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Real-time demands and calibration of water distribution systems

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ABSTRACT

All computer models of water distribution systems (WDS) have to contain information about demands. Usually demands are derived based on customer's water meters weekly or monthly readings. It gives information only about the average demand. Dynamics of hourly, daily and weekly demands are usually estimated based on typical demand patterns of different type of consumer groups like domestic households, hospitals or hotels. Estimation of demand dynamics by this manner inevitably decreases precision of calibration. Calculations show that differences between real-time and typical demand can influence results of calibration. The paper proposes some methods to minimize this influence. Special software has been developed for estimation of real-time water demands in a WDS. Algorithms and software checked on an operational WDS.

1. Introduction

Computer models of water distribution systems (WDS) contain information on demands. Summarised water consumption is usually measured for quite long periods (e.g. month) that gives information only on the average base demand. Dynamics of these demands are obtained based on typical dynamic patterns for different type of consumer groups. These consumption patterns are used because of lack of detailed information. Results may differ from actual demands in time (e.g. during different weekdays) and in location of demand (e.g. because of different daily movement of the residents at different parts of the region). Great differences between typical and actual demand patterns have been indicated in [2,3]. Thus base demands and corresponding patterns contain large uncertainties which decrease precision of calibration of model. Calibration of computer model is necessary to achieve as near real-life representation of actual WDS as possible. Because of the corrosion and deposition processes, which occur over time after the pipes have been installed, the pipes roughness and diameters changes. Using of good calibrated model is an example very important for estimation of propagation rate of the contaminated zones in case of deliberate or accidental chemical or biological threats. This task may be accomplished only on the basis of WDS model calibrated with good precision [4]. This constraint is especially important in the light of necessity to improve drinking water security management in large cities in EU [5]. The aim of this investigation was to make an effort to decrease errors of calibration. Quality of calibration depends on number of reasons. One of them is difference between actual and typical demands. Correct estimation of the water consumption and demand pattern at demand nodes is rather difficult [6]. This information is significant for calibration [7] and for further use of the model [8]. Therefore quite detailed measurements were accomplished in one of the District Metered Area (DMA) of WDS of Tallinn. Calculations showed that differences between actual and typical demands influence results of calibration even in area that consists mainly of residential consumers.

Other aim was to obtain and analyse differences in actual water demands and demands obtained based on typical demand patterns. Estimation of the actual demands is formulated as optimisation task, which minimizes differences between measured and modelled pressures and water flow. All calculations have been accomplished using measurements executed in operational WDS in the year 2012. Special software has been developed for estimation of actual water demands in a WDS. The software is based on the TOOLKIT developed for the EPANET2 [9]. Subroutines were developed and programmed in Visual Basic and in Visual C++. Multiple processors are used simultaneously in order to decrease computational time. Current paper is based upon Vassiljev and Koppel paper [1], but text has been rewritten and additional analysis of relationships between head losses and water inflows is added.

2. Analysis

2.1. Brief description of WDS, measurements and variants of calibration

All calculations are accomplished using the results of measurements taken in the part of WDS of the city of Tallinn in 2012. This part of WDS has one water source and contains from ca 2000 pipes that serve about 1000 consumers. Overwhelming majority of pipes

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Table 1
Information on pipes construction times and materials

Cast iron		*Plastic*		*Steel*	
Number of pipes	Installation years	Number of pipes	Installation years	Number of pipes	Installation years
1727	1961-2011	625	1999–2011	53	1970–2000

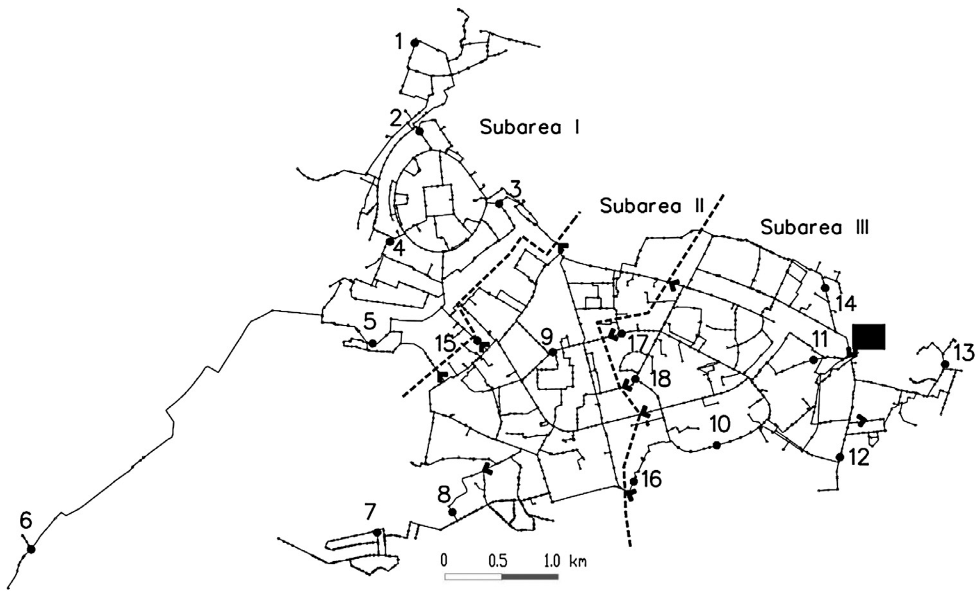

Fig. 1. Location of measurements in the WDS (bold circles present points of pressure measurements, bold arrows – water flow measurements, black rectangle – water source, dashed lines – boundaries of subareas).

are cast iron pipes. WDS contains also plastic pipes and very small proportion of steel pipes. Table 1 gives the summary of main pipes construction times and materials.

Water pressures have been measured in 18 points and water flow in 13 points. Locations are shown in Fig. 1. Fig. 1 contains 11 water flow measurement points because 3 points located at pumping station overlap each other. Water flow and pressure were measured also at pumping station that is supplying the WDS. Pressures were measured by using sensors (CDL 1U, 2U) and portable data loggers of the "Sensus" company. Water flows were measured by common turbine and electromagnetic flow meters that have impulse output for using data. Measurement locations were chosen so, that it would be possible to divide the WDS into 3 subareas showed in Fig. 1 using information on the pipes closed. That enabled to evaluate total demand for each subarea. Average pressure and water flow were saved with time interval 15 min.

Calibration was performed in two different scenarios:

1 Calibration based only on pressure measurements.
2 Calibration based on pressure and water flow measurements.

2.2. Method of calibration

The calibration process attempts to adjust the model parameters in such a way that the field observations and the predicted results are in reasonable agreement. The optimisation method searches for a solution, which will try to minimize the objective function that describes the matching of the observed and modelled pressures and water flows. The objective function is usually given as [10]:

$$OF = \sum_{i=1}^{nh} w_H (H_i^o - H_i^p)^2 + \sum_{j=1}^{nq} w_Q (Q_j^o - Q_j^p)^2 \quad (1)$$

where

OF – objective function (sum of squares) to be minimised;
$H_i{}^o$ and $H_i{}^p$ – observed and predicted pressure head;
$Q_i{}^o$ and $Q_i{}^p$ - observed and predicted pipe flow;
w_H and w_Q - weighting factors;
nh and *nq* – number of pressure head and pipe flow observations.

Several approaches are proposed for estimation of weighting factors [11–13]. In current study, the calibration of roughness is accomplished using pressure measurements. Water flow measurements were used to verify calibration results and to correct modelled demands. Since the number of measurements is usually much smaller than the number of pipes and nodes, it is clear that we cannot calibrate each pipe separately. If a WDS contains pipes with different age, it will be reasonable to approximate the pipe roughness value by the functional dependence on age and try to find the parameters of the function [14]. This approach reduces our problem to search for a small number of parameters of this function. Sharp and Walski [15] showed that roughness height grows approximately linearly over time. Echávez [16] also notes that the dependence of roughness on age is usually approximated by linear increment with time

$$\varepsilon = \varepsilon_0 + \alpha^* t \quad (2)$$

where

ε_0 – roughness of the new pipe (mm);
t – age of the pipe (years).

Coefficient α is within the limits 0.061–2.13 mm/year depending on water quality, pipe material and other factors. Experiments [16] have also shown that the dependence of roughness on age may be nonlinear. Therefore Koppel and Vassiljev [14] proposed to use nonlinear dependence of ε on age of pipe

$$\varepsilon_i = \varepsilon_{\max} - (\varepsilon_{\max} - \varepsilon_{\min})[(t_{\max} - t_i)/(t_{\max} - t_{\min})]^b \quad (3)$$