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Dynamic attribution of water quality indexes in a multi-reservoir optimization model

Giovanni M. Sechi, Andrea Sulis*
Hydraulic Sector, Department of Land Engineering, University of Cagliari, Italy
Tel. +39 (070) 675-5303; Fax +39 (070) 675-5310; email: andrea.sulis@unica.it

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Abstract

In the southern regions of Mediterranean Europe, the greatest part of water resources for supply systems come from artificial reservoirs. Eutrophication is one of the most serious problems affecting the quality of water stored in reservoirs. A simplified approach that includes water quality aspects as water use limiting factors in a multi-reservoir optimization model can be achieved by adoption of the Trophic State Index (TSI). This paper makes some improvements on the optimization model already presented by Sechi and Sulis in the management of large systems. Particularly, it addresses the possibility of dynamic attribution of quality indexes in the LP model. The application of the optimization approach to different operating rules in a real multi-reservoir system in southern Sardinia highlights the need for joint consideration of quality and quantity aspects for effective water management.

Keywords: Complex water systems; Trophic status; Optimization model

1. Introduction

Eutrophication is one of the most serious problems affecting the quality of water in multi-reservoir systems. The increase in nutrients leads to greater productivity of the water system which may lead to excessive increase in algal biomass or other primary producers such as macrophytes. Excessive algal biomass can seriously affect water quality, especially if it creates anaerobic conditions. Therefore, even when using a simplified approach in a mathematical optimization tool, there is a requirement to include water quality indexes associated with the trophic state of reservoirs [1].

*Corresponding author.

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This paper can be considered as a development of the optimization approach presented by Sechi and Sulis [2]. It is a modelling tool intended to assist decision-makers in identifying and evaluating management alternatives when considering simplified forms of water quality classification.

It is well known that mathematical optimization procedures for large water resource systems are still unable to deal with all real-world complexities even when they can be easily incorporated in a simulation model. Nevertheless, optimization results can be seen as a reference target for simulation since optimization results can be considered as obtained by an ideal system manager [3]. Many studies have been carried out on the development of optimization models for multiple reservoir systems. However, few of them have taken water quality as an objective. Dandy and Crawley [4] modified an existing linear programming model to identify policies minimizing average salinity in water supply. A network optimization model for water allocation to demands with different quality requirements was described by Mehrez et al. [5]. Hayes et al. [6] integrated water quantity and quality modelling in an operational model for use in multi-reservoir hydropower systems.

An essential step in the construction of an advanced optimization model for addressing real problems is linked to the definition of water quality in water bodies and the identification of constraints so as to set out correct system management criteria. In Sechi and Sulis [2], a criterion for classifying reservoirs in multiple reservoir systems was defined using Carlson's Trophic State Index [1]. Trophic State Index (TSI), which in recent years appears to have attained general acceptance by the limnological community, can be evaluated using chlorophyll-a, total phosphorus and Secchi disk transparency measurements. In Sechi and Sulis [2] the formulation of water quality constraints was addressed using chlorophyll-a measurements by means of which it is possible to evaluate the TSI(Chl) trophic index. In this paper an improvement on that approach is presented. It considers the dynamic introduction of quality index values in the optimization model. Instead of static introduction of quality values, the proposed model defines TSI(Chl) values according to changes in stored volumes in reservoirs. Two different operating rules are tested to highlight significant increases in system performance when water quality is considered as well as quantity in a common system management strategy.

2. Split-storage graph for quality index attribution

The paper describes a linear optimization tool for multiple reservoir systems under water scarcity conditions and different water uses (urban, irrigation, industrial, and hydroelectric). This tool was developed using modeling methods appropriate for the structural complexity of the optimization problem.

In the optimization approach presented by Sechi and Sulis [2] the physical system status in a single period is represented by a direct network (basic graph) consisting of nodes and arcs. A dynamic multi-period network is generated by replicating the basic graph for each period $t = 1,T$ in the time-horizon T and then connecting the corresponding reservoir nodes for different consecutive periods. Objective function (OF) in the model incorporates operation, maintenance and repair (OMR) costs, user-defined costs to assure efficiency of the system and purification costs. Purification costs can be either fixed or dependent on water quality. As usual, optimization model constraints are introduced in order to take into account relationships between system variables: continuity equations at the nodes, relationships between the flow variables and project variables, bounds attributed to these two sets of variables and, finally, water quality constraints. In particular, for each reservoir, quality constraints