Reservoir system optimisation using a penalty approach and a multi-population genetic algorithm

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Abstract

A multi-population genetic algorithm (GA) was used to optimise a system of two reservoirs that supplies monthly varying demands and environmental flow requirements. Optimisation aimed at minimising the penalty resulting from non-supply of water and the occurrence of low reservoir storage states that would limit non-consumptive utilisation of water in the reservoirs. Four cases were analysed viz. Case I: Reservoir capacities and demands were fixed and the operating rules were optimised; Case II: Demands were fixed and the reservoir capacities and operating rules were optimised; Case III: Reservoir capacities were fixed and the demands and operating rules were optimised; and Case IV: Reservoir capacities, demands and operating rules were optimised. The genetic algorithm obtained reasonable solutions for all cases. A detailed analysis of Case IV obtained several high-performance solutions of varied sizes and supply capabilities. This analysis revealed specific limitations of supply reliability and the expected storage states of one of the reservoirs. The analysis also obtained the ranges within which the optimal monthly operating rules for the system are expected.

Keywords: genetic algorithm, penalties, operating rules, demands, reservoir capacities

Introduction

The reservoir system optimisation problem is often quite complex. At the planning and design stage, decisions on system configuration and component sizes have to be made. Once this has been done, the operating rules that will maximise system performance need to be formulated. Ideally, the two problems should be dealt with together although system yield and sizing analysis is often taken as separate from the system operation problem. The comprehensive analysis of reservoir management and operations models by Yeh (1985) and Loucks et al. (1981) and others provides ample evidence of this. Yield analysis methods that incorporate operation scheduling are, however, in practical use. For example, the water resource yield model that is widely used in South Africa applies the storage state balancing space rule approach (Basson et al., 1994). The space rule operating policy ensures that all reservoirs in the system are drawn down together in a manner that allows all the water stored in the reservoirs and all water entering the system to be available to meet the target draft without a shortfall until all the reservoirs have failed simultaneously. The reservoirs are thus operated in a manner that utilises the overall storage capacity to the maximum and prevents any unnecessary water spillages. Johnson et al., (1991) have used this approach in reservoir operation analysis. The associated water resource planning model also widely used in South Africa refines these rules using an iterative network flow programming approach (Basson et al., 1994). This approach defines the system as a network configuration of arcs and nodes with each arc having a lower and an upper flow bound and also an associated cost per unit of flow. The optimisation aims at minimising the total cost of flow in the network and the operating rules are derived from the optimal solution. Hsu and Cheng (2002) have used the network flow approach to optimise a water resource system in Taiwan. This paper is aimed at demonstrating the application of the genetic algorithm (GA) method to a practical reservoir system optimisation problem including capacity and yield analysis and also system operation. The hydrology is based on a real system but hypothetical demands and environmental flow requirements are applied. The GA is a good candidate for reservoir system optimisation as it possesses some unique advantages over many classical optimisation methods. These are discussed in the next section. Although the GA has been researched and applied fairly extensively, it is only recently that applications to reservoir operation have been reported (Oliviera and Loucks, 1997, Wardlaw and Sharif, 1999, Sharif and Wardlaw, 2000). As Van Vuuren (2002) indicates, the potential of the GA has not been fully utilised in the South African water industry.

A water resource system could be designed to maximise yield or to minimise the penalty caused by non-supply of water and/or non-utilisation of reservoirs due to low storage levels. The application of the GA to maximise system yield, subject to probability constraints of supply and reservoir storage states for the same system is reported elsewhere (Ndiritu, 2002) while the penalty approach is applied here. Penalties should ideally be obtained from socio-environmental-economic analysis of the costs of non-supply and non-availability of water in reservoirs. As Basson et al. (1994) indicate, data availability in general is extremely limited while many intangible social and political factors also often come into play. Relative penalties agreed upon by the water management body and all the stakeholders could be a reasonable alternative. The penalties applied here are hypothetical but are not considered unrealistic.

The hydrology of the system analysed is based on the Elands River catchment in South Africa up to Mkombo Dam which supplies domestic and industrial needs. The other dam in the catchment, Rust de Winter, supplies irrigation water.

The genetic algorithm

Because detailed descriptions of the basics of the GA are widely available, only a brief explanation of how the GA works is given

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