Improved of Huai Luang Reservoir Rule Curve by using Genetic Algorithm Search

Niwat Bhumiphan[1,*] and Visrut Phetcharat[2]
[1]Faculty of Technology, Udon Thani Rajabhat University, Udon Thani 4100, Thailand
[2]Academic Office of General Education, Udon Thani Rajabhat University, Udon Thani 4100, Thailand

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*Coordinator: Niwat Bhumiphan: E-mail niwat.bh@udru.ac.th

บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อปรับปรุงเส้นโค้งควบคุมอ่างเก็บน้ำที่เหมาะสมด้วยการค้นหาแบบเจเนติอัลกอริทึม (GAs) ร่วมกับแบบจำลองอ่างเก็บน้ำ โดยใช้ฟังก์ชั่นวัตถุประสงค์ 3 กรณีในกระบวนการค้นหาคำตอบ ได้แก่ ค่าเฉลี่ยของการขาดแคลนน้ำน้อยที่สุด ความถี่ของการขาดแคลนน้ำน้อยที่สุด และปริมาณการขาดแคลนสูงสุดที่น้อยที่สุด โดยพิจารณาข้อมูลน้ำท่าแบบรายเดือน ข้อมูลความต้องการใช้น้ำ ข้อมูลอุทกวิทยา และข้อมูลทางกายภาพของอ่างเก็บน้ำห้วยหลวง จังหวัดอุดรธานี ตั้งแต่ปี พ.ศ. 2527 - 2564 นอกจากนั้นยังได้สังเคราะห์ข้อมูลน้ำท่าแบบรายเดือน จำนวน 1,000 ชุดเหตุการณ์ เพื่อประเมินประสิทธิภาพของเส้นโค้งควบคุม โดยแสดงผลเป็นปริมาณน้ำที่ขาดแคลนและไหลล้น ในรูปของความถี่ ปริมาณน้ำเฉลี่ย และช่วงเวลาที่ได้จากแบบจำลอง ผลการศึกษาพบว่าเส้นโค้งควบคุมอ่างเก็บน้ำใหม่ที่สร้างขึ้น จากการนำฟังก์ชั่นวัตถุประสงค์ทั้ง 3 กรณี ได้ค่าเฉลี่ยของการขาดแคลนน้ำน้อยที่สุด สามารถลลดสภาวะการขาดแคลนน้ำและน้ำไหลล้นได้ดีกว่าเส้นโค้งควบคุมเดิม ยิ่งไปกว่านั้นได้นำเส้นโค้งควบคุมใหม่มาทดสอบและเปรียบเทียบกับเส้นโค้งควบคุมเดิม โดยใช้ข้อมูลที่สังเคราะห์ในอดีตย้อนหลัง จำนวน 38 ปี 1,000 ชุดเหตุการณ์ โดยเพิ่มการใช้น้ำชลประทานและฝนใช้การ 10% และ 20% พบว่ายังดีกว่าเส้นโค้งควบคุมใหม่ยังคงดีกว่าเส้นโค้งควบคุมเดิม

คำสำคัญ: เส้นโค้งควบคุมอ่างเก็บน้ำ, การหาค่าเหมาะสมที่สุด, การค้นหาแบบเจเนติกอัลกอริทึม, การบริหารจัดการอ่างเก็บน้ำ

ABSTRACT

The objective of this study was to improve the optimal reservoir rule curve by using the Genetic Algorithm (GAs) search with the reservoir model. The objective function of three cases was used in the process of finding answers, namely the minimal average water shortage, minimal frequency of water shortages, and a minimal amount of water shortage. This study considered the monthly rule curves, the inflow, water demand, hydrological data, and physical data of Huai Luang reservoir located in Udon Thani Province from 1984-2021. Besides, 1,000 sets of situations of monthly rule curves were synthesized to assess the efficiency of the rule curve by showing the result of water shortage and overflowing. In terms of frequency and duration, amount of average and maximum. The trial found that the new reservoir rule curve created by using the objective function of three cases, the minimal average water shortage is the least and able to reduce water shortage and overflow conditions better than the original rule curve. Furthermore, the new rule curves were examined and compared with the previous rule curve by using the synthesized data in the past 38 years with1,000 setsofsituationswithincreasingirrigationwateruseandeffectiverainfall 10% and 20%, it is found that the new reservoir rules curve still better than the old rule curve.

Keywords: Reservoir rules curves, Optimization techniques, Genetic Algorithm-Gas, Reservoir management.

1. Introduction

Water is an important resource for Thailand, especially water shortage become a controversial problem that comes from many factors including population increase, urbanization, national economic growth, climate change, land-use change, water demand change, water supply change, and reservoir change characteristic change, etc [1]. Moreover, the less appropriate reservoir constructions encounter with the inappropriate problem or the constraints of environment and ecosystems, which become a new condition to the water source development whereas the increase of water use demand and water resource allocation becomes a new problem. Therefore, water is an important resource which must have a concrete effective management quantitatively and qualitatively in both short-term and long-term by the factual base policy and informative practicable. Nowadays, water management should base on the important mechanisms including participation from every party and integrative solution operation in every aspect from the government sector, private sector, involve organizations, and people who live in the basin to prevent the social conflict and lead to the competitiveness sustainably.

The important basic tools of the reservoir manage called “rule curve” which compound with the upper rule surface and lower rule surface. These two graphs represent the rule curves in the reservoir. Their scope covers the upper and lower of the control phase of the water level in the reservoir. They attempt to control the water level in the reservoir limit in the upper and lower scope mostly under the capacity of the reservoir. However, there are some changes and variations of the information for frequent management that becoming a dynamic problem. Consequently, if use the rule curve of the reservoir dynamically, the reservoir practice would increase the conformation and effectiveness in reservoir management.

The impose the level of the reservoir rule curves use trial and error methods combine with reservoir simulation studies. Besides this, there are some optimization techniques to study reservoir simulation including; Genetic Algorithm [2-6] particle swarm optimization [7,8] linear programming [9] Dynamic programming [10] Differential Evolution Algorithm (DE) [11] Ant Colony Optimization (ACO) [12,13] Cuckoo Search Algorithms (CS) [14,15] Tabu Search [16,17,18] and Wind Driven Optimization [19,20]. Each technique remains a good point, difficulties, and easiness differently. It was found that GAs is the most appropriate optimization technique to search and solve the problem. GAs was developed by simulating the methods from the genetic process, which imitates the principle assumes that living things have both good and bad points thus good points would pass on the next generations.

Huay Luang reservoir is an important water source for main consumption in Udon Thani Province located in Huay Luang Basin. It originates from Phu Phan

Mountains in Nong Wua So District, Udon Thani Province, where Huay Tan Hiam and Huay Dam Pa Streams concentrated as Huay Luang river 100 kilometers length. The Huay Luang River Basin remains a flooding risk. Especially in 2011, when there was a huge raining in its basin that fill water over its capacity and become flooding (Water Resource and Environment Institute, 2015). Moreover, the fluctuation of the water level in the reservoir especially in the long-dry season has become a risk of water shortage in the whole province thus Udon Thani Province. This could impact many sectors in the area including the urban communities, industries, and agriculture.

Therefore, this research aims to use GAs to improve the optimal reservoir rule curve of Huay Luang Reservoir.

2. Materials and methods

The study simulated the reservoir in each river basin, which likely to model HEC-3, HEC-5, and HEC-RAS9 [21]. by using the principle of water balance. This study built the model to simulate the reservoir system by using the same principle above to connect the GAs and the future development model. The model could search for the situation of water shortage and flooding in detail such as the frequency, size, and time duration. On inception, the calculation of the simulation of the reservoir system will impose the water volume at the full capacity. Besides this, the volume release from the reservoir in each month can found out according to the standard operating rule as illustrated in figure 1 and equation (1) below;

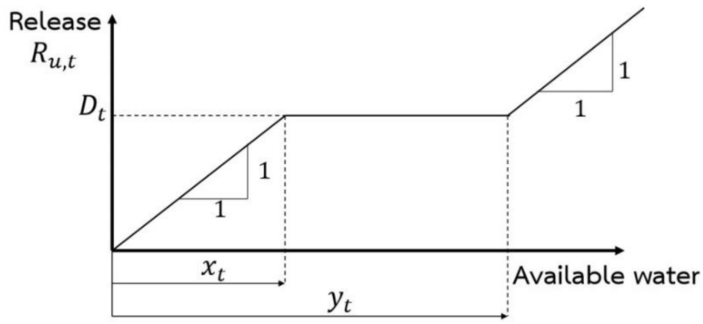

Figure 1. Standard operating rule

$$R_{u,t}\begin{cases} D_t + W_{u,t} + y_t\ ,\ for\ W_{u,t} \geq y_t, +D_t \\ D_t,\ for\ x_t \leq\ W_{u,t} < y_t + D_t \\ D_t + W_{u,t} + x_t\ ,\ for\ x_t\ , -D_t \leq W_{u,t} < x_y \\ 0, otherwies. \end{cases} \quad (1)$$

By $R_{u,t}$ is the water volume release form the reservoir (unit million cubic meters) in a year n of the month t (t = 1 to 12 means January to December) Dt is water consumption demand at last sate of a current of the month t (unit million cubic meters) x_t is the lower bound of the rule curve in each month t , y_t is the upper bound of the rule curve in moth and $W_{u,t}$ is the water volume cost remains in the reservoir in a month (unit million cubic meters)

Then calculate the water cost remains in the reservoir in next month by using the water balance equation as equation (2) below;

$$R_{u,t} + 1 = S_{u,t} + Q_{u,t} + R_{u,t} + E_t + DS \quad (2)$$

By $S_{u,t}$ is the water volume remain in the reservoir when the end of the month (unit million cubic meters) $Q_{u,t}$ is the inflow volume that flows to the reservoir monthly in month year (unit million cubic meters) E_t the evaporate monthly average month (unit million cubic meters) DS (dead storage) is the watervolume remains unused (unit million cubic meters)

Operating the model the water balance to simulates the reservoir since it was built until the current year as its fact. Then getting the result of the water shortage situation and the surplus water situation which is illustrated in the form of frequency, quantity, and time duration. Then record the information and bring it to run the process of optimal value.

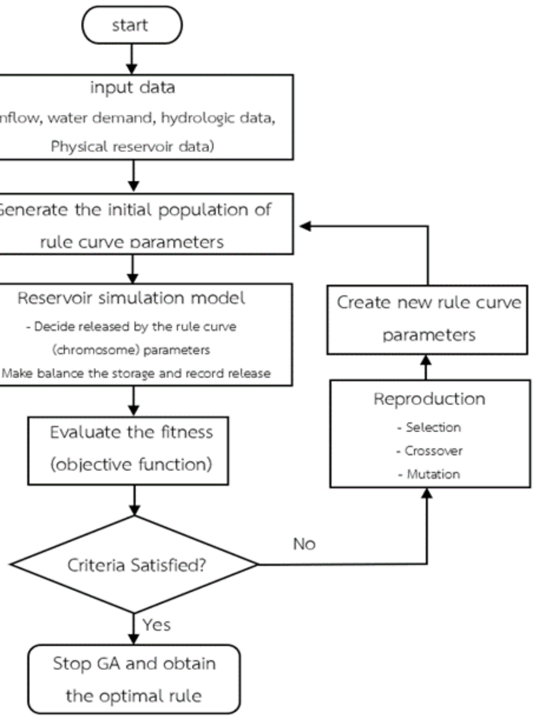

Figure 2. Application of GAs and Simulation Modeling

The application of the GAs to find the optimal value connecting to the model to simulate the situation to find the optimal rule curve of the reservoir as illustrated in figure 2. The GAs has encoding schemes for adjusting in the form of chromosome then run the genetic operation of reproduction which is compound with the process of selection, crossover, and mutation that generate new chromosome cluster after the process. The decision variable is the water volume remains every in each month of the reservoir rule curve, which determines the upper bound as the pairs in between the existing rule curve. After 1 set of chromosomes, which compound with 12 upper curve values and 12 lower curve values as the 24 rule curves of the initial population was calculated, the volume of water released will be recalculated by simulation of the situation by using this rule curve. The release water volume will be used to calculate the objective function with the objectives to evaluate the fitness of GAs. Then the genetic process which including the process of selection, crossover, and mutation will generate the new rule curve in the next generation. This step will be rerun until reach the 24 optimal rule curve values.

By imposing the objective function to build the optimal rule curve that is the less average overflow water volume as illustrated in equation (3)

$$Min(Aver_{Sh}) = \frac{1}{n}\sum_{v=1}^{n} SH_v \quad (3)$$

By n is the summation of considered years.

Sh is the volume of the overflow water between year.

The case of the water minimizes water shortage will change the objective function of searching for the frequency of the shortage as the equation (4)

(Amount of Shortage Year / All amount of year information of inflow) (4)

3. Application of GAs to Huay Luang Reservoir Optimal Rule Curve

This study was selected to apply GAs with the Huay Luang Reservoir in Kud Chab District, Udon Thani Province. Huay Luang reservoir is the soil dike high 13 meters and length 4.90 kilometers with water contain capacity 135.57 million cubic meters and a dead shortage of 6.82 million cubic meters. Its main objectives are tube water, industries, and agriculture. The area of the reservoir is about 32 square kilometers with a beneficial area of about 134.4 square kilometers From the survey in 2018 (Figure 3), Huay Luang Reservoir has water inflow station KH.53 run by the Hydrology Irrigation Center for Upper Northeastern Thailand, Department of Irrigation, which illustrates the detail of the water inflow station in a year duration statistics information of the average inflow daily, monthly and yearly (figure 4), demonstrate the inflow in Huay Luang Reservoir during 1984-2021. To evaluate the efficiency of the GAs model, the operation will control by the rule curve of the optimal reservoir operation that uses in the long-term reservoir operation based on the information of the amount of inflow water in the reservoir by the synthesized information from 1,000 sets of situation. The information of the inflow water within 38 years since 1984-2021 covers the future projection situation as well as the pass situations. The simulate the rule curve of the reservoir in the long- term by simulating the reservoir operation to study the behavior of the system of the rule of management and control. Then calculate the water volume that has to release monthly under the rule curve of the reservoir. The result of the calculation is demonstrated in the form of frequency, quantify, and time duration of the water shortage and overflow water situation.

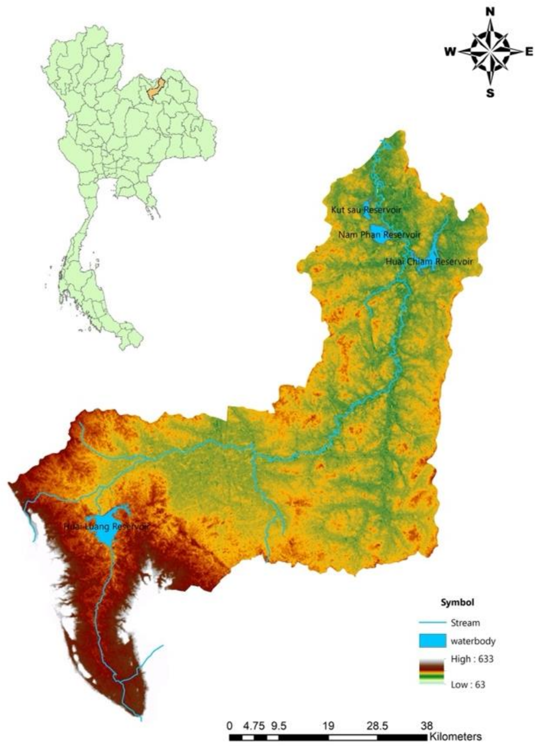

Figure 3. Location of the Huai Luang Basin

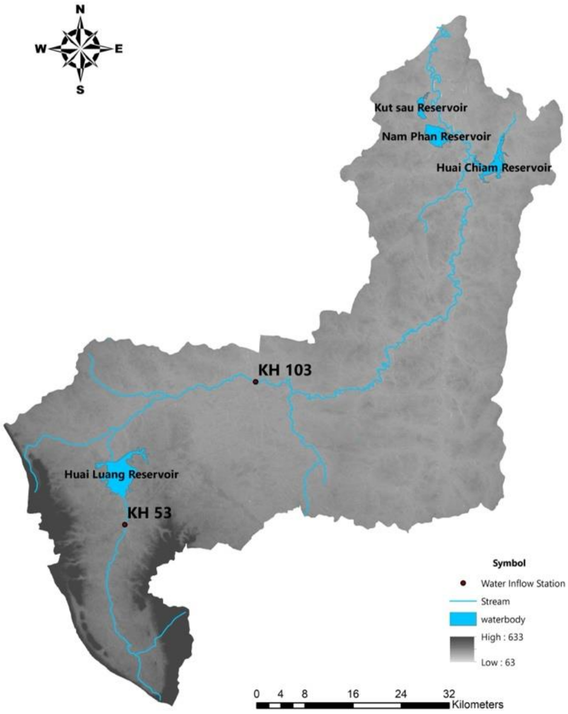

Figure 4. Water Inflow Station

4. Findings and discussion

The rule curve is generated from the past information by the GAs method then compares the rule curve by the use of the inflow in the reservoir information in the past 38 years during 1984-2021 with monthly water use demand. The finding of rule curves will use for the normal water situation as demonstrated below (figure 5). They indicated that the new rule curve and the former curve all 3 objective functions have similar character and form, thus they influenced directly from the monthly inflow in the reservoir. While the new rule curve similar to the former rule cove whereas there are some different points such as from GAs the lower rule curve is lower than the former one and the upper rule curve is higher than the former one, which aims to reserve the water for the demand in the dry season.

Evaluation of the efficiency of GAs optimal value model may compare the efficiency to the former rule curve to evaluate the efficiency of 3 objective functions of the minimal water shortage including; the average minimal water shortage, the frequency of minimal water shortage, and the minimal high water shortage value, which is calculated by simulate water balance incidence of the Huay Luang Reservoir by the use of the 38 years information in the past that including the inflow water cost in the reservoir, the water surface, the capacity of the Huay Luang Reservoir and information of the highest and lowest water volume remains in the reservoir. Then bring them to evaluate the situation of water shortage and overflow as well as evaluate the efficiency of the rule curve in each case by the use of the synthesized inflow information 1,000 incidence sets within 38 years.

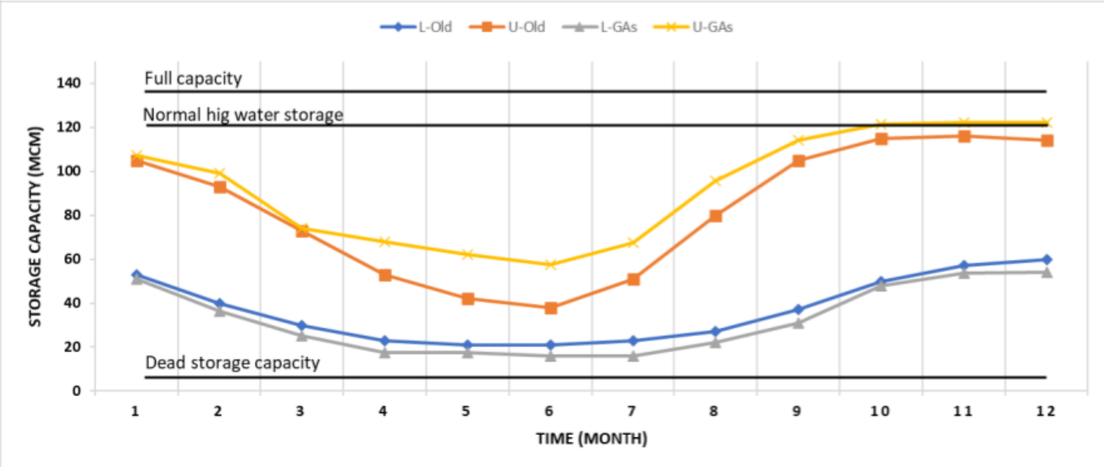

Figure 5. Reservoir rule curves Huay Luang reservoir original and characteristic GAs curves

The former rule curve and the new rule curve was created from the GAs. If evaluate the rule curve from the inflow in the past, we can see that the former rule curve, from table 1, the result of the water shortage situation of the former rule curve value is 0.152 times per year whereas the new rule curve value is 0.061 times per year, thus it assists to reduce the water shortage situation from 1.848 million cubic meters to 0.182 million cubic meters as well as decrease the average time of water shortage from 1.667 times per year to 1 time per year, decrease the overflow frequency from 1.00 times per year to 0.939 times per year, decrease the overflow from 89.599 million cubic meters to 88.557 million cubic meters that lower than the former rule curve existing nowadays. These findings elucidate the rule curve, which was generated by the GAs is more efficient from the former rule curve and optimal to the normal water situation.

Table 1 Assessment of reservoir performance curve control to assess the situation of water shortage and Overflow a reservoir of Huay Luang 38 years from 1984 – 2021.

Situations (times/year)	Curve	Frequency	Magnitude (MCM/year)		Duration (year)	
		Time/year	Average	Maximum	Average	Maximum
Shortage	Old	0.152	1.848	19.000	1.667	2.000
	GAs	0.061	0.182	4.000	1.000	1.000
Overflow	Old	1.000	89.599	355.635	33.000	33.000
	GAs	0.939	88.557	356.627	10.333	21.000

The finding found the efficiency of the new rule curve generated by the GAs, by the information that synthesized 1,000 sets of incidence, according to figure 2 dedicated that decrease the potential water shortage incident from 0.097 times per year to 0.008 times per year, decrease the amount of water shortage from 0.763 million cubic meters to 0.054 million cubic meters, decrease the average time duration of water shortage from 1.468 years to 0.2762 years, decrease the potential frequency overflow from 0.974 to 0.962 times per year, decrease the average overflow from 95.450 million cubic meters to 95.137 million cubic meters as well as decrease the average time duration of overflow from 22.511 years to 19.173 years.

The findings from the efficiency of the new rule curve found that the rule curve from the objective function generated from the average minimal water shortage can decrease the water shortage and overflow more effectively than the former rule curve. Therefore, the trial adds more the incident of change of water consumption demand to the experiment by increase the amount of the irrigation water demand

10% and 20% and effective rainfall 10% and 20% the use of the previous 38 years of information which has 1,000 sets of incidents.

Table 2. Evaluate the performance curve control of the reservoir to assess the situation of water shortage by determining the average of the lowest frequency of water shortages, water scarcity and the minimal amount of shortage maximum minimal use of synthetic Huay Luang Reservoir. in the past 38 years from 1984 – 2021 1,000 sets

Situations (times/year)	Curve		Frequency	Magnitude (MCM/year)		Duration (year)	
			Time/year	Average	Maximum	Average	Maximum
Shortage	Old	μ	0.097	0.763	10.236	1.468	1.754
		σ	0.067	0.626	6.300	0.722	0.927
	GAs	μ	0.008	0.054	1.299	0.262	0.262
		σ	0.018	0.166	3.545	0.584	0.584
Overflow	Old	μ	0.974	95.450	336.407	22.511	26.904
		σ	0.028	12.912	59.741	9.578	6.620
	GAs	μ	0.962	95.137	338.691	19.173	24.807
		σ	0.034	13.198	82.080	9.259	6.771

Table 3. Evaluate the performance curve of reservoir control for the irrigation rose 10%-20% to assess the situation of water shortage by determining the average minimum water shortages. A reservoir of Huay Luang synthesized in the past 38 years from 1984 – 2021, 1,000 sets

Situations (times/year)	Curve		Frequency	Magnitude (MCM/year)		Duration (year)	
			Time/year	Average	Maximum	Average	Maximum
Shortage	Old 10%	μ	0.137	1.354	15.113	1.582	2.056
		σ	0.073	0.902	6.992	0.634	0.956
	GAs 10%	μ	0.026	0.216	4.661	0.654	0.694
		σ	0.035	0.367	6.783	0.785	0.844
		μ	0.189	1.354	20.754	1.678	2.445

	Old 20%	σ	0.079	1.213	8.017	0.497	1.030
	GAs 20%	μ	0.056	0.597	10.492	1.066	1.199
		σ	0.049	0.679	9.657	0.774	0.906
Overflow	Old 10%	μ	0.960	89.161	329.467	18.461	24.472
		σ	0.034	12.929	81.536	9.116	6.853
	GAs 10%	μ	0.922	88.302	331.220	12.806	19.944
		σ	0.050	13.158	81.927	7.465	6.840
	Old 20%	μ	0.938	83.097	322.756	14.312	21.306
		σ	0.042	12.818	81.428	7.943	6.770
	GAs 20%	μ	0.877	81.669	323.756	8.686	15.741
		σ	0.060	13.078	81.660	4.747	5.982

Figure 3 indicated that the water shortage situation, in case increases the water demand for irrigation 10% and 20%, by the optimal value from the Genetic Algorithm Search. The trial found that the average minimal water shortage is 0.216 and 0.597 million cubic meters, the overflow situation found that overflow from the reservoir is 88.302 million cubic meters and 81.669 million cubic meters subsequently. Whereas the water shortage of the former rule curve of the Huai Luang Reservoir has average minimal water shortage equally is 1.354 million cubic meters and the overflow incident has an average value is 89.161 million cubic meters and 83.097 million cubic meters subsequently. This elucidated that the water shortage volume of the new rule curve less than the former rule curve regarding the objective of the study which the percentage of the water shortage are 0.011 and 0.007 consequently.

Table 4. Evaluate the performance curve of reservoir control for the rain increased 10%-20% to assess the situation of water shortage by determining the average minimum water shortages. A reservoir of Huay Luang synthesized in the past 38 years from 1984 – 2021, 1,000 sets

Situations (times/year)	Curve		Frequency	Magnitude (MCM/year)		Duration (year)	
			Time/year	Average	Maximum	Average	Maximum
Shortage	Old 10%	μ	0.079	0.565	8.309	1.361	1.575
		σ	0.061	0.519	5.922	0.749	0.894
	GAs 10%	μ	0.005	0.029	0.764	0.153	0.153
		σ	0.014	0.125	2.927	0.436	0.436
	Old 20%	μ	0.078	0.555	8.136	1.360	1.561
		σ	0.060	0.511	5.822	0.775	0.913
	GAs 20%	μ	0.004	0.026	0.688	0.136	0.136
		σ	0.012	0.114	2.701	0.406	0.406
Overflow	Old 10%	μ	0.980	98.275	339.754	24.277	27.900
		σ	0.025	13.071	81.802	9.340	6.337
	GAs 10%	μ	0.971	98.161	342.160	21.729	26.432
		σ	0.030	13.207	82.189	9.759	6.772
	Old 20%	μ	0.981	99.327	340.725	24.773	28.120
		σ	0.025	13.076	81.762	9.286	6.332
	GAs 20%	μ	0.975	99.250	343.170	22.822	27.090
		σ	0.028	13.207	82.174	9.584	6.581

Figure 4 indicated water shortage situation in case increase the effective rainfall 10% and 20% by the optimal value from the GAs found that the average minimal water shortage is 0.029 million cubic meters and 0.026 million cubic meters subsequently, the average overflow situation is 98.161 million cubic meters and 99.250 million cubic meters. Whereas the water shortage of the former rule curve of the Huay Luang Reservoir has the average minimal water shortage is 0.565 million cubic meters and 0.555 million cubic meters consequently as well as the overflow situation has average overflow are 98.275 million cubic meters and 99.327 million cubic meters. These elucidated that the volume of the water shortage regarding the new rule curve is less than the former rule curve as the objective of the study the percentage of the water shortage between 2 models has differences at 0.005.

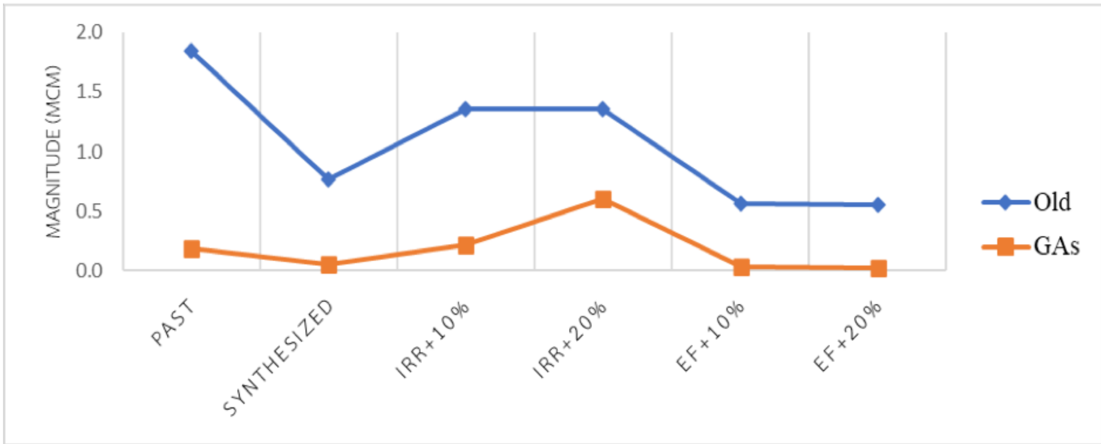

Figure 6. Compare the water shortage situation

5. Conclusion

The application of the optimal values by the GAs improving the rule curves of the Huay Luang Reservoir has been divided into 3 case study including an average of minimal water shortage, frequency of water shortage, and volume of the minimal high-water shortage. Changing the objective function found that 3 cases generated similar rule curve figures and the result of the water shortage situation more effective than the former rule curves. Nevertheless, there are some different points such as the rule curve by the GAs that have a lower bound lower than the former rule curve from January to July and higher than the former rule curve from August to December which could contain the water supply the water consumption demand [18]. And the upper rule curve’s figure is similar to the former rule curve but has a different point during is that during January to March the upper rule cure is lower than the former rule curve as well as during April to December, the upper rule curve is higher than the former rule curve, which is to contain the water for the demand in the dry season. Then bring the new 3 rule curves cases to trial and compare to the former rule curves, it was found that the new rule curve of the objective functions can reduce the flooding and water shortage more efficiently than the former rule curve. By increase the water demand for irrigation 10% - 20% and increase the effective rainfall 10% - 20% based on the synthesized information in the past 38 years amount 1,000 sets of incidences, it was found that the rule curve which generated by the GAs is more effective than the former rule curve.

6. Acknowledgments

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