Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 13 (1): 154-160, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.154.160

Optimal Reservoir Rule Curves Considering Conditional Ant Colony Optimization with Simulation Model

Anongrit Kangrang and Chetthaphan Lokham
Department of Civil Engineering, Faculty of Engineering, Mahasarakham University, Kantarawichai, Maha Sarakham, 44150, Thailand

Abstract: Reservoir rule curves are guideline for long term operation of multi-purpose reservoir that affected from severe flood and drought situations. This study proposed an alternative technique for searching optimal rule curves of multi-purpose reservoir. The proposed model consists of a Conditional Ant Colony Optimization (CACO) and a reservoir simulation model. Monthly rule curves of the Lampao Reservoir located in the northeast of Thailand was considered in this study. Four hundred samples of generated inflow data of reservoir were used to evaluate the performance of the proposed model and the results were compared with those of the genetic algorithm technique (GAs) and currently used. The results found that the new rule curves produced by the CACO and simulation method provided a similar pattern of rule curves as compared with the rule curves provided by genetic algorithm technique. The patterns are different from the existing pattern. The situations of water shortage and flood of using the new rule curves with reservoir operation considering generated inflow are lower than those of using existing rule curves. However, these situations are closely to the situations of using the rule curves of genetic algorithms technique. In conclusion, the proposed model could enhance the performance of the Lampao Reservoirs and it might be applied to other reservoirs by modifying the objective functions and constraint equations of searching process.

Key words: Reservoir rule curves, ant colony optimization, genetic algorithm, simulation model, optimization technique

INTRODUCTION

Water resource requirements for agriculture, water supply, industry, power generation, ecology and environment have increased in concern with population growth, lifestyle changes and economic expansion. It is obviously that in the northeast region of Thailand where the population faces annual problematic droughts and floods. As such, a criterion of optimal water operation for storage reservoirs should be established that recognizes that the amount of water storage in the area is limited. 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 (Reznicek *et al*., 1991; Kim and Wurbs, 2011).

Generally, reservoir operating systems function with a water release budget and amount of storage water. The stored water is released under certain conditions for multipurpose that are defined by water use criteria and reservoir operating rule curves. The reservoir operating rule curves have been found to provide the best all around budgeting solution for long term operation. Typically, reservoir operating systems have been large and complex especially area having both drought and flood situations (Kangrang *et al*., 2011).

The searching for 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). The rule curves obtained by this method are not guaranteed to yield the optimal curves because of human adjustment in the trial and error process during perform. Later, Dynamic Programming (DP) was applied to solve non-linear problems in water resource areas (Esogbue, 1989; Kumar and Baliarsingh, 2003). The DP/PPO was developed to search the optimal rule curves of single and multiple reservoirs (Chaleeraktrakoon and Kangrang, 2007). However, this method is complex and specific system.

The Genetic Algorithm (GA) is a robust searching technique that has been applied to solve complex problems worldwide (Yeh, 1997). The best part of the GA is that it can handle any type of objective function of the

Corresponding Author: Anongrit Kangrang, Department of Civil Engineering, Faculty of Engineering, Mahasarakham University, Kantarawichai, Maha Sarakham, 44150, Thailand Tel: (66) 43-754316

search problem. The GA was applied to search rule curves of reservoir, it has been in several studies (Chang *et al*., 2005; Kim and Heo, 2006; Hormwichian *et al*., 2009). The Differential Evolution (DE) is another search technique that was developed by Storn and Price (1997). It uses a simulation of natural evolution, the same as the GA (Storn and Price, 1997). The DE is a search technique based on the mechanism of natural selection and genetics. It has a robust random search capability and an approach to global optimum values.

In the last decade, a simulated annealing algorithm (SA) was applied to solve the optimization problem (Locatelli, 2000; Teegavarapu and Simonivic, 2002; Lamom *et al*., 2008). Recently, the SA has been applied to connect with simulation for searching the optimal reservoir rule curves (Kangrang *et al*., 2011). It revealed that the SA could be used to find the optimal rule curves effectively. In addition, the influence of climate fluctuations on summer and fall reservoir inflows affected by the El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) was investigated with a reservoir operation model (Sellars *et al*., 2008).

The Ant Colony Optimization (ACO) is another search optimal technique motivated by the natural phenomenon that ants deposit pheromone on the ground in order to mark some favorable path that should be followed by other members of the colony. The ACO is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. This algorithm is a member of ant colony algorithms family, in swarm intelligence methods and it constitutes some heuristic optimizations. The first ACO algorithm called the ant system (Dorigo *et al*., 1991). ACO has been widely applied in various problems (Jalali *et al*., 2006; Yin and Wang, 2006; Afshar, 2010).

This study proposed Conditional Ant Colony Optimization (CACO) to connect with simulation model for searching the optimal reservoir rule curves. A minimum average water shortage was used as the objective function for searching procedure. The proposed model has applied to determine the optimal rule curves of the Lampao Reservoir in the Northeast region of Thailand. Comparison of the CACO and the new Simulation Model (SM) as well as the existing simulation model were shown to demonstrate the effectiveness of the proposed model.

MATERIALS AND METHODS

The proposed CACO model aims to utilize a number of ants to calculate on reservoir simulation for constructing a pheromone matrix, each entry of which represents the situation water shortage of the reservoir during run period. Furthermore, the movements of the ants are steered by average water shortage of the system for iteration run. The procedure of development model consists of reservoir simulation model and conditional ant colony optimization model that combined together for searching the optimal rule curves. The detail of each model will be described as the following.

Reservoir simulation model: Normally, a reservoir system comprises available water that flows into the reservoir with a single or multipurpose downstream covering service area. The reservoirs usually operate under water usage criteria and reservoir rule curves for long term perform. The reservoir rule curves have been found to offer the most equitable solution to all operational problems. A modified reservoir operation model was constructed on the concept of water balance and it can be used to simulate reservoir operation effectively (Hormwichian *et al*., 2009). The reservoir operating policies are based on the rule curves of individual reservoirs and the principles of water balance equation under reservoir simulation model. The reservoir system operated along the standard operating policy as expressed Eq. 1:

$$R_{\upsilon,\tau} = \begin{cases} D_\tau + W_{\upsilon,\tau} - y_\tau, \text{ for } W_{\upsilon,\tau} \geq y_\tau + D_\tau \\ D_\tau, \text{ for } x_\tau \leq W_{\upsilon,\tau} < y_\tau + D_\tau \\ D_\tau + W_{\upsilon,\tau} - x_\tau, \text{ for } x_\tau - D_\tau \leq W_{\upsilon,\tau} < x_\tau \\ 0, \text{ otherwise} \end{cases} \tag{1}$$

which, $R_{\nu,\tau}$ 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; and $W_{\nu,\tau}$ is the available water calculated by simple water balance as described in Eq. 2:

$$W_{\upsilon,\tau+1} = S_{\upsilon,\tau} + Q_{\upsilon,\tau} - R_{\upsilon,\tau} - E_\tau - DS \tag{2}$$

where, $S_{\delta,\tau}$ is the stored water at the end of month τ; $Q_{\delta,\tau}$ is monthly reservoir inflow; E_τ is average value of evaporation loss and DS is the minimum reservoir storage capacity (the capacity of dead storage). In Eq. (1), if available water is in the range of the upper and lower rule level, then demands are satisfied in full. If available water over the top of the upper rules level, then the water is spilled from the reservoir in downstream river in order to maintain water level at the upper rule level. If available water is under the lower rules level, a reduction of supply is required. The policy usually reserves the available water ($W_{\nu,\tau}$) for reducing the risk of water shortage in the future, when $0 \leq W_{\upsilon,\tau} < x_\tau - D_\tau$ under long term operation.

The release water of the reservoir 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. The results will be recorded for using in the developed CACO model.

Development of conditional ant colony optimization model: The developed CACO for searching rule curves is described as follows. Reservoir simulation run that mentioned in previous section needs the rule curves information for release condition module. Hence, the CACO model has to produce rule curve data (24 variables for both upper and lower data). The proposed approach starts from the initialization process and then runs reservoir simulation to construct the pheromone matrix by iteratively performing both the construction process and the update process. Finally, the decision process is performed to determine the optimal rule curves (the set of upper and lower rule curves). Each of these processes is presented in detail as follows, respectively.

Totally K ants are randomly assigned on a reservoir operation using rule curves. The initial value of the pheromone T ($x_{\tau,0}$, $y_{\tau,0}$) is set to be a constant T. Then, a set of rule curves is randomly selected to use in reservoir simulation, the release water is calculated by the simulation model using these rule curves. Then, the release water is used to calculate the objective function for determining pheromone of ACO. The objective function of searching the optimal rule curves is the minimum of the average water shortage (Z) subject to constraints on the simulation model as the following:

$$\text{Min } Z\,(x_\tau, y_\tau) = \left(\frac{1}{n}\sum_{v=1}^{n} Sh_v\right) \tag{3}$$

$$\text{if } R_\tau < D_\tau;\ \text{Then } Sh_\upsilon = \sum_{\tau=1}^{12}(D_\tau - R_\tau) \tag{4}$$

$$\text{Else } Sh_\upsilon = 0$$

where, n is the total number of considered year. Sh_υ is water deficit during year υ. (year that releases does not meet 100% of target demand) and i is iteration number.

Next, the evaporation rate of pheromone is performed. This evaporation rate also used to evaluate in order to accept the route (rule curves). The update pheromone is done in next step. The new set of rule curves is created randomly for next iteration. This procedure is repeated until the criterion is satisfied as described in Fig. 1.

Let T ($x_{\tau,\upsilon}$, $y_{\tau,\upsilon}$) be the total pheromone obtained from using x_τ, y_τ on reservoir simulation model at time υ and Min Z (x_τ, y_τ) be the heuristic value of using x_τ, y_τ at time υ according to the calculation of the objective function. The x_τ are y_τ random values within the boundary of the search that are 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 for all iterations. The evaporation rate of pheromone can be calculated by this equation:

$$\Delta T(x_{\tau,v}, y_{\tau,v}) = \begin{cases} 1/Z^{K,v} & \text{if } (x_{\tau,v}, y_{\tau,v}) \in \text{ tour done by ants K} \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

Let ρ is random variable uniformly distributed over [0, 1]. The pheromone is updated by the following equation:

$$T(x_{\tau,v}, y_{\tau,v}) = \begin{cases} \rho T(x_{\tau,v-1}, y_{\tau,v-1}) + (1-\rho)\Delta T(x_{\tau,v}, y_{\tau,v}) & \text{if } \Delta T(x_{\tau,v}, y_{\tau,v}) > 0 \\ T(x_{\tau,v-1}, y_{\tau,v-1}) & \text{otherwise} \end{cases} \tag{6}$$

In this study, the shortest route of ant represents by above objective function using a monthly level of the

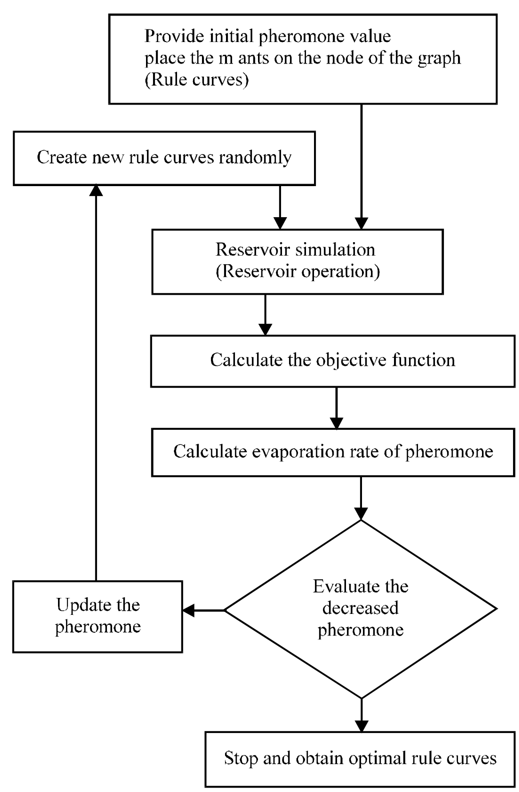

Fig. 1: Integration of CACO and simulation model

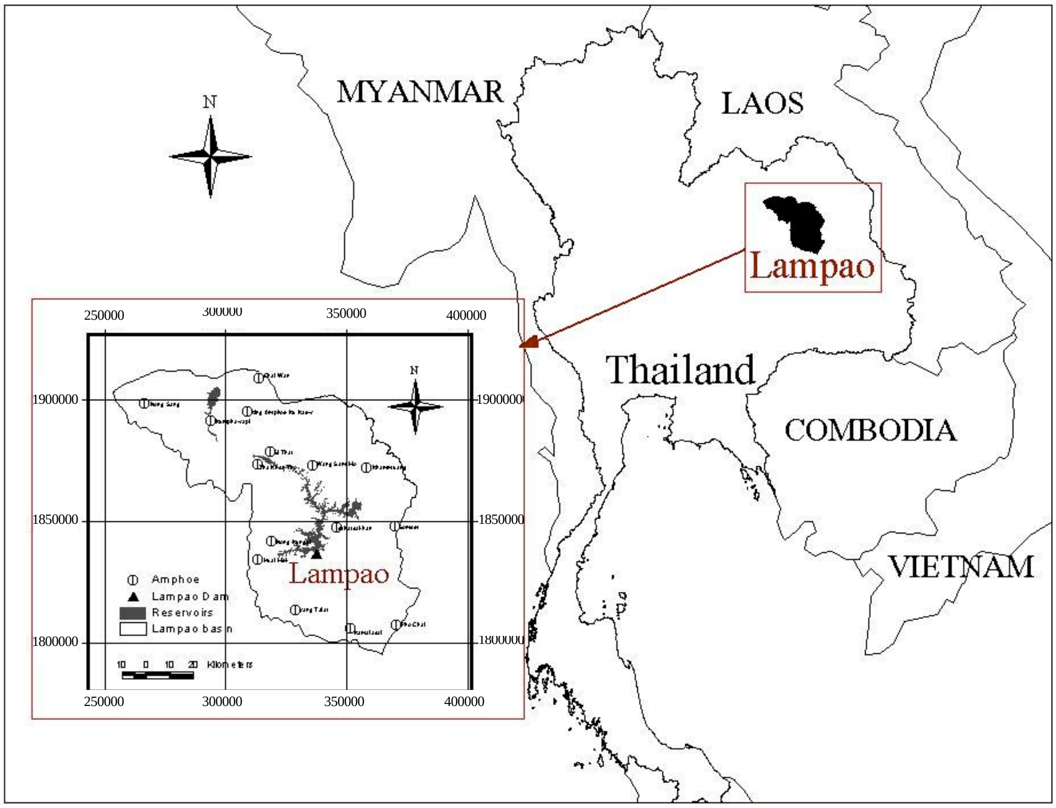

Fig. 2: Location of the Lampao reservoir

reservoir rule curves that will be used in the mentioned release policies. The pheromone is also calculated from the situation of water shortage using the monthly rule curves.

Illustrative application: In this study the Lampao Reservoir was considered to apply the proposed model. It is another one important reservoirs in the northeast of Thailand located on the Chi river basin as shown in Fig. 2. The beginning capacity of the Lampao Reservoir is 1,430 MCM (million cubic meters) with an irrigation covering area of 502.4 square kilometers, the normal water level 162 meters (MSL.). The reservoir was reconstructed in order to add more storage at 1,980 MCM at the level 164 m (MSL.) and their rule curves were adjusted last year (2011). The available water was released for water supply, industrial demand and irrigation demand, livestock, aquaculture. This project planned to increase irrigation area of 80 km^2 for new storage level.

The schematic diagram of the Lampao basin is shown in Fig. 3. The average yearly rainfall of the Lampao basin is approximately 1,400 mm per year. The average inflow of the reservoir is 2,230 MCM/year and maximum flood volume at 500 years of return period is 5,482 m^3 sec^{-1} which uses monthly inflow data of the Lampao Reservoir from 1968 to 2011 (44 years). The historic inflow data are presented in Fig 4.

The study used CACO algorithm in connection with a reservoir operation model to find optimal rule curves through the MATLAB toolbox. The optimal rule curve can then be applied to an actual scenario depending on whether the rule curve can be used to cover every case or event that might occur. Thus, the HEC-4 model was used to create the synthetic inflow data into the monthly inflows as a synthetic data set of 500 events. Then, input synthetic inflow data were used to assess the efficiency of the new rule curves and compare them with the existing rule curves and also between the SM and CACO models under the same conditions (objective function and constraints). Moreover, the new rule curves were assessed in various other situations, i.e., irrigation area increases to judge the impact of how these things will effect future operations.

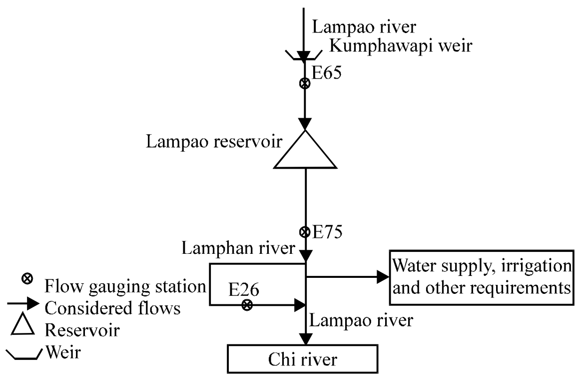

Fig. 3: Schematic diagram of flows in the Lampao river basin, the other requirements consist of pollution control and navigation demands

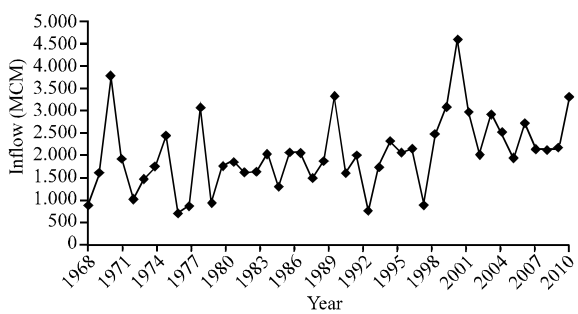

Fig. 4: The observed inflows of Lampao reservoir

RESULTS AND DISCUSSION

When the data of inflow, evaporation, water requirement and monthly rainfall were imported for processing in the CACO model, the optimal rule curves were obtained. These new rule curves are plotted in order to compare them with the existing rule curves of the SM and the new rule curves of the SM approach as shown in Fig. 5. The results show that the patterns of rule curve obtained from the proposed CACO and the new SM are similar. The obtained rule curves also indicated that the water storage levels of the CACO lower rule curves are lower than the existing rule curves during the dry season (January-May) in order to release more water to reduce water scarcity. In the beginning of rainy season (May-August) the CACO upper curves are lower than their curves of new SM in order to add a volume for flood protection. Whereas during August-November, their upper curves are higher than the curves of new SM because of decreasing spill water in order to met a full capacity at the end of rainy season. This will help alleviate water shortages in the next year. These patterns of the obtained curves are similar to the

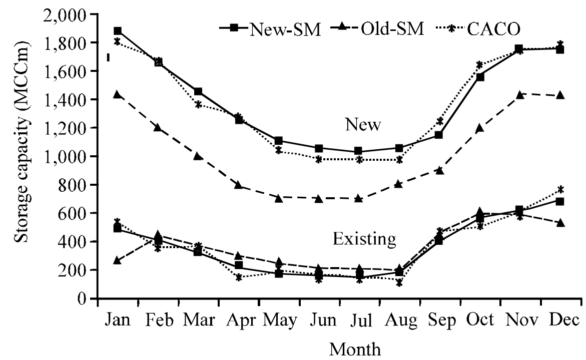

Fig. 5: Optimal rule curves of the Lampao Reservoir (new and existing system)

pattern of the other reservoirs in Thailand on the other studies (Chaleeraktrakoon and Kangrang, 2007; Hormwichian *et al*., 2009) because of seasonal effect. However, the different points of each reservoir are on lower rule curves during dry season (December-May) and on the upper rule curves during wet season (Jun-November).

The proposed CACO model is another search optimal technique, so the results are near optimality that closed to the results of the other search techniques based on the same condition (Chang *et al*., 2005; Kim and Heo, 2006; Kangrang *et al*., 2011). However, the efficiency of each technique was carried out on many studies (Locatelli, 2000; Teegavarapu and Simonivic, 2002; Sellars *et al*., 2008).

The performance of the proposed model was evaluated with monthly synthetic inflow data, these results of the Lampao Reservoir are shown in Table 1. The results show that, the average frequency of water shortage was 0.415 per year, the average magnitude of water shortage was 92.5 million cubic meters per year and the maximum magnitude of water shortage was 450.0 million cubic meters per year. These are smaller than the results of using the existing rule curves. The average frequency of excess water release was 0.918 times per year, the average magnitude of excess water release was 815.6 million cubic meters per year and the maximum magnitude of excess water release was 2,558.9 million cubic meters per year. These are less than the results of using both existing curves and new SM's curves.

Table 2 shows the situations of water shortage and excess release of Lampao Reservoir using the rule curves from the proposed CACO model and the existing SM model when the irrigation demands were increased by 80 km^2. The results present that the water shortage situation increased when the irrigation demands were

Table 1: Situations of water shortage and excess release of the systems

Situations	Rule curves	Frequency (times/year)	Magnitude (MCM/year) Average	Magnitude (MCM/year) Maximum	Duration (year) Average	Duration (year) Maximum
Water shortage	Old-SM					
	μ	0.961	139.4	379.7	14.8	18.2
	σ	0.035	15.6	93.9	6.5	4.6
	New-SM					
	μ	0.546	127.6	500.5	2.3	4.5
	σ	0.066	18.6	86.0	0.6	1.5
	CACO					
	μ	0.415	92.5	450.0	1.8	3.3
	σ	0.068	18.2	116.0	0.5	1.1
Excess release water	Old-SM					
	μ	0.920	885.8	2687.2	10.2	14.5
	σ	0.051	22.7	532.0	5.6	4.8
	New-SM					
	μ	0.936	853.0	2550.8	11.4	15.4
	σ	0.045	25.9	526.7	6.1	4.9
	CACO					
	μ	0.918	815.6	2558.9	9.9	14.2
	σ	0.050	25.8	539.6	5.4	4.9

μ: Mean, σ: Standard deviation

Table 2: Situations of water shortage and excess release of the systems for additional irrigation area (80 km^2)

Situations	Rule curves	Frequency (times/year)	Magnitude (MCM/year) Average	Magnitude (MCM/year) Maximum	Duration (year) Average	Duration (year) Maximum
Water shortage	Old-SM					
	μ	0.855	151.4	177.0	7.6	12.4
	σ	0.043	7.7	0.0	3.3	3.9
	New-SM					
	μ	0.595	166.5	598.9	2.6	5.1
	σ	0.065	21.4	77.8	0.8	1.8
	CACO					
	μ	0.471	127.1	561.8	2.0	3.9
	σ	0.067	21.4	126.3	0.5	1.3
Excess release water	Old-SM					
	μ	0.986	1293.9	3351.9	19.6	21.0
	σ	0.023	14.6	543.8	5.6	3.6
	New-SM					
	μ	0.904	751.4	2416.7	8.6	13.2
	σ	0.050	28.2	521.2	4.5	4.4
	CACO					
	μ	0.880	710.4	2411.9	7.6	12.2
	σ	0.058	28.3	536.3	4.3	4.3

μ: Mean, σ: Standard deviation

increased. The results also indicate that the situations of water shortage and excess release of water using the proposed CACO model are smaller than the situations of the existing rule curves when increasing the irrigation water requirement. The results of using the new rule curves of CACO model present that their efficiency are higher than the others in all cases according to the previous studies (Hormwichian *et al*., 2009; Kangrang *et al*., 2011). For this reason, on considering water requirements, land use and crop management the CACO model would be one acceptable method of reducing water shortage.

CONCLUSIONS

In this study, an optimal rule curves has been developed for Lampao Reservoir using a CACO model connected with a reservoir simulation model. The results found that the new rule curves are more suitable for using than the existing rule curves because the frequency and magnitude of water shortage and excess water release are lower than the existing rule curves. In the future, new rule curves can be used to operate effectively when the downstream water irrigation demand increase up by 80 Km^2. When comparing the rule curves of the CACO method with the existing simulation method, it was found that these rule curves are similar. The proposed CACO model is an effective method for application to find optimal reservoir rule curves.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support by research fund of Mahasarakham University and Faculty of Engineering, Mahasarakham University.

REFERENCES

Afshar, M.H., 2010. A parameter free continuous ant colony optimization algorithm for the optimal design of storm sewer networks: Constrained and unconstrained approach. Adv. Eng. Software, 41: 188-195.

Chaleeraktrakoon, C. and A. Kangrang, 2007. Dynamic programming with the principle of progressive optimality for searching rule curves. Can. J. Civil Eng., 34: 170-176.

Chang, J.F., L. Chen and C.L. Chang, 2005. Optimizing reservoir operating rule curves by genetic algorithms. Hydrol. Process., 19: 2277-2289.

Dorigo, M., V. Maniezzo and A. Colorni, 1991. The ant system: An autocatalytic optimizing process. Technical Report TR91-016, Politecnico di Milano.

Esogbue, O.A., 1989. Dynamic Programming for Optimal Water Resources Systems Analysis. Prentice Hall, Englewood Cliffs, New Jersey, ISBN-10: 0132215160.

Hormwichian, R., A. Kangrang and A. Lamom, 2009. A conditional genetic algorithm model for searching optimal reservoir rule curves. J. Applied Sci., 9: 3575-3580.

Jain, K.S., K.M. Goel and K.P. Agarwal, 1998. Reservoir operation study of sabamati system, India. J. Water Res. Plan. Manage., 124: 31-38.

Jalali, M.R., A. Afshar and M.A. Marino, 2006. Reservoir operation by ant colony optimization algorithms. Iran. J. Sci. Technol., Trans. B, Eng., Vol. 30.

Kangrang, A., S. Compliew and R. Hormwichian, 2011. Optimal reservoir rule curves using simulated annealing. Proc. Inst. Civil Eng. Water Manage., 164: 27-34.

Kim, T. and J.H. Heo, 2006. Application of multi-objective genetic algorithms to multireservoir system optimization in the Han River basin. KSCE J. Civil Eng., 10: 371-380.

Kim, T.J. and R.A. Wurbs, 2011. Development of monthly naturalized flow using Water Rights Analysis Package (WRAP)-based methods. KSCE J. Civil Eng., 15: 1299-1307.

Kumar, D.N. and F. Baliarsingh, 2003. Folded dynamic programming for optimal operation of multireservoir system. Water Resour. Manage., 17: 337-353.

Lamom, A., T. Thepchatri and W. Rivepiboon, 2008. Heuristic algorithm in optimal discrete structural designs. Am. J. Applied Sci., 5: 943-951.

Locatelli, M., 2000. Simulated annealing algorithms for continuous global optimization: Convergence conditions. J. Optim. Theory Appl., 104: 121-133.

Reznicek, K.K., S.P. Simonovic and C.R. Bector, 1991. Optimization of short-term operation of a single multipurpose reservoir-a goal programming approach. Can. J. Civil Eng., 18: 397-406.

Sellars, C.D., M. Garrett and S. Woods, 2008. Influence of the pacific decadal oscillation and el nino southern oscillation on operation of the Capilano water supply reservoir, Vancouver, British Columbia. Can. Water Resour. J., 33: 155-164.

Storn, R. and K. Price, 1997. Differential evolution-A simple and efficient heuristic for global optimization over continuous spaces. J. Global Optim., 11: 341-359.

Teegavarapu, R.S.V. and S.P. Simonivic, 2002. Optimal operation of reservoir system using simulated annealing. J. Water Recour. Res., 16: 401-428.

Yeh, C.H., 1997. Applying multiobjective genetic algorithms for planning of flood detention dams system. Taiwan Water Conservancy, 45: 70-81.

Yin, P.Y. and J.Y. Wang, 2006. Ant colony optimization for the nonlinear resource allocation problem. Applied Math. Comput., 174: 1438-1453.