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Optimal Timah Tasoh Reservoir in, Perlis: An Operation Using the Gravitational Search Algorithm (GSA)

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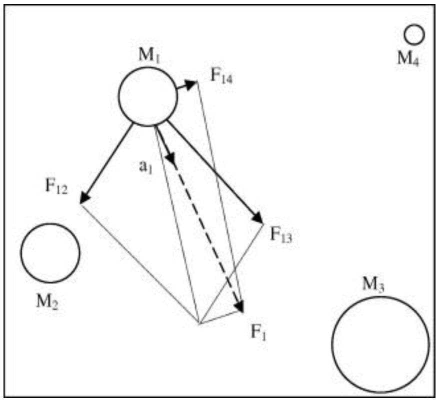
Graphical abstract



Abstract

The construction of a dam or a reservoir can have a serious impact the environment. When dealing with the increasing water demand from irrigation and water supply, alternative solution has to be sought way rather than building a new dam. Therefore, reservoir optimization can be employed as a new approach in sustainable engineering to solve this kind of problem. In this paper an optimization algorithm based on the Newton law of gravity, which is called Gravitational Search Algorithm (GSA), is introduced for optimal reservoir operation study. In GSA, every mass has four specifications, which are position, inertial mass, active gravitational mass, and passive gravitational. The location of the mass is the solution of the problem, with the gravitational and inertial masses being determined by using a fitness function. Furthermore, The algorithm was applied to the Timah Tasoh reservoir and the release policy was tested by using simulation of demand and release. The result revealed that 72% of the times the reservoir managed to fulfill the demand to the users. Moreover, with the new optimized release policy, the dam operator can manage the reservoir release for the users by determining the inflow pattern, as well as by and observing the current storage condition as a guideline

Keywords: Gravitational search algorithm, reservoir optimization, simulation, water resources, sustainable engineering

1.0 INTRODUCTION

Reservoirs have been built for irrigation, water supply to domestic and industrial applications, hydropower generation, and flood mitigation. Improper approaches in planning, constructing, and operating the reservoir might pose risk to the environmental sustainability in the catchment area in the long run, especially during the operational phase. However, many developing countries tend to build a new dam as an alternative rather than to enhance the optimization strategies, when facing the problem of increase in water demand, as well as changes in demographic and land use area [1]. Moreover, both the direct and indirect costs to construct the reservoir, at some point, can beat the economic benefit, especially when the intangible losses, such as effect to the environment, are considered in the cost-benefit analysis. Thus, dam developers should change this traditional way of thinking and start adopting a more sustainable engineering approach, such as optimizing the existing reservoir for the best operational strategy to cope with the present and future water demands.

1.1 Reservoir Optimization

Optimization can be interpreted as to find the best solution to a mathematical problem that is normally represented as an objective function. Whether the solution needs to be minimized or maximized, the set of constraint must be considered if it is applicable to the system or problem involved. Besides, optimization is a popular subject in water resources studies. It has been used in many decades as a solution tool for water resource system planning and management. Besides, the application of optimization in water resources during planning, designing, and operational phases of water resources has been discussed in text books [2]. However, this paper had looked into the use of optimization in reservoir operation. In fact, the optimization techniques have been used in studies concerning reservoir that involve optimal operation for flood [3], irrigation [4], hydropower [5], and environment conservation [6].

On top of that, reservoir optimization algorithms can be classified into two categories, which are Implicit Stochastic Optimization (ISO) or Deterministic Method and Explicit Stochastic Optimization (ESO) [7]. The linear, nonlinear, and dynamic programming applications are belonging to the ISO category, while chance-constraint and stochastic linear programming applications are two examples of the for ESO category. Furthermore, in order to ensure the effectiveness successful of the reservoir operation optimization, the reservoir operators must be involved as well in the development of the model [8].

Besides, an increase in the number of new algorithms for optimization has been noted; whether they enhanced from the existing algorithm or a combination/hybrid of from two or more algorithms, they it have their own unique abilities, advantages, and disadvantages that must be tested on or various applications. With the enhancement of computer software and hardware, the algorithms based on Evolutionary Computation (EC) are growing to be popular due to its capability suggesting a solution that is nearly similar to the optimal result within a reasonable timeframe. Moreover, the evolutionary algorithms, such as Genetic Algorithm, Simulated Annealing, Tabu Search, Particle Swarm Optimization, and Honey Bees Mating Optimization, have been proven to be good and potential tools when dealing with nonlinear and multi-objective analyseis [9]. Besides, they can be incorporated into the simulation model to provide give a better picture to the decision maker. Therefore, the potential use of GSA in reservoir optimization is high because the algorithm uses less parameters compared to other EC algorithms [10].

1.2 Gravitational Search Algorithm

Gravitational Search Algorithm (GSA) is a new optimizing method applied in operation research [11]. GSA was developed based on the Newton Law of gravity and mass interaction. In GSA, every mass has four specifications, which are position of the mass, inertial mass, active gravitational mass, and passive gravitational. The locations of the mass that match the solution of the problem, with the gravitational and inertial masses, are determined by using a fitness function, as illustrated in Figure 1.

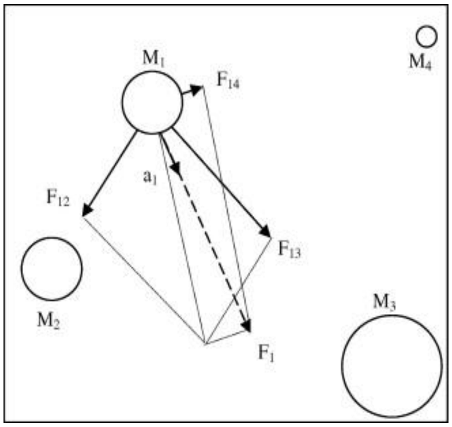


Figure 1 Illustration of Gravitational Search Algorithm

The typical steps of the algorithm are listed in the following
(a) Search for space identification
(b) Randomized initialization
(c) Fitness evaluation of agents
(d)Update G (t),best (t),worst (t),and Mi (t) for i=1, 2,3,… N
(e)Calculation of the total force in different directions
(f)Calculation of acceleration and velocity
(g)Updating the position of agent
(h)Repeat steps c to g until the stop criteria are reached
(i) End

In addition, the GSA has been compared to other optimization algorithms like modified particle swarm optimization (MPSO) and GSA has been proven to be better than MPSO in terms of computational time and final fitness value [12]. Moreover, the GSA hasbeen successfully appliedin other areas, such as for optimal power flow13, and filter modeling [14].

3.0 STUDY AREA

3.1 Study Area

The Timah Tasoh Reservoir is located in Perlis, Malaysia as shown in Figure 2. The catchment area is about 191 km2 and itsstorage capacity is about 40million cubic meter. The dam was completed in

1992 and began its operation in 1995. The reservoir was built to supply water for irrigation, domestic, and industrial for Perlis state area. It also operates as flood mitigation measure during the monsoon season.

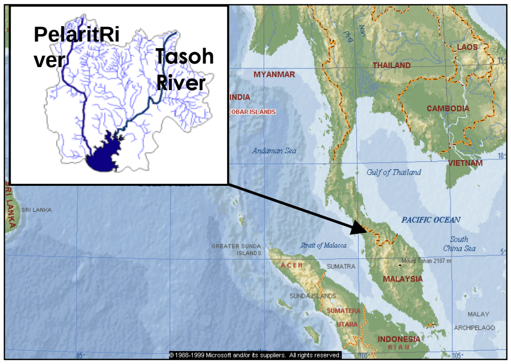


Figure 2 Location of the Timah Tasoh reservoir

3.2 Data Collection

Monthly inflows from 1989 to 2008 were analyzed and were classified into five inflow patterns, as listed in Table 1. Besides, the two main rivers that have contributed to the most inflow to the reservoir are Pelarit River and Tasoh River.

Table 1 Data input to GSA algorithm
(In Million Cubic Meter, MCM)

Month	High Flow	Medium High Flow	Medium Flow	Med Low	Low
Jan	3.78	2.94	2.10	1.26	0.42
Feb	2.79	2.17	1.55	0.93	0.31
Mar	5.50	4.28	3.06	1.83	0.61
Apr	6.48	5.04	3.60	2.16	0.72
May	3.93	3.06	2.19	1.31	0.44
Jun	9.67	7.52	5.37	3.23	1.08
Jul	8.30	6.45	4.61	2.77	0.92
Aug	11.36	8.84	6.31	3.79	1.26
Sep	5.09	3.96	2.83	1.70	0.57
Oct	26.82	20.86	14.90	8.94	2.98
Nov	23.31	18.13	12.95	7.77	2.59
Dec	23.01	17.90	12.78	7.67	2.56

3.3 The Demand of Timah Tasoh

Demands from Timah Tasoh are mostly from irrigation and water supply. In fact, more than 70% of the total annual demands come from the Irrigation scheme surrounding the Perlis state area. The demand is higher in April, October, and November due to the peak paddy season plantation, while January and February show the lowest demand because these months are not involved in the planting season. See Figure 3.

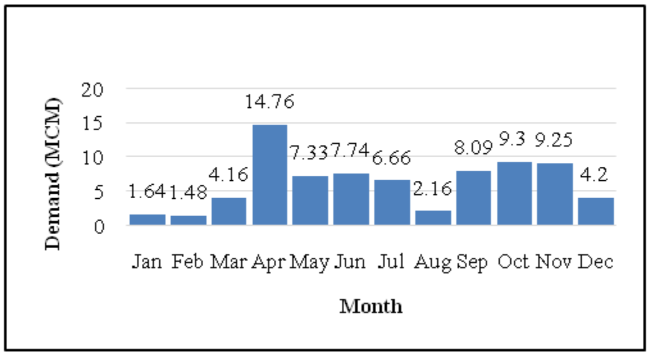


Figure 3 Irrigation and Water Supply Demand

3.4 Model Formulation

The reservoir system for Timah Tasoh is shown in Figure 4. In this study, the seepage losses had been negligible, whereas the losses from the average monthly evaporation had been considered with respect to the average of reservoir surface area of the month.

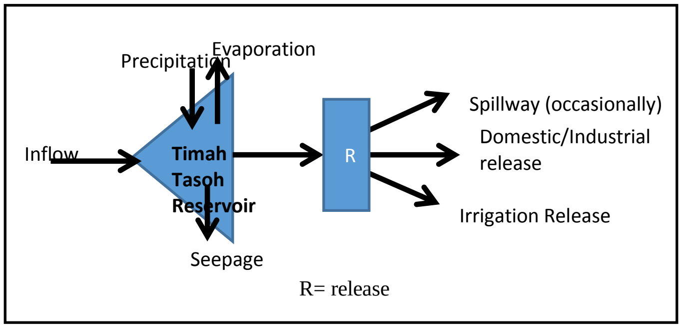


Figure 4 Reservoir system of Timah Tasoh

Furthermore, the objective of this study had been to minimize the monthly water deficit, as given in the following expression (see Equation 1).

$$MinZ = \sum_{t=1}^{12}(D_t - R_t)^2 \quad \text{R=release} \tag{1}$$

where, the months in a year are represented by t, while D_t and R_t are monthly demand and release of the subsequent month.

a) Continuity Constraint:

Meanwhile, the continuity constraint is given in Equation 2 below:

$$S_{t+1} = S_t + I_t - R_t - L_t \tag{2}$$

where, St+1 and Stare the final and initial storagesfor time period t (monthly). Next, the inflow to the reservoir is indicated by It, whileRt is the release information from the reservoir, and Losses (Lt) in this study are obtained from the evaporation of the water body and seepage from the reservoir.

b) Constraint of the Reservoir Capacity:

At any time, the storage capacity must be within the limit depicted below:

Storage capacity = 6.7×10^6 m^3 $\leq S_t \leq 40 \times 10^6$ m^3

c) Release Constraint

Monthly release for both domestic and industry is (R_{Dl})= 1.48 x 10^6m^3; while annual release for irrigation is (R_{irr}) ≥ 46.49 x 10^6m^3; and outlet volume dischargecapacity is1.48 m^3/s ≤ R_{Cap}≤ 18 m^3/s.

4.0 METHODOLOGY

The reservoir optimization analysis was developed by using MATLAB version R2012a software by MathWork [15]. The objective function was solved by using the GSA code in MATLAB with the monthly releases being the decision variable, which had been the algorithm that had to be optimized. Besides, the constraint, maximum, and minimum releases were defined in the programming code, while the monthly inflow and losses were employed as the input data to the analysis. Furthermore, penalty functions had been introduced to penalize the release variable decision if the storage capacity constraint had been violated. In fact, the model was tested with various initial storage statesin order to obtain the best optimal release policy with different types of inflows.

5.0 RESULTS AND DISCUSSION

5.1 Sensitivity Analysis

In the sensitivity analysis, GSA wastested by measuring the sensitivity of the iteration number and the number of Agent, N, to the best result or Fitness function, which is presented by Fbest value. As for minimization problem, the lower value of Fbesthad been the better solution provided by the algorithm. Thus, the resultrevealed that the GSAwasinsensitive to the iteration number.Even though the number of iterations was increased, the value of Fbestdid not increase much after 200 iterations (see Figure 5).

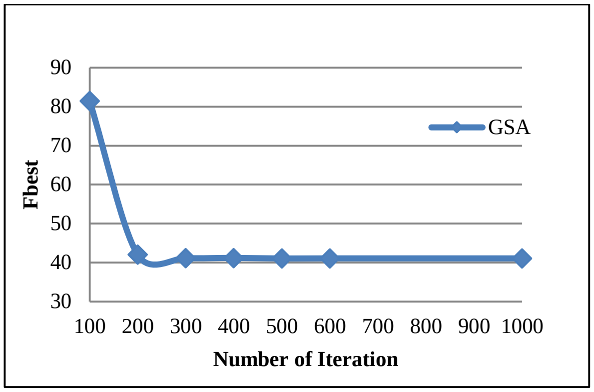


Figure 5 GSA sensitivity to a number of iterations

In Figure 6, the sensitivity analysis for a number of Agents showed that the GSA was very sensitive with the best number of agent, N, equal to 250. It also displayed that the use of lower or higher values in agent number did not provide better result for fitness function *Fbest*.

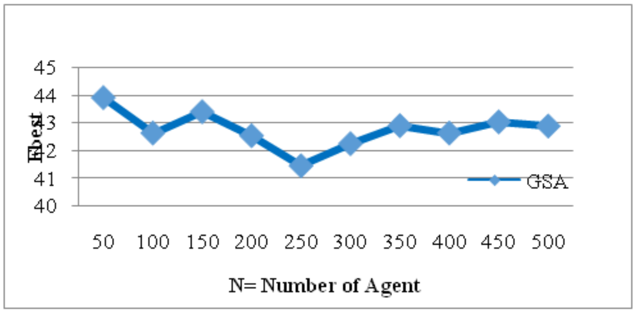
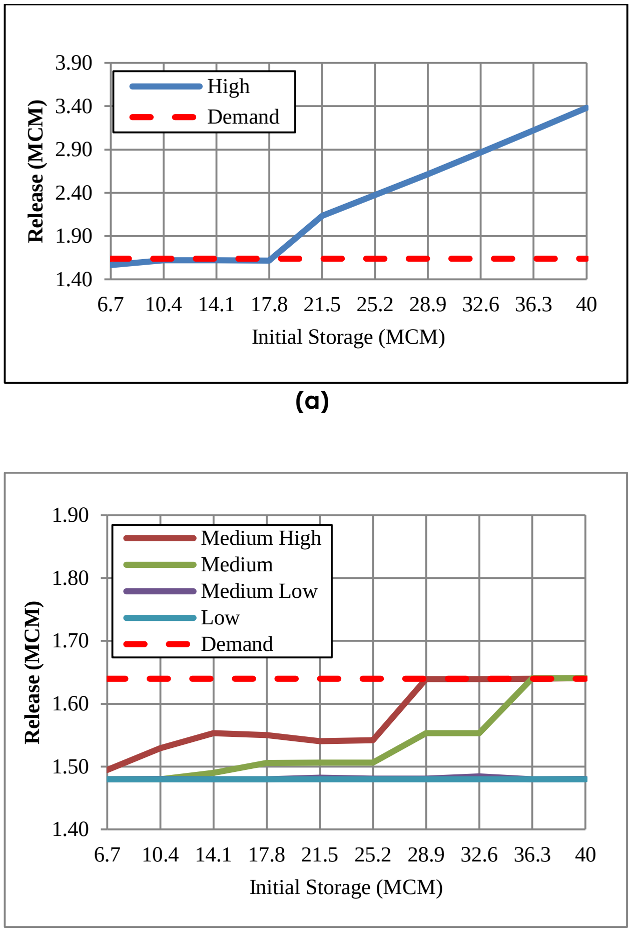


Figure 6 GSA sensitivity to a number of agents

5.2 Optimized Release Policy

Reservoir release policy is a sequence of release decision in monthly operational period, which is specific as a function of storage and class of inflow. In this study, the monthly optimized reservoir release was developed for five inflow categories by employing the GSA optimization model. When the inflow is higher, the reservoir needs to release more water to the downstream area at an earlier stage to protect the dam from being breached, and when the inflow is low, the proposed minimum release will ensure that the storage in the reservoir is adequate to satisfy the demand of the current month. Hence, twelve release policies from January to December had been generated in this study to correspond with the classes of inflow categorized for each month. However, in this paper, only the optimized release for the month of January is shown in Figures 7 (a) and (b). The release policy had been better for high, medium high, and medium; but for the low and medium low classes, the results exhibited that the reservoir failed in fulfilling the demand because the

GSA proposed a minimum release to ensure that the storage had been within the storage capacity. Moreover, since the stochastic optimization was applied in this study, the release policy for January could be used in the current Timah Tasoh operation, provided that the type of inflow in the month is perfectly forecasted.



(a)

(b)

Figure 7 Optimized release curve for the month of January

5.3 Simulation

The results from the optimization procedure had been tested with the inflow and the storage during reservoir operation from 2005 to 2011, as shown in Figure 8.Furthermore, the demand and the proposed release were compared and showed satisfactory result with 72% of the demands had been satisfied. However, since some of the years had been considered as dry years with lower inflow to the dam, the demand in those years was not completely fulfilled because the optimized release had a tendency to discharge the water to a minimum release value in order to save more water during those years.

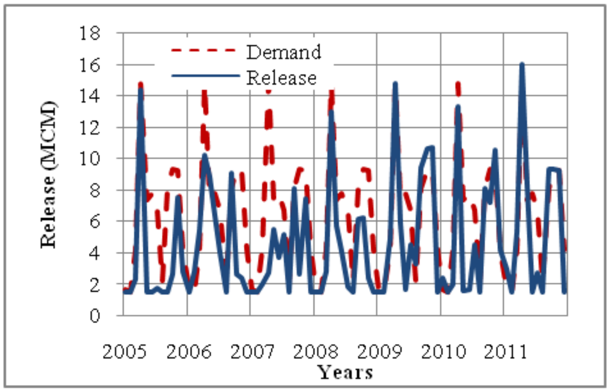


Figure 8 Simulation of the proposed release and demand

6.0 CONCLUSION

The new release policy for the Timah Tasoh Reservoir had been proposed in this study. The results displayed a possible usage of GSA for reservoir optimization in water resources. With that, the dam operator can manage the release for users by monitoring the inflow pattern, as well as by observing the current storage condition as a guideline. Besides, the optimization of the reservoir operation is one of the non-structural measures that can be applied to avoid any interested party from building or expanding the reservoir capacity, which can affect the environment in the catchment involved.

References

[1] W. C. o. 2011. Dams, *Dams and Development: A New Framework for Decision-making: The Report of the World Commission on Dams*. Earthscan, 2000.

[2] L. W. Mays and Y.-K. Tung. 1992. *Hydrosystems Engineering & Management*. McGraw Hill.

[3] Chuntian, C. 1999. Fuzzy Optimal Model for the Flood Control System of the Upper and Middle Reaches of the Yangtze River. *Hydrological Sciences Journal*. 44(4): 573-582.

[4] Consoli, S., B. Matarazzo and N. Pappalardo. 2007. Operating Rules of an Irrigation Purposes Reservoir Using Multi-Objective Optimization. *Water Resources Management*. 22(5): 551-564.

[5] Moeini, R. and M. Afshar. 2011. Arc-based Constrained Ant Colony Optimisation Algorithms for the Optimal Solution of Hydropower Reservoir Operation Problems. *Canadian Journal of Civil Engineering*. 38(7): 811-824.

[6] Yin, X., Z. Yang, W. Yang, *et al*. 2009. Optimized Reservoir Operation to Balance Human and Riverine Ecosystem Needs: Model Development, and a Case Study for the Tanghe Reservoir, Tang River Basin, China. *Hydrological Processes*. 24(4): 461-471.

[7] J. W. Labadie. 2004. Optimal Operation of Multireservoir Systems: State-of-the-Art Review, *Journal of Water Resources Planning And Management*. 130: 93-111.

[8] W. W. G. Yeh. 1985. Reservoir Management and Operations Models: A State-of-the-Art Review. *Water Resources Research*. 21: 1797-1818.

[9] D. Rani and M. M. Moreira. 2009. Simulation–Optimization Modeling: A Survey and Potential Application in Reservoir

Systems Operation. *Water Resources Management*. 24: 1107-1138.

[10] A. Ahmad, A. El-Shafie, S. Razali, and Z. Mohamad. 2014. Reservoir Optimization in Water Resources: A Review. *Water Resources Management*. 28: 3391-3405, 2014/09/01.

[11] E. Rashedi, H. Nezamabadi-Pour, and S. Saryazdi. 2009. GSA: a Gravitational Search Algorithm. *Information Sciences*. 179: 2232-2248.

[12] A. Chatterjee, G. K. Mahanti, and N. N. Pathak. 2010. Comparative performance Of Gravitational Search Algorithm and Modified Particle Swarm Optimization Algorithm for Synthesis of Thinned Scanned Concentric Ring Array Antenna. *Progress In Electromagnetics Research B*. 25: 331-348.

[13] S. Duman, U. Güvenç, Y. Sönmez, and N. Yörükeren. 2012. Optimal Power Flow Using Gravitational Search Algorithm. *Energy Conversion and Management*. 59: 86-95.

[14] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi. 2011. Filter Modeling Using Gravitational Search Algorithm, *Engineering Applications of Artificial Intelligence*. 24: 117-122.

[15] Mathworks. 2012. *Global Optimization Toolbox: User's Guide*(r2012b). Retrieved June 10, 2015 from www.mathworks.com/help/pdf_doc/gads/gads_tb.pdf.