BTO *Executive Summary*

New approach produces network blueprints that are robust to alternative water demand scenarios

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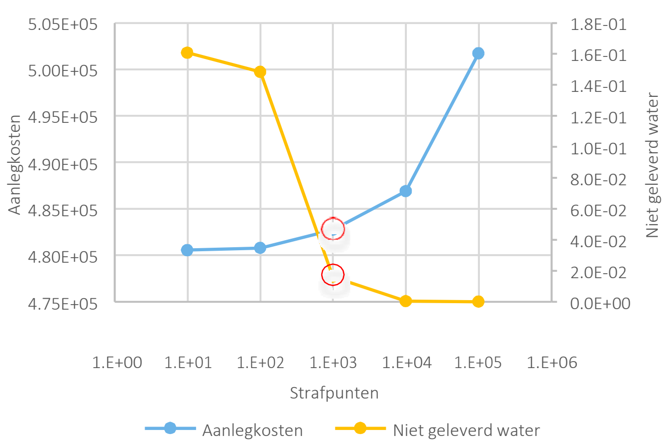
Water demand is an essential factor in the design of network blueprints. The current design process usually follows a deterministic approach. This produces a single design that satisfies the chosen water demand, but it can under-perform if the water demand turns out to be different. This research elaborated a new approach in which different water demand scenarios are taken into account in the design process. This provides insight in the trade-off between costs and performance of of different designs. The proposed approach allows designers to choose their desirable level of risk aversion, and the performance of the design can be assessed on the water demand effectively supplied under different scenarios. In this research the water demand scenarios were elaborated on the basis of historical water demand measurements and on future scenarios. These were used for the design of a network blueprint for a Dutch city. The results clearly show the relationship between the costs and performance under the different scenarios: a more robust design involves higher costs. The application of optimisation techniques helps finding better design solutions when compared to manual approaches. Thanks to the approach developed, drinking water utilities can make informed choices about how much to invest in a network blueprint and how to design it in order to achieve a certain level of robustness.



Left: relation between installation costs and total volume of non-delivered water for 13 future scenarios: the blue line shows the construction costs (€) for different penalty coefficients in the model; the orange line represents the associated volume of non-delivered water for all weighted future scenarios (m^3, during peak hour). Right: mains diameters for the network blueprint which refer to the design marked with a red circle in the figure on the left (installation costs 483 k€).

Interest: an ideal opportunity to install future-proof networks

Drinking water utilities are busy with the (proactive) replacement of their water distribution networks. This offers an ideal opportunity to improve these networks with an optimally designed, robust and future-proof network blueprint. The current design process does not take sufficient account of uncertainty in water demand, one of the greatest and most influential uncertainties in the design of distribution networks. In view of the long lifespan of these systems, it is extremely important that the newly-installed network be robust and future-proof: a network that can handle changes in water demand and continues performing as well as possible. This means that not one, but several water demand scenarios are taken into consideration in the design phase. Such an approach requires the calculation of several scenarios and designs: a task which quickly becomes unmanageable when done manually. It is here that numerical optimisation techniques offer a helping hand.

Approach: generate water demand scenarios and incorporate them in the design process

For the generation of water demand scenarios, a top-down approach was chosen that makes use of time series of water consumption, measured at a pumping station. The historical peak factors and associated probabilities were obtained in this way. The peak factors chosen were then attributed to all water-use nodes in the model. Moreover, future scenarios were also generated. To take account of the water demand scenarios and associated probabilities during the design of a network blueprint, a mean-variance optimisation problem was elaborated. This allowed for the optimisation of the design's costs and the performance (pressure and delivered water) over all the chosen scenarios. Taking the variance into account favours designs whose performance varies less between scenarios. The importance of this can be determined by the designer through the use of a variance factor: the higher the variance factor, the better designs will deal with uncertainty. The approach was implemented in the design of a network blueprint for a neighbourhood in a Dutch city. The calculations were carried out in *Gondwana.* Pressure-driven simulations were conducted in order to calculate the performance under the different scenarios.

Results: insight into the trade-off between costs and robustness

The results of this research show that it is possible to elaborate informed water demand scenarios based on the historical water demand. This also enables the attribution of probabilities to peak factors. This remains more difficult when it comes to future scenarios, and there is room for improvement in this area. In the case study, the trade-off between costs and the total (weighed) performance under the different water demand scenarios was made clear. This confirms that the more robust the design, the higher the costs of the design. The variance plays an important role: the designs perform better under the different scenarios when the variance factor is higher. The performance difference for the different scenarios is in this case also much smaller. This means that the designer is more certain about the design's performance, whatever the demand might be. Furthermore, the case study shows that the application of optimisation techniques leads to significant savings in design costs. When only the current peak water demand is taken into account, the optimised design for the case study is 33% less expensive than the currently installed distribution network, while still meeting the pressure requirement at all of the nodes. The security of supply and continuity have not (yet) been taken into account in this regard.

Implementation: first application of the approach in pilots

Drinking water utilities are advised to design their network blueprints for different water demand scenarios. To this end, they can apply the approach described here for the generation of water demand scenarios. These scenarios can be used to assess the performance of designs and, when necessary, adjust them by means of trial-and-error. The calculation of several scenarios is however a labour-intensive process, and this approach leads to a single design that to a certain degree satisfies the scenarios. The use of the mean-variance optimisation problem, and taking into account the probabilities of the scenarios during the course of the design process, requires the use of numerical methods. These are available in the *Gondwana* optimisation platform. For application in practice, it is first important to broadly implement the approach in pilot form at one or more drinking water utilities. This should take security and continuity of supply , and other utility-specific aspects, into consideration. Boundary conditions along with any possible problem areas for application of the method in practice can also be identified in this way.

Report

This research is described in the report *Optimaal ontwerp van robuuste en toekomstbestendige streefstructuren* (BTO 2020.002).

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