	119.20	81.056
5	Animal corn	May-August	18.40	128.20	1.19	152.30	28.023
6	Sugarcane	February-April	260.80	144.50	1.01	145.90	380.507
7	Cassava	April-May	251.20	151.90	0.62	94.20	236.630
8	Soil bean	December-April	95.52	126.50	0.89	112.60	107.556
9	Para rubber	January-December	103.20	124.80	2.33	290.80	300.106
10	Pumpkin	February-March	37.76	137.00	0.98	134.30	50.712
11	Calabash	January-March	4.16	127.40	1.00	127.40	5.300
12	Watermelon	March-May	27.84	153.50	1.32	202.60	56.404
Total			1023.36	-	-	-	1554.065

Table 3. Water requirement from Huay Ling Jone reservoir by collecting and calculating

No.	Plant type	Cultivation period (month)	Irrigation size (ha)	ETo (mm/month)	Kc	ETc (mm/month)	Water requirement (m^3)
1	Sticky rice	May-October	524.00	126.20	1.24	156.50	843.907
2	Jasmine rice	May-October	1228.96	126.20	1.31	165.30	2031.741
3	Sugarcane	February-April	466.88	144.50	1.01	145.90	681.178
4	Corn	May-August	14.72	128.20	0.93	119.20	17.546
5	Cassava	April-May	33.92	151.90	0.62	94.20	31.953
6	Para rubber	January-December	43.84	124.80	2.33	290.80	127.487
Total			2327.04	–	–	–	3732.731

Table 4. Water requirement from Huay Ling Jone reservoir by farmer participating correction

No.	Plant type	Cultivation period (month)	Irrigation size (ha)	ETo (mm/month)	Kc	ETc (mm/month)	Water requirement (m^3)
1	Rice	March-August	334.40	126.20	1.12	141.30	129.770
2	Sugarcane	February-December	466.88	151.90	1.01	145.90	147.301
3	Corn	May-August	14.72	128.20	0.93	119.20	17.546
4	Cassava	April-May	33.92	151.90	0.62	94.20	47.025
5	Para rubber	January-December	43.84	124.80	2.33	290.80	127.478
6	Gourd	October-December	76.64	151.90	1.31	199.00	88.834
7	Cucumber	March-June	57.12	153.50	1.32	202.60	50.893
8	Cantaloupe	December-February	55.84	127.40	1.32	168.20	40.099
Total			1083.36	–	–	–	648.953

been corrected by farmer participation. These eight crops; rice, sugarcane, corn, cassava, para rubber, cucumber and cantaloupe, were approved by farmer participation to cultivate in downstream area of the reservoir. The number of types of crops recorded after correction by famers was larger than before correction However, the total irrigation water requirement is 948.953 m^3/year and that is less than the irrigation requirement calculated before the farmer participation process. The highest irrigation demand is for sugarcane and the least water requirement is for cassava. This lower water requirement enhances the ability to save more water in the reservoir for promoting a larger irrigation area or for other purposes.

Table 5 shows monthly water demand in the downstream side of Huay Sabag reservoir comprising irrigation demand, water supply demand, livestock demand and environmental conservation demand. The results indicated that water demand before and after correction by farmer participation are quite different. However, the corrected water demand was more guaranteed to accept than the existing demand from field observation and data collection. Furthermore, they also show that the monthly water demands of farmer participation are less than existing monthly demands. This is because correction demand is current demand whereas existing demand is planning demand that was estimated at the beginning of the project start (Sivanpheng et al., 2014).

Table 6 shows monthly water demand in the downstream side of Huay Ling Jone reservoir. The results indicated that monthly water demands after correction by farmer participation are less than existing water demand for irrigation demand, water supply demand and environmental conservation demand, except for livestock. Table 6 also shows that the

Table 5. Monthly water demand from Huay Sabag reservoir by field data collection and farmer participating correction

Month	Water demand (Million Cubic Meter: MCM)									
	Irrigation		Water supply		Livestock		Environmental control		Total	
	E	C	E	C	E	C	E	C	E	C
January	0.332	0.413	0.037	0.024	0.006	0.015	0.600	0.253	0.643	0.680
February	0.428	0.844	0.037	0.024	0.006	0.015	0.600	0.253	1.071	1.111
March	0.428	1.048	0.037	0.024	0.006	0.015	0.600	0.253	1.071	1.315
April	0.505	1.228	0.037	0.024	0.006	0.015	0.600	0.253	1.148	1.495
May	3.053	1.010	0.037	0.024	0.006	0.015	0.600	0.253	3.696	1.277
June	2.975	0.717	0.037	0.024	0.006	0.015	0.600	0.253	3.618	0.984
July	2.975	0.717	0.037	0.024	0.006	0.015	0.600	0.253	3.618	0.984
August	2.975	0.717	0.037	0.024	0.006	0.015	0.600	0.253	3.618	0.984
September	2.864	0.459	0.037	0.024	0.006	0.015	0.600	0.253	3.507	0.726
October	2.864	0.459	0.037	0.024	0.006	0.015	0.600	0.253	3.507	0.726
November	0.224	0.459	0.037	0.024	0.006	0.015	0.600	0.253	0.867	0.726
December	0.332	0.042	0.037	0.024	0.006	0.015	0.600	0.253	0.975	0.309

Note: E = existing demand by field observation and data collection, C = correction demand by farmer participation

Table 6. Monthly water demand from Huay Ling Jone reservoir by field data collection and farmer participating correction

Month	Water demand (Million Cubic Meter: MCM)									
	Irrigation		Water supply		Livestock		Environmental control		Total	
	E	C	E	C	E	C	E	C	E	C
January	0.127	0.168	0.045	0.028	0.001	0.009	0.400	0.190	0.573	0.384
February	0.809	0.315	0.045	0.028	0.001	0.009	0.400	0.190	1.255	0.531
March	0.809	0.455	0.045	0.028	0.001	0.009	0.400	0.190	1.255	0.671
April	0.841	0.502	0.045	0.028	0.001	0.009	0.400	0.190	1.287	0.718
May	3.052	0.520	0.045	0.028	0.001	0.009	0.400	0.190	3.498	0.736
June	3.020	0.473	0.045	0.028	0.001	0.009	0.400	0.190	3.466	0.689
July	3.020	0.422	0.045	0.028	0.001	0.009	0.400	0.190	3.466	0.638
August	3.002	0.422	0.045	0.028	0.001	0.009	0.400	0.190	3.448	0.638
September	3.002	0.275	0.045	0.028	0.001	0.009	0.400	0.190	3.448	0.491
October	3.002	0.364	0.045	0.028	0.001	0.009	0.400	0.190	3.448	0.580
November	0.127	0.364	0.045	0.028	0.001	0.009	0.400	0.190	0.573	0.580
December	0.127	0.404	0.045	0.028	0.001	0.009	0.400	0.190	0.573	0.620

Note: E = existing demand by field observation and data collection, C = correction demand by farmer participation total water demands of farmer participation are less than total water demand of the existing collection. These situations are similar to the results of Huay Sabag reservoir. Therefore, remaining stored water from farmer participation can release to downstream for the other water requirements more than the existing demand by field observation and data collection from observation and data collection.

Optimal accepted rule curves

The collecting water demand and the participating water demand were used in the reservoir simulation model with the historic inflow data for searching optimal rule curves. The results of using both collecting water demand and participating water demand are shown in Fig. 4 and Fig. 5 for the Huay Sabag and the Huay Ling Jone reservoirs respectively. The results show that the patterns of optimal rule curve obtained from GA using existing water demand and GA using participating water demand are similar.

Efficiency of optimal accepted rule curves

The performance of both optimal rule curves from using existing water demand and participating water demand as well as current rule curves was evaluated with historic inflow data considering the existing water demand case and participating water demand case and the results are shown in Table 7 and Table 8, and Table 9 and Table 10 for Huay Sabag and Huay Ling Jone reservoirs respectively. Table 7 shows frequency, magnitude and duration of water shortage and excess water release of Huay Sabag reservoir considering the existing demand case. The results indicate that, the average excess water of using optimal rule curves from considering existing water demand (RC2-existing demand) is the least (6.005 million m^3/year) as compared with other rule curves. These are suitable for objective function of searching condition. Table 8 shows frequency, magnitude and duration of water shortage and excess water release of Huay Sabag reservoir considering the participating demand case. The re-

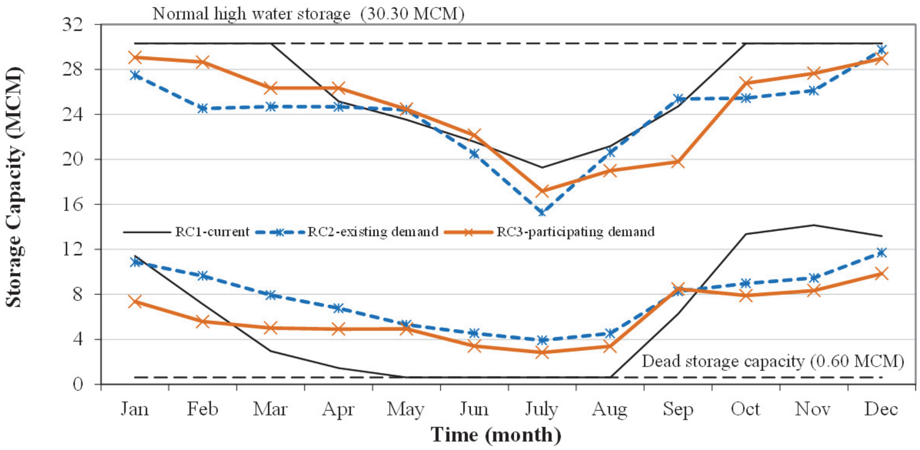

Fig. 4. Optimal rule curves of the Huay Sabag reservoir

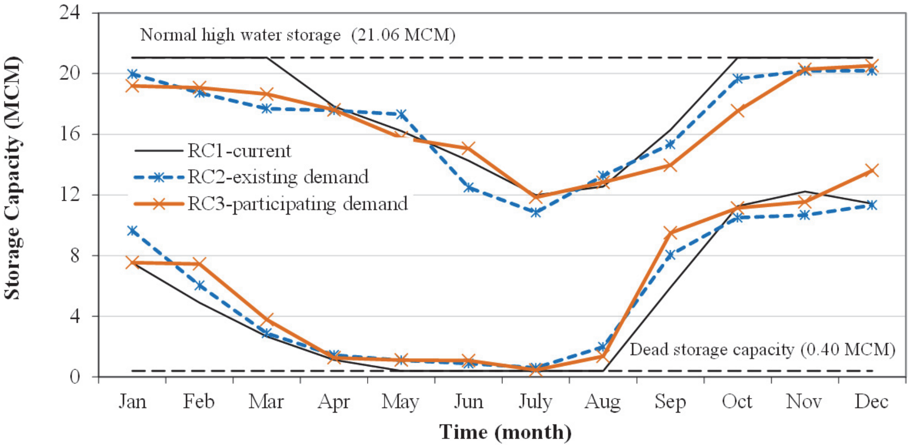

Fig. 5. Optimal rule curves of the Huay Ling Jone reservoir

sults indicate that, the average excess water of using optimal rule curves from considering participating water demand (RC3-existing demand) is the least (6.853 million m^3/year) as compared with other rule curves. These are suitable for objective function of searching condition too.

Table 9 shows the frequency, magnitude and duration of water shortage and excess water release of Huay Ling Jone reservoir considering the existing demand case. The results indicate that, the average excess water of using optimal rule curves from considering existing water demand (RC2-existing demand) is the least (5.091 million m^3/year) as compared with other rule curves.

Table 7. Frequency, magnitude and duration of water shortage and excess water release of Huay Sabag reservoir considering existing demand

Situations	Rule curves	Frequency (times/year)	Volume (MCM/year)		Time period (year)	
			Average	Maximum	Average	Maximum
Water deficit	RC1-current	0.000	0.000	0.000	0.000	0.000
	RC2-existing demand	0.000	0.000	0.000	0.000	0.000
	RC3-participating demand	0.000	0.000	0.000	0.000	0.000
Excess water	RC1-current	1.000	6.237	6.305	22.000	22.000
	RC2-existing demand	1.000	6.005	6.305	22.000	22.000
	RC3-participating demand	1.000	6.241	6.305	22.000	22.000

Table 8. Frequency, magnitude and duration of water shortage and excess water release of Huay Sabag reservoir considering participating demand

Situations	Rule curves	Frequency (times/year)	Volume (MCM/year)		Time period (year)	
			Average	Maximum	Average	Maximum
Water deficit	RC1-current	0.000	0.000	0.000	0.000	0.000
	RC2-existing demand	0.000	0.000	0.000	0.000	0.000
	RC3-participating demand	0.000	0.000	0.000	0.000	0.000
Excess water	RC1-current	1.000	6.900	6.981	22.000	22.000
	RC2-existing demand	1.000	6.917	6.917	22.000	22.000
	RC3-participating demand	1.000	6.853	6.917	22.000	22.000

Table 9. Frequency, magnitude and duration of water shortage and excess water release of Huay Ling Jone reservoir considering existing demand

Situations	Rule curves	Frequency (times/year)	Volume (MCM/year)		Time period (year)	
			Average	Maximum	Average	Maximum
Water deficit	RC1-current	0.042	0.042	1.000	1.000	1.000
	RC2-existing demand	0.042	0.042	1.000	1.000	1.000
	RC3-participating demand	0.042	0.042	1.000	1.000	1.000
Excess water	RC1-current	1.000	5.146	5.500	24.000	24.000
	RC2-existing demand	1.000	5.091	5.500	24.000	24.000
	RC3-participating demand	1.000	5.206	5.500	24.000	24.000

Table 10. Frequency, magnitude and duration of water shortage and excess water release of Huay Ling Jone reservoir considering participating demand

Situations	Rule curves	Frequency (times/year)	Volume (MCM/year)		Time period (year)	
			Average	Maximum	Average	Maximum
Water deficit	RC1-current	0.000	0.000	0.000	0.000	0.000
	RC2-existing demand	0.000	0.000	0.000	0.000	0.000
	RC3-participating demand	0.000	0.000	0.000	0.000	0.000
Excess water	RC1-current	1.000	5.308	5.677	24.000	24.000
	RC2-existing demand	1.000	5.353	5.677	24.000	24.000
	RC3-participating demand	1.000	5.168	5.677	24.000	24.000

Table 10 shows the frequency, magnitude and duration of water shortage and excess water release of the Huay Ling Jone reservoir considering the existing demand case. The results indicate that, the average excess water of using optimal rule curves from considering existing water demand (RC3-participating demand) is the least (5.168 million m^3/year) as compared with other rule curves. Furthermore, the results show that the situations of water shortage were zero whereas the situations of water shortage of using existing demand cases were higher than using participating demand because of water requirement of existing demand was higher than water requirement of participating demand.

Table 11 shows frequency, magnitude and duration of water shortage and excess water release of Huay Sabag reservoir using 1000 samples of synthetic inflow when considering the existing water demand case. The results indicate that, the average excess water of using optimal rule curves from considering existing water demand (RC2-existing demand) is the least (6.003±0.015 million m^3/year) as compared with other rule curves. These are still suitable for objective function of searching condition. Table 12 shows frequency, magnitude and duration of water shortage and excess water release of Huay Sabag reservoir using 1000 samples of synthetic inflow when considering participating water demand case. The results indicate that, the average excess water of using optimal rule curves from considering existing water demand (RC3-participating demand) is the least (6.755±0.020 million m^3/year) as compared with other rule curves. These are still suitable for objective function of searching condition too.

Table 11. Frequency, magnitude and duration of water shortage and excess water release of Huay Sabag reservoir systems when considering existing demand

Situations	Rule curves		Frequency (times/year)	Volume (MCM/year)		Time period (year)	
				Average	Maximum	Average	Maximum
Water deficit	RC1-current	μ	0.000	0.000	0.000	0.000	0.000
		σ	0.000	0.000	0.000	0.000	0.000
	RC2-existing demand	μ	0.000	0.000	0.000	0.000	0.000
		σ	0.000	0.000	0.000	0.000	0.000
	RC3-participating demand	μ	0.000	0.000	0.000	0.000	0.000
		σ	0.000	0.000	0.000	0.000	0.000
Excess water	RC1-current	μ	1.000	6.231	6.305	22.000	22.000
		σ	0.000	0.021	0.000	0.000	0.000
	RC2-existing demand	μ	1.000	6.003	6.305	22.000	22.000
		σ	0.000	0.015	0.000	0.000	0.000
	RC3-participating demand	μ	1.000	6.244	6.305	22.000	22.000
		σ	0.000	0.019	0.000	0.000	0.000

Note: μ = mean, σ = standard deviation

Table 12. Frequency, magnitude and duration of water shortage and excess water release of Huay Sabage reservoir considering participating demand

Situations	Rule curves		Frequency (times/year)	Volume (MCM/year)		Time period (year)	
				Average	Maximum	Average	Maximum
Water deficit	RC1-current	μ	0.000	0.000	0.000	0.000	0.000
		σ	0.000	0.000	0.000	0.000	0.000
	RC2-existing demand	μ	0.000	0.000	0.000	0.000	0.000
		σ	0.000	0.000	0.000	0.000	0.000
	RC3-participating demand	μ	0.000	0.000	0.000	0.000	0.000
		σ	0.000	0.000	0.000	0.000	0.000
Excess water	RC1-current	μ	1.000	6.829	6.917	22.000	22.000
		σ	0.000	0.022	0.000	0.000	0.000
	RC2-existing demand	μ	1.000	6.915	6.917	22.000	22.000
		σ	0.000	0.015	0.000	0.000	0.000
	RC3-participating demand	μ	1.000	6.755	6.917	22.000	22.000
		σ	0.000	0.020	0.000	0.000	0.000

Note: μ = mean, σ = standard deviation

Table 13 shows frequency, magnitude and duration of water shortage and excess water release of Huay Ling Jone reservoir using 1000 samples of synthetic inflow when considering existing water demand case. The results indicate that, the average water shortage and the average excess water of using optimal rule curves from considering existing water demand (RC2-existing demand) are the least at 0.014±0.012 million m^3/year and 5.274±0.148 million m^3/year respectively.

Table 14 shows frequency, magnitude and duration of water shortage and excess water release of Huay Ling Jone reservoir using 1000 samples of synthetic inflow when considering participating water demand case. The results indicated that, the average excess water of using optimal rule curves from considering participating water demand (RC3-participating demand) is the least (5.460±0.154 million m^3/year) as compared with other rule curves. Whereas, their water shortage situations were zero because water requirement of participating demands was less than the water requirement of existing demand. Therefore, the newly obtained rule curves formed using participating demand of both reservoirs provided more reserve stored water for irrigation water requirement or other requirements than the rule curves from using existing demand and the previous rule curves.

Conclusions

This study explored water resource management and improved reservoir operation by a participation process. The

Table 13. Frequency, magnitude and duration of water shortage and excess water release of Huay Ling Jone reservoir considering existing demand

Situations	Rule curves		Frequency (times/year)	Volume (MCM/year)		Time period (year)	
				Average	Maximum	Average	Maximum
Water deficit	RC1-current	μ	0.016	0.016	0.307	0.342	0.345
		σ	0.026	0.026	0.461	0.543	0.550
	RC2-existing demand	μ	0.016	0.014	0.305	0.337	0.340
		σ	0.026	0.021	0.460	0.535	0.543
	RC3-participating demand	μ	0.017	0.016	0.307	0.366	0.373
		σ	0.029	0.026	0.461	0.589	0.606
Excess water	RC1-current	μ	0.997	5.342	5.500	23.121	23.465
		σ	0.011	0.156	0.000	3.188	2.079
	RC2-existing demand	μ	0.997	5.274	5.500	23.148	23.475
		σ	0.011	0.148	0.000	3.141	2.064
	RC3-participating demand	μ	0.998	5.387	5.500	23.342	23.586
		σ	0.010	0.150	0.000	2.787	1.862

Note: μ = mean, σ = standard deviation

Table 14. Frequency, magnitude and duration of water shortage and excess water release of Huay Ling Jone reservoir considering participating demand

Situations	Rule curves		Frequency (times/year)	Volume (MCM/year)		Time period (year)	
				Average	Maximum	Average	Maximum
Water deficit	RC1-current	μ	0.000	0.000	0.000	0.000	0.000
		σ	0.000	0.000	0.000	0.000	0.000
	RC2-existing demand	μ	0.000	0.000	0.000	0.000	0.000
		σ	0.000	0.000	0.000	0.000	0.000
	RC3-participating demand	μ	0.000	0.000	0.000	0.000	0.000
		σ	0.000	0.000	0.000	0.000	0.000
Excess water	RC1-current	μ	0.997	5.515	5.677	23.121	23.465
		σ	0.011	0.162	0.000	3.188	2.079
	RC2-existing demand	μ	0.997	5.547	5.677	23.148	23.475
		σ	0.011	0.156	0.000	3.141	2.064
	RC3-participating demand	μ	0.998	5.460	5.677	23.342	23.586
		σ	0.010	0.154	0.000	2.787	1.862

Note: μ = mean, σ = standard deviation field activities within the pilot projects of Huay Sabag and Huay Ling Jone Irrigation Schemes in Yasothorn province, Thailand were studied by undertaking field observations, interviewing stakeholders and collecting data about water requirements and allocation; assessment of agricultural water requirements and correction data. Then, the water requirements were corrected using farmer participation. The results showed that monthly water requirements of farmer participation are less than monthly water requirements of the existing demand. The improvement of water resource management was performed by improving reservoir rule curves that provide release water following the corrected water requirement. The reservoir operation model was conducted on a genetic algorithm and reservoir simulation model. A synthetic inflow of 1000 samples was used to evaluate the performance of the proposed method, and the results were compared with those of the existing model. The results also found that the new obtained rule curves of both reservoirs provided more reserve stored water for irrigation water requirement or other requirements than the previous rule curves. The new rule curves of genetic algorithm with participation were acceptable to operate reservoirs.

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