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# OPTIMAL RESERVOIR OPERATION FOR WATER SUPPLY USING GENETIC ALGORITHM: A CASE STUDY OF BHUMIBOL DAM, THAILAND

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Abstract. *This paper studies the approach of Genetic Algorithm (GA) for the optimal reservoir operation for water supply by using the existing case of Bhumibol Dam. The main aim of the study is to develop a policy for optimizing the release of water for the purpose of irrigation. The fitness function used is minimizing the squared deviation of monthly irrigation demand. The considered months are March, July, and December that represent for summer, rainy and winter season, respectively, in the year 2016 and 2017. The decision variables are daily releases for irrigation from the reservoir and initial storages in the reservoir at the beginning of the month. The considered constraints for this optimization are the bounds for the releases and reservoir capacity. This model comprises real-value coding, tournament selection, uniform crossover, and Gaussian mutation. The results show that release by GA is slightly similar to actual and demand values. Nevertheless, the obtained release water from GA, the number of days with constraint violation is less than the actual release. Furthermore, the release based on the GA approach result is a lower amount of deficit than the actual release. Meanwhile, the accumulation of reservoir storage in each month found that the obtained release by GA is greater than the actual release in the summer season. Hence based on the present case study it can be concluded that the GA model has the capability to perform efficiently if applied in the real-world operation of the reservoir.*
**Keywords:** Optimization, Genetic algorithm, Reservoir operation, Bhumibol Dam

1. **Introduction.** Reservoirs are recognized as one of the most efficient infrastructure components in integrated water resources management and development. At present, with the ongoing advancement of social economy and requirement of water, the operation of reservoirs has become significantly important. To achieve optimal operating policies for reservoirs, large numbers of simulation and optimization models have been developed in the course of recent decades, which are very notable in their applications and working. Application of optimization techniques for determining the optimal operating policy of reservoirs is a major issue in water resources planning and management.

All of reservoirs and dams in Thailand are under supervisory of the water management committee in which royal irrigation department plays a vital role. The committee is conducting under all water-using sectors, policy, regulation, and other requirements.

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The committee will come out with annual, seasonal, monthly and weekly for water released plans which is mainly for irrigation purpose. The hydropower plant is using the water released plan for managing generation scheduling after that. Most of Thailand's hydropower system is part of a broader multi-use system; with power generation purpose not the first priority. The dams also serve water supply, flood control, recreation, and other beneficial uses. Temperature and precipitation effects from global climate change could alter future hydrologic conditions in the country especially the northern part and, as a result, future hydropower generation. The hour-to-hour, day-to-day, and seasonal electricity generation pattern of a hydropower scheme will influence the water releases from a dam.

To determine how water management could change with climate change, the existing reservoirs infrastructure and river basin were delineated. After reviewing climate change, a range of future hydrologic scenarios is established. These scenarios were then used to determine reservoir operation impacts on key watersheds. All operating rule curves for all major dams are revised to cope with both flood and drought. For example, the upper rule curve is decreased to cope with flood prevention and lower rule curve is decreased for the agricultural and downstream ecosystem in the dry season at principal dams such as Bhumibol Dam. Water management in Thailand is now set up under the approval of the Water and Flood Management Committee (WFMC) which comprises a representative from government and many water-related sectors. The committee is likely to reduce water storage level in the two major EGAT dams – Bhumibol and Sirikit Dams – to 45% to ensure there is enough capacity for new inflows during the approaching rainy season in accordance with a flood prevention plan. The WFMC assigns the Flood Analysis and Water Management Sub-committee, chaired by Royal Irrigation Department (RID), to run a weekly meeting on water released plan considering mainly on crop cultivation, flood protection in the rainy season and reserve water for drought in summer. The optimizing release of water for the purpose of irrigation is one of significant guidelines for the committee decision.

In the present study, a GA model has been developed to derive operational policies for a multi-purpose reservoir. The objective of this study is to maximize the irrigation release thereby reducing the square of the irrigation deficit. The decision variables are released for irrigation demand from the reservoir and desired storage in each time period. The constraints for this optimization are reservoir capacity and storage continuity equations. The upper rule curve and lower rule curve of the decision variables are fixed, and each decision variable is the real code to determine the fitness of each chromosome. These chromosomes are operated with reproduction, cross over and mutation. These will produce new values of decision variables and again the fitness is determined. The procedure is continued till the daily release is equal to the daily demand with minimum irrigation deficit and not out of constraints.

The paper is organized as follows. Section 2 presents related work. Section 3 depicts the study area. In Section 4, the GA modeling has been proposed. Then, Section 5 states results and discussion. Section 6 concludes the paper.

2. **Related Work.** In the past, numerous researchers have developed reservoir-operating policy during the past four decades using several techniques. Among different optimization techniques for reservoir operation, they are different pros and cons. Many mathematical models have been developed; however, researchers are still not fully satisfied as new problems such as high dimensionality are coming up [1,2]. Whereas applying optimization techniques for reservoir operation is not a new idea. Various techniques have been adopted in an attempt to improve the efficiency of reservoir operation. The choice of techniques usually depends on the reservoir specific system characteristics, data availability, the objectives specified, and the constraints imposed [3].

These techniques include Dynamic Programming (DP) [2], Stochastic Dynamic Programming (SDP) [4,5], Genetic Algorithms (GA) [6,7], Shuffled Complex Evolution, Fuzzy logic, and Neural Networks, etc. [8,9]. In spite of extensive research in reservoir optimization, researchers are still in search of new optimizing techniques, which can derive more efficient reservoir operating guideline for reservoir operation. Furthermore, many of the aforementioned techniques have been implemented in realistic scenarios, and many reservoir systems worldwide are operated based on the decision rules generated from these techniques. However, there exists a gap between theory and practice, and full implementation has not been achieved yet [10].

The use of genetic algorithm in determining the optimal reservoir operation policies is receiving vital attention from water resources engineers. One of its advantages is that it identifies alternative near-optimal solutions and can be used in identifying effective operation policies and solving problems in water resource development [11-13]. Genetic algorithm as a technique can be applied to solving a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is considered. The technique is an effective search method for modeling the operation guideline of a multipurpose reservoir which leads to a more realistic and reliable optimal value for the improvement of reservoir management [14].

3. **Study Area.** The reservoir chosen for the application of the GA model is the Bhumibol Dam reservoir. The Bhumibol Dam, one of the multipurpose dams of the Electricity Generating Authority of Thailand (EGAT), is a concrete arch dam that walls the Ping River at Khaokaew area of Sam Ngao district, Tak province with, the geographic coordinates: 17°14′33″N 98°58′20″E. The reservoir capacity is 13,462 million cubic meters (MCM) with about 300 square kilometers of water surface. The reservoirs operation policy involved operational factors to fulfill various demands from different reservoir stakeholders viz, meeting irrigation demand, meeting emergent demand for power, and so on. The water that is released from the Bhumibol Dam reservoir is recommended on the basis of water availability in the reservoir at the end of monsoon season, irrigation water demand of the Water and Flood Management Committee (WFMC). Certainly, the multipurpose reservoir requires to meet irrigation demand and hydropower demand, which are different in different seasons. This study mainly concentrates on how to arrange a water release from the reservoir to best satisfy irrigation demands. The researchers collected data the irrigation demands, inflow in the reservoir, reservoir release for irrigation, and initial storage in the reservoir in daily time in the year 2016 and 2017 for the GA model.

4. **GA Modeling.** For a single reservoir system in the present study, there are 31 daily releases in the optimization horizon, the chromosome representing a solution to such a problem consists of 31 genes (sub-string) representing the decision variables (releases) of the problem. The total length of the chromosome is 31 genes. The genes are generated using random numbers. The fitness function is set to the monthly sum of squared deviation from the desired irrigation release and desired storage volume. After the fitness function evaluation, the survival of the fittest is applied to the strings based on the Tournament Method to form the next generation. Hence, the strings of better fitness will have a higher probability of being copied to the next generation. This way, weak solutions are eliminated, and strong solutions survive to form the next generation, which clearly depicts Darwin's theory of "the survival of the fittest". This way, in the present study, some population will be eliminated, and some will be copied based on the Tournament Method. Since the string length is high, it was recommended to select the uniform crossover, which operates on individual genes of the selected chromosomes and each gene is considered in turn for crossover or exchange. An important aspect of the crossover application in real number coding is that the crossover should occur only at gene boundaries. The mutation is

an important process that permits new genetic material to be introduced to a population. In the present study, a modified Gaussian mutation operator has been used. Gaussian mutation permits the modification of a gene by a specified amount. After mutation again the fitness function is evaluated to find the optimal values of the decision variables.

4.1. **Chromosome encoding.** In prior to applying GA in searching for an optimal solution to this problem, the candidate solution needs to encode into a chromosome suitable to manipulate by GA operations including crossover and mutation. In this research, the candidate solution should indicate the daily water release which influences others to feature of the evaluation function. Therefore, the chromosome for this research should be a sequence daily water release as the following:

| | | | | |
|---|---|---|---|---|
| $R_1$ | $R_2$ | $R_3$ | $\dots$ | $R_n$ |

FIGURE 1. Example of encoding water release to chromosome

where $R_1, R_2, \dots, R_n$ is a daily water release of the $n$th day.

4.2. **Objective function.** The objective function of the GA model is minimizing the sum of squared deviations of releases from demands for irrigations. The objective function is given by Equation (1).

$$\text{Minimize } DF = \sum_{t=1}^{31}(R_t - D_t)^2 + \sum_{t=1}^{31}(S_t - S_{(t+1)} + I_t - R_t - E_t)^2 \quad (1)$$

where, $DF$ is the deficit, $R_t$ is the daily irrigation release for the day '$t$', $D_t$ is the daily downstream irrigation demand for the day '$t$', $S_t$ is the initial storage in the beginning of day '$t$', $S_{(t+1)}$ is the final storage at the end of day '$t$', $I_t$ is the daily inflow during the period '$t$' and $E_t$ is the daily evaporation loss from the reservoir during the day '$t$'. The optimization is subject to the following constraints.

**Release Constraint.** The irrigation release during any day should be more than or equal to the irrigation demand in that day and this constraint is given by Equation (2).

$$R_t \geq D_t, \quad t = 1, 2, 3, 4, \dots \quad (2)$$

where, $R_t$ is the daily irrigation release for the day '$t$', $D_t$ is the daily downstream irrigation demand for the day '$t$' and $t$ is the day of $1, 2, 3, 4, \dots$.

**Storage Constraint.** The reservoir storage in any day should be more than the upper rule curve of reservoir storage, and should not be less than the lower rule curve of reservoir storage. Mathematically this constraint is expressed as:

$$S_{\min} \leq S_t \leq S_{\max}, \quad t = 1, 2, 3, 4, \dots \quad (3)$$

where, $S_{\min}$ is the lower rule curve of reservoir storage in MCM, $S_{\max}$ is the upper rule curve of reservoir storage in MCM and $S_t$ is the initial storage at the beginning of day '$t$'.

4.3. **GA operations.** The parameters considered in GA population size is 2000, probability of crossover is 0.6, probability of mutation is 0.4, the number of generations is 500 and the selection method is tournament selection in which the size is 3. The study limited the evolution of the GA to 500 generations because the studied simulations demonstrated that there is no improvement in the objective value beyond 500 generations. This study sets the rate of crossover and mutation close to the lower bound of its typical range as 0.6 to 0.9 and 0.1-0.5 [1]. By experimenting, the study found that the appropriate crossover rate is 0.6 and the mutation rate is 0.4.

Pseudo code of GA in this study is the following line of codes.

```
evaluate(population)
for i = 0 to 500
{population = selectTournament(population,offspringSize = len(population),
                    tournamentSize = 3)
 offspring = crossover(population, cxUniform, cxProbability = 0.6)
 offspring = mutation(population, mutGaussian, mutProbability = 0.4)
 evaluate(offspring)
 population = offspring}
```

First, the initial population was evaluated by the objective function as defined in Equation (1), Second, 3 chromosomes in the sorted population were randomly selected in a tournament. The best fitness chromosome in the tournament is selected to be added to the offspring. This selection process continues until offspring size is equal to the initial population size. Third, the offspring was evolved by a two-step evolution. This process starts with the conducting of the mated pairs of consecutive chromosomes by a uniform crossover operation at a 60% probability, resulting children replaced their respective parents. Then the step of mutating the chromosomes by the Gaussian method at 40% probability is considered. Fourth, evaluate all offspring from the previous step by using the objective function. Finally, the final offspring is used as a population for the next loop of the evolution.

5. **Results and Discussion.** After applying GA to the formulated model, the following results are generated which provides the releases by GA and that the study considers as the optimum release for 2016 to 2017. The result of this experiment is shown in Figures 2(a)-2(c).

Figure 2 presents the comparisons of daily release water with respect to demand release for each of month; March, July, and December for the year 2016 and 2017. These can be found that daily release by GA is slightly similar to actual and demand values in the summer (Figure 2(a)) and winter season (Figure 2(c)). While in the rainy season (Figure 2(b)), the release by GA is higher than demand water in some days because the resetting of the lower and upper rule is adjusted according to release constraint for increasing reservoir capacity in monsoon period. This causes the actual release of water is higher than demand and GA can provide similar values as the actual release, in this case, to compile with the constraint. The demand water of same month in each year may be different in each year due to many constraints such as in a dry year, the required water may not be enough for off season rice farming and restricted to do only in season farming (only one time a year) and causes the demand of water less than a wet year. The reservoir can be managed to store more water during the summer season when considering the accumulation of storage at the end of that month, the amount of water in the reservoir will be greater than the actual water release. The demand water or released water plan will be decided in advance by the committee. The advantage of this work is proposing the model which can be used for planning of water management with more efficiency and reliability. In case of impact to water users, the more accurate prediction from the model can be beneficial for preparedness plan when water release schedule needs to be adjusted in a shortly manner.

In addition to the obtained release water from GA, the number of days with constraint violation is less than the actual release as shown in Table 1. For example, in March 2016, there are 11 days that violate the constraints in the actual release but there are only 2 days that violate the constraints in the release obtained by GA. When considering the fitness function value of release obtained by GA, the value is also less than the actual

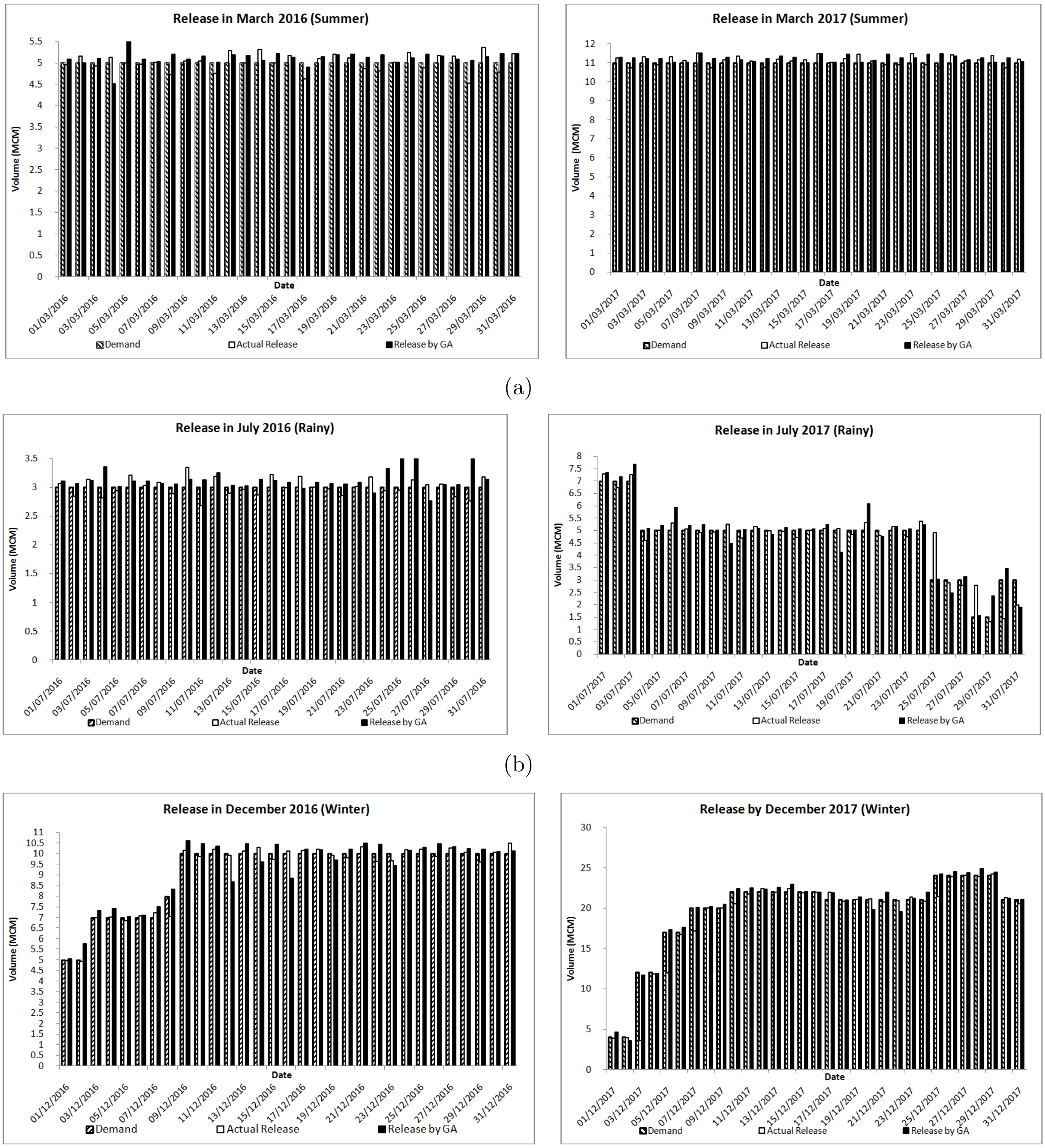


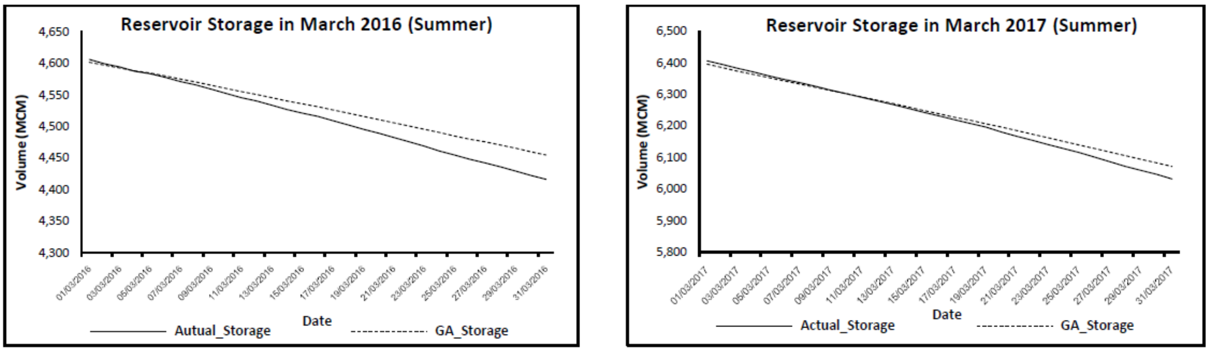

FIGURE 2. Daily water supply in actual operation compared to the simulated water supply using reservoir releases based on operating rule curve to meet water demand in 3 seasons: (a) summer, (b) rainy, (c) winter

release. This can be concluded that the release based on the GA approach result is a lower amount of deficit than the actual release.

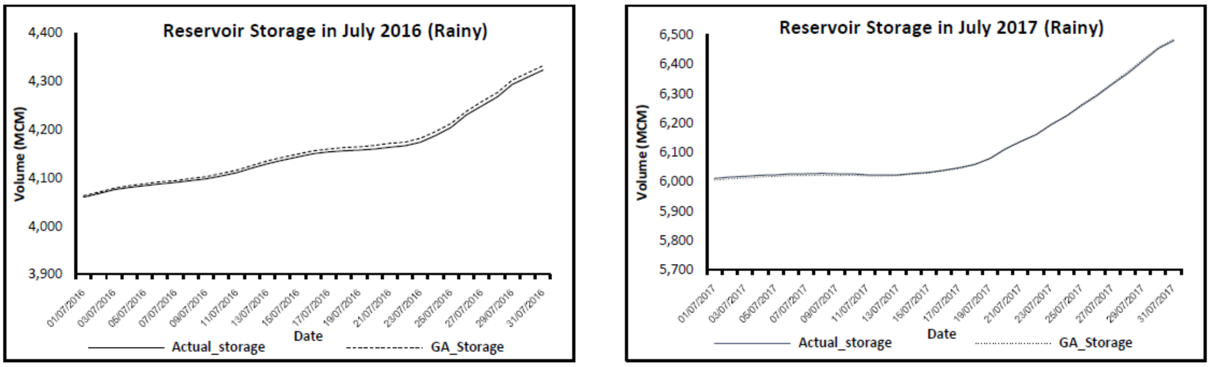
After investigating the accumulation of reservoir storage in each month as depicted in Figures 3(a)-3(c), it is founded that the obtained release by GA is greater than the actual in the summer season (Figure 3(a)). This is one of the objectives of the GA approach to supporting water management decision making. While in rainy and winter seasons (Figures 3(b)-3(c)), the accumulation of reservoir storage in each month for both obtained by GA and actual releases are quite close with a slightly higher value of GA over actual release.

Table 1. The optimal operational policies for three months in 2016 and 2017

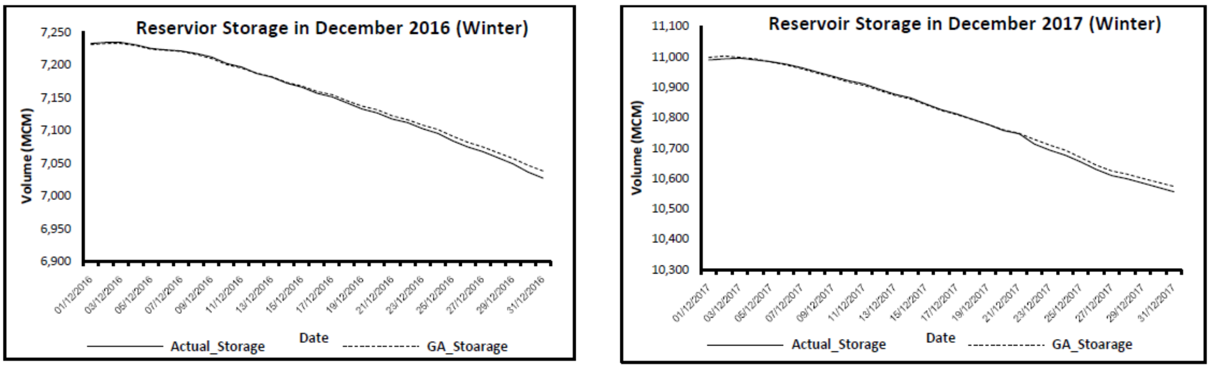
| | Summer | | | | Rainy | | | | Winter | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | March 2016 | | March 2017 | | July 2016 | | July 2017 | | December 2016 | | December 2017 | |
| | No. of days with constraint violation | Fitness function value | No. of days with constraint violation | Fitness function value | No. of days with constraint violation | Fitness function value | No. of days with constraint violation | Fitness function value | No. of days with constraint violation | Fitness function value | No. of days with constraint violation | Fitness function value |
| Actual release | 11 | 15.17 | 9 | 12.82 | 16 | 434.51 | 18 | 1,032.99 | 14 | 257.58 | 20 | 779.98 |
| Release by GA | 2 | 6.71 | 0 | 9.83 | 4 | 349.49 | 8 | 867.55 | 5 | 210.31 | 5 | 585.35 |




(a)




(b)




(c)

FIGURE 3. Reservoir storage for each month in three seasons: (a) summer, (b) rainy, (c) winter

6. **Conclusions.** The proposed model is concluded that a real-valued representation, tournament selection with elitist strategy, crossover and mutation will produce the best results. A crossover probability of 0.60 and 0.40 mutations per chromosome is suitable for the water allocation problem. The obtained result using the proposed genetic algorithm has high ability in generating optimal operation rule and strategies to handle the dam's reservoir system that minimizes the deficit of water under the reservoir storage constraint and the release constraint. Furthermore, the total amount of water in the reservoir will increase in the summer season. Hence, this study shows that operating policy derived by GA is promising and competitive and can be efficiently used for deriving operating policy for the reservoir. The optimal final storage that was obtained in this research may provide decision makers and reservoir operators with informative and valuable information that is needed for the efficient operation of the Bhumibol Dam reservoir. This work may be further enriched by using multi-objective function for irrigation and power generation.

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