# Modified Firefly Algorithm for Solving Multireservoir Operation in Continuous and Discrete Domains

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**Abstract:** Reservoir systems are essential for water resources management. The application and development of optimization techniques for optimal reservoir operation is therefore a valuable undertaking. This paper presents a modified firefly algorithm (MFA) and applies it to optimally solve reservoir operation problems. Three well-known benchmark multireservoir operation problems are optimized for energy production. The results of the MFA are compared with results obtained with other mathematical programming approaches, such as linear programming (LP), differential dynamic programming (DDP), and discrete DDP (DDDP), the genetic algorithm (GA), the multicolony ant algorithm (MCAA), the honey-bee mating optimization (HBMO) algorithm, the water cycle algorithm (WCA), the bat algorithm (BA), and the biogeography-based optimization (BBO) algorithm. The MFA was found to be more effective than alternative optimization methods in solving the test problems demonstrating its strong potential to tackle multireservoir operation problems. This paper's results indicate that the MFA differed by 0.01 and 0.79% with the LP global optimal solutions of a continuous four-reservoir problem (CFP) and a continuous 10-reservoir problem (CTP), respectively. The objective function of a discrete four-reservoir problem (DFP) obtained with the MFA is equal to the LP's objective function. This paper demonstrates that the MFA is a competitive optimization method with which to solve a variety of reservoir operation problems. **DOI:** **10.1061/(ASCE)WR.1943-5452.0000644.** 

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## Introduction

Water resources management is a very important and pressing topic, particularly when dealing with reservoir operation issues. A step forward in solving reservoir operation problems is to use optimization methods, including mathematical programming approaches and evolutionary or metaheuristic algorithms. The fact that mathematical programming approaches are time consuming and cannot solve complex problems, in some cases (Bozorg-Haddad et al. 2016), reinforces the need to resort to more reliable algorithms. To achieve this goal, researchers have increasingly resorted to evolutionary or metaheuristic algorithms because of their effectiveness and versatility, instead of mathematical programming approaches such as linear programming (LP) and dynamic programming (DP).

Novel optimization techniques are commonly tested with well-known benchmark problems whose optimal solutions are known. A brief outline of several approaches that have been used to solve well-known benchmark reservoir problems, namely, discrete four-reservoir problem (DFP), continuous four-reservoir problem (CFP), and continuous ten-reservoir problem (CTP), is presented below.

The application of DFP was first reported by Larson (1968). Subsequently, other researchers applied other optimization techniques such as DP, differential DP (DDP), and discrete DDP (DDDP) to solve DFP as reported by Heidari et al. (1971) and Murray and Yakowitz (1979). The limitations of mathematical programming techniques in solving complex real multireservoir operation problems contributed to the rise of evolutionary or metaheuristic algorithms owing to their solution capacity and versatility. DFP subsequently served as an example for the genetic algorithm (GA) in research by Wardlaw and Sharif (1999) and HInçal et al. (2011). Bozorg-Haddad et al. (2011) implemented the honey-bee mating optimization (HBMO) algorithm to demonstrate its advantageous performance over other optimization techniques in solving multireservoir operation problem.

The second benchmark problem, CFP, was introduced by Chow and Cortes-Rivera (1974) who applied LP and DDDP to solve this problem. This problem was solved by several researchers using mathematical programming optimization techniques such as Murray and Yakowitz (1979). Mathematical programming optimization techniques exhibit several limitations. For this reason, CFP has relied primarily on evolutionary and metaheuristic algorithms as the optimization technique of choice, which replaced mathematical programming optimization techniques. As an example, Bozorg-Haddad et al. (2011) applied the HBMO algorithm in solving the CFP. Recently, Bozorg-Haddad et al. (2015a, b) evaluated the performance of two new metaheuristic algorithms, including the water cycle algorithm (WCA) and the bat algorithm (BA), in solving the CFP. The latter two studies concluded that the WCA and the BA perform better than the GA in solving the CFP. More recently, Bozorg-Haddad et al. (2016) used biogeography-based optimization (BBO) algorithm to reservoir operation problems, particularly

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