HENRY
Hydraulic Engineering Repository

Ein Service der Bundesanstalt für Wasserbau

Conference Paper, Published Version

Chou, Frederick N.-F.; Nguyen Thi Thuy, Linh

Comparing the Generating Strategies of Hydropower of Cascade Reservoirs to Mitigate the Shortage of Water Supply

Zur Verfügung gestellt in Kooperation mit/Provided in Cooperation with:
Kuratorium für Forschung im Künsteningenieurwesen (KFKI)

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/108576

Vorgeschlagene Zitierweise/Suggested citation:
Chou, Frederick N.-F.; Nguyen Thi Thuy, Linh (2016): Comparing the Generating Strategies of Hydropower of Cascade Reservoirs to Mitigate the Shortage of Water Supply. In: Yu, Pao-Shan; Lo, Wie-Cheng (Hg.): ICHE 2016. Proceedings of the 12th International Conference on Hydroscience & Engineering, November 6-10, 2016, Tainan, Taiwan. Tainan: NCKU.

Standardnutzungsbedingungen/Terms of Use:

Die Dokumente in HENRY stehen unter der Creative Commons Lizenz CC BY 4.0, sofern keine abweichenden Nutzungsbedingungen getroffen wurden. Damit ist sowohl die kommerzielle Nutzung als auch das Teilen, die Weiterbearbeitung und Speicherung erlaubt. Das Verwenden und das Bearbeiten stehen unter der Bedingung der Namensnennung. Im Einzelfall kann eine restriktivere Lizenz gelten; dann gelten abweichend von den obigen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Documents in HENRY are made available under the Creative Commons License CC BY 4.0, if no other license is applicable. Under CC BY 4.0 commercial use and sharing, remixing, transforming, and building upon the material of the work is permitted. In some cases a different, more restrictive license may apply; if applicable the terms of the restrictive license will be binding.

Verwertungsrechte: Alle Rechte vorbehalten

12th International Conference on Hydroscience & Engineering
Hydro-Science & Engineering for Environmental Resilience
November 6-10, 2016, Tainan, Taiwan.

Comparing the Generating Strategies of Hydropower of Cascade Reservoirs to Mitigate the Shortage of Water Supply

Frederick N.-F. Chou, Linh Thi Thuy Nguyen
Department of Hydraulic and Ocean Engineering, National Cheng Kung University
Tainan, Taiwan

ABSTRACT

There are four reservoirs in series located on the Be River in the Southern Vietnam. The major purpose of the three upstream reservoirs is hydropower generation; however the fourth one has the major purposes of water supply and irrigation. The management of water resources up to date of this river always focuses on hydropower. However the increasing water demands for household, industry and agriculture may be satisfied by improved policy of water management. This study will recommend a better strategy to increase energy generated and mitigate the shortage of water supply.

This paper applied the GWASIM model (Chou and Wu 2010) to simulate the daily hydropower generation and water resources allocation of the system. The results showed that when domestic and industrial demand has prior priority access to water and energy generation comes second, the shortage index for all demands reduced and the hydropower generation was quite the same in both scenarios. This better strategy for operating cascade reservoirs can improve energy production from hydropower and water supply.

KEY WORDS: hydropower; water supply, cascade reservoirs, Be River Basin, simulation.

INTRODUCTION

Water is one the most important resources and irreplaceable for the maintenance of life. However, pressures related to overpopulation, urbanization and industrialization having the serious impact on water resources. Vietnam is located in the tropical monsoon and faces various disasters. Drought is one of the most frequent natural disasters and which has been becoming more severe due to the impact of climate change. This urgent situation requires national attention toward suitable solutions to protect and develop sustainability of critical water resources.

The Dong Nai River Basin is the largest national river basin and the economic center of the country in southern Vietnam. This river basin ranks second in hydropower potential in the country and in 2000, total installed hydropower capacity reached 1,182 MW (Ringler et al., 2004). The Be River basin is one of sub-basins in the Dong Nai River Basin in the South Vietnam. It lies between latitudes 11º10' to 12º16'N and longitudes 106°36' to 107°30'E. It is located in the Dak Nong, Binh Phuoc, Binh Duong, and Dong Nai provinces and has a basin area of 7,650 km^2, including a small part of the basin in Cambodia with an area of about 200 km^2. The average density of the river network is about 0.56 km/km^2. Fig. 1 shows a map of the Be River Basin with four reservoirs which are Thac Mo, Can Don, Srok Phu Mieng and Phuoc Hoa. The Be River Basin has hydropower potential with three hydropower plants. Furthermore, this catchment is an important water resource provides water for urban water supplies, agriculture, and the industry in not only Be River basin but also Sai Gon River basin. The conflicting objectives lead to significant challenges so it is necessary to have comprehensive solutions for this river basin. Moreover, the increasing water demands for household, industry and agriculture may be satisfied by improved policy of water management. In order to improve the existing situation, studies on generating strategy of hydropower are needed.

LITERATURE REVIEW

Many studies have concerned reservoir problems and also cascade reservoirs problems about planning and operation. It is difficult to give the best solution for water management. A reservoir system is in general made to meet many purposes, such as, water supply (domestic, industrial and irrigation), flood control, hydropower production etc (Ko et al., 1992). Many studies have concerned reservoir problems and also cascade reservoir problems about planning and operation. Studies vary in several ways, including the objective optimized, time horizon for optimization (long- vs. short-term), system size and configuration, and the representation of uncertainty (Olivares, 2008). Some studies concerned about operating rules such as optimal upper and lower rule curves studied by Rani and Moreira (Rani et al., 2010) and optimize the decision variables studied by Fang et al (Fang et al., 2014). Operating rules are always identified using either fitting or simulation-based optimization methods (Celeste et al., 2009; Rani et al., 2010). Simulation-based optimization methods are one of the most important and efficient methods of deriving reservoir operating rules within an implicit stochastic optimization framework (Celeste et al., 2009; Rani et al., 2010). Deterministic optimization techniques, including linear programming, nonlinear programming and dynamic programming, can be implemented to produce samples for fitting (Labadie, 2004; Rani et al., 2010; Yeh, 1985).

Hydroelectricity is a renewable energy source that has been exploited in many countries, so the scheduling optimal hydropower problem has been studied. To solve the problem of scheduling optimal hydropower, several hydropower optimization techniques have been developed. These techniques can be classified into two main categories. Firstly, mathematical programming techniques, which are applied to quantitative information with well-structured algorithmic processes, such as network flow optimization, linear programming, stochastic linear programming, nonlinear programming and dynamic programming (Fu et al., 2011). The second is these heuristic programming techniques. Moreover, simulation is a modeling technique that is used to approximate the behavior of a system on a computer, representing all the characteristics of the system largely by a mathematical or algebraic description (Yeh, 1985). In addition, optimization models involve allocating resources, developing stream flow regulation strategies and operating rules, and making real-time release decisions within the guidelines of the operating rules (Wurbs, 1993). Some study combined the simulation model and optimization model to get an optimal solution. Chen et al. (2013) proposed a simulation-based optimization model of dynamic control of the flood level water level that made an effective trade-off between the flood control and hydropower generation of the Qingjiang River cascade reservoirs (Chen et al., 2013). In a study by Suiadee and Tingsanchali (Suiadee et al., 2007), combined simulation-Genetic algorithm (GA) model software with graphical interface capability was developed to determine the optimal upper and lower rule curves and to optimal control of water quality, downstream of a reservoir (Dhar et al., 2008).

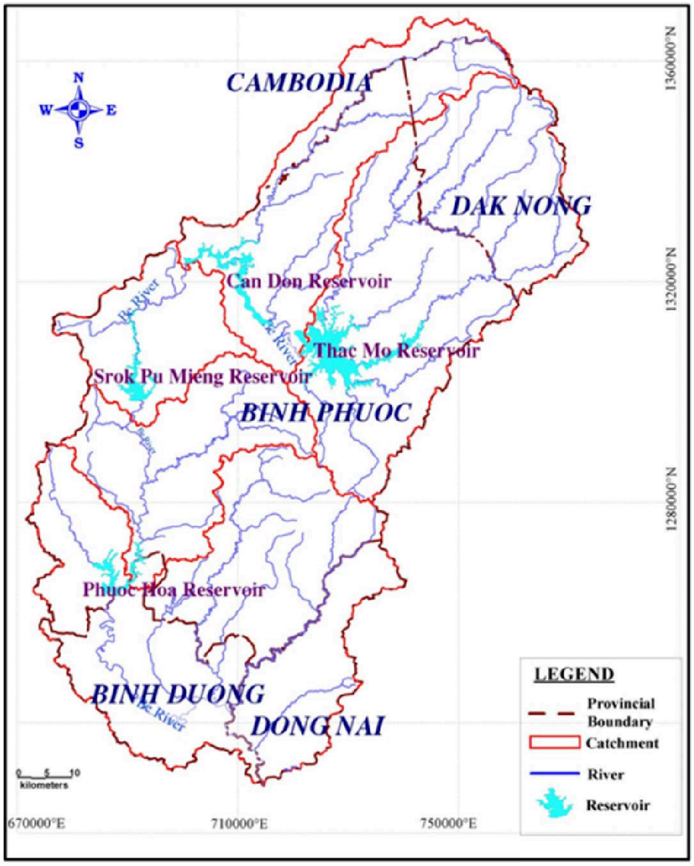

Fig. 1 Location map of the Be River Basin

METHODOLOGY

Generalized Water Allocation Simulation Model

The generalized water allocation simulation model (GWASIM) was developed based on Network Flow Programming (NFP). It is a generalized water allocation model referencing MODSIM of Colorado State University (Labadie) intended to resolving NFP problems by using the Out-of-Kilter Algorithm (Barr et al., 1974; Fulkerson, 1961). GWASIM sets cost coefficients on the artificial demand and storage arcs in order to guide the water allocation mechanism. The cost of arcs is not referring to the actual value of currency, but rather refers to some priority (or weighting factor). The cost of artificial storage or demand arcs in GWASIM is hypothesized as below:

$$c_i = -10000 + 10 \times prior_i \tag{1}$$

where: c_i = Unit shipping cost of artificial arc$_i$; prior$_i$ = Priority of artificial arc i

In analyzing the reservoir operations, GWASIM precisely simulates the operating rule, non-consumptive demand such as minimum environmental flow or power generation demand, reservoir evaporation and channel losses, reduced yield in treatment plants. Since a regional water supply system can be schematically represented as a capacitated network flow, users can simulate the water allocation with GWASIM by preparing the data files and input hydrologic and demand data only, and without altering any computer code.

A well-designed water-shortage index plays an important role in water-resources planning and management. The GWASIM can simulate the yield of a regional system under specific design criteria, SI, with a simulation time step of 1 day

$$SI = \frac{100}{N}\sum_{i=1}^{N}\left(\frac{DF_i}{D_i}\right)^2 \tag{2}$$

where: SI = The shortage index; N = Total years of analysis duration; DF_i = The water demand in the i-th year; D_i = The shortage in the i-th year

SIMULATION AND RESULT

Simulation strategy

The Strategy

This study analyzed two strategies concerned with setting the first priority as hydropower generation and domestic and industrial demand. In strategy 1, water will be delivered to the hydropower plant demand first, and other water users will be satisfied later. This means that the main purpose of the Be River is to generate electricity. This object has been applied to Be River basin to date. However, domestic demand is a special demand, which is one of the most important for survival of the life. Domestic demand will be considered as the first target in the strategy 2. A decision made by the Prime Minister (No. 1590/QD-TTg dated October 9th, 2009) made industrial demand at the same level of priority as domestic demand.

The scenario

In the original GWRASIM, rule curves based operation is simulated by assigning ordered cost coefficients to artificial storage and demand arcs to reflect the operating regulations. The discounting strategies adopted by this study are referred from the project report reservoir system operation studies in the Dong Nai - Sai Gon Basin for flood prevention of Ho Chi Minh City (2009). Comparative scenarios were simulated through changing the released water rations in different zones of the rule curve. The rations for scenario 1 which followed the current rule curve of the cascade reservoirs and those rations are descried below. When the storage is under the lower limit of rule curve, only 80% of the total domestic and industrial water demands and 70% of the agricultural demand will be satisfied first. When the storage lies between lower and upper limits, the water supplied to domestic and industrial demands should be restricted to 90% and the agricultural demand should be restricted to 90% of demand. When the storage is below the low hydropower limit, the hydropower plant should be generated with low hydropower generation hours (H_L). When the storage is higher than high hydropower limit, the hydropower plant should be generated with high hydropower generation hours (H_H).
In scenario 2, the water supply rations in different reservoir storage zones are described below.

When the total storage is under the lower limit, only 90% of the total domestic and industrial water use demand and 80% of the agricultural demand should be satisfied. When the total storage lies between the lower and upper limits, each consumptive demand in this system should be fulfilled. When the storage is below the low hydropower limit, the hydropower plant should be generated with low hydropower generation hours (H_L). When the storage is higher than high hydropower limit, the hydropower plant should be generated with high hydropower generation hours (H_H).

The alternative

Each scenario has six alternatives which consider about hydropower demand. According to the operating rule, the reservoir will release water to satisfy hydropower demand with low hydropower hours when water level in reservoir is below high hydropower limit and with high hydropower hours when water level in reservoir is higher than high hydropower limit. In six alternatives, the low and high hydropower hours are 6 hours and 13 hours; 9 hours and 13 hours; 9 hours and 15 hours; 11 hours and 15 hours; 11 hours and 24 hours, and 24 hours and 24 hours.

Results

Comparison of priorities of allocating water

Strategy 1 is when the hydropower demand is the main purpose, and the domestic and strategy 2 is when industrial demand as the first priority. The performance indices of strategy 1 are listed in Table 1, and Table 2. These tables give the information about shortage index for all demand sites. In general, the drought was less serious when hydropower generation hours were reduced, and the drought for agricultural demand was more serious than it was for other water users. The water supply increased sharply at the Thac Mo and Can Don agricultural demand sites in all scenarios from alternative 6 to alternative 1. For agricultural demand, the water shortage decreased from 81.69 to around 5.65 in Thac Mo and from 50.49 to 3.68 in Can Don (Table 1).For domestic demand, the shortage index of Thac Mo and Can Don demand sites dropped sharply from near 57.75 to 1.39 in Case 1-1 (Table 1). The Thac Mo and Can Don demand sites have the largest shortage index. In table 1, the highest shortage index of the downstream area was 9.96 in alternative 6 while in upstream area, it was 81.69.

Table 1 Shortage index of each demand site in scenario 1 (Case 1-1)

Purpose	**Demand**	Alternative					
		1	2	3	4	5	6
		$H_H = 13$	$H_H = 13$	$H_H = 15$	$H_H = 15$	$H_H = 24$	$H_H = 24$
		$H_L = 6$	$H_H = 9$	$H_L = 9$	$H_L = 11$	$H_L = 11$	$H_L = 24$
Domestic and Industry	Upstream	0	0	0	0	0	0
	Thac Mo	1.39	9.74	10.63	22.09	28.41	57.75
	Can Don	1.51	6.67	7.69	16.10	21.21	48.85
	SRPM	0	0.01	0.01	0.05	0.06	0.30
	Downstream	0	0.01	0.01	0.05	0.06	0.29
Agriculture	Upstream	0.00	0.00	0.00	0.00	0.00	0.00
	Thac Mo	5.65	18.79	20.29	35.48	46.76	81.69
	Can Don	3.68	8.34	10.08	16.72	25.05	50.49
	SRPM	0.00	0.00	0.01	0.09	0.10	0.97
	Phuoc Hoa	0.00	0.05	0.06	0.36	0.41	1.45
	Downstream	0.00	0.04	0.05	0.55	0.66	5.36
Others	Phuoc Hoa environment	0.00	0.28	0.31	1.47	1.73	9.96
	Water diversion	0.00	0.21	0.23	0.93	1.08	8.56

Table 2 Shortage index of each demand site in scenario 1 (Case 2-1)

Purpose	Demand	Alternative					
		1	2	3	4	5	6
		$H_H = 13$	$H_H = 13$	$H_H = 15$	$H_H = 15$	$H_H = 24$	$H_H = 24$
		$H_L = 6$	$H_H = 9$	$H_L = 9$	$H_L = 11$	$H_L = 11$	$H_L = 24$
Domestic and Industry	Upstream	0	0	0	0	0	0
	Thac Mo	1.39	1.83	2.03	2.12	2.85	2.88
	Can Don	1.66	1.67	1.81	1.96	2.57	2.66
	SRPM	0.00	0.00	0.00	0.02	0.02	0.31
	Downstream	0.00	0.00	0.00	0.02	0.11	0.30
Agriculture	Upstream	0.00	0.00	0.00	0.00	0.00	0.00
	Thac Mo	5.65	16.63	18.04	32.94	43.15	81.67
	Can Don	3.68	9.15	10.69	19.05	28.93	55.05
	SRPM	0.00	0.00	0.00	0.02	0.02	0.99
	Phuoc Hoa	0	0.00	0.00	0.12	0.12	1.49
	Downstream	0	0.00	0.00	0.10	0.11	5.53
Others	Phuoc Hoa environment	0	0.04	0.04	0.51	0.53	9.95
	Water diversion	0	0.05	0.05	0.37	0.38	8.17

The obvious difference between the two strategies is the significant reduction in the shortage indexes for domestic and industrial demand in all sub-catchments in strategy 2. The Table 1 shows that the highest domestic and industrial shortage index for the Thac Mo and Can Don were 57.75 and 48.85 in alternative 6 while those indexes were only 2.88 and 2.66 in alternative 6, as shown in Table 2. As shown in Table 1, the highest water shortage in strategy 1 of the Thac Mo and Can Don demand sites were 57.75 and 48.85 respectively while the highest indices were 2.88 and 2.66 in strategy 2, as shown Table 2. This was significant with regard to guarantee water supply for the most important water user.

Comparison of different rations

As mentioned a strategy has two scenarios, which were Case 1-1 and Case 1-2 analyzed in strategy 1 and Case 2-1 and Case 2-2 also analyzed in strategy 2. The difference of two scenarios is changing of the rations. The scenario 1 is the current rule curve rations and scenario 2 use of changing rule curve rations. Six alternatives were considered with increasing hours for electric generation from alternative 1 to alternative 6. In general, all demand sites of scenario 2 involved the water shortage supply less than water shortage of scenario 1. Considering the Can Don agricultural demand and domestic and agriculture demand, in alternative 6 of strategy 2, the water shortage was 2.66 and 55.05 in Table 2, while this shortage was 0.59 and 51.48 shown in Table 3. This was explained that the changing of the rations in rule curve in scenario 2 improved water supply in this basin. Beside average energy, the firm energy and secondary energy are critical issues in a restructured power market. These are commonly used to measure the reliability of supply. In this study, firm energy is defined that the energy that a plant can generate 95% of the time (Linsley et al., 1992) and secondary energy is interruptible but is available more than 50% of the time (Mays, 2010).

Although the total annual average energy in all alternatives was quite the same, firm energy and secondary energy were significantly different between all alternatives Fig. 2 shows that the firm energy and secondary energy reduced sharply when hydropower generation hours were increased. The firm and the secondary energy in alternative 1 were the highest compared to the other alternatives, which were 1,459 Mwh/day and 1,649 Mwh/day, respectively. Firm energy and secondary energy dropped to around less than 200 Mwh/day and 600 Mwh/day.

Table 3 Shortage index of each demand site in scenario 2 (Case 2-2)

Purpose	Demand	Alternative					
		1	2	3	4	5	6
		$H_H = 13$	$H_H = 13$	$H_H = 15$	$H_H = 15$	$H_H = 24$	$H_H = 24$
		$H_L = 6$	$H_H = 9$	$H_L = 9$	$H_L = 11$	$H_L = 11$	$H_L = 24$
Domestic and Industry	Upstream	0	0	0	0	0	0
	Thac Mo	0.21	0.39	0.41	0.47	0.53	0.71
	Can Don	0.18	0.33	0.35	0.41	0.46	0.59
	SRPM	0.00	0.00	0.00	0.02	0.02	0.31
	Downstream	0.00	0.00	0.00	0.02	0.02	0.30
Agriculture	Upstream	0.00	0.00	0.00	0.00	0.00	0.00
	Thac Mo	2.28	9.70	9.91	25.12	33.62	80.16
	Can Don	1.43	4.46	4.99	12.90	18.98	51.48
	SRPM	0	0.00	0.00	0.02	0.02	0.99
	Phuoc Hoa	0.00	0.00	0.00	0.12	0.12	1.50
	Downstream	0	0.00	0.00	0.10	0.11	5.55
Others	Phuoc Hoa environment	0.00	0.04	0.04	0.51	0.53	9.95
	Water diversion	0.00	0.06	0.07	0.37	0.38	8.17

Moreover, all of the scenarios had the same power generated while strategy 2 was a better policy for total firm power and secondary power as shown in Fig. 2. In addition, this figure also shows that annual total hydropower generation of the cascade reservoirs in all strategies and scenarios were stable and quite similar.

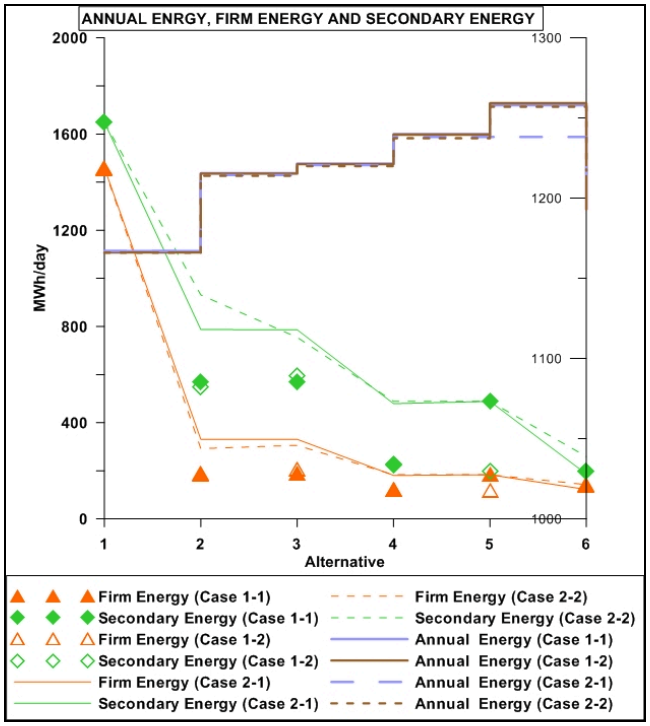

Fig. 2 Annual average energy, firm energy and secondary energy in the Be River Basin

CONCLUSIONS

This study focused on reducing the water shortage of a cascade reservoir system of the Be River Basin of Vietnam by altering the reservoir operation in different hydropower generation policies. The GWASIM model for simulating water allocation was adopted to evaluate different policies while satisfying the requirement for generated energy. Two strategies, two alternatives, and six scenarios were considered. With various generating hours of hydropower in a day, six scenarios were analyzed in each alternative and strategy.

Under different strategies, the trade-off between water shortage and hydropower generation of this cascade reservoir system was obtained. The results showed that strategy 2 which used different water release rations had less water shortage compared to strategy 1, which was actual operation adopted. With respect to hydropower generation, the average annual energy has a stable value in all strategies.

In addition, the priorities of either hydropower or water supply were considered with two scenarios. Scenario 2 has the water shortages of all demand sites were less compared to another scenario, while the annual average energies were essentially the same for both scenarios.

The results also showed that the alternative of generating hydropower in which hydropower is generated with fewer hours than in a day was better than 24-hour generation in terms of water supply and hydropower.

The results demonstrated that the model could efficiently simulate the system performance of multipurpose cascade reservoirs and assist in decision-making for improving the performance of water supply and hydropower generation of the cascade reservoirs of the Be River Basin. The efficient operation of this system is the most important task of water resources management. In the next phase, optimization of the cascade reservoir operation may be carried out with not only joint rule curves but also the balance curves among the reservoirs.

REFERENCES

Barr, R. S., Glover, F., and Klingman, D. (1974). An improved version of the out-of-kilter method and a comparative study of computer codes. *Mathematical programming, 7*(1), 60-86.

Celeste, A. B., and Billib, M. (2009). Evaluation of stochastic reservoir operation optimization models. *Advances in Water Resources, 32*(9), 1429-1443.

Chen, J., Guo, S., Li, Y., Liu, P., and Zhou, Y. (2013). Joint operation and dynamic control of flood limiting water levels for cascade reservoirs. *Water Resources Management, 27*(3), 749-763.

Dhar, A., and Datta, B. (2008). Optimal operation of reservoirs for downstream water quality control using linked simulation optimization. *Hydrological processes, 22*(6), 842-853. doi: 10.1002/hyp.6651

Fang, H.-b., Hu, T.-s., Zeng, X., and Wu, F.-y. (2014). Simulation-optimization model of reservoir operation based on target storage curves. *Water Science and Engineering, 7*(4), 433-445.

Fu, X., Li, A., Wang, L., and Ji, C. (2011). Short-term scheduling of cascade reservoirs using an immune algorithm-based particle swarm optimization. *Computers & Mathematics with Applications, 62*(6), 2463-2471.

Fulkerson, D. R. (1961). An out-of-kilter method for minimal-cost flow problems. *Journal of the Society for Industrial and Applied Mathematics, 9*(1), 18-27.

Ko, S. K., Fontane, D. G., and Labadie, J. W. (1992). Multiobjective Optimization of Reservoir Systems Operation: Wiley Online Library.

Labadie, J. W. (2004). Optimal operation of multireservoir systems: state-of-the-art review. *Journal of water resources planning and management, 130*(2), 93-111.

Linsley, R. K., Franzini, J. B., Freyberg, D. L., and Tchobanoglous, G. (1992). *Water resources engineering*.

Mays, L. W. (2010). *Water resources engineering*: John Wiley & Sons.

Olivares, M. A. (2008). *Optimal hydropower reservoir operation with environmental requirements.* University Of California Davis.

Rani, D., and Moreira, M. M. (2010). Simulation–optimization modeling: a survey and potential application in reservoir systems operation. *Water Resources Management, 24*(6), 1107-1138.

Ringler, C., and Nguyen, V. H. (2004). Water allocation policies for the Dong Nai River Basin in Vietnam: an integrated perspective. *Environment and Production Technology Division Discussion Paper*(127).

Suiadee, W., and Tingsanchali, T. (2007). A combined simulation–genetic algorithm optimization model for optimal rule curves of a reservoir: a case study of the Nam Oon Irrigation Project, Thailand. *Hydrological processes, 21*(23), 3211-3225. doi: 10.1002/hyp.6528

Wurbs, R. A. (1993). Reservoir-system simulation and optimization models. *Journal of water resources planning and management, 119*(4), 455-472.

Yeh, W. W. G. (1985). Reservoir management and operations models: A state-of-the-art review. *Water resources research, 21*(12), 1797-1818.