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# Application of an Max-Min Ant System Algorithm for Optimal Operation of Multi – Reservoirs (Case study: Golestan and Voshmgir Reservoir Dams)

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**ABSTRACT:** One of the most important problems in water resources management is the optimum exploitation of dam reservoir. This task has been accomplished by various ways. Heuristic algorithms have been used for sometimes because of the old methods are difficult and expensive. One of the most important algorithms is ant colony algorithm. In this paper, the Max-Min Ant Colony Optimization Algorithm (MMACO) is used to investigate the optimum operation of multi-reservoir systems. For this research ACO is used to solve the operation of a two-reservoir system in Gorganrood Basin (Golestan and Voshmgir reservoir dams), north Iran. The solution must determine monthly releases from the two reservoirs and their optimum allocations among the two agricultural demand areas. Meanwhile, a minimum discharge must be maintained within the river reaches for environmental concerns. The current study shows that the spillway inflow in the reservoir is more than and also to procure irrigation demand.

***Key Words***: Max-Min Ant Colony Algorithms, Multi Reservoir, Optimization, Application, Operation.

## INTROUDUCTION

Most of the real world optimization problems often involve large scale optimization. In the past, many optimization techniques used to find optimal solutions were constrained by the complexities of non-linear relationships in model formulation and by increase in the number of variables and constraints. For this reason, recently many heuristic and metaheuristic algorithms have been proposed, which though do not always ensure the global optimum solution, however give quite good results in an acceptable computation time. So researchers are persistently looking for newer techniques and their improvements over the years. Recently, a new metaheuristic technique, namely Ant Colony Optimization (ACO) technique has been proposed and is becoming increasingly popular in tackling various large-scale optimization problems [7]. In the field of water resources, reservoir operation is one such problem that involves many complexities in its operation.

So far, very few applications of ACO algorithms to water resources problems have been reported [6,4]. Abbaspour et al. (2001) employed ACO algorithms to estimate hydraulic parameters of unsaturated soil. Maier et al. (2003) used ACO algorithms to find a near global optimal solution to a water distribution system, indicating that ACO algorithms may form an attractive alternative to genetic algorithms for the optimum design of water distribution systems. Jalali et al. (2003) proposed ACO algorithms for monthly operation of reservoir system. In their study three alternative formulations of ACO algorithms were tested for a single purpose reservoir operation. But they have not explored the potential of ACO for large scale optimization problems. Moeini et al (2009) used an application of the Max-Min Ant System for optimal operation of reservoirs using three different formulations.

In this paper, MMAS is applied to the problem of multi reservoir operation. To do so, the reservoir operation will be structured to fit an MMAS model and the features related to MMAS algorithm (such as heuristic information, pheromone trails, problem specific formulation, and pheromone update) will be introduced.

## METHODOLOGY

### *General and geographical situation of the region*

Gorgan Valley & Plain is located in the northeast of Iran between 45º,30' - 55º,30' longitude and 36º,46' - 37º,30' north latitude. Gorgan plain is bounded by Turkmenistan to the north, the Alborz Mountain chain in the south, Binaloud and Aladaq Mountains in the east and the Caspian Sea in the west. These plains are seen as the country's potent lands for agricultural purposes. The supply resources of the water necessary for irrigation of these lands include surface waters and underground water reserves. Gorgan - River which stretched its range across the central parts of the plain is one of the region's surface waters resources. This river serves as a source of irrigation waters needed for the nearby agricultural lands and eventually flows into the Caspian Sea. For the purpose of collecting the surface waters running across the region the Voshmgir reservoir dam was constructed across the Gorgan River with annual water control capacity of one hundred million cubic meters ($m^3$).

### *Gorganrood -River watershed*

The watershed of Gorganrood River is located in southeast of the Caspian Sea between 54º,02' - 56º,16' east longitude and 36º,34' - 37º,47' north latitude. The Gorganrood River originates from the high lands of the Alborz mountain chains at the watershed's eastern part and, after passing through the city of the Gonbad Kavous, enters into Voshmgir Dam, and finally joins the Caspian Sea. The watershed of Gorgan River spreads over an area of 13170 $km^2$ approximately, 7838 $km^2$ (60%) of which account for the watershed's highlands and the remainder includes foothills and plain. Nearly 8500 $km^2$ of the watershed is covered by the basin of Gorganrood River which extends to the Voshmgir dam. The figure 3-2 shows the location of the Gorganrood River basin and Voshmgir dam.

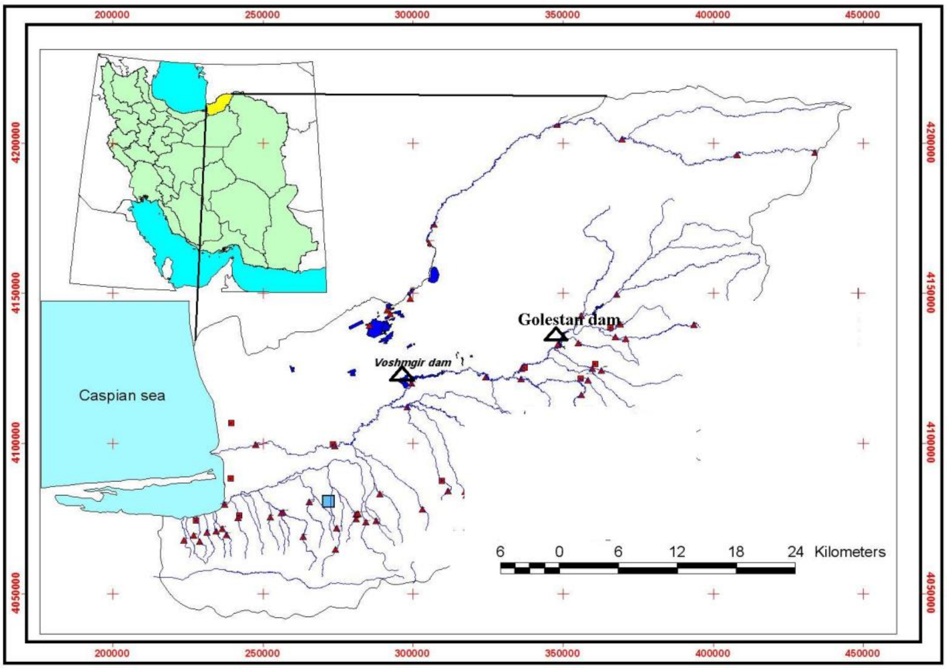


Figure1. location of the Gorganrood River basin, Voshmgir and Golestan dams

### *Ant Colony Optimization*

In the early 1990s, the ant colony optimization (ACO) was introduced by M. Dorigo as a novel nature-inspired metaheuristic for the solution of hard combinatorial optimization (CO) problems. ACO belongs to the class of metaheuristics [2,3], which are approximate algorithms used to obtain good enough solutions to hard CO problems in reasonable computation time [7] The inspiring source of ACO is the foraging behavior of real ants. When searching for food, ants initially explore in a random manner the area surrounding their nest. As soon as an ant finds a food source, it evaluates the quantity and the quality of the food and carries some of it back to the nest. During the return trip, the chemical pheromone trail on the ground, the ant deposits. The quantity of pheromone deposited, which may depend on the quality and quantity of the food, will guide other ants to the food source. As it has been shown in [5], indirect communication between the ants via pheromone trails enables them to find the shortest paths between their nest and food sources. This characteristic of real ant colonies is exploited in artificial ant colonies in order to solve CO problems. The central component of an ACO algorithm is a parameterized probabilistic model, which is called the pheromone model. The pheromone

model is used to probabilistically generate solutions to the problem under consideration by assembling them from a finite set of solution components. At runtime, ACO algorithms update the pheromone values using previously generated solutions. The update aims to concentrate the search in regions of the search space containing high quality solutions. In particular, the reinforcement of solution components depending on the solution quality is an important ingredient of ACO algorithms. It implicitly assumes that good solutions consist of good solution components. To learn which components contribute to good solutions can help assembling them into better solutions. In general, the ACO approach attempts to solve an optimization problem by repeating the following two steps:
Candidate solutions are constructed using a pheromone model, that is, a parametrized probability distribution over the solution space;
The candidate solutions are used to modify the pheromone values in a way that is deemed to bias future sampling toward high quality solutions.

***MAX–MIN Ant System***
In order to avoid the stagnation situation in which all ants are stuck within a local optimum, Stuzle and Hoos [11,12] propose the MMAS algorithm to have more control on the pheromone trail. The state transition rule used is either the random-proportional rule or the pseudo-random-proportional rule. The pheromone trail is updated when all ants complete their solution construction by $\tau_{ij}^{new} = \rho\tau_{ij}^{old} + \Delta\tau_{ij}^{e}$ where either the best solution in this iteration and the best solution found so far is used for $\Delta\tau_{ij}^{e}$ All $\tau_{ij}$ are initialized as $\tau_{\max}$ and $\tau_{\min} \le \tau_{ij} \le \tau_{\max}$. Stutzle and Dorigo (2002) also propose a variation of the state transition rule as $P_{ij} = \frac{\tau_{ij}}{\sum_{l \Xi u} \tau_{il}}$ because (as shown in an MMAS application to the TSP) when local search is used to improve the algorithm, the importance of local heuristic information is replaced by local search. Therefore, local heuristic information is ignored in this version of state transition rule [11,12]. Research on ACO has shown that improved performance may be obtained by a stronger exploitation of the best solutions found during the search and the search space analysis in the previous section gives an explanation of this fact. Yet, using a greedier search potentially aggravates the problem of premature stagnation of the search. Therefore, the key to achieve best performance of ACO algorithms is to combine an improved exploitation of the best solutions found during the search with an effective mechanism for avoiding early search stagnation. MAX–MIN Ant System, which has been specifically developed to meet these requirements, differs in three key aspects from AS.
(i) To exploit the best solutions found during an iteration or during the run of the algorithm, after each iteration only one single ant adds pheromone. This ant may be the one which found the best solution in the current iteration (iteration-best ant) or the one which found the best solution from the beginning of the trial (global-best ant).
(ii) To avoid stagnation of the search the range of possible pheromone trails on each solution component is limited to an interval [τ_min; τ_max].
(iii) Additionally, we deliberately initialize the pheromone trails to τ_max, achieving in this way a higher exploration of solutions at the start of
algorithm.

***Pheromone trail updating***
In MMAS only one single ant is used to update the pheromone trails after each iteration. Consequently, the modified pheromone trail update rule is given by

$$(1) \qquad \tau_{ij}(t+1) = \rho\tau_{ij}(t) + \Delta\tau_{ij}^{best}$$

Where $\Delta\tau_{ij}^{best} = \frac{1}{f(S^{best})}$ and *f*($S^{best}$) denotes the solution cost of either the iteration-best ($S^{ib}$) or the global-best solution ($S^{gb}$). Using one single ant for the pheromone trail update was also proposed in ACS . While in ACS typically only ($S^{gb}$) is used (although some limited experiments have also been performed using ($S^{ib}$), *MM*AS focuses on the use of the iteration-best solutions.

***ACO Algorithms for Optimum Reservoir Operation***
To apply ACO algorithms to a specific problem, the following steps have to be taken: (1) Problem representation as a graph or a similar structure easily covered by ants; (2) Assigning a heuristic preference to generated solutions at each time step (i.e., selected path by the ants); (3) Defining a fitness function to be

optimized; and (4) Selection of an ACO algorithm to be applied to the problem. In the following subsections, these steps will be introduced to solve the optimum reservoir operation problem.

***Problem representation***

To apply ACO algorithms to the optimum multi reservoir operation problem, it is convenient to see it as a combinatorial optimization problem with the capability of being represented as a graph. The problem may be approached considering a time series of inflow, classifying the reservoir volume to several intervals, and deciding for releases at each period with respect to an optimality criterion. Links between initial and final storage volumes at different periods form a graph which represents the system, determining the release at that period. [8,9].

***Model Application***

To illustrate the performance of the model, the Golestan and Voshmgir reservoirs in North of Iran, with an effective storage volume of 60 and 45 MCM are selected. For illustration purposes, a period of 63 is employed. In this study releases formulation considers as the decision variable of the problem. The releases taken as the decision variable, each period of the operation is considered as the decision point of the problem. Discretizing the range of possible values of release at each period, the options available at each decision point are then represented by the set of discretized values of the releases optimal operation of a multiple reservoir for water supply may be stated mathematically as follows:

(2) $$\text{Minimize } F = \sum_{t=1}^{NT} \left\{ \left[\frac{R_u^k(t) - D_u(t)}{D_{u.max}}\right]^2 + \left[\frac{R_d^k(t) - D_d(t)}{D_{d.max}}\right]^2 \right\}$$

subject to continuity equations at each period:

(3) $$S(t+1) = S(t) + I(t) - r(t) - l(t)$$

$s_{min} \leq S(t) \leq S_{max}$
$r_{min} \leq r(t) \leq r_{max}$

NT: total number of periods;
D(t) :water demand in time period t;
r(t): water release from the reservoir in time period t;
$D_{max}$ :maximum water demand (constant);
s(t) reservoir storage at the beginning of period t;
I(t) :water inflow to the reservoir in period t;
r(t): water release from the reservoir in period t;
l(t): evaporation loss in period t;
$s_{min}$ :minimum water storage of the reservoir;
$s_{max}$ :maximum water storage of the reservoir;
$r_{min}$ :minimum water release from the reservoir;
$r_{max}$ :maximum water release from the reservoir.

It is also assumed that the starting point for ants could be any time along the 60-month operation horizon. Thus, ants are also uniformly random distributed along the operation horizon (Fig. 2). Feasible paths for ants to follow are constrained by the continuity equation, and the minimum and maximum permitted release volume (Eqs. 10). By completion of the first tour by all ants, there will be a finite number of feasible solutions with values for the objective function. Now, realizing the values of the fitness function, the pheromones must be updated to continue the next iteration.

## RESULTS

In this section, the results obtained for optimal operation of the Golestan and Voshmgir reservoirs, using the proposed formulations, are presented. Table 1 shows the values of MMAS parameters used in optimal operation model.

Table 1. Value of MMAS parameters in the first formulation

| ρ | Nom. Ant |
|---|---|
| 0.5 | 150 |

Table 2 shows the results of the model application in Golestan and Voshmgir Reservoirs obtained in 5 independent runs. It shows that the best value of objective function is 3253.0616, and the mean of 5 different runs equals to 3671.6329.Also variation of best, mean and worst value of solution costs of water supply operation showed in Figure 2.

Table 2. results of 5 iterations for Max- Min ant system Algorithm

| Operation | 1 | 2 | 3 | 4 | 5 | Mean |
|---|---|---|---|---|---|---|
| Objective function value | 4870.7158 | 3520.4709 | 3307.1205 | 3406.7957 | 3253.0616 | 3671.6329 |
| Iterations | 50 | 100 | 100 | 150 | 150 | |

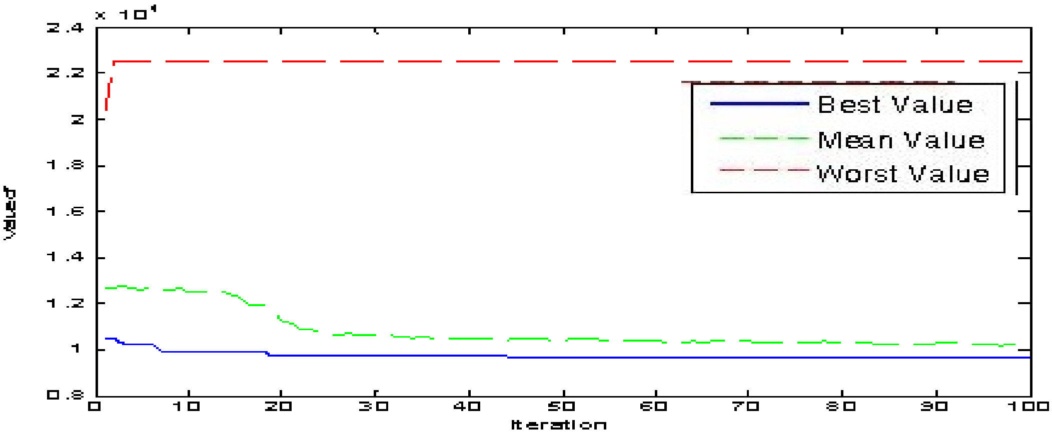


Figure 2. Variation of best, mean and worst value of solution costs of water supply operation over 100 iterations (third formulation).

Operation of Golestan and voshmgir reservoirs over 63 monthly periods obtained using the formulation in the releases are taken as the decision variables. Figure 3 and 4 shows the comparison between demand and releases obtained with MMACO algorithm and last release in Golestan and Voshmgir dams.

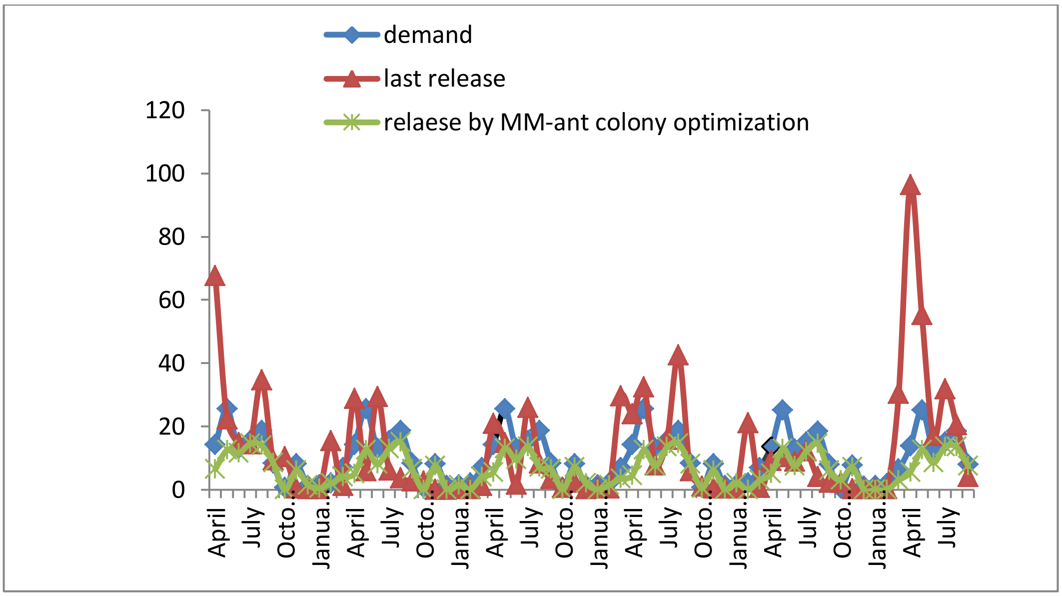


Figure 3. Comparison between demand and releases obtained with MMACO algorithm and last release in Golestan dam

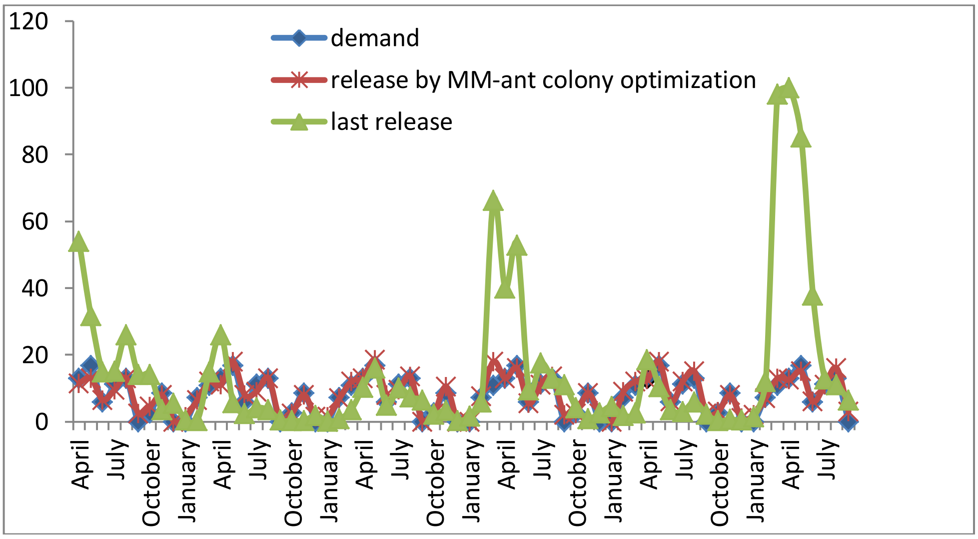


Figure 4. Comparison between demand and releases obtained with MMACO algorithm and last release in Voshmgir dam

Storage volume of Golestan and voshmgir operated by MMACO are presented in figure 5 and 6.

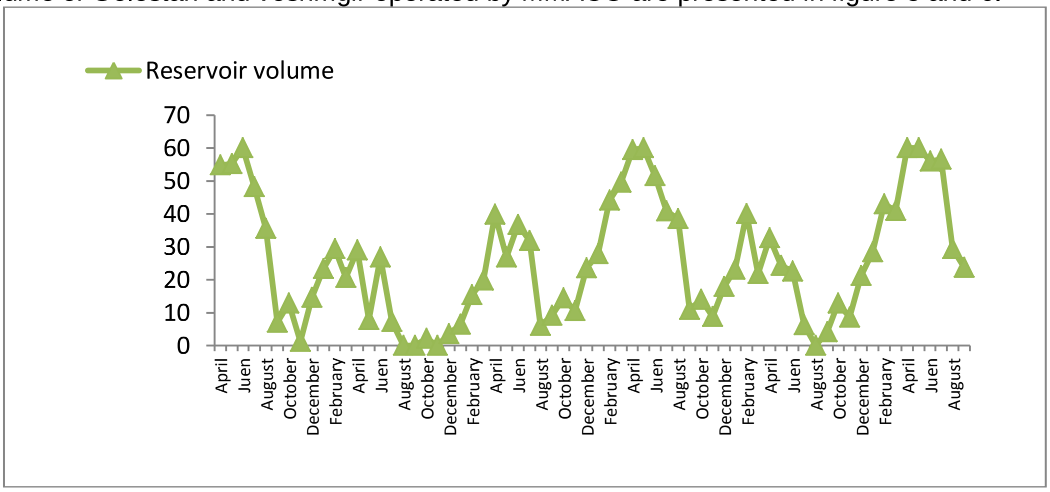


Figure 5. volume of Golestan reservoir operation by MM-ant colony optimization

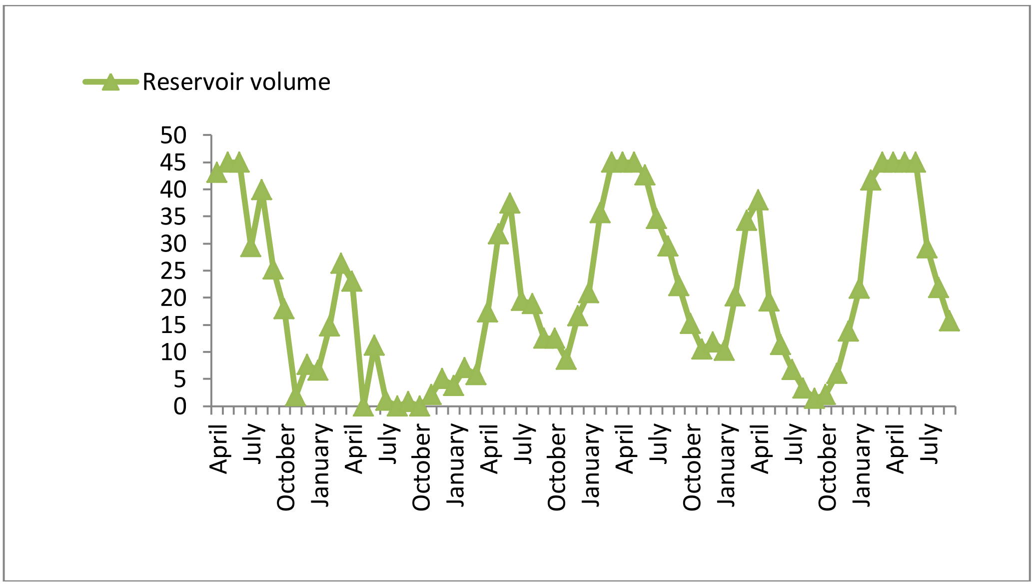


Figure 6. volume of Voshmgir reservoir operation by MM-ant colony optimization

## DISCUSSION

In this paper, the formulations were used to multi reservoir operation problems in proper form, to be solved with Max-Min ant colony optimization algorithms. In the formulation, each period was taken as the decision point of the problem at which the value of the release, as the decision variable, is to be decided. This formulation allowed for definition of the heuristic information only for the case of water supply operation problem.

A recent variant of the ACOA's, namely MMAS, was then used to solve the problem of the water supply multi reservoir operation problems over 63 months and the results were presented and compared to the available solutions. The results indicated the capability of the MMAS, in multi reservoir operation problems. It can be concluded that MMACO appears to be a very useful technique for solving global optimization problems in civil engineering, especially in water reservoir engineering.

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