University of Tabriz

Journal of Civil and Environmental Engineering
Volume 53 (2023), Issue 2 (Summer), 50-60

EXTENDED ABSTRACT

Probabilistic Zoning of Hydraulic Performance of Water Distribution Network by Applying Key Parameter Uncertainty

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Received: 03 February 2021**; Review:** 05 May 2021**; Accepted:** 04 July 2021

Keywords:
EPANET, Hydraulic performance, Kaleybar WDN, MATLAB, Monte carlo simulation, NPRI, Uncertainty.

1. Introduction

Generally, the modeling of the Water Distribution Networks (WDNs) is done by the conventional methods that cause the outputs of the network are normally deterministic value by assuming certain inputs and parameters. But, in real ones, there are many uncertainties in model parameters. which causes, the results obtained by the conventional methods may not be satisfactory in practice, Therefore, the variation of key parameters in WDNs such as pipe roughness and diameter and also nodal demand can change nodal pressure and pipe flow that affected the performance of the network. However, by understanding the parameter uncertainties and how the uncertainties affect the accuracy of the model, the decision-makers can make the best decision that can prevent the WDNs from the unreliable events.

2. Methodology

2.1. Hydraulic simulation

Generally, the pipe head loss and the continuity equation at each node are calculated by equations (1-2).

$$h_f = \frac{1.68LQ^{1.852}}{C_{HW}^{1.852}D^{4.87}} \quad (1)$$

$$\sum_{i=1}^{NPj}(Q_i) + q_j = 0 \quad (2)$$

Where h_f is the head loss in a pipe, L is the pipe length, Q is the pipe flow, C_{HW} is the Hazen Williams coefficient, D is the pipe diameter, NPi is the number of pipes connected to node i, q_j is the nodal demand at node i.

2.2. Parameter estimation

To calculate changes of the Hazen-Williams coefficient in each operational period for modeling the effects of aging in pipe capacity in the distribution network, the equation proposed by Sharp and Walski (1988) is used:

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$$C_{HW}(i,t) = 18 - 37.2 log \left(\frac{(e_{0i} + a_i(t + g_i)}{D_i}\right) \quad (3)$$

where, $C_{HW}(i,t)$: is the Hazen-Williams coefficient of pipe i at year t, e_{0i}: initial roughness in pipe p at the time of installation when it was new, a_i: is the roughness growth rate in pipe i, g_i: is the age of pipe i at the present time (year); t = is the elapsed annual time (year), D_i: is the diameter of pipe i, Np: is the total number of existing pipes in the network and T: is the operational time period. The demand changes in the network are considered based on a geometrical growth equation during the operational period (Taebi and Chamani 2005):

$$q(j,t) = q(j,0)\text{Exp}\ (K_g\ t), \quad (4)$$

Where $q(j,t)$ is the nodal demand in node j at year t, $q(j,0)$ is the nodal demand in node j at year zero, K_g is the geometrical growth rate of demand during the time. Also to calculate the pipe diameter uncertainty, first, it was assumed that a little portion of the inner diameter of the pipe would be blocked during the operation period due to sedimentation and other factors. Therefore, the risk of occurrence during time t is obtained from the equation (5) (Salas and Obeysekera, 2014):

$$R(t) = 1 - (1 - 1/T)^{(t)} \quad (5)$$

Then the opened portion of the inner diameter of the pipes at year t can be calculated by equation (6):

$$D(i,t) = D(i,0) - r_D D(i,0)R(t) \quad (6)$$

Where $D(i,t)$ is the diameter of pipe i at year t, $D(i,0)$ is the diameter of pipe i at year 0, r_D is the rate of the inner diameter of the pipe would be blocked during operation period.

2.3. Network reliability

To evaluate the effect of parameters uncertainty in the hydraulic performance of WDNs during its operational Period, Nodal pressure Reliability Index (NPRI) is used (Dini and Tabesh, 2017, 2019).

$$\text{NPRI}(j,t) = \begin{cases} 0 & P_{j,t} < 10 \\ \frac{1}{32}(P_{j,t} - 10) & 10 < P_{j,t} < 26 \\ \frac{1}{10}(P_{j,t} - 26) + 0.5 & 26 < P_{j,t} < 31 \\ 1 & \text{P} = 31 \\ -\frac{1}{38}(P_{j,t} - 31) + 1 & 31 < P_{j,t} < 50 \\ -\frac{1}{40}(P_{j,t} - 50) + 0.5 & 50 < P_{j,t} < 60 \\ 0.25 & 60 < \text{P} \end{cases} \quad (7)$$

$$NPRI = \frac{\sum_{j=1}^{NN} Q_{j.t}^{req}(NPRI\ (j.t))}{\sum_{j=1}^{NN} Q_{j.t}^{req}} \quad (8)$$

Where; $P_{j,t}$ is the nodal pressure in node j at time t, $\text{NPRI}(j,t)$ *is the* pressure reliability index of node j at time t, $NPRI$ is the network reliability index, NN is the number of nodes, Q^{req} is the required demand in node j at time t.

2.4. Probability function

In the Normal PDF, mean and standard deviation of parameters have defined for normal PDF and then the probabilistic variable x, is calculated by equation (9) (Seifollahi-Aghmiuni et. al., 2013):

$$F_x(x) = \frac{1}{\sigma_x\sqrt{2\pi}} exp\left[-\frac{1}{2}\left(\frac{x - \mu_x}{\sigma_x}\right)^2\right] \quad (9)$$

Where μ_x is the mean of variable x, σ_x is the standard deviation of variable x, and $F_x(x)$ is the probability density function of variable x. The coefficient of variation (CV) is the ratio of the standard deviation of an uncertain variable to its mean, is used to evaluate the effects of uncertainty during the operational period. In this study two mode of CV with value of 10 and 20 percent is considered for evaluation of the uncertainty of the parameters.

2.5. Procedure summary

Fig. 1. shows all the steps in the processing of uncertainty, proposed in this study.

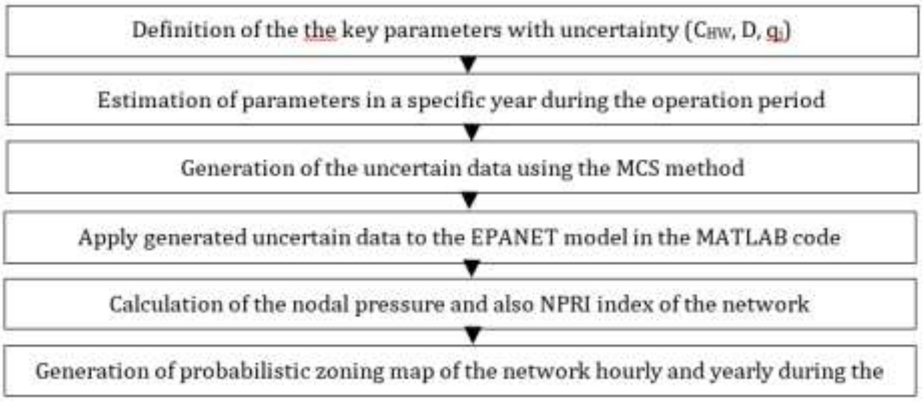

Fig. 1. Procedure summary

3. Results and discussion

In this section, the probabilistic performance zoning map of the Kaleybar WDN based on the NPRI index is done hourly all day long and yearly in the operational period, but, the yearly results are presented. In Figures 2 and 3 the probabilistic performance zoning map of the network is shown over the operational period with CV values of 10 and 20 percent. Comparison of the results for Figures 2 and 3 shows that the service levels of the Kaleybar network initially increases from the first year to midlife and then decrease to the end year in its operational period. However, there is a difference in the years with the highest probability of acceptable service for the two modes. While it happens for the CV value of 10 percent in the 23rd year and for the CV value of 20 percent in the 20th year. This is due to the effect of the uncertainty of the parameters, which shows that with increasing the uncertainty of the parameters, the best acceptable service life of the network can be decreased in its operational period.

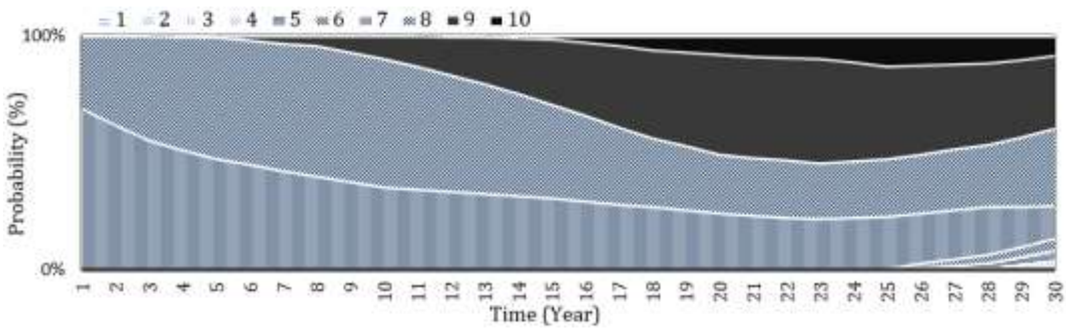

Fig. 2. Probabilistic performance zoning map of the network during the operation period (CV=10%)

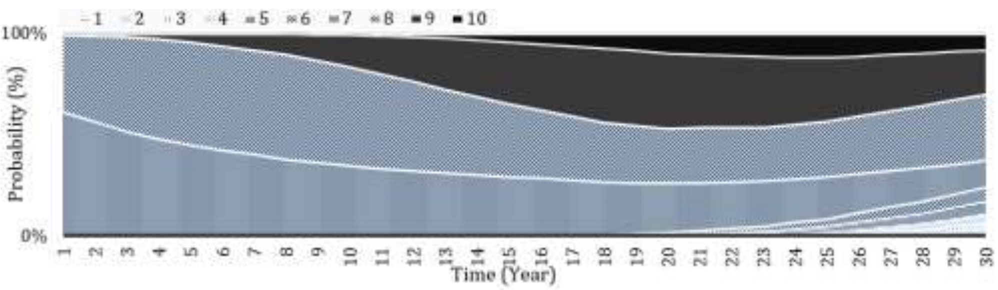

Fig. 3. Probabilistic performance zoning map of the network during the operation period (CV=20%)

4. Conclusions

In this paper, first, the uncertainty of key input parameters such as pipe diameter and roughness and also nodal demand was generated and then they were simultaneously applied to the model, and the hydraulic performance (NPRI index) of the network was evaluated. By defining network performance levels based on network reliability, probabilistic zoning maps were obtained hourly all day long and yearly in the operational period. For this purpose, the MCS method was used to simulate the parameter uncertainty, and the EPANET software was used to simulate the hydraulic performance of the network by programming in MATLAB. The study was performed on the Kaleybar WDN using different values of the Coefficient of Variation (CV). The results of yearly probabilistic zoning maps of the network showed that in the cases with a CV value of 10 and 20 percent, the network had an acceptable service level with a higher probability in the 23rd and 20th years respectively. In general, the study of hydraulic zoning maps of the network at different hours during a day and in different years during the operation period makes it possible to decide on the implementation of operational plans or reconstruction and renovation and also determine the critical operational years.

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