Towards intrinsically smart drinking water networks

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The concept of smart drinking water networks has gained ground over the past ten years. This not only involves the installation of smart sensors and algorithms, but also a smart design of the drinking water and measurement networks.

Smart networks are drinking water networks equipped with sensors, which allow a water company to better control the network in terms of quantity (flow, pressure), the condition of the pipes (strain gauges), or for example remotely controlled valves. The term may also refer to the use of algorithms to identify failures (such as pipe breaks) or for advanced process control.

All this can be considered as adding a nervous system to the body of the infrastructure. It enables water companies to make 'smarter' use of the networks, but it does not really make the networks themselves smarter.

In this article we present the concept of 'intrinsically smart networks': a design based on smart design philosophies and a smart use of materials.

Smart design philosophies

Self-cleaning networks

The drinking water network is subdivided into functional groups: the primary part (transmission network), the secondary part (distribution up to neighborhood level) and the tertiary network (distribution to customers). Since the early 2000s, the tertiary network in the Netherlands has been constructed in such a way that the risk of water discoloration is minimal and no cleaning is required. Discoloration is generated when particles accumulated in the pipeline network are resuspended at a suddenly higher flow velocity. Discolored water is harmless but leads to dissatisfied customers. Such an accumulation of particles can be prevented by generating a high flow velocity once a day. This requires a tertiary network with pipes of non-corrosive material and with a small diameter; moreover, one-way flow is required and no dead ends may occur in the last tens of meters. Such a branched network design, to be realized with a tool like DiVerDi, is about 20 percent shorter and therefore cheaper.

Climate-proof networks
The drinking water temperature is largely determined by the temperature of the soil surrounding the pipes of the secondary and tertiary network. Due to climate change and increasing urbanization, the temperature of the tap water will more often exceed 25 °C, with negative consequences for the biological quality of the drinking water (figure 1). This can be prevented with a climate-proof design: keep pipes away from district heating pipes and electricity cables, install 20 centimeters deeper, and/or put pipes, wherever possible, on the shady side of the street or under grass (cooling because the grass evaporates soil moisture).

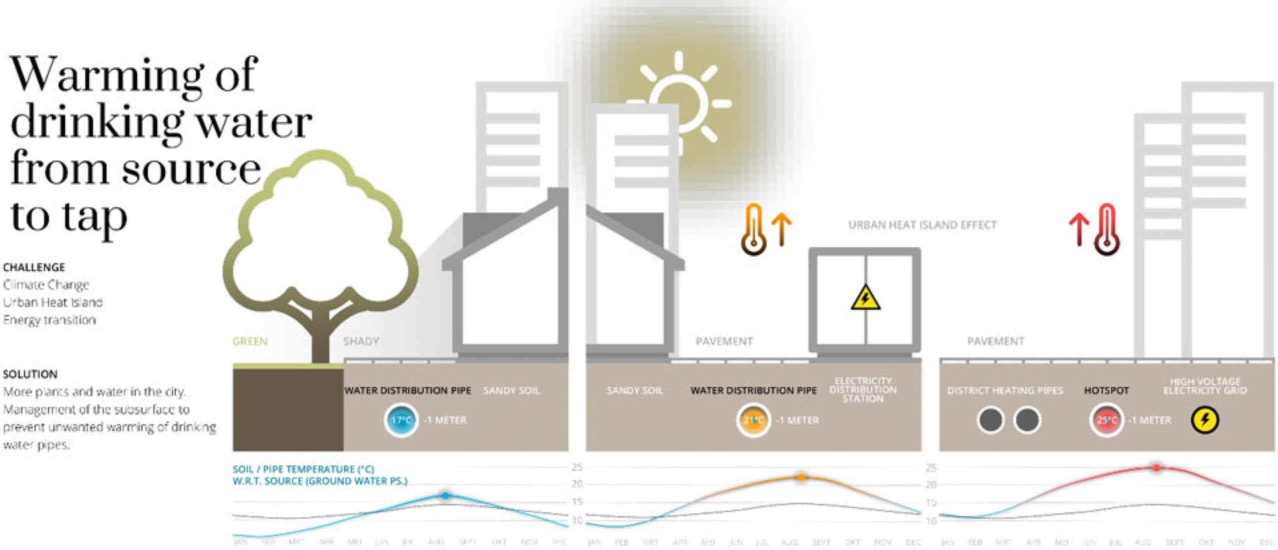

Figure 1: Drinking water heating from source to tap: influence of weather and urbanisation, including anthropogenic heat sources in the subsurface. From Agudelo-Vera (2018).

Numerical techniques for smart network design

Pipe diameters
Drinking water networks are normally designed with hydraulic modelling software. However, the number of possible designs is so large that it is practically impossible to examine even a small number of the possible well-functioning configurations. Numerical optimization techniques, as implemented in Gondwana, generate designs that meet all requirements and perform optimally on user-defined criteria. A water utility wants to install a pipeline network as cheaply as possible and at the same time meet the requirements for pressure and, for example, water quality on all connections (see figure 2a). Since networks have to last for decades, it is important to think about the future water demand.

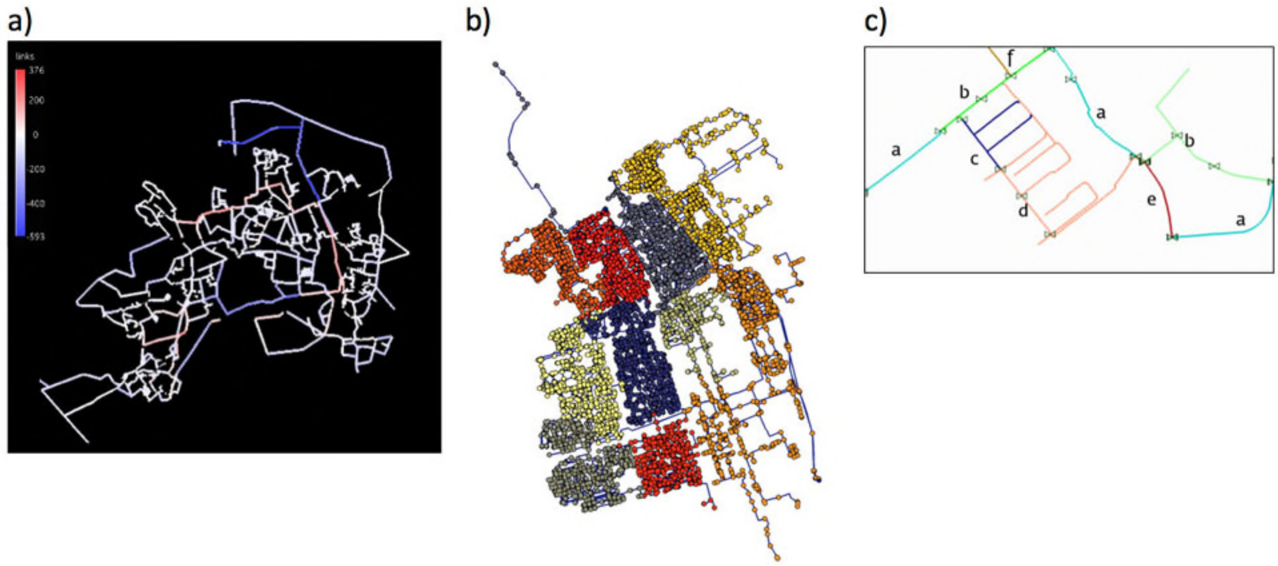

Figure 2. Examples of numerical optimization of different aspects of drinking water networks. a) optimization of pipe sizing - colors indicate changes in diameter compared to the current situation (from Vertommen et al 2018); b) optimal subdivision of a network into DMAs for anomaly detection (from van Laarhoven et al 2017); c) optimal order of replacement of the pipes (from Vertommen et al 2018).

Conversion of an existing network

Once a desired network layout is generated, the question arises as to what the best path is to realize this layout. The key question is: what is the best order to replace pipes? Objectives such as minimizing inconvenience to the customer or a faster improvement in system performance can be leading. This is another optimization problem that can be addressed with a tool like Gondwana (see Figure 2c for an example).

Valve placement

In the design of the secondary network, well considered valve placement is essential. Valves are necessary to isolate parts of the network during work to minimize the number of customers affected. Currently, a network is usually designed without valves, which are added to the plan afterwards. This is not ideal. Valves sometimes do not work properly or are even impossible to find, which means that sometimes more customers are affected than necessary. An optimal location choice of the valves (with a minimum number of valves per isolation section and without dependent sections) is necessary to guarantee maximum reliability. Tools such as CAVLAR help assess a design at this point.

Philosophies and numerical techniques for smart 'nervous systems'

Network design with smart meters and sensors

The main advantage of smart water meters for customers is that they provide detailed knowledge about where and when the water demand is high or low. By installing pressure or water quality sensors and processing their data in a model, the knowledge can increase further.

Water quality sensors (generic or specific) are becoming increasingly available. However, water distribution systems are so complex that even hydraulic experts have difficulty identifying optimal locations for water quality sensors. Nonetheless, good sensor networks can be designed using numerical optimization techniques, included in software tools such as TEVA-SPOT and Contamination Source Toolkit.

The interpretation of the large volumes of measurement data requires a good understanding of the system. A smart design of the pipe network including sensor network can greatly improve the interpretability of these 'big data'.

DMA design

DMAs or district metered areas are parts of the distribution network that are isolated from the rest by flow meters and/or closed boundary valves. This makes it possible to calculate a water balance for such a DMA, which contributes to the most common purpose of DMAs: leak detection. The design of DMAs may be trivial for simple network structures, but for open and meshed networks the subdivision into DMAs may be less obvious. Here too, numerical optimization techniques can be applied. The objective is to determine the locations for flow meters in such a way that the required number of meters is minimal at a desired detection limit for e.g. leakages. Figure 2b shows an example (for more details see the article by Van Laarhoven and Gardien elsewhere in this edition of Water Matters).

From dumb to smart networks

With these philosophies and tools, the design and construction of a real, intrinsically smart network is within reach. This applies in the first place to new infrastructure, to be built without the burden of history. But also existing infrastructure can be made intrinsically smarter. This requires the following steps:

1. defining objectives and boundary conditions;
2. collecting accurate and up-to-date information about the existing pipe network and its use;
3. determining possible future scenarios for the spatial and demographic development of the area and water consumption;
4. optimizing the design of the network and/or configuration of DMAs / valves / sensors;
5. optimizing the transition to this optimal design;
6. realizing the design of step 4 using the transition of step 5;
7. developing decision models for autonomous functioning.

For the first two points, many water companies have already made a considerable effort, although additional steps remain necessary to successfully implement points 4 and 5 in particular. The third point remains a challenge. The last three steps have been developed in a research context, and have not yet been applied in practice.

Ultimately, we expect that the intrinsically smart grids approach will lead to a better performing water supply system with more control and knowledge for less money.

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Summary

The concept of 'smart drinking water networks' has gained ground over the past ten years. It is mainly sensors and algorithms that make a network smart in their use. By also taking a smart approach to the design of pipe and sensor networks, drinking water networks become 'intrinsically smart'. The move towards such 'intrinsically smart networks' should lead to a better water supply network with more control and knowledge for less money.

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