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IWA World Water Congress & Exhibition
11-15 SEPTEMBER 2022 | COPENHAGEN, DENMARK | www.worldwatercongress.org

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Abstract: Norway's water utilities lose on average 30 % of valuable drinking water through leaks. Many municipalities are transitioning from a passive to an active leak control strategy to reduce these unnecessary losses by utilizing model-based leak localization approaches. These model-based methods find leaks by combining sensor data with hydraulic computer models. Initial results obtained from virtual data show that the Dual Model gives good results even with errors introduced in the model, which is a significant advantage for water utilities dealing with uncertainty. This paper aims to display the possibility of reducing the leak localization time using the recently developed Dual Model and test the model for the first time on actual measurement data.

Keywords: Drinking water leakages; model-based leak localization; pressure sensitivity

Introduction

On average 30 % of treated drinking water is lost prior to reaching the customer, but some municipalities struggle even more, with distribution losses as high as 60 % (RIF, 2021). The large water losses in Norway cause economic, and environmental consequences in contrast to the sustainability goals of the utilities, and the reason why Norwegian water utilities implement leak detection and localization strategies.

Leak strategies can be differentiated into two main categories, passive, and active leakage control. In the passive approach leaks are only fixed after they are reported by the public (Puust et al., 2010). Contrary, active leakage control aims to reduce water losses through pressure management (Vicente et al., 2016), or through examining the network at regular intervals. Consequently, the active approach results in lower water losses and is, therefore, the preferred method (Farley and Trow, 2003). However, all current active methods are either time-consuming, expensive, or inefficient (Puust et al., 2010).

Model-based approaches try to circumvent these shortcomings in finding leaks by comparing measurement data with estimates obtained from hydraulic models (Perez, 2011, Hu et al., 2021). The main advantages of the model-based approach are that they are low in cost, simple to apply, and perform well regardless of pipe material (Li et al., 2015). The main drawback of model-based approaches is that they require a lot of data to develop a well calibrated model. In this work, we apply a recently developed dual modelling approach by overcoming the drawbacks of model-based approaches (Steffelbauer et al, 2022) to a real-world case study. It will be investigated if the Dual Model can maintain its promising results from the artificial case studies in the past.

Methodology

The Dual Model is created by adding a virtual reservoir and a valve to actual pressure measurement nodes, as shown in Figure 1. The head of the reservoir node is set to be equal to the measured pressure plus the elevation of the node. When a new leak occurs, the flow towards the leakage increases, which creates a pressure drop in the system. The pressure difference between the leak-free model and the measured pressure causes flows to/from the virtual reservoir since the Dual Model tries to restore equilibrium conditions. The discharge serves as an amplifier of the leak signal and can be used as a first indication of the leak's location and size. The advantages of the Dual Model are higher sensitivities compared to other models (Steffelbauer et al., 2020) and that the leak and the system imbalances have the same unit of flow (Steffelbauer et al., 2022).

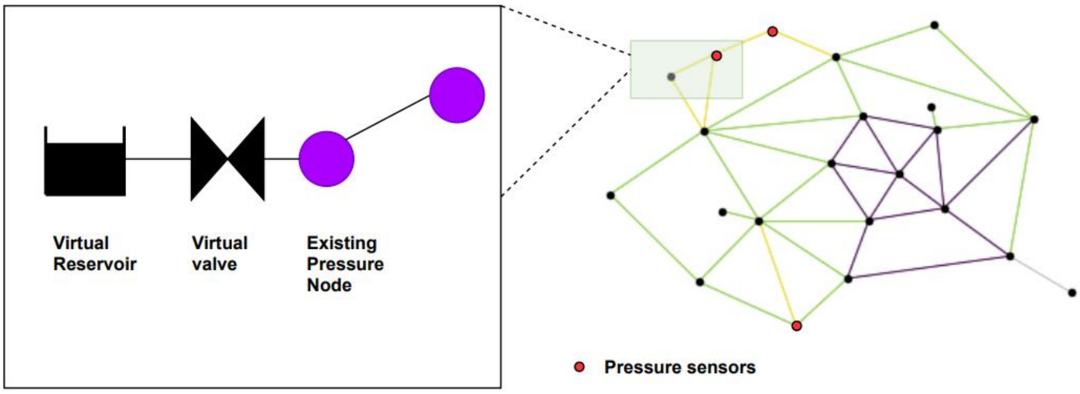

Figure 1: Dual Model principle. Pressure sensors marked in red.

To evaluate the leak localization performance several different parameters are used:

1. The topological distance between the actual leak and the pipe with the highest correlation (D_T).
2. The fraction of false-positive links (FP_f).
3. The maximum distance between two FP-links measured along the shortest pipeline (MD_{FP}).

Results and Discussion

As a first step before applying the Dual Model to the real-world case study, its performance on varying roughness coefficients was investigated. The Dual Model showed to be robust to errors in roughness (see Table 1). These results are highly promising for the applicability of the model to a real-world system with unknown roughness.

Table 1 Leak localization performance with varying Hazen-Williams roughness coefficients in the model compared to the known roughness coefficient. The known roughness coefficients range from 70 to 130 for different pipes. A roughness error of -5 indicates that all pipes in the model are given a lower roughness value than the actual roughness, i.e., 115 instead of 120. A roughness error of ±2 randomizes the roughness change for each individual pipe.

Leak size (L/s):		Model: 50	Measured leak: 10				
Roughness error	-5, -2	0, 2, 5	±2, ±5	10	20	-20	-40
D_T [m]	3200	183	183	183	183	183	107
FP_f [%]	80.0	2.5	12.5	12.5	12.5	12.5	17.5
MD_{fp} [m]	3658	0	2210	2210	2210	2210	3658

Table 2 shows that the Dual Model obtains the best results when the modelled leak and the measured leak are of similar magnitudes. The FP-fraction and maximum span increases for smaller leaks, but the model performance does not significantly deteriorate.

Table 2 Leak localization performance with varying leak outflows. The model leak outflow is constant for each simulation at 50 L/s

Roughness model:		True roughness coefficient + 2.0				
Leak size (L/s)	402	50	10	5	1	0.5
D_T [m]	3200	183	183	183	183	183
FP_f [%]	80.0	2.5	12.5	12.5	12.5	12.5
MD_{fp} [m]	3658	0	2210	2210	2210	2210

Four different leak locations were tested to see how the leak location affected model performance (see Figure 2). The results obtained with the Dual Model give FP-ratios between 12.5% and 27.5% for all leakages except for pipe 72, where the FP-ratio is as high as 95% (see Table 3). It was possible to significantly improve these results by placing the sensors in an optimal way (Steffelbauer et al., 2016).

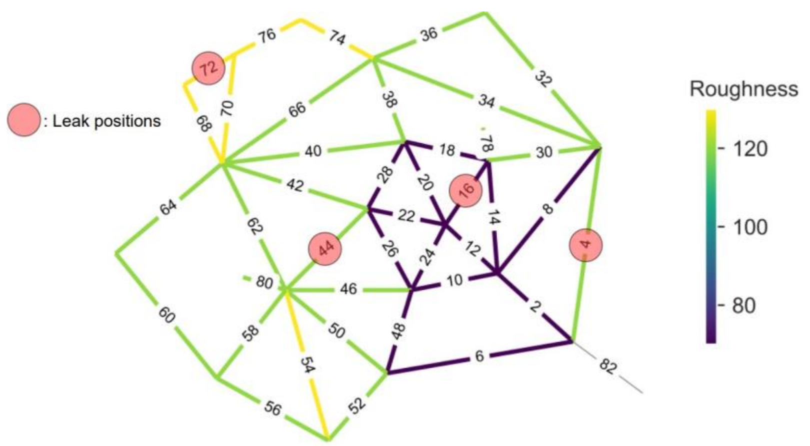

Figure 2: Leak positions

Table 3: Performance at different leak positions

Roughness model:	True roughness coefficient + 2.0			
Leak size (L/s)	Model: 50	Measured: 10		
Pipe with leak	16	4	72	44
D_T [m]	107	2103	3200	548
FP_f [%]	12.5	27.5	95.0	20.0
MD_{fp} [m]	2210	3200	4200	2210

Conclusion

Model-based approaches enable water utilities to transition to active leakage control, by introducing real-time system monitoring, while exploiting rapid digitization and increased computational power. The most important finding for applying a dual modelling approach, which inherently connects measurements and hydraulic models, is the ability to give good leak localization results even under modelling errors (i.e., pipe roughnesses, leak magnitudes). The main limitation of the results presented in this paper is that they are obtained from simulations on an artificial network. Therefore, the Dual Model will be tested on actual measurement data in further work.

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