Optimal pressure management in water distribution systems for the reduction of water losses and leaks by means of a predictive real-time control model

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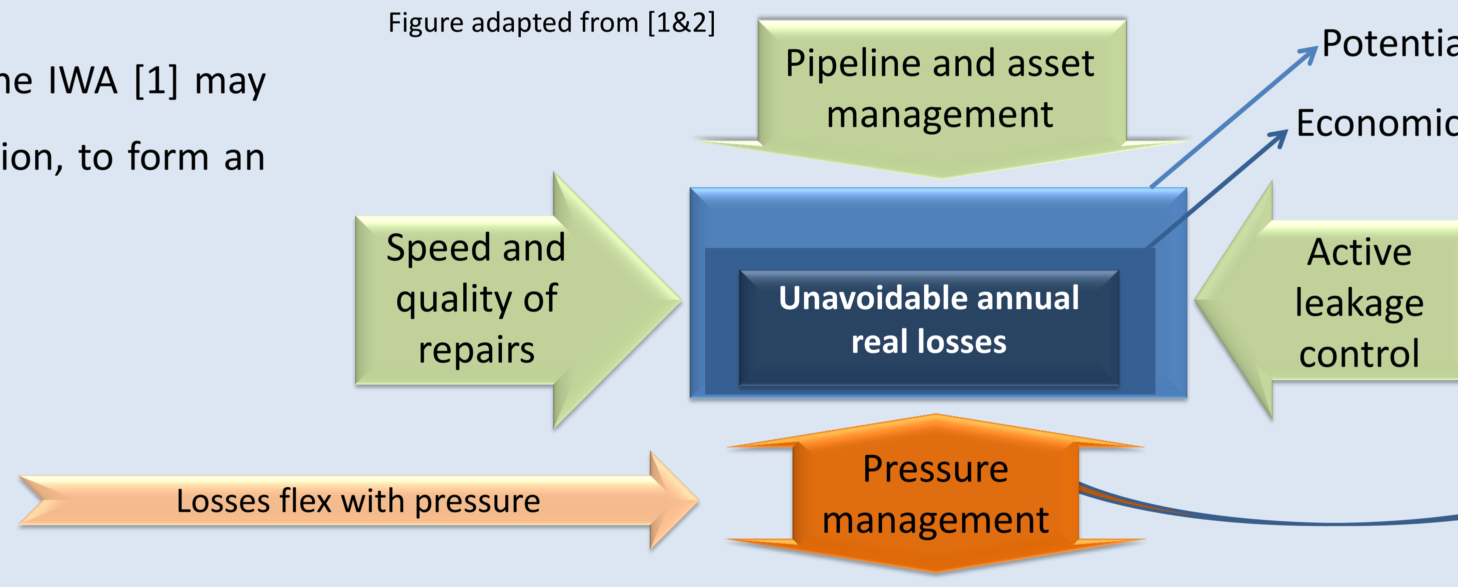
Introduction

The intervention methods proposed by the IWA [1] may be considered individually or in combination, to form an intervention program against real losses.

"Pressure management" is one of the most effective and interesting solutions to reduce water losses in water distribution systems (WDSs).

Figure adapted from [1&2]



Proposed model : Develop a Predictive Real-Time Model (PRTM) to control pressure in WDSs.

Objective: Continuously adjusting the PRV settings at the entrances of the district metered areas, while respecting various operational constraints, under demand fluctuations.

Methodology

Main steps of the model:

1. Forecast the water demand.
2. Optimize the PRVs setpoints for an ideal pressure control.
3. Evaluate the performance of the control solution.

Aim of the model : Maintaining the system pressure near the required minimum pressure to avoid excess.

Figure 1. Design of the Predictive Real-Time Control Model

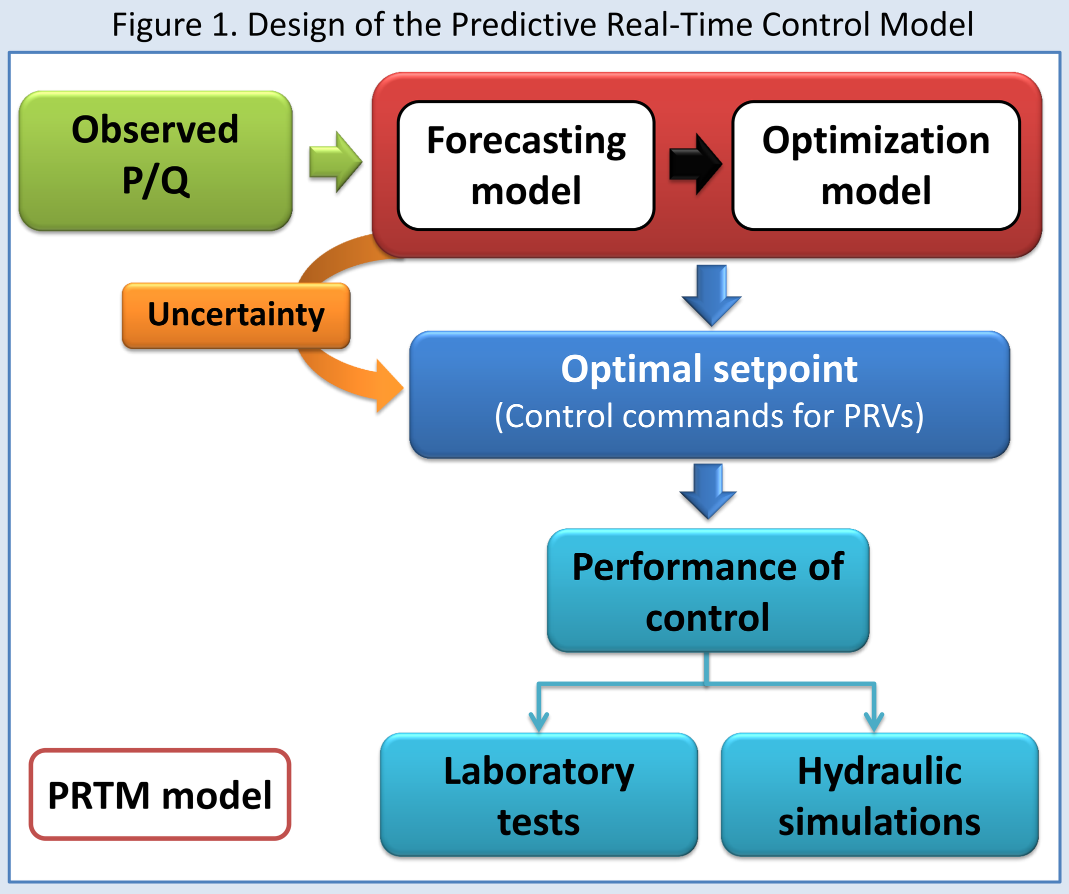
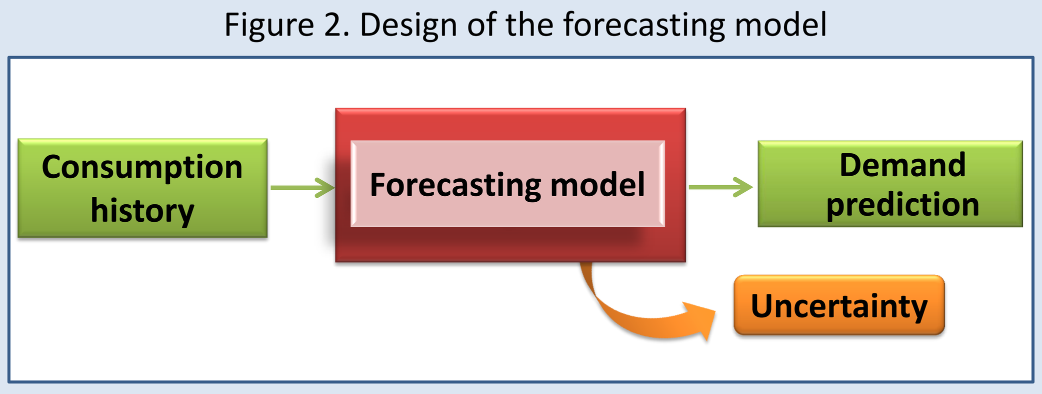


Figure 2. Design of the forecasting model



The forecasting model generates a 15min time-step prediction (short-term) and its uncertainty.

The considered models are : ARIMA models, Spline regression models and a hybrid model (FAFM) based on calendar day [3].

The objective function to minimize is :

$$f(p_i)_t = \sum_{i=1}^{N} \left[\left(P_{cal,i,t} - P_{min} \right)^2 \right]_t$$

with:

- N : number of critical nodes;
- P_{min} : minimum pressure required;
- P_{cal} : pressure calculated by the hydraulic model;
- t : time-step.

Figure 3. Design of the optimization model

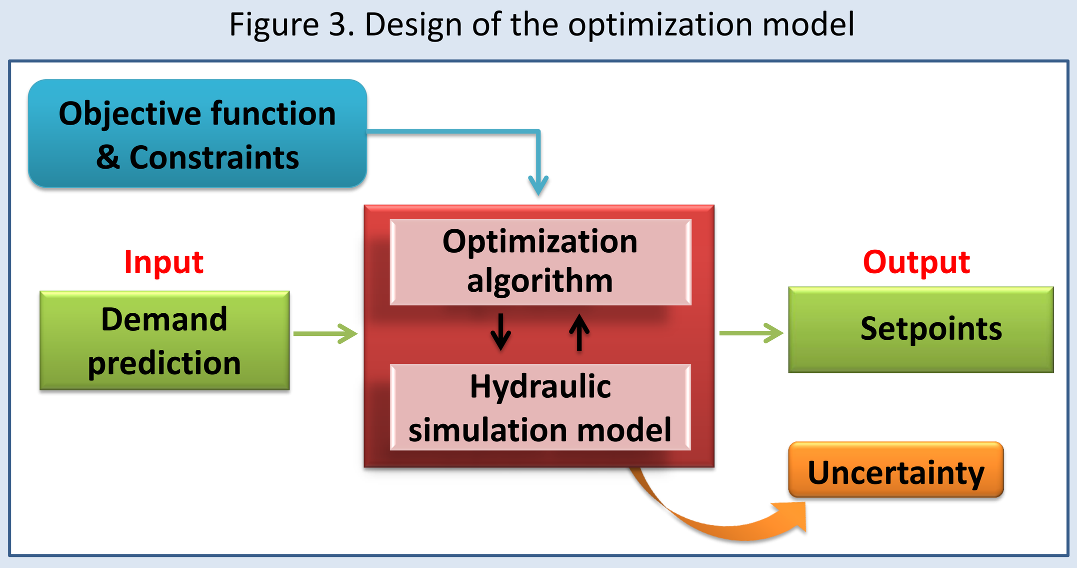
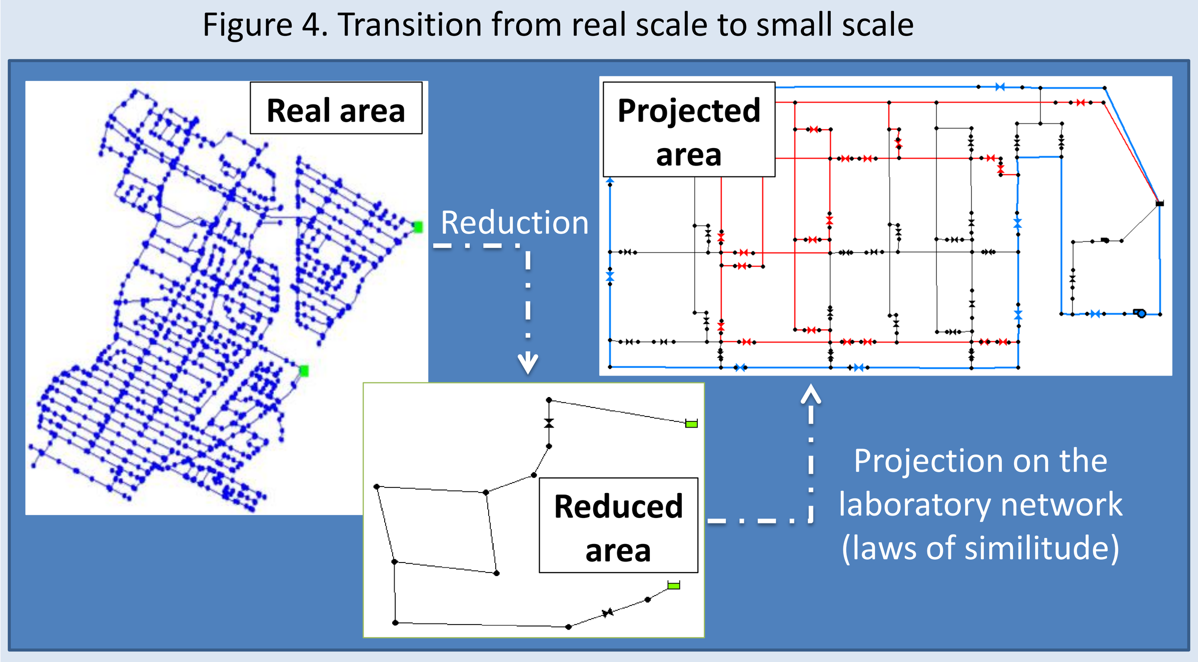


Figure 4. Transition from real scale to small scale



Experimental protocol:

1. Reduction of the real WDS and projection into the laboratory network.
2. Launch predefined scenarios control and start experimenting.
3. Monitor the real-time system behavior.
4. Analyze the parameters of interest.

Laboratory tests

Functions :

- Reproduction at a small scale of a real municipal WDS.
- Testing optimized real-time control commands.
- Operational validation of PRV control commands.

Figure 5. Laboratory tests in INRS

Results

Forecasting model

Characteristics of the dataset used :

- Source : city in the province of Quebec
- 5 years of data (from 2009 to 2013)
- 15 min records
- Total average consumption : 1.31 10^4 m^3/day
- Standard deviation : 5.43 10^3 m^3/day
- Average consumption per capita : 560 l/day

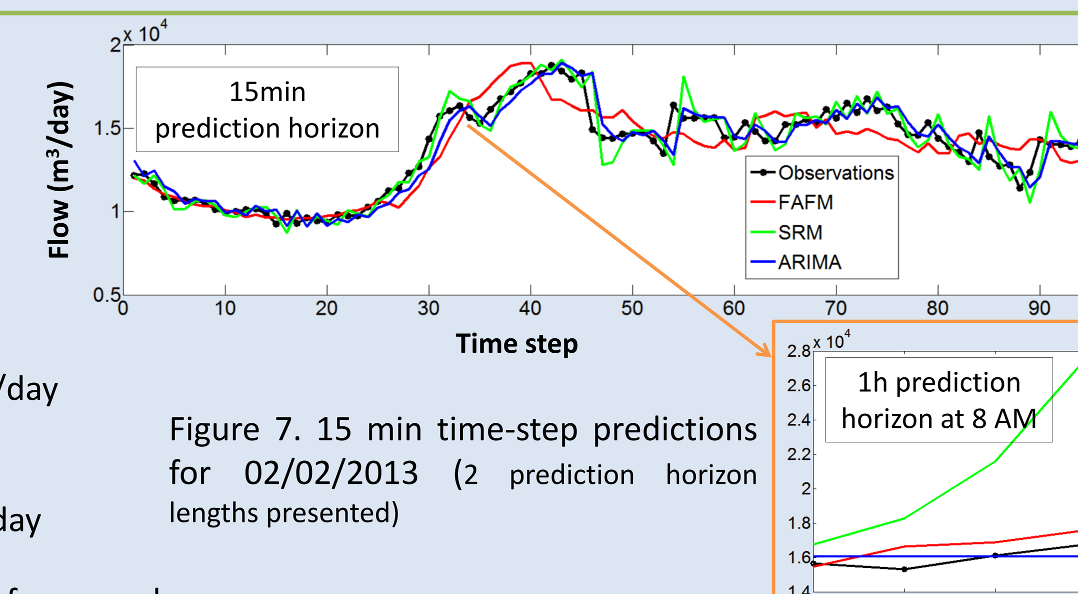


Figure 7. 15 min time-step predictions for 02/02/2013 (2 prediction horizon lengths presented)

Table 1. Forecasting model's performance for several prediction horizon lengths (Relative Root Mean Square Error)

Horizons	FAFM	SRM	ARIMA
15 min	13.2 %	10.2 %	**7.9 %**
1 hour	**13.3 %**	74.7 %	**14.5 %**
6 hour	**13.4 %**	> 100 %	34.9 %
1 day	**13.6 %**	> 100 %	35.2 %

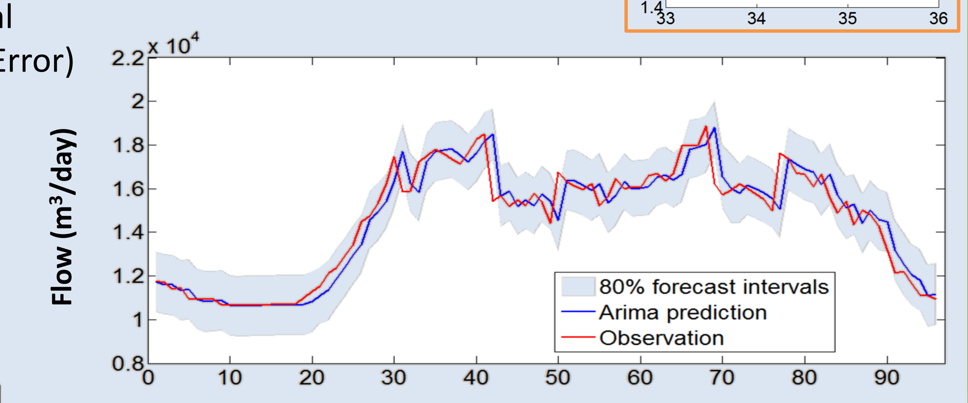


Figure 8. ARIMA model : 1 day prediction (from 12 AM to 11:45 PM) with 15 min time-step

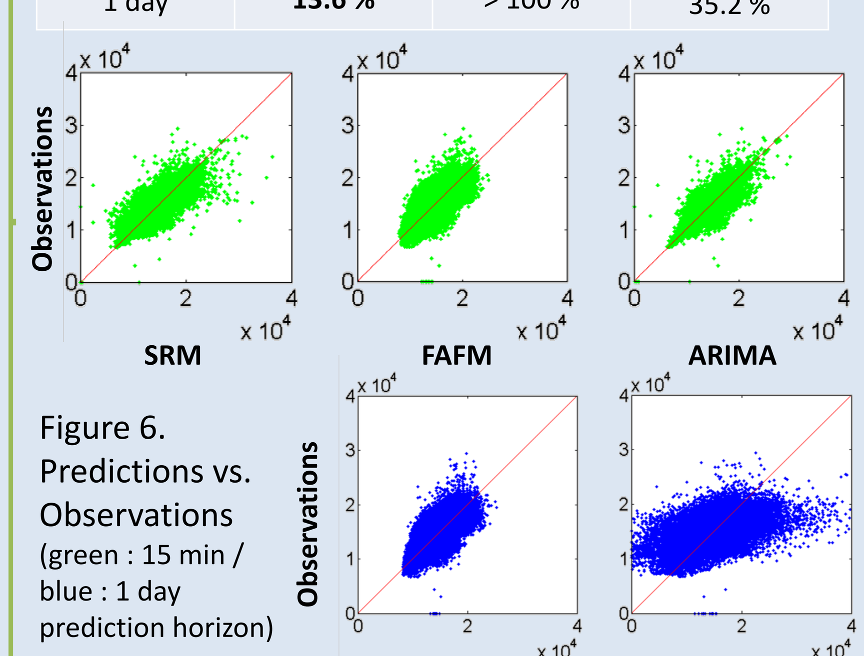


Figure 6. Predictions vs. Observations (green : 15 min / blue : 1 day prediction horizon)

Laboratory

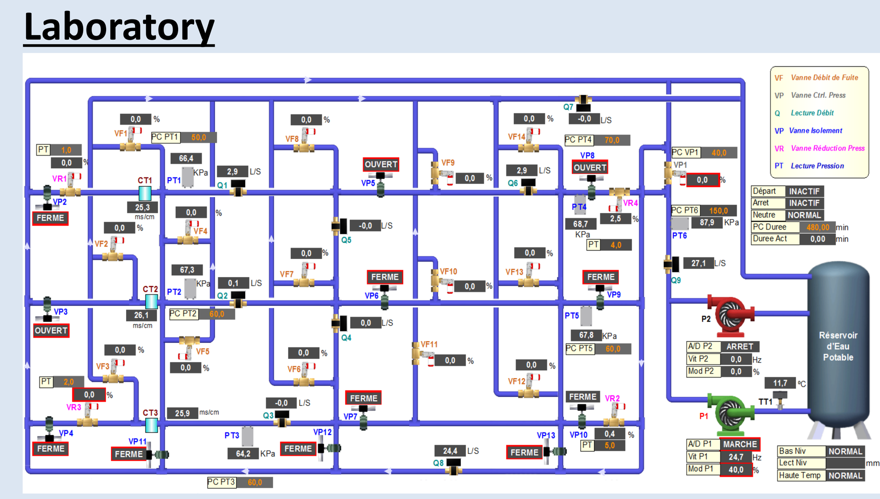


Figure 9. Laboratory monitoring station

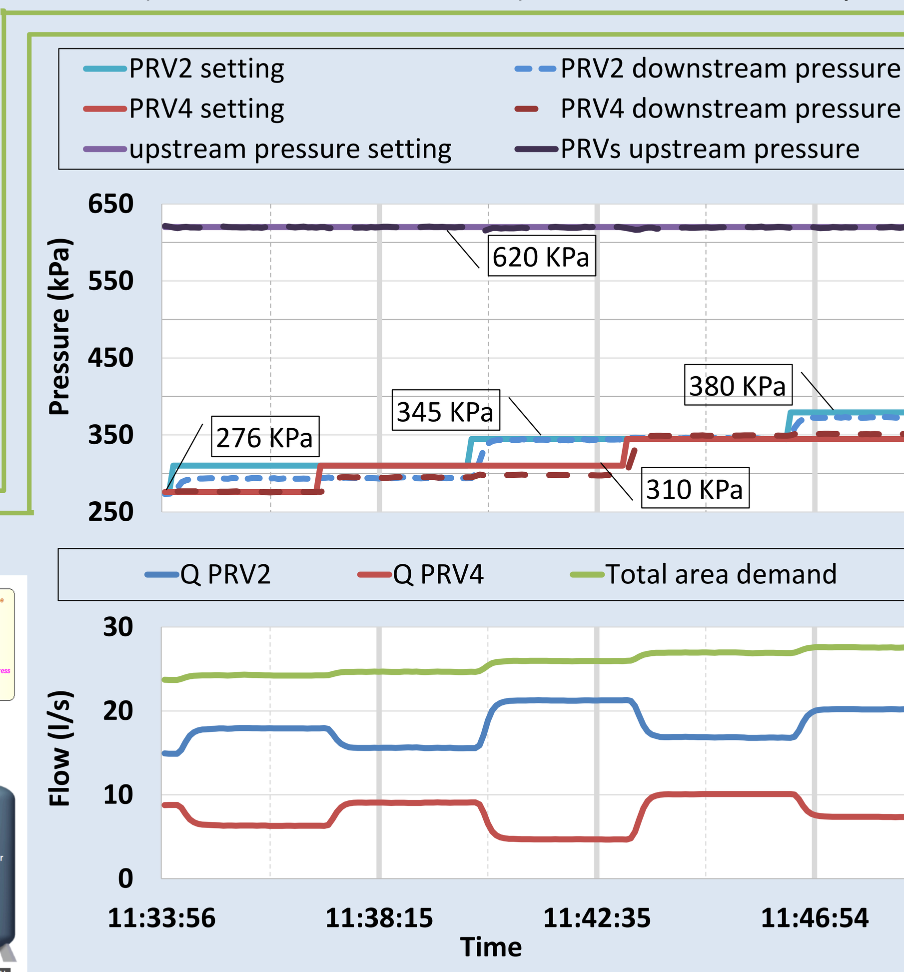


Figure 10. Impact of the variation of the PRVs setpoints on P&Q in the projected area

Summary

To ensure an optimal management of WDSs, in order to extend the life of underground infrastructure and to reduce the costs of intervention for the repair and maintenance of the networks, a PRTM is proposed. The proposed model lies on : 1) the capacity of real-time monitoring; 2) the inclusion of short-term demand forecasts to define control commands; 3) the integration of uncertainties and the assessment of their impact on the performance of the defined control. For validation of the PRTM, hydraulic simulations and laboratory tests are realized based on a consistent database (real and fictive WDSs, water consumption records, etc.). The model is currently under development.

References

[1] American Water Works Association (2008) *Water Audits and Loss Control Programs: M36* (Vol. 36). American Water Works Association (AWWA).

[2] Thornton J, Sturm R & Kunkel G (2008) *Water Loss Control.* McGraw-Hill, Toronto, Canada.

[3] Bakker M, Vreeburg JHG, van Schagen KM & Rietveld LC (2013) A fully adaptive forecasting model for short-term drinking water demand. *Environmental Modelling & Software* 48: 141-151.

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