Environmental Modelling & Software xxx (2014) 1–16

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

# A computational software tool for the minimization of costs and greenhouse gas emissions associated with water distribution systems☆

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ARTICLE INFO

*Article history:*
Received 28 April 2014
Received in revised form
3 November 2014
Accepted 4 November 2014
Available online xxx

*Keywords:*
Multi-objective optimization
Greenhouse gas emissions
Water distribution system
Computational software tool

ABSTRACT

While evolutionary algorithms have been applied extensively to water resource problems, there remains a need to unify and consolidate computational and software approaches to solving these problems. In order to facilitate this for the minimization of costs and greenhouse gas emissions of water distribution systems, the water distribution cost-emissions nexus (WCEN) computational software framework is introduced in this paper. The software is freely available and can be easily modified in order to facilitate consistency of modeling, simulation and evaluation within different research studies. In addition, it enables consideration of the time-dependent variation of operational choices, such as emissions factors, electricity tariffs and water demands, which has not been done previously. The utility of the framework is demonstrated for a case study, the results of which show that consideration of such variations can significantly affect optimal design and operational decisions, as well as their costs and GHG emissions.


**Software and data availability**

Description Water Distribution Cost-Emissions Nexus Computational Software Framework (WCENsoft)
Developers C.S. Stokes, A.R. Simpson, H.R. Maier
Year First Available 2014
E-mail christopher.stokes@alumni.adelaide.edu.au
Website http://www.ecms.adelaide.edu.au/civeng/research/water/software/wcen-framework/
Hardware Requirement General-purpose computer
Software Requirement C compiler, EPANET 2.0 Toolkit
Programming Language C
Licensing This software is made available under the terms and conditions of the GNU General Public License Version 2 (1991), as published by the Free Software Foundation
Description Time-dependent emissions factors for South Australia
Developers C.S. Stokes, A.R. Simpson, H.R. Maier
Format Spreadsheet data file
E-mail christopher.stokes@alumni.adelaide.edu.au
Website http://www.ecms.adelaide.edu.au/civeng/research/water/software/wcen-framework/

## 1. Introduction

The application of evolutionary optimization algorithms to water resources problems has been covered extensively over the last 20 years (Nicklow et al., 2010; Maier et al., 2014). However, there is a need to better unify and consolidate the computational and software implementation of these approaches in order to facilitate a level platform on which studies can be performed, to allow researchers to easily access algorithms and benchmark studies (Maier et al., 2014). In order to facilitate these improvements, it is necessary to develop computational software frameworks that are applicable to a range of real-world studies, can be easily integrated with existing research needs and can be easily segmented and upgraded as new technology and approaches become available (Maier et al., 2014; Robson, 2014).

The minimization of greenhouse gas (GHG) emissions associated with water distribution systems (WDSs) is a key example of where these improvements are required. As a result of the recognition of the potentially negative impact GHG emissions due to the construction and operation of WDSs can have on the environment,

☆ Special Issue on Evolutionary Algorithms.

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http://dx.doi.org/10.1016/j.envsoft.2014.11.004
1364-8152/

research focusing on the minimization of GHG emissions from WDSs, in addition to the minimization of costs, has gained popularity (Stokes et al., 2014b). However, much of this research has emerged from optimization studies focusing solely on cost minimization. Consequently, many of the computational methods used for cost minimization have been adopted for the minimization of costs and GHG emissions. However, this has resulted in the simplified representation of some aspects of the underlying system, particularly in relation to the temporal variation of emissions factors, electricity tariffs and water demands (Stokes et al., 2014b).

In order to highlight these issues, Stokes et al. (2014b) developed the water distribution cost-emissions nexus (WCEN) conceptual framework, which considers the nexus of elements required to accurately simulate a WDS for the purposes of minimizing costs and GHG emissions. In particular, the WCEN conceptual framework includes consideration of both short-term (e.g. daily) and long-term (e.g. monthly and annual) time-dependency of operational conditions (e.g. emissions factors, water demands and electricity tariffs), the consideration of pumping operational management choices, including those for multiple operational conditions, and consideration of the simulation requirements necessary to apply these to the multi-objective (MO) optimization of WDSs for the minimization of costs and GHG emissions.

In order to facilitate implementation of the elements of the WCEN conceptual framework in practice, and to enable this to be done in a consistent manner, the WCEN conceptual framework needs to be converted into a computational software framework. In order to achieve this, the objectives of this paper are (1) to present some general considerations for the development of computational software frameworks (2) to introduce the structure, features and benefits of the WCEN computational software framework (WCENsoft) and (3) to use a case study to demonstrate how the WCEN framework can be used to address some of the knowledge gaps identified in Stokes et al. (2014b) by providing a platform with which a range of time-dependent operational conditions (e.g. emissions factors, electricity tariffs, water demands, pumping operational management options) can be considered. WCENsoft introduced in this paper integrates hydraulic and pumping operational simulation, cost and GHG emissions calculation and MO heuristic optimization tools into one freely available, easy to use and easily accessible package. Importantly, specific components of the software framework (e.g. the optimization algorithm) can be updated and integrated into other computational software frameworks, as required. WCENsoft allows the user to optimize a WDS for the reduction of costs and GHG emissions, while considering real-world operational conditions, by using the most accurate emissions factor, water demand and electricity tariff information available, while incorporating operational management strategies that can take full advantage of this information.

The remainder of this paper is organized as follows. In the next section, some general considerations for the development of computational software frameworks are presented. Next, the novelty of WCENsoft, developed with consideration of these guidelines, is explained, followed by a discussion of the software architecture used for WCENsoft. Following this, the case study WDS and methodology used to demonstrate the capabilities and benefits of WCENsoft are introduced. Finally, results from the case study are discussed and conclusions are drawn.

## 2. General considerations for the development of computational software frameworks

The application of computational software frameworks is an important part of addressing water resources problems. While these frameworks can be case study specific, it is preferable that they are developed with broader application in mind, facilitating the benchmarking of problems and approaches used to solve these problems (Maier et al., 2014). The broader application of these frameworks can allow more direct comparison between studies and results, allowing better understanding as to whether case study specific approaches are required or whether more generic approaches can be employed when solving these problems (Maier et al., 2014). As such, it is important to consider general methods or steps to the development of simulation and optimization components, the application of uncertainty assessment and the implementation of the framework itself. Ultimately, the broad application and longevity of a framework may rest on its ability to be adapted to different situations, such as the requirement of high evaluation accuracy or high computational efficiency. Therefore, it is desirable that a computational software framework be developed with flexibility in mind.

### 2.1. Simulation and optimization

Simulation models can be critical to the understanding and evaluation of complex, real-world water resources systems. It is important to select a simulation model appropriate for the application. Consideration should be given to why a simulation model is required (e.g. how it links to the purpose and objectives of the study), what the model is required to do (e.g. required features of the model, possible integration with other simulation models, availability of data, simulation parameters and performance criteria), how output is resolved (e.g. trial and error, analytical, optimization), how and whether uncertainty is quantified and how to validate the model to ensure robustness (Jakeman et al., 2006; Refsgaard et al., 2007; Bennett et al., 2013; Kelly et al., 2013). Simulations can sometimes be computationally expensive. Therefore, it can also be desirable to consider computational resources and time availability. For example, when absolute accuracy is important, the use of more complex yet computationally time-consuming simulation may be required. However, if computational time is limited, it may be necessary to reduce simulation complexity at the expense of accuracy (Robson, 2014). If computational expense is a likely burden, such as when optimization or uncertainty assessment (discussed below) are incorporated, surrogate meta-models, such as artificial neural networks, may be able to be used to reduce the computational time of simulation while retaining the evaluation accuracy of a more complex simulation model (Broad et al., 2005, 2010; Razavi et al., 2012; Kelly et al., 2013; Broad et al., 2014; Maier et al., 2014; Wu et al., 2014). In order to facilitate broader application of computational software frameworks, it is desirable that the simulation model can be flexibly applied with respect to the above considerations and can be easily upgraded or exchanged with a different model without the need to redevelop the entire framework.

### 2.2. Optimization

Optimization (when based on evolutionary algorithm techniques) requires the repetitive use of simulation models, which may severely limit the computational effort afforded to the simulation model. Appropriate choice of optimization technique (e.g. search ability and computational efficiency of the optimization algorithm), limitations to search space size and the employment of surrogate meta-models can help to reduce the burden of computational constraints (Razavi et al., 2012; Kelly et al., 2013; Maier et al., 2014; Wu et al., 2014). As optimization techniques may be improved upon and updated over time, it is desirable for the longevity of a computational framework that the optimization