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A procedure for spatial aggregation of synthetic water demand time series

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Abstract

A procedure for spatial aggregation of synthetic water demand time series is presented. Starting from synthetic water demand time series generated at user level and reproducing mean and variance of the corresponding observed series, the procedure allows the aggregated series to preserve the statistics of interest observed at the aggregation level considered. The procedure uses a method proposed by Iman and Conover (1982): the synthetic user water demand time series are reordered to preserve the observed spatial correlations of appropriate lag-time; then, the spatial aggregation of these series leads to a series representative of the user group reproducing the corresponding means and variances for the different hours of the generic day. Four different ways of performing this aggregation have been investigated and compared. Application to a case study consisting of the water demands of 21 users highlights that the approaches considered show different levels of effectiveness in reproducing the statistics, but overall the procedure proposed is a valid tool for the bottom-up generation of synthetic water demand time series.

Keywords: water demands; spatial aggregation; time series.

1. Introduction

Users' water demands are the main driver of water distribution systems (WDSs). Their proper characterization thus represents a fundamental prerequisite in order to set up robust and accurate hydraulic model of a WDS. To this

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end several models for the generations of synthetic user water demand time series have been proposed in the last decades; these models allow for the characterization of the user water demand even with fine time steps and are typically based on stochastic processes, like Poisson rectangular pulses (e.g. Buchberger and Wu, 1995; Guercio et al., 2001), Neyman-Scott rectangular pulse (e.g. Alvisi et al., 2003; Alcocer et al., 2006) or based on the characterization of the uses of individual devices such as washing machines, toilets, etc., typically used in houses (e.g. Blokker et al., 2010). These models showed to be very effective in statistically reproducing the observed data at level of single users and at low temporal aggregation levels, but it is worth remembering that in WDS simulation models the water demands are typically allocated at the nodes of the model aggregating the consumptions of many users adjacent to the node considered, and hourly or semi-hourly time steps are generally used. Thus, it is necessary to transfer the information from one level of spatial-temporal aggregation to another in order to set-up synthetic water demand time series to be effectively used within hydraulic models of real/complex WDSs.

Indeed, several studies (e.g. Alvisi et al., 2003; Moughton et al., 2006) showed that both the simple temporal aggregation of the synthetic series, from, for example, 1-minute to 1-hour time step, and the spatial aggregation from single users to a group of users, performed through a simple sum, can lead to time series which do not reproduce the corresponding observed statistics (mainly variance and covariances at different time lags). More in details, Alvisi et al. (2003) highlighted that reproducing the covariances (and thus the cross-correlation) among the series to be aggregated (both temporally and spatially) is a prerequisite in order to proper reproduce the variances of the aggregated series.

Summing up, it is important to be able to "transfer" the time series generated at low temporal and spatial aggregation levels (e.g. at 1-minute time step for single users) to higher aggregation level (e.g. at 1-hour time step for groups of users), since these latter are the series typically used within the simulation models for the design and management of the WDSs. At the same time, the main statistics (mean and variance) should be reproduced at these higher aggregation levels since they can have a significant impact on the hydraulic performances of the WDSs, as demonstrated by some recent studies (e.g. Babayan et al., 2005, Filion et al., 2007).

The temporal aggregation problem of time series from minute to hourly time step has been recently addressed by Alvisi et al. (2013). Thus, in this paper attention is focused only on the spatial aggregation of hourly water demand time series of single users in order to obtain hourly time series representative of a group of users to be used within a hydraulic simulation model, which can reproduce the main statistics observed at the same spatial aggregation level. To this end, a spatial aggregation procedure based on the method proposed by Iman and Conover (1982) is presented; four different ways of applying this method are presented and compared. In the following, the proposed procedure is described and the results obtained by its application to the cases study consisting of the water demands of 21 users of the water distribution system of Milford (Ohio) (Buchberger et al. 2003) are discussed; finally, conclusions are presented.

2. The procedure

The spatial aggregation procedure consists of summing up the water demands of an assigned number n_{us} of single users in order to obtain the water demand of the group of users considered. Let us assume that synthetic water demand time series of the single user at Δt = 1 hour time step are available; in particular, let us assume that these series have been generated independently each other and in such a way that they reproduce at hourly level mean, variance and temporal covariances (at the proper time-lag, as better explained in the subsequent sections) of the corresponding observed time series (see, for example, Alvisi et al., 2013 for a possible procedure for the generation of series with these characteristics). The total water demand of the n_{us} users in the generic hour h of the k-th day (with h=1:24, k=1:n_{die} where n_{die} is the number of days considered/generated) is given by:

$$Q_{h,k} = \sum_{j=1}^{n_{us}} q_{h,k}^{j} \tag{1}$$