Maximising water supply system yield subject to multiple reliability constraints via simulation-optimisation

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Abstract

The realistic incorporation of reliability into the optimisation of reservoir system design and operation remains a particularly difficult task after decades of research. While most of this research has worked with methods based on linear or dynamic programming, little has been done to find out how well the problem could be handled by a simulation model linked to an optimisation model (SO model). Water supply systems have to satisfy different demands that each require various levels of reliability and these need to be incorporated in analyses for efficient system design and operation. This study presents an approach for determining the reservoir sizes and monthly operating rules that maximise the yield of a water supply system subject to multiple reliability constraints of supply and reservoir storage. A behaviour analysis model linked to a genetic algorithm is applied and the constraints are implemented using multiplicative penalties. This approach is found to deal with multiple reliability constraints realistically and effectively with multiple runs clearly identifying the active and the redundant constraints. The long computation times are, however, a drawback for the approach and suggestions to reduce these are suggested. Powell's conjugate direction method is also used to optimise one of the cases analysed and obtains a slightly lower yield than the genetic algorithm but with a lower number of simulations. The method obtains yields comparable to the South African Water Resources Yield Model (WRYM) and has the advantage of automating the derivation of inter-reservoir operating rules.

Keywords: multiple reliability constraints, reservoirs, yield, simulation, optimisation

Notation

$a_{i,j,k}$	surface area of reservoir k in month j of year i
$AS_{i,j}$	vector of the direct diversions to supply
$as_{i,j,k}$	direct diversion from reservoir k in month j of year i
c_k	capacity of reservoir k
$d_{j,k}$	demand for reservoir k in month j
d_k	annual demand for reservoir k
$ev_{j,k}$	average Symon's pan evaporation for reservoir k in month j
$mpres_l$	specified maximum probability that restrictions of level l should occur
$mprst_n$	specified maximum probability that a reservoir state lower than n should occur
N	total number of years of simulation
$NEV_{i,j}$	vector of net evaporation losses in month j of year i
$nev_{i,j,k}$	net evaporation loss from reservoir k in month j of year i
$nres_l$	number of times that restrictions of the l^{th} level are imposed in the simulation period
$nrst_n$	number of times the reservoir is in a state lower than the n^{th} state
$pr_{l,k}$	l^{th} percentage supply of the demand $d_{j,k}$
$Q_{i,j}$	vector of the inflows in month j of year i
$q_{i,j,k}$	inflow to reservoir k in month j of year i
$ra_{i,j,k}$	point rainfall at reservoir k in month j of year i
$RF_{i,j}$	vector of regulated flows from the upper to the lower reservoir in month j of year i
$rf_{i,j,k}$	regulated flow from reservoir k in month j of year i
$rl_{j,l,k}$	l^{th} operating rule curve value for reservoir k for month j
$rs_{n,k}$	n^{th} storage state for reservoir k
$rsm_{j,k}$	parameter for optimising reservoir state variability for reservoir k in month j
$S_{i,j}$	vector of the initial storage volumes at the beginning of month j of year i
$s_{i,j,k}$	storage volume of reservoir k in month j of year i
SO	Simulation-optimisation
$SP_{i,j}$	vector of spill in month j of year i
$sp_{i,j,k}$	spill from reservoir k in month j of year i
tc	total system capacity
TR	total runoff in the simulation period.
$trl_{j,l}$	lth operating rule curve value for the total storage state for month l
$ts_{i,j}$	total storage in month j of year i
we	weighting parameter for obtaining the rule curves of total storage
$WRYM$	Water Resources Yield Model
Y	ratio of total actual supply (yield) to total runoff in simulation

Introduction

The construction of large-scale reservoir systems has declined significantly in many parts of the world for various reasons. In South Africa, most of the suitable sites for large reservoirs have already been exploited. Cui and Kuczera (2003) mention constraints on further development and the limited availability of funds in Australia. Labadie (2004) states that the construction of large-scale water storage projects is at a virtual standstill in the US and other developed countries and points out the increasing

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