KWR | March 2014

How future proof is our drinking water infrastructure?

Hydraulic stress test for drinking water distribution systems

KWR Watercycle Research Institute

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Summary

The drinking water distribution system (DWDS) is a critical infrastructure and a costly asset with a life time of several decades. With rapidly changing urban environments and increasing technological innovation, drinking water demand is likely to change in the coming decades. However, quantifying these changes involves large uncertainties. In this study we developed a methodology to analyse the robustness of the DWDS to deal with a wide range of future demands. We developed a stress test to investigate the effects of a set of demand scenarios on the network performance. In a first stage ten scenarios considering technological and demographic changes were applied. We tested this approach with 4 networks. For each scenario, ten diurnal patterns with a 5 minute time interval were simulated for each connection with the stochastic end-use model SIMDEUM®. The consequences in the networks were quantified using four indicators: 1) daily water demand, 2) daily peak demand, 3) head losses and 4) residence time. This study shows that the consequences for head losses and water quality cannot be generalized, although comparison of different networks provides an insight into the effect of a given scenario. These consequences have to be quantified per network due to variations in size (connections, length and volume), number of loops and demand.

In a second stage, a more in depth analysis comparing the performance of a looped versus a branched design was performed, simulating 30 patterns per connection. The performance of the network was evaluated on three criteria: i) network pressure, ii) water quality and iii) continuity of supply. The results showed that the two network layouts are able to cope with rather extreme changes in demand, i.e. both are robust. The branched layout proved to be the most efficient alternative in terms of material use: diameters and length, manageability and controllability, and with better water quality conditions.

The proposed “stress-test” showed to be a robust methodology to investigate functionality of the system under a broad range of changing water demand scenarios. Results showed that even in the most extreme scenarios management and operation of the network can be adapted or adjusted to cope with head losses, low velocities or long residence times. However, special attention should be given to the limits for the appropriate functioning of DWDS. Further research is needed to determine the limits for each of the of the criteria allowed in DWDS. However, those limits will be only surpassed with scenarios which may take place in a time horizon longer than 25 years.

Contents

1 Introduction

1.1 Problem description

The future water demand is uncertain, since different factors, the so called, SEPTED dimension – Social, Economic, Political, Technological, Environmental, and Demographic - will have an influence on water use. In the Netherlands, different regions face different trends and therefore different challenges to operate drinking water infrastructure. Some areas face shrinking of cities, while other areas are concerned about the impact of technological changes in water appliances, e.g. vacuum toilets or luxurious showers heads. In the coming decades changes in life style, technology, etc., can influence the water demand patterns and therefore influence the functionality of the drinking water infrastructure. For this project specifically, Waternet was interested on the consequences of alternative sanitations systems, while WML interest focused on the flexibility of the network to cope with decreasing demand.

In this study we focus on the drinking water distribution systems (DWDS). DWDS represent a large percentage of the investments of the drinking water companies and the life time of the distribution networks is estimated in decades or even centuries. Compared with other components of the system, the network is much more difficult to adjust or change. The DWDS represents 80% of the total length of the network. In this 80% customers are connected and most of the residence time, water quality changes and pressure loss take place. The life cycle of treatment systems is much shorter and can be adjusted more easily to changes. Due to the changes in the DWDS are more difficult to realise, there is concern about the robustness of this system. The main question that arises is if the current DWDS will be able to cope with future changes in demand. Water companies need to know the robustness of the network to cope with future changes in demand. Water companies can decide whether they should adjust the operation of the system, influence the customers if there is a development that cannot be coped with, or if it is needed to modify the current infrastructure.

This project explored the robustness of the DWDS under changing future demand given the uncertainty of changes in water demand, we have developed a “stress test” to analyse the consequences of changing water demand on the drinking water distribution network, based on the scenario approach. In this study, instead of trying to design with uncertain parameters, the robustness of the DWDS was tested by determining changes in the performance of the DWDS under extreme loads.

1.2 Research steps

Within this project, a workshop on March 4th, 2013 was held to define the objective and methodology to assess the robustness of the DWDS. On July 1st, 2013, the preliminary results were presented and discussed. The final results were presented in a workshop “Drinking water infrastructure of the Future” on November 20th, 2013. The minutes of the workshops are included as appendix (in Dutch).

Three main steps were performed in the project:

1. Networks simulation of 3 existing networks and 1 theoretical branched network: 10 scenarios and 10 patterns per connection.

2. Comparison of looped and branched layout: 12 scenarios and 30 patterns per connection, including a Customer Minutes Lost (CML) analysis.
3. Analysis of speed of change of the residential drinking water.
4. Study of the drinking water temperature in domestic systems

Step 1 is reported in a conference paper (3 existing networks), step 2 in a scientific article and step 4 in a master thesis report. In this rapport, a summary of all the results is reported, as well as supportive information. The outcome of the project is:

- Stress-test methodology to determine network robustness (inclusive SIMDEUM codes for the SIMDEUM Pattern Generator (SPG) for the studied scenarios).

1.3 Approach

During the first workshop the approach was discussed. The conceptual model is described in Figure 1-1a. The proposed approach consisted of defining a number of “plausible” scenarios that will describe a broad range of changes in the water demand as well as in the peak demand. With the different “plausible” scenarios tests for a number of networks were performed to determine the acceptable limits for proper functioning of the network. Looking at a time frame of 25 years, we identified potential changes in the SEPTED dimensions and investigated the effect that those changes will have on the current distribution network, Appendix I. Four indicators were used to evaluate the consequences of the scenarios on the DWDS: 1) daily water demand, 2) daily peak demand, 3) head losses and 4) residence time. In the first stage of the project, the four networks were analysed, using 10 scenarios. The scenarios included technological as well as demographic changes. Ten diurnal patterns were simulated with SIMDEUM.

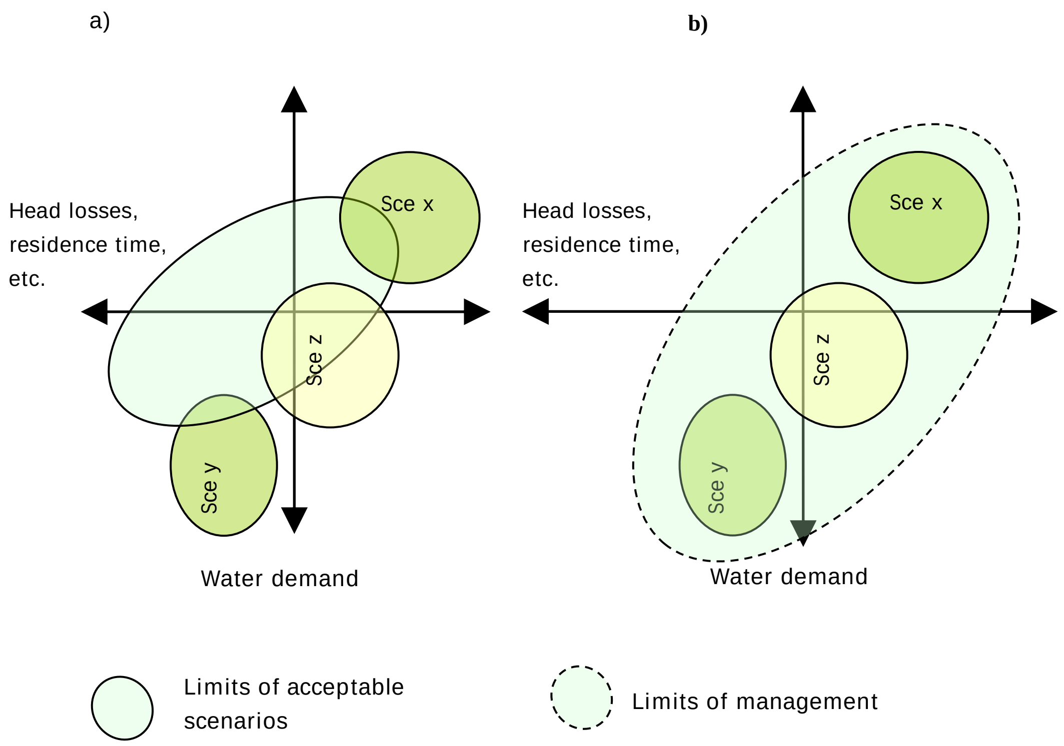


Figure 1-1a) Approach proposed to analyse the robustness of the networks, b) outcome after analysis of the four networks

In a second stage, a more in depth analysis was performed by comparing the performance of a looped versus a branched design. In this case, 30 patterns per connection were simulated. The performance of the network was evaluated on three criteria: i) network pressure, ii) water quality and iii) continuity of supply.

1.4 Outcomes

The proposed “stress-test” showed to be a robust methodology to investigate functionality of the system under a broad range of changing water demand scenarios. The approach was tested in four networks. Results showed that even in the most extreme scenarios management and operation of the network can be adapted or adjusted to cope with head losses, low velocities or long residence times, Figure 1-1b. However, special attention should be given to the limits for the appropriate functioning of DWDS. Further research is needed to determine the limits for each of the of the criteria allowed in DWDS. However, those limits will be only surpassed with scenarios which may take place in a time horizon longer than 25 years. This bottom-up approach allows the quantification of the consequences on the water demand and daily peak per scenario. This information is crucial when evaluating future adaptations in extraction and treatment facilities. Moreover quantifying the range of variability of head losses, velocities and residence time provides insights in potential future operational adaptations.

2 Stress-test to determine network robustness

The results reported in this chapter are submitted for the WDSA conference 2014 with the title: "ROBUSTNESS OF THE DRINKING WATER DISTRIBUTION NETWORK UNDER CHANGING FUTURE DEMAND"

2.1 Introduction

Determining future demand involves large uncertainties. In this study the scenario approach was used to deal with these uncertainties. Scenarios are not predictions or forecasts of the future, but a set of alternative views of how the future might unfold (Kang and Lansey, 2013). Water demand is determined by users and their routines and the type of the water appliances (Blokker, 2010). In this study, instead of trying to design with uncertain parameters, the robustness of the net was tested by determining changes in the performance under extreme loads. This study focused on the distribution pipes that supply the customers: the pipes in the streets; transport mains were not included. The networks were tested considering changes in demand, reflecting different life styles and technological changes, or aging infrastructure. Four indicators were used to evaluate the consequences of the scenarios on the DWDS: 1) daily water demand, 2) daily peak demand, 3) head losses and 4) Residence time.

The purpose of the DWDS is to supply water of good quality at adequate pressure and flow. In the Netherlands the customer should receive water with a pressure of at least 150 kPa after the water meter at 1 m^3/h flow (Drinking Water Act, 2009). To determine the minimum pressure delivered to the customer, head losses in the DWDS were quantified. In this study, the maximum head losses (m) in the network are considered. The water quality in the DWDS was quantified using maximum residence time as surrogate variable. Residence time is an important aspect of water quality in a DWDS as it influences bacterial regrowth, corrosion, sedimentation and temperature. More specifically, the maximum water age (or residence time) is most important (Machell et al., 2009). In this study, the 99th percentile of the residence time in the network was used to compare the different scenarios.

2.2 Scenarios description

First a baseline analysis was done to determine the current situation, based on data provided by the drinking water companies and statistical information of the areas. After that different demand scenarios were defined. Different sources and time horizons were used to define the scenarios. The water use prognosis for the Netherlands for 2025 was used (Baggelaar and Geudens, 2008). Additionally, the four future scenarios for 2040 proposed by the planning agencies in the Netherlands for 2040: Regional Communities (RC), Strong Europe (SE), Global Economy (GE) and Transatlantic Markets (TM) (Janssen et al., 2006) were used as base scenarios Figure 2-1shows the four scenarios: Regional Communities, Strong Europe, Global Economy, and Transatlantic Markets and their main characteristics. The four scenarios emerge from variation along two axes; one is the extent to which the government stimulates free market forces, the other is the international orientation, or the extent to which the borders and economy are open for international influences. This results in four scenarios that differ from each other in terms of welfare, demography, labour force and environmental awareness. The implications of these scenarios in residential water use are described by Blokker et al., (2012).

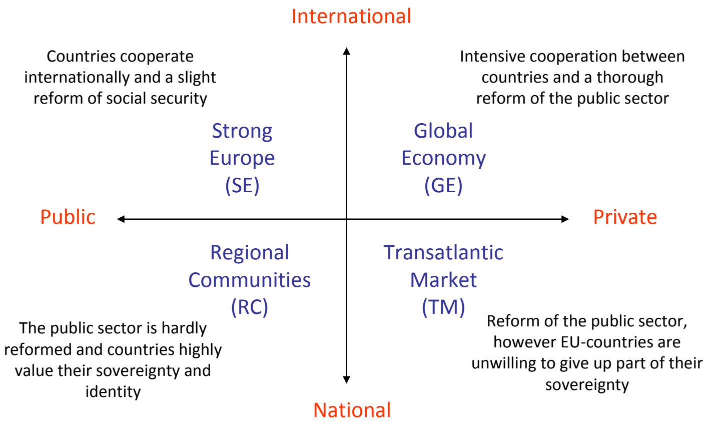


Figure 2-1 Two axes create four scenarios - Regional Communities, Strong Europe, Global Economy, and Transatlantic Market – with the main characteristics per scenario.

Additionally, five scenarios were defined during a workshop held with representatives of two Dutch water companies. The scenarios are a combination of different feasible factors based on the scenarios for 2040, or technological development combined with the current situation, for instance 100% of penetration of new technologies, such as vacuum toilets (1 L per flush), dual systems for non-potable demand, or luxurious shower. Not only technological changes influence drinking water demand. Therefore a scenario considering increasing leakage rate due to aging of infrastructure (Leak) was analysed. All the scenarios (10) are briefly described in Table 2-1.

Table 2-1 Description of the ten scenarios

Sce.	Name	Characteristics
0	Now	Baseline: current situation, specific for each of the networks.
1	Pr.	Prognosis 2025.
2	RC	Regional Communities: per capita demand declines because the economic downfall results in (water) saving behaviour, coupled with decreasing population. The average age of the population increases.
3	SE	Strong Europe: Despite low economic growth, mobility increases due to open borders. Personal hygiene habits have changed with an increase in shower frequency. Water pricing based on real cost drives alternative water resources to be adapted on a larger scale; e.g. rain water tanks for watering the garden.
4	TM	Transatlantic Market: Population growth causes increases in drinking water demand. Innovations aim at luxury and wellness products.
5	GE	Global Economy: Economic growth causes increases in consumption. Innovations are aimed at luxury and wellness, people shower longer and water their garden more frequently to diminish the effects of climate change.
6	Dual	Toilet, laundry machine and outside tap are not supplied by DWDS.
7	Eco	Based on RC with innovative sanitation concepts. 100% adoption of 1 L flushing toilets.
8	Lux	Luxury, based on current situation with 100% adoption of luxurious shower, with a shower frequency of one shower per day.
9	GE+	Based on "GE" but with a shower frequency of one shower per day.
10	Leak	Based on "Now" with leakage of 20%.

Other possible scenarios considered but not simulated were the food grinder processor (FGP), Figure 2-2 left. The FWP macerates organic kitchen waste use electricity and water. Water usage rates reported by the provider *insinkerator* are 3 l/p.d, which represents ca. 2% increase in the daily demand, which is relatively low compared with the other scenarios which are more extreme. Also instant hot water devices were considered, Figure 2-2 right. Instant hot water devices have a low penetration in the Netherlands. Although there are not official records of the degree of penetration, a low effect on water demand patterns is estimated.

Figure 2-2 Left: food grinder processor and right: instant hot water dispenser.

2.3 Networks description

Four networks were analysed. Two networks from Waternet: Bemenrijk (looped) en IJburg West (branched). For WML, an existing looped network in Sittard was analysed, and a new design for a branched network (for the same location), specifically design for this study were used to analysed influence of the layout on the robustness. Figure 2-3 shows the layout of the networks. The characteristics of the networks are described in Table 2-2.

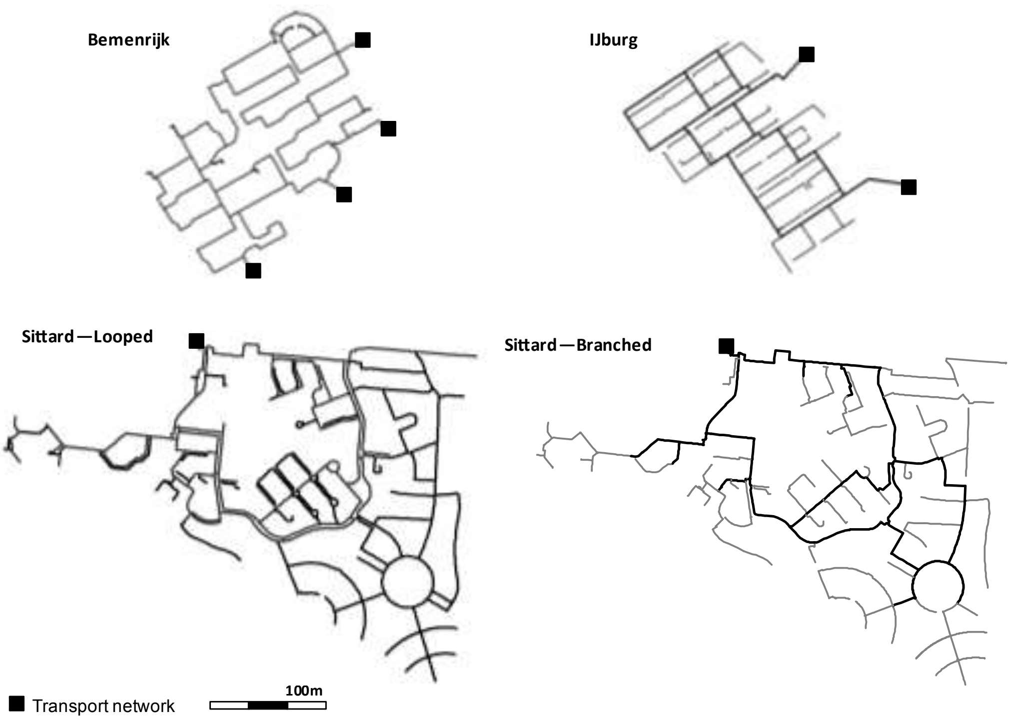


Figure 2-3 Networks layout

Table 2-2 Description of the networks

	Bemenrijk Looped	IJburg Branched	Sittard Looped	Sittard Branched
Connections	682	334*	1019**	1019**
Volume (m^3)	107	39	111	60
Length (Km)	4.9	13.9	14.2	10.8
Q_{mean} (m^3/h)	8.5	5	15	15
T_{mean} (hours)	13	8.2	7.3	4
# Loops***	14	5	48	3
# reservoirs	4	2	1	1
Reservoir head (m)	25	25	100	100
Max. difference on node elevation (m)	0.70	1.25	13.0	13.0

* 20 connections are SME's (see Appendix IV)
** In the area there is a residential building with 32 dwellings, one school and one care farm for mental patients. For the non-residential functions the pattern library for SIMDEUM was used. These patterns remained equal for all scenarios.
***Number of loops= number of pipes – number of joins + 1 (Blokker, 2013)

2.4 Simulating drinking water demand

Ten diurnal patterns with a time interval of 5 minutes were simulated for each connection and for each scenario with SIMDEUM (Blokker et al., 2010). This means that a unique stochastic drinking water demand pattern is constructed for each demand node by summation of the individual household's drinking water demand patterns. SIMDEUM uses statistical information as well as information regarding end-uses, allowing the simulation of changes in technologies and in user behaviour. For the current situation the input data were based on Blokker et al. (2010), for the future scenarios the input data were based on Blokker et al. (2012). The networks were simulated for a three day period, using EPANET software (Rossman, 2000). As input data, SIMDEUM uses detailed information of the users, Table 2-3. For each location, statistical information regarding household size, gender and age division was used from the Dutch Statistics (CBS). Information regarding job division is based on Blokker et al., (2010).

Table 2-3 Input data for SIMDEUM based on CBS (2013) and (Blokker et al. 2010) for the baseline analysis

			One person households			Two person households			Families with children (average)		
			Bem.	IJb.	Sit.	Bem.	IJb.	Sit.	Bem.	IJb.	Sit.
Number of people per household				1			2		3.7	3.7	3.6
Number of households (%)			34	30	24	30	18	29	36	52	47
Gender division: Male / Female (%)							50 / 50			50 / 50	
Age division (%)	Children (0-12 years old)						0		25	46	31
	Teens (13 – 18 years old)						0		17	9	18
	Adults (19 – 64 years old)		70	92	82	70	92	82	50	44	51
	Subdivision: % of adults with out-of-home job	Both persons				49	49	49	39	39	39
		Only male adult		68			26			52	
		Only female adult		52			6			3	
		Neither person					18			5	
	Seniors (> 65 years old)		30	8	18	30	8	18		0	

2.5 Results overview

The overview of the results for the networks are presented in the following subsections. For detailed information regarding each scenario, see Appendix V.

2.5.1 Daily water demand and peak demand

The daily water consumption in litres per capita per day for each scenario is shown in Table 2-4. Daily demand and peak demand were determined for the complete network. For the case of Sittard, the peak does not depend on network layout, but only on the demand scenario. Each scenario was characterised by the average daily drinking water demand (m^3/day) and the peak demand (m^3/h), Figure 2-4. The peak demand, defined as the 90% percentile of the 10 simulations. For the four cases it was found that the peak was related to the average daily demand. It was difficult to define a plausible scenario with high average demand and low peak demand and the other way around. The scenario with the lowest demand per capita is the “Dual”, and the scenario with the highest demand per capita is the “Lux.” scenario.

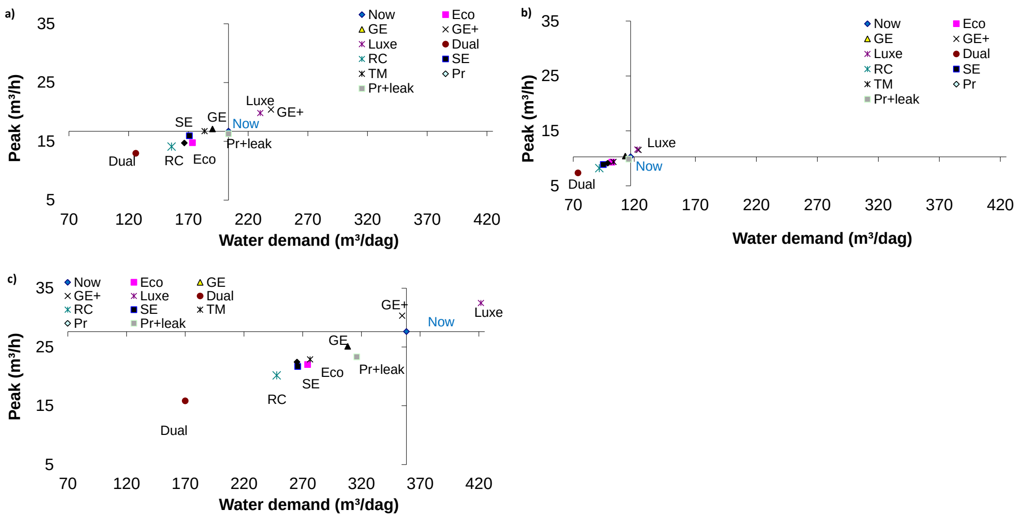


Figure 2-4 Daily water demands versus Peak demand a) Bemenrijk, b) IJburg and c) Sittard

There appears to be strong relation between peak and total demand. Water companies know that on normal days the peak is determined by the water use in the morning, whereas on warm days, the peak is determined by the use in the late afternoon. We did not simulate these warm day patterns here.

Table 2-4 Average daily water consumption in litres per person per scenario

	Bemenrijk			IJburg			Sittard			General scenarios for the three networks							
End Use	**Now**	**Dual**	**Lux**	**Now**	**Dual**	**Lux**	**Now**	**Dual**	**Lux**	**Pr. 2040**	**Eco**	**GE**	**GE+**	**RC**	**SE**	**TM**	**Pr.+ Leak (20%)**
Bath	3.5	3.5	3.5	4.1	4.1	4.1	4.1	4.1	4.1	2.7	3.1	2.7	2.7	2.7	2.7	2.7	2.7
Bath room tap	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Dish washer	1.6	1.6	1.6	1.7	1.6	1.6	1.7	1.7	1.7	2.6	2.8	2.6	2.6	2.6	2.6	2.6	2.6
Kitchen tap	14.8	14.8	14.8	13	13	13	13.6	13.6	13.6	16.3	11.7	17.2	17.2	14.8	15.4	16.8	16.3
Outside tap	13.4	13.4	13.4	13.4	13.4	13.4	23.1	0	23.1	15.2	2.6	21.7	21.7	2.6	4.6	17.1	15.2
Shower	45.9	45.9	71.4	45.9	45.9	71.4	45.9	45.9	71.4	55.4	49.8	69.5	97.8	48.3	55.9	65.9	55.4
WC	35.4	0	35.4	35.4	0	35.4	35.4	0	35.4	21.1	6	22.4	22.4	20.7	20.7	20.8	21.1
Wash machine	14.2	0	14.2	14.2	0	14.2	14.2	0	14.2	14	12.2	15.6	15.6	12.7	14	13.8	14
Leak																	26.26
Daily total	**132.8**	**83.2**	**158.3**	**131.7**	**82**	**157.1**	**142**	**69.3**	**167.5**	**131.3**	**92.2**	**155.7**	**184**	**108.4**	**119.9**	**143.7**	**131.3**

2.5.2 Maximum head loss

Figure 2-5 shows the maximum losses per scenario for the two network layouts. Although the scenarios are the same, the effect of the scenarios varies per network. The maximum head loss was 4 meters for Bemenrijk, ca. the double of the current head loss. While the maximum head loss was 1.1 m for IJburg, 0.95 m for Sittard (looped) and 1.90 m for Sittard (branched). The most extreme scenarios, with highest head losses were “Lux” and “GE+”. The scenario with smaller head losses was the “Dual”. Direct comparison of the networks is not possible due to the difference in size of the networks.

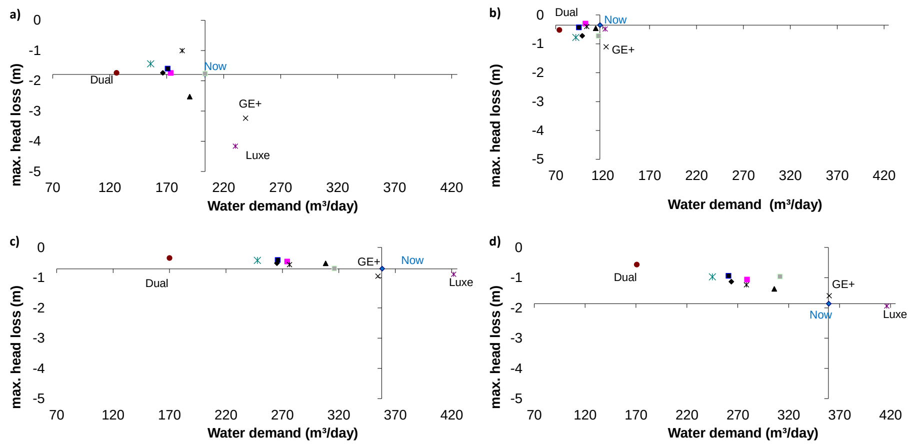


Figure 2-5 Daily water demands versus maximum head loss a) Bemenrijk, b) IJburg and c) Sittard (looped) and d) Sittard (Branched).

2.5.3 Maximum residence time

The medium residence time in the networks varies from 4 – 13 hours, Table 2-2. However, from the network analysis, the 99th percentile of the residence time in the networks varies from 36 to 72 hours, Figure 2-6. The “Dual” and “RC” scenarios had the maximum residence time, but in all cases the maximum residence time was above 21 hours. Bemenrijk showed the largest residence time. Additionally, the cumulative distribution of the residence time in the network shows that the “Dual” scenario has a large influence in the residence time in the complete network for the three studied cases. Note that the residence time is not from pumping station but from transport mains at the entrance of the network.

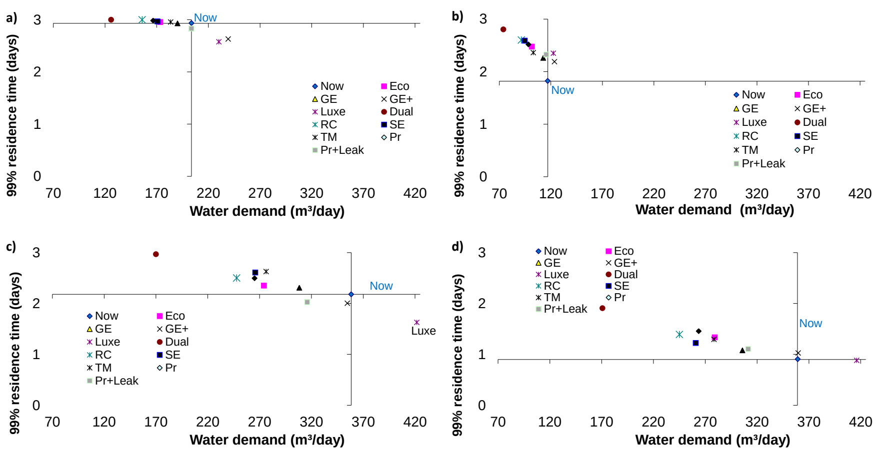


Figure 2-6 Daily water demands versus maximum residence time a) Bemenrijk, b) IJburg and c) Sittard (looped) and d) Sittard (Branched).

2.5.4 Overview of the results

Table 2-5 shows the overview of the results for the four networks. The current situation is compared with the minimum and maximum values obtain with the simulation of the future scenarios. Results show that the same future scenario can have different effects on the performance of different DWDS systems. Although, comparison of different networks provides an insight into the effect of a given scenario, the consequences for head losses and water quality cannot be generalized. These consequences have to be quantified per network due to variations in size (connections, length and volume), number of loops and demand.

Table 2-5 Overview of the results for the four networks

	Now	Min	Max	Max % increase	Max % reduction
Bemenrijk					
Demand (m^3/day)	203.6	126.0	239.2	17	-38
peak (m^3/h)	16.7	13.0	20.4	22	-22
Age (days)	2.9	2.6	3.0	2	-12
head loss (m)	1.8	4.2	1.0	132	-44
IJburg					
Demand (m^3/day)	117.0	73.9	123.5	6	-37
peak (m^3/h)	10.3	7.3	11.6	13	-29
Age (days)	1.8	1.8	2.8	54	0
head loss (m)	0.4	1.1	0.3	212	-16
Sittard (looped)					
Demand (m^3/day)	358.4	170.1	421.8	18	-53
peak (m^3/h)	27.6	15.8	32.5	18	-43
Age (days)	2.2	1.6	3.0	36	-25
head loss (m)	0.7	1.0	0.3	35	-50
Sittard (branched)					
Demand (m^3/day)	359.2	170.8	416.2	16	-52
peak (m^3/h)	28.1	15.7	34.6	23	-44
Age (days)	0.9	0.9	1.9	111	-3
head loss (m)	1.9	1.9	0.6	4	-70

3 Stress-test to determine network robustness – Two networks layouts and 30 scenarios

The results reported in this chapter are submitted for a peer-review journal with the title: "STRESS TEST FOR THE ROBUSTNESS OF DRINKING WATER DISTRIBUTION SYSTEMS UNDER CHANGING DRINKING WATER DEMAND".

To further compare the consequences of the future scenarios, the two networks of Sittard were selected. Table 3-1 shows the criteria and the indicators used to determine the robustness of the DWDS. A revised selection of 12 scenarios was applied. Thirty diurnal patterns were simulated for each connection and for each scenario. Only the residential connections were analysed. A time interval of 5 minutes was used to analyse peak demand, head loss and residence time, and a time interval of 36 seconds (0.01 h) was used to determine self-cleaning capacity.

Table 3-1 Criteria for network robustness

	Criteria	Indicator	Units	Remarks
1	Minimal pressure	Maximum head loss	m	Maximum head loss in a node with at least one customer
2	Water Quality	Residence time	days	In the pipes, 99th percentile of the network weighted per length of the pipe section
		Self-cleaning capacity	%	Percentage of the network with a median of the maximum velocity (m/s) larger than 0.20 m/s. In the pipes Ø<100mm, weighted per length of the pipe section.
3	Supply continuity	Customer Minutes Lost (CML)	Minutes	Average minutes per customer per year with no supply due to bursts and repair

3.1 Networks description

Table 3-2 and Figure 3-1 provide more detailed information of the two networks in Sittard.

Table 3-2 Network characteristics

		Looped layout	Branched layout
Diameters distribution in km and (%)	< 100mm	7.2 (51%)	6.8 (63%)
	≥ 100mm	7.0 (49%)	4.0 (37%)
Number of control valves		140	26
Number of connections per meter		0.07	0.09

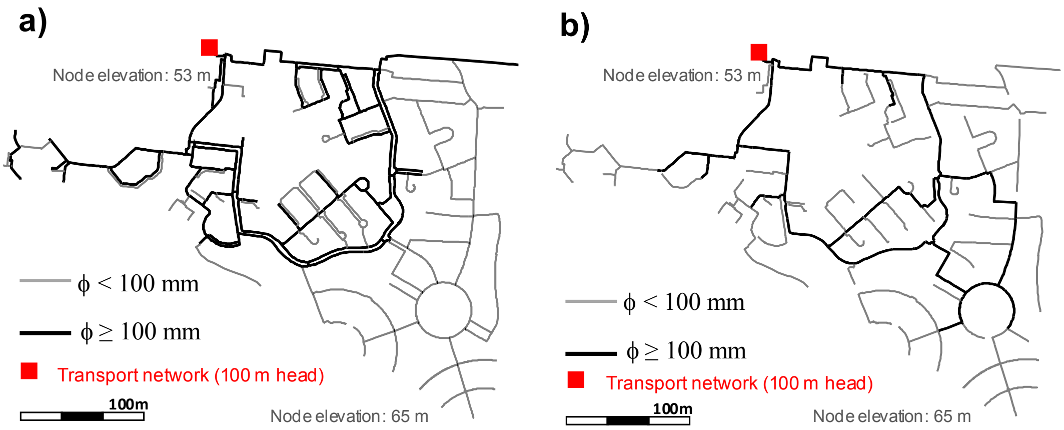


Figure 3-1 Network layout a) looped (current) and b) branched (theoretical) for Sittard

For this analysis two levels of stress are differentiated: medium stress (MS) scenarios and high stress (HS) scenarios. During the second workshop three new scenarios were defined: Lux+dual, Eco+ and DP. The Pr scenario (Prognosis for 2025) was excluded. The twelve scenarios are briefly described in Table 3-3, MS are 1-4 and HS are 5-12.

Table 3-3 Scenarios description

Scen	Name	Characteristics
0	Now	Baseline: current situation
1	RC	Regional Communities: per capita demand declines because the economic downfall results in (water) saving behaviour, coupled with decreasing population. The average age of the population increases.
2	SE	Strong Europe: Despite low economic growth, mobility increases due to open borders. Personal hygiene habits have changed with an increase in shower frequency. Water pricing based on real cost drives alternative water resources to be adapted on a larger scale; e.g. rain water tanks for watering the garden.
3	TM	Transatlantic Market: Population growth causes increases in drinking water demand. Innovations aim at luxury and wellness products.
4	GE	Global Economy: Economic growth causes increases in consumption. Innovations are aimed at luxury and wellness, people shower longer and water their garden more frequently to diminish the effects of climate change.
5	Dual	Toilet, laundry machine and outside tap are not supplied by DWDS
6	Eco_RC	Based on RC with innovative sanitation concepts. 100% adoption of 1 L flushing toilets
7	Lux.	Luxury, based on current situation with 100% adoption of luxurious shower
8	GE+	Based on “GE” but with a shower frequency of one shower per day.
9	Leak	Based on “Now” with leakage of 20%
10	Lux. + dual	Based on “Now” with 100% adoption of luxurious shower with dual system for toilet, laundry machine and outside tap
11	Eco+	Adoption of innovative sanitation concepts plus water use efficient showers, washing machines and dishwashers
12	DP	Diminishing population: 30% reduction of the population in the area due to empty houses

3.2 Daily water consumption and peak demand

The water consumption in litres per capita per day for each scenario is shown in Table 3-4. Daily consumption is specified per end-use. The current daily drinking water demand per capita is 142 litres (l.). The range of variation of the daily drinking water demand per capita in this study was a minimum of 47 l. – 67% reduction – for the “Eco+” scenario and a maximum of 198 l. – 39% increase – for the “Lux.” scenario. The current average daily drinking water demand in the network was 363 m³. Due to variations of household size per scenario the range of variation of the average daily drinking water demand of the MS scenarios is a reduction of 16% - 32% for daily demand in the network. For the HS scenarios the range of variation was 143 m³ – 509 m³, ca. 60% reduction and ca. 40% increase.

For the current situation, the peak demand, defined as the 99% percentile of the 30 simulations, is 49 m³/h. *Figure 3-2*a shows the variation of the daily demand and the peak demand for the different scenarios. The MS scenarios (RC, SE, TM and GE) showed a reduction in the average daily demand and on the peak demand. The range of variation of the peak demand for the MS scenarios was a reduction of 18% to 31%. While, the HS scenarios showed peak variations between -57% and 39%. The most extreme scenarios are “Lux.” and “Eco+”. Moreover, in general there is a strong correlation between average daily demand and peak demand. For the majority of the scenarios it was found that the peak was approximately 14% of the average daily demand.

Table 3-4 Average daily water consumption in litres per person per scenario

		MS scenarios				HS scenarios							
	Now	RC	SE	TM	GE	Dual	Eco_RC	Lux.	GE+	Leak	Lux._dual	Eco+	DP
Bath room tap	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Bath	4.1	2.7	2.7	2.7	2.7	4.1	3.1	4.1	2.7	4.1	4.1	0	2.7
Dishwasher	1.7	2.6	2.6	2.6	2.6	1.7	2.8	1.7	2.6	1.7	1.7	0.2	2.6
Kitchen tap	13.6	14.8	15.4	16.8	17.2	13.6	11.7	13.6	17.2	13.6	13.6	11.7	17.2
Outside tap	23.1	2.6	4.6	17.1	21.7	0	2.6	23.1	21.7	23.1	0	0	21.7
Shower	45.9	48.3	55.9	65.9	69.5	45.9	49.8	102	97.8	45.9	102	24.9	97.8
WC	35.4	20.7	20.7	20.8	22.4	0	6	35.4	22.4	35.4	0	6	22.4
Wash machine	14.2	12.7	14	13.8	15.6	0	12.2	14.2	15.6	14.2	0	0.3	15.6
Leak	0	0	0	0	0	0	0	0	0	28.4	0	0	0
Daily total per capita (lcd)	142	108	120	144	156	69	92	198	184	170	125	47	184
household size (inhabitants)	*2.5*	*2.3*	*2.2*	*2.0*	*1.9*	*2.5*	*2.3*	*2.5*	*2.0*	*2.5*	*2.0*	*2.9*	*2.5*

Lux.: luxury, GE: global economies; RC: Regional communities, SE: Strong Europe and TM: Transatlantic Markets, DP: Diminishing population

*Figure 3-2*a, shows that RC and GE are the extremes of the MS scenarios, and that “Lux.” and “Eco+” are the extremes of the HS scenarios. These four scenarios were selected to determine the ranges of variation of the two stress levels. *Figure 3-2*b shows the cumulative distribution of the daily demand. The “Lux.” scenario showed an overall increment of the demand during the day, without changing the minimum daily demand (ca. 40% higher compared to the current situation at 50 percentile and ca. 45% higher at 90 percentile). The “Eco+” scenario presents a reduction in both the peak and the minimum daily demand – ca. 80% lower compared with the current situation.

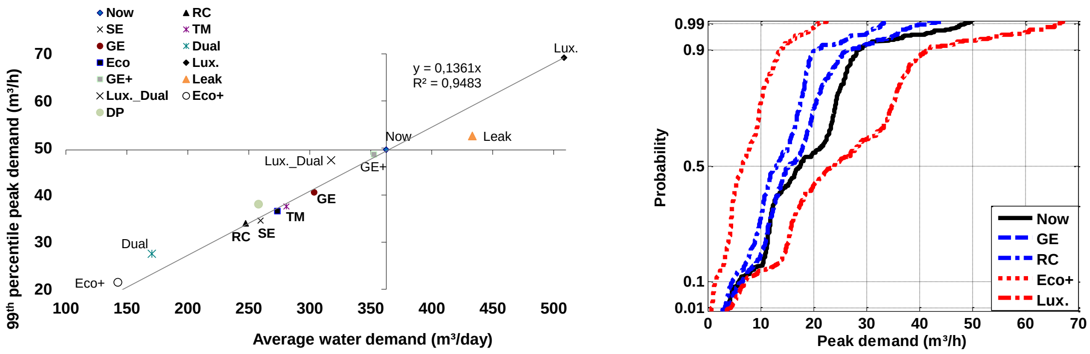


Figure 3-2 a) Variation in daily drinking water demand and in peak demand for the 13, (incl now) scenarios, b) variation in the variation of the daily peak demand for five selected scenarios

3.3 Head loss

Head loss was analysed only for the non-zero demand nodes. Figure 3-3a shows the maximum losses per scenario for the two network layouts. Two main characteristics are observed. Firstly, the branched layout had shorter lengths, but smaller diameters, resulting in larger head losses than the looped design, varying from 1.1 to 2.9 times larger head losses. Secondly, the “Lux.” scenario had the largest head loss for both network layouts, while the Dual and Eco+ scenarios showed to have the smallest head losses. The maximum head loss found was 2.97 m for the “Lux.” scenario in the branched network. This head loss, however, does not represent a threat for the functioning of the network. It appears in the periphery of the network and could be compensated by varying the head in the transport network within the same range of pressure.

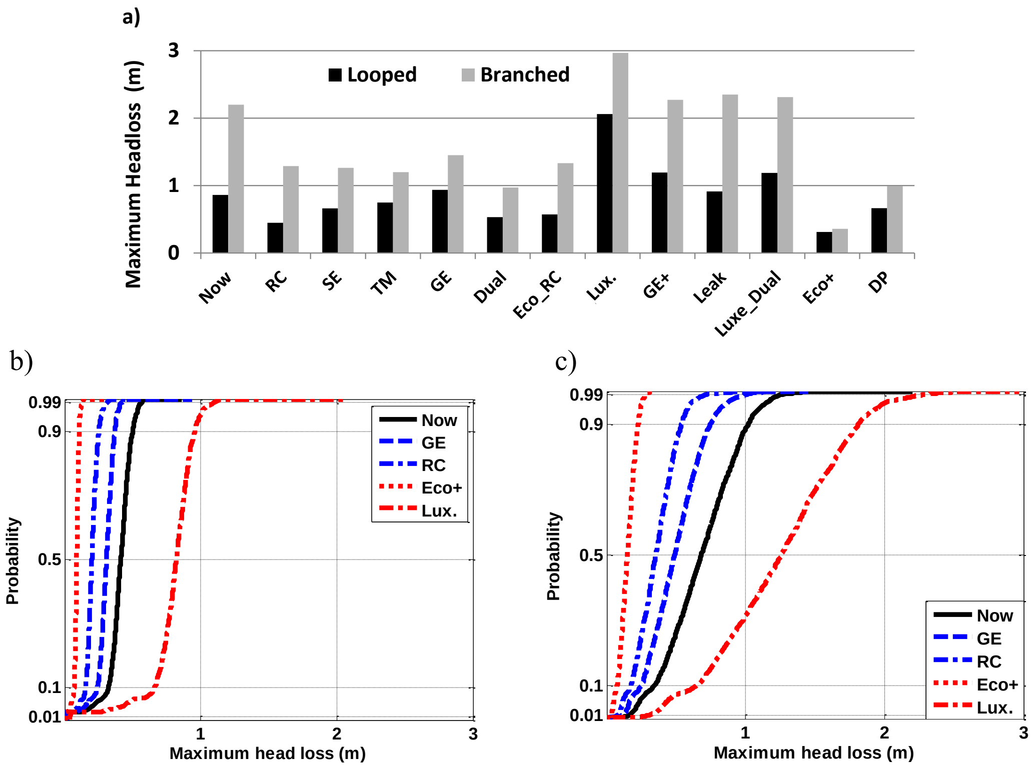


Figure 3-3 a) Variation in maximum head loss for the 13, (incl. now) scenarios. Cumulative distribution of head losses in the network per connection for five selected scenarios b) looped network and c) branched network.

Figure 3-3b-c show the head losses in the network for each connection. For the looped layout in the current situation 90% of the connections had less than ca. 0.5 m. of head loss, while for the branched design 90% of the connections had ca. 1.0 m of head loss. In the looped layout, the head losses showed less variation than in the branched layout. For scenarios with low consumption, for instance "ECO+", there are less variations in the head losses in the network due to less variations in demand in this scenario..

An advantage of this approach, with detailed network calculations, is that with the network model the node(s) with the minimum head on the network can be easily identified, as well as the time during the day when the maximum head losses are most likely to occur. This provides additional information about variation of the network performance on location and time, which is relevant for network management.

3.4 Water quality: residence time and self-cleaning capacity

Although maximum residence time for both networks and for the 12 scenarios is almost three days in all cases (*Figure 3-4*b-c), looking at the 99th percentile there are large differences between the scenarios and network layouts. As shown in Table 2-2 in the current situation, the medium residence time in the looped network is 7.3 hours. However, from the network analysis, the 99th percentile of the residence time in the network is almost two days. For the branched network, mean residence time is 4 hours and the 99th percentile of the residence time in the network is 1 day. This shows that the network layout and dimensions are the most important for the residence time. *Figure 3-4* a shows the maximum residence time per pipe length in the networks for the 12 scenarios. For the looped layout, it varies from 1.4 till 3 days, while for the branched design it varies between 0.8 and 2.4 days. This may have an influence on water quality. Note that there is also a residence time from the production station to the beginning of our test network. In this case this residence time is less than 2 hours, but in other cases this may be larger influencing the water quality.

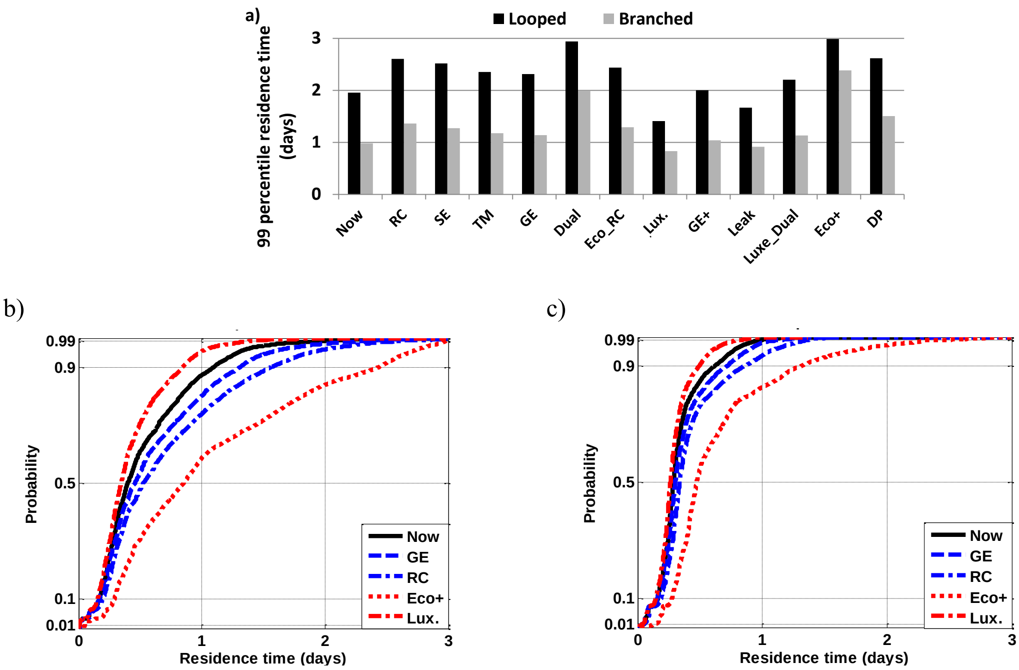


Figure 3-4 a) Variation in the residence time for the 13, (incl now) scenarios. Cumulative distribution of the residence time in the network per meter for five selected scenarios b) looped network and c) branched network.

*Figure 3-4*b-c show the cumulative frequency distribution per meter of network. In general, the residence time increases with respect to now for the “ECO+” scenario, while the residence time decreases for the “lux.” scenario. ***Figure 3-4***b-c also show that in the extreme scenario “Eco+ ”, the 90th percentile is ca. 2.5 days for the looped design, for the branched design it is almost half. ***Figure 3-4***b-c show that for the looped layout there is a clear difference between the MS and the HS scenarios in network performance, this difference is less strong in the branched layout, in which smaller differences are found between the current situation, the MS scenarios (GE and RC) and the HS scenario “Lux”.

The median of the maximum flow velocity per meter of network per scenario was used to determine the self-cleaning capacity of the network, for the pipes with a diameter smaller than 100 mm. If the median was larger than 0.20 m/s then the pipe has a self-cleaning capacity. For the current situation, 6% of the pipes with small diameters in the looped network have a self-cleaning capacity, while this percentage is 68% for the branched network. For the twelve scenarios the self-cleaning capacity varies between 2% and 11% for the looped layout and between 25% and 89% for the branched design. The “Eco+” scenario represents the worst case for the looped network, and the “Dual” scenario represents the worst case for the branched layout.

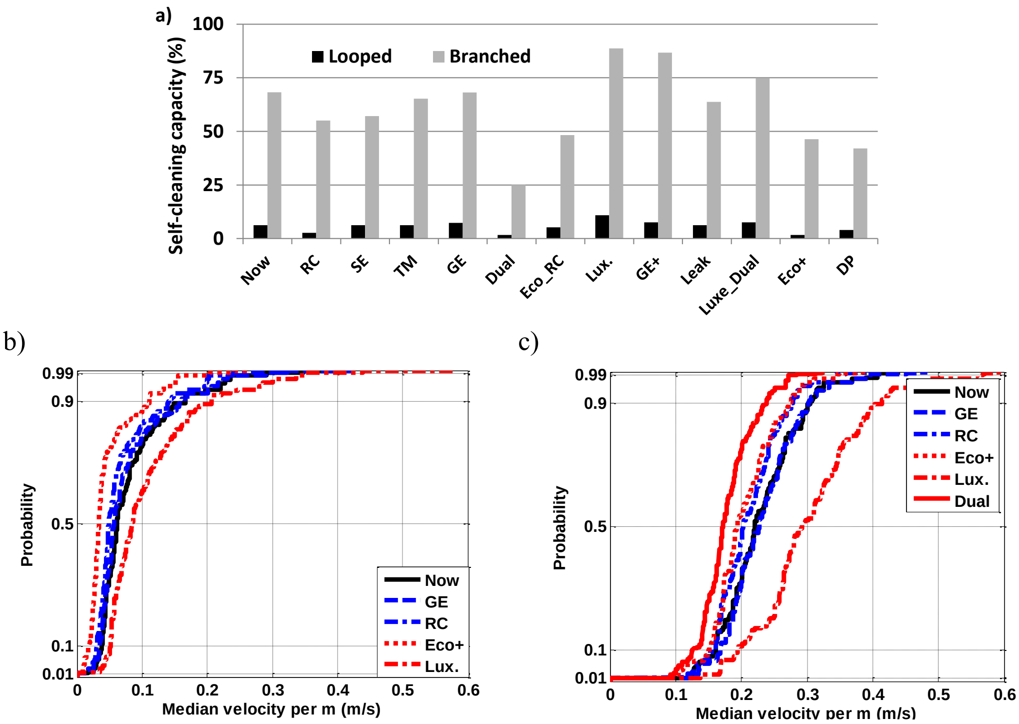


Figure 3-5 Variation in the self-cleaning capacity for the 13, (incl now) scenarios. Cumulative distribution of the median velocity in the network per meter b) for five selected scenarios for the looped network and c) for six selected scenarios for the branched network.

Figure 3-5b-c show the cumulative frequency distribution of the median of the maximum velocity per meter for pipes with a diameter smaller than 100mm. When comparing the two networks, it is important to consider that the network length with diameters smaller than 100 mm is 51% for the looped network and 63% for the branched network, Table 3-2. This means that even a larger portion of the branched network is self-cleaning compared to the looped system. Figure 3-5 shows that for the looped network, in the worst case, “Eco+”, the maximum self-cleaning capacity is 5%, while for the branched network this percentage can be up to 64%. In the looped layout, the low velocities allow settling of particles, and therefore, cleaning of the network is needed. For the branched design the percentage of the self-cleaning capacity is 50% of higher, except for the "Dual" scenario, resulting in lower operational costs.

3.5 Customers minutes lost

Interruption of supply expressed in Customer Minutes Lost (CML) per year was calculated per network, independently of the demand scenarios. Table 3-5 shows the variation of CML for different valve reliability values, considering equal conditions on failure rate and repair time. A direct comparison of the CML for the two networks is not possible due to differences in their layout, section size, customers per section and number of valves. For instance, in the branched network, the number of valves has decreased considerably, leading to on average larger sections. This means that when something will happen with the valve and a section cannot be isolated successfully, a larger number of customers will be affected, resulting in a larger value for the CML. However, a reduction of number of valves by a factor of 5.4, only represents a CML increase of 2.6 times. A limited number of valves facilitates maintenance and controllability, which are related to improved valve reliability, reducing costs and limiting CML. A eight minutes CML in the looped network will require an 75% valve reliability for 140 valves, while a comparable CML in the branched network will require 90% valve reliability of only 26 valves.

Table 3-5 CML for the two network layout for different valve reliability.

Valve reliability	CML (minutes/customer)	
	Looped	Branched
75%	8.38	13.05
80%	6.39	11.20
85%	5.12	9.05
90%	4.08	8.32
95%	3.19	7.26
100%	2.40	6.29

3.6 Network performance, robustness and operability

In this study different scenarios were tested to evaluate the performance of two networks. Figure 3-6 summarises the results for the two networks. Figure 3-6a shows peak demand versus head loss. In general, for the same peak demand (same scenario), the head losses are higher in the branched network. However, in the Eco+ scenario, the difference was minimal. Figure 3-6b shows the two variables that are related to water quality. A clear difference is found between the two network layouts, where the branched design performs better under all scenarios compared with the looped layout with shorter residence times and higher percentage of self-cleaning capacity. Table 3-6 shows the overview of the lowest performance for the two levels of stress.

Since pressure can be controlled and adjusted in the piped network for different demands, and reservoirs can be designed to allow fluctuations in demand, quality remains the most critical performance factor. Comparing the performance of the two layouts, the branched network performs better than the looped one, regarding residence time and self-cleaning capacity. Those are crucial parameters for water quality, especially in the Netherlands where water is distributed without chlorine. In the looped layout, ten scenarios showed residence times larger than two days, while in the branched layout only two scenarios had residence times larger than two days. Though intuitively not a sustainable solution, the negative environmental impact of a higher energy demand is compensated by smaller pipe diameters and shorter pipes. For the case study the potential extra energy demand is compensated by a 24% reduction in pipe length (3,4 km) and pipe diameter and 80% reduction in valves.

Moreover, the self-cleaning capacity minimizes flushing of the network and reduces operational costs.

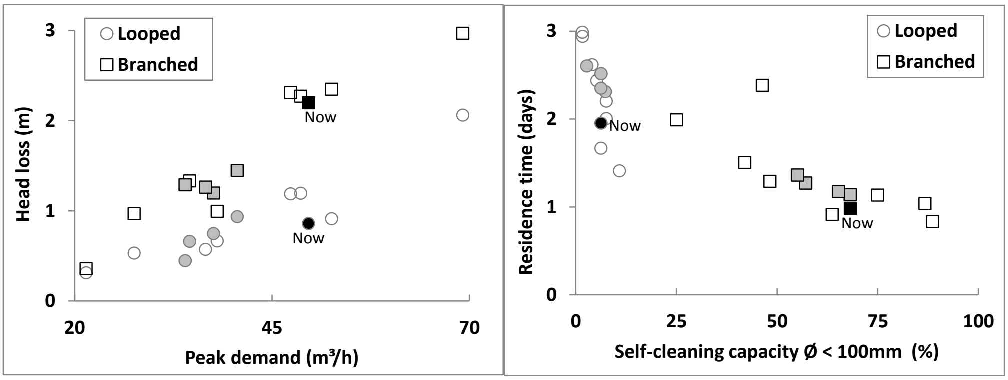


Figure 3-6 Comparison of the performance of the two network layouts for the 12 scenarios; left Peak demand vs. head loss and right self-cleaning capacity vs. residence time. ●Looped: now, ● Looped: MS scenarios, ○ Looped: HS scenarios, ■ Branched: now, ■ Branched: MS scenarios, □ Branched: HS scenarios.

Table 3-6 Overview of lowest performance per network for the two types of stress level

	Head loss (m)	99th percentile residence time (days)	Self-cleaning capacity (%)	CML (minutes) – 90% valve reliability
Looped				
Now	0.9	2.0	6.3	4.1
MS	0.9	2.6	2.7	4.1
HS	2.1	3.0	1.7	4.1
Branched				
Now	2.2	1.0	68.2	8.3
MS	1.5	1.4	55.1	8.3
HS	3.0	2.4	46.3	8.3

For the branched network, only in the eco+ and “”DP” scenarios, the current pipe diameters are too large, resulting in flow velocities that are insufficient for self-cleaning pipes. Then this network would need to be cleaned. Looking at threats such as climate change and increasing heat waves in urban areas, it will be desirable to have relatively short residence times to guarantee good water quality. The branched design shows short residence times. For the studied case, the branched layout has 45% less volume than the conventional looped network. The branched self-cleaning layout, which deals with several extreme scenarios concerning drinking water demand, performs better than the looped network mentioned in this study.

The results show two robust networks, which are able to cope with extreme changes on the water demand, while maintaining its functionality by adapting the operations in the production and pumping station. For this specific case, the maximum head losses - of one meter - can be compensated by increasing the pressure in the network, without representing a risk of increasing leakages. For larger and more complex networks the impact of changes in the network pressure can result in higher occurrence of leakages. Peak demand needs adjustments in the extraction and storage in the production facilities. Water quality in the DWDS can be improved by flushing the system. Results also showed that although the two networks are robust, the branched network performs better regarding water quality. The costs and environmental impact of the extra energy use for pumping, related to the branched system in extreme high demand scenarios, can probably be compensated with the reduced use of materials and less maintenance needed. Given the long life time of DWDS, rehabilitation is distributed over time. This incremental replacement offers possibilities to transition from traditional looped systems to branched systems. The results of the stress test do not show a need to further adjust the network layout of diameters based on predicting future drinking water demand.

The general observation is that the current looped drinking water infrastructure is robust enough for the future drinking water demands of most scenarios. Also the branched infrastructure is well capable to deal with variation in drinking water demand. Overall the branched infrastructure is more efficient, because with less and smaller pipes similar performance is reached. On the water quality parameters of residence time and velocity the branched network performs consistently better. Although CML is higher for the branched design, this is compensated by the limited number of isolation valves, resulting in better manageability and controllability of the system.

4 Transitions in the drinking water demand

The results reported in this chapter were presented in the Amsterdam Water Week in Amsterdam 2013 with the title: "ANALYSING THE DYNAMICS OF TRANSITIONS IN RESIDENTIAL WATER CONSUMPTION IN THE NETHERLANDS".

The variation of the daily residential water consumption in the Netherlands since 1960 is shown in Figure 4-1. In 1960 the water consumption was 80 litres per person per day. Changes in technology penetration and in user behaviour, led to an increase in the water demand, with a peak in the 1990s. Transitions after the 1990s can be logically related to technological development such as water saving devices, where, National and European regulations have been a catalyst. In 1997 European legislation made energy labelling mandatory for washing machines, and for dish washers in 1999, which specifies the energy and water consumption of an appliance and grades overall energy performance. As a consequence, the average consumption per washing load of washing machines is almost halved starting from 100 litres in 1992, Figure 4-2b. Most of the energy consumption of washing machines is for heating water, thus less water per cycle means lower energy use. Furthermore, new European norms of sanitary fixtures were developed that take specific water consumption into account, e.g. NEN-EN 1112 of 1997. Energy efficiency has been a constant driver in the last two decades, as shown in the transition towards more energy-efficient systems to heat water at residential level, Figure 4-2b. This transition has been supported by technological developments while comfort and user behaviour were not affected.

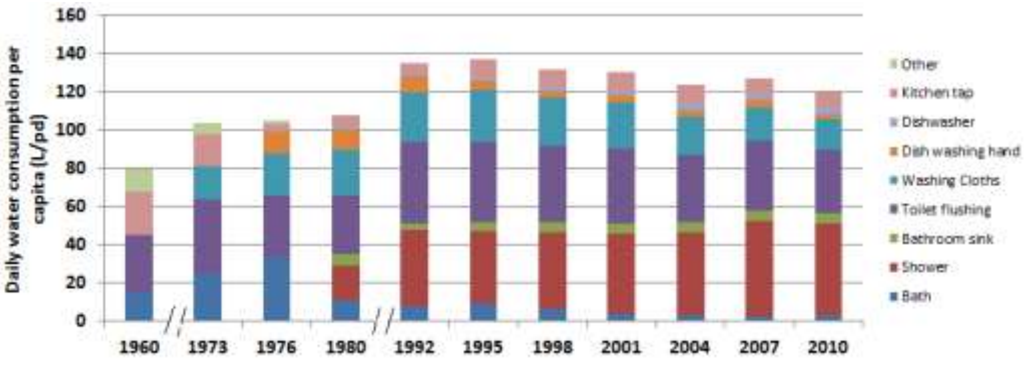


Figure 4-1 Changes in the daily water consumption per capita in the Netherlands.

In general, domestic water use can be estimated using technical and behavioural determinants. Technical determinants refer to the water using properties embedded in a portfolio of water using appliances in the home. Figure 4-2a shows large differences on the penetration trajectories for different water appliances. Diffusion of showers increased by 4% per year from 1960 to 1970, after that the average rate declined to 1% per year. Full penetration of showers took approximately 60 years. The fastest penetration – 9% annual – was found for washing machines between 1960 and 1970. Dishwashers also showed a fast penetration rate (5.3% per year between 1995-2001). However, this penetration stagnated around 60%. A similar trend is seen for water saving toilets and water saving showers.

During the last 15 years technological development has resulted in more efficient appliances. Figure 4-2b shows the percentage of capacity reduction of different household appliances since 1992, e.g. the consumption of washing machines has almost halved starting from 100 litres in 1992. This capacity reduction was driven mainly by energy efficiency requirements; most of the energy consumption of washing machines is used for heating water, less water per cycle means less energy use. Behavioural determinants refer to the intensity with which households use such appliances. Figure 4-2c shows the variation of routines described as frequency of certain activities per day per person. The clearest change is the decrease of bathing and the increase of showering frequency.

Based on these trends, changes such us full adoption of dual systems or luxurious showers, will take decades. This gives room for adapting the drinking water infrastructure, and specially adapting the operations of the DWDS. More extreme scenarios where the functionality of the network will be affected may take place over a longer time frame than 25 years.

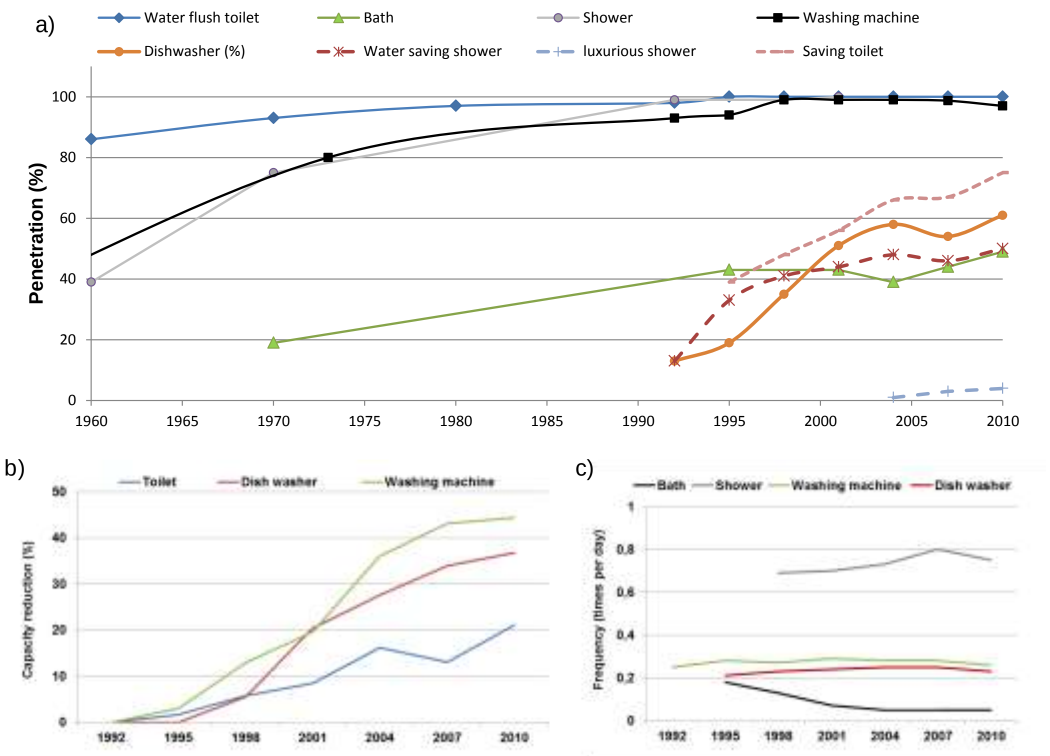


Figure 4-2 Describing transitions a) penetration of different technologies, b) increasing efficiency of appliances since 1992 and c) changes in routines.

5 Conclusions and recommendations

In this project we developed a method to test the robustness of the DWDS. First the test was applied to existing networks. The test included 10 scenarios, for each scenario 10 patterns with a short time step were simulated. Results show that the same future scenario can have different effects on the performance of different DWDS systems. Although comparison of different networks provides an insight into the effect of a given scenario, the consequences for the DWDS cannot be generalized. These consequences have to be quantified per network due to variations in size (connections, length and volume), number of loops and demand.

We did not investigate the likelihood that these scenarios will occur. The pilot areas showed to be robust in all scenarios, therefore, investigating the probability of occurrence of the scenarios was less relevant. For other parts of the drinking infrastructure (extraction, treatment), this can be more relevant and further analysis of the likelihood is needed. However, with this bottom-up approach the consequences on the water demand and daily peak per scenario can be quantified. This information is crucial when evaluating future adaptations in extraction and treatment facilities. Moreover quantifying the range of variability of head losses, velocities and residence time provides insights in potential future operational adaptations.

We have shown that the introduction rate of new water use appliances is relatively slow, resulting in a slow changing water demand per capita. Changes such us full adoption of dual systems or luxurious showers, will take decades to take place. This gives room for adapting the drinking water infrastructure, and specially adapting the operations of the DWDS. More extreme scenarios were the functionality of the network will be affected may take place in a longer time horizon than 25 years. Demographic changes, specifically shrinking areas such as in Limburg, can be caused by smaller households (considered in the stress test), or less households (which was considered in the stress test up to 30% reduction). To prevent the shrinking of cities, municipalities plan re-development of areas - demolition of old buildings and renewing the building stock. These renovation activities require or offer the opportunities to lay down a new DWDS; while capacity for extraction and treatment should be adjusted to lower capacity. Within the studied scenarios, the influence of climate change was not specifically studied. The scenario's considered, though, have characteristics that will include the effects of climate change.

Systematically monitoring of the drinking water demand is needed to adjust operations to changing water demand. This does not require much research at this moment, but rather a regular monitoring and recording of pressures and flows in the network. By keeping track on technological and demographic changes, drinking water companies can analyse the trends and the impact on the drinking water infrastructure, and adapt their operations based on the pressure and flow monitoring, to guarantee the functionality of the system.

As second step, a looped and a branched network were compared, using 12 scenarios and 30 patterns per connection. Results showed that the two networks are robust. By adapting the operability of the system it is possible to cope with rather extreme changes in the water demand, while maintaining its functionality. For these specific cases, the maximum head losses can be compensated by increasing the pressure in the network. For larger and more complex networks the impact of changes in the network pressure can result in higher occurrence of leakages. Peak demand needs adjustments in the extraction and storage in the production facilities. Water quality in the DWDS can be improved by flushing the system. Overall the branched infrastructure is more efficient, because with less and smaller pipes similar performance is reached. On the water quality parameters of residence time and velocity the branched network performs consistently better. Although CML is higher for the branched design, this is compensated by the limited number of isolation valves, resulting in better manageability and controllability of the system.

Residence time and self-cleaning capacity were used as indicators for water quality. Unknown is still which residence time is absolutely acceptable, and this requires further research. An additional indicator is water temperature. Water temperature at the customer's tap is determined by the temperature of the soil and by the design of the domestic drinking water system, also investigated within the framework of this research (Moerman, 2013). For the domestic drinking water system, it was found that residence time influences the microbial growth more than temperature does. Demand pattern changes in time have more influence than demand volume changes since water in the domestic drinking water system is heated relatively fast. The effect of the domestic drinking water system on water quality should be further investigated.

For implementation, a selection of the four most extreme scenarios provides a good insight on the range of variation of the studied indicators. Per scenario seven daily patterns with a minute interval are recommended. These patterns can be simulated with the Simdeum Pattern Generator. Given the long life time of DWDS, rehabilitation is distributed over time. This incremental replacement offers possibilities to transition from traditional looped systems to branched systems.

The concept of robustness is not easily to quantify. The scenario approach combined with detailed network calculations is a powerful approach to assess the robustness of DWDS to deal with extreme scenarios for the drinking water demand. The stress test approach presented in this study, using the broad range of scenarios, represents a robust approach to determine the performance levels of networks under different operating conditions. Moreover this approach can also be used during the design phase. This methodology shows to be useful to quantify the range of variation of key variables that describe network performance. This scenario approach showed that it is not needed to forecast in detail each change in drinking water demand. It is possible to test the robustness of a network by describing a range of possible scenarios.

6 References

Agudelo-Vera, C.M., Blokker, E.J.M., Büscher, C.H., Vreeburg, J.H.G., 2013. Analysing the Dynamics of Transitions in Residential Water Consumption in the Netherlands. In proceedings: International Water Week Amsterdam 2013. Amsterdam.

Blokker, E.J.M. 2010. Stochastic Water Demand Modelling: Hydraulics in Water Distribution Networks. IWA publisher. 200 p. London, UK..

Blokker, E.J.M., Vreeburg, J.H.G., van Dijk, J.C., 2010. Simulating residential water demand with a stochastic end-use model. Journal of Water Resources Planning and Management 136 (1), 19-26.

Blokker, E.J.M., Pieterse-Quirijns, E.J., Postmus, E., Marmelo, V.M., Mendes, L.L., 2011. Asset management of valves. Water asset management international 7.4, 12-15.

Blokker, M., Vloerberg, I., 2011. Quantitatieve future scenarios for drinking water (in Dutch). KWR. Nieuwegein, the Netherlands.

Blokker, M., Vloerberg, I., Buchberger, S., 2012. Estimating peak water demand in hydraulics systems II - Future trends. WDSA 2012, 1138-1147. Adelaide, Australia.

Blokker, E.J.M. 2013. Datamining in waterkwaliteitsdata. KWR. KWR 2013.067 (in Dutch).

CBS, 2013. Neighbourhood information The Hague/Heerlen. Website. www.cbs.nl. Last accessed June 2013.

Drinking Water Act, 2009. http://wetten.overheid.nl/BWBR0026338/geldigheidsdatum_01-12-2013#HoofdstukIX. Last accessed December 2013.

Frijns, J., Büscher, C., Segrave, A., Van Der Zouwen, M., 2013. Dealing with future challenges: A social learning alliance in the Dutch water sector. Water Policy 15 (2), 212-222.

Janssen, L.H.J.M., Okker, V.R., Schuur, J., 2006. Welfare and environment: a scenario study for the Netherlands 2040 – background document. Centraal Planbureau. (in Dutch). 520p. The Hague, The Netherlands.

Kang, D., Lansey, K., 2013. Scenario-based robust optimization of regional water and wastewater infrastructure. Journal of Water Resources Planning and Management 139 (3), 325-338.

Machell, J., Boxall, J., Saul, A., Bramley, D., 2009. Improved representation of water age in distribution networks to inform water quality. Journal of Water Resources Planning and Management 135 (5), 382-391.

Moerman, A. 2013. Drinking water temperature modeling in domestic systems. KWR/ TU-Delft. Master Thesis.

Rossman, L. A., 2000. EPANET 2 user manual, United States Environmental. Protection Agency. 200p. Cincinnati, United States.

Vreeburg, J.H.G., 2007. Discolouration in drinking water systems: a particular approach. Dissertation, Delft University. 183 p. Delft, The Netherlands.

Vreeburg, J.H.G., Blokker, E.J.M., Horst, P., Van Dijk, J.C., 2009. Velocity-based self-cleaning residential drinking water distribution systems. Water Science and Technology: Water Supply 9 (6), 635-641.

Appendix I Minutes of meeting on March 2013

Aanwezig:

Jan Peter van der Hoek, Sanne Hillegers, Marc Balemans, Tim Bongard, Henk Vogelaar; Mirjam Blokker, Jan Vreeburg, Andreas Moerman en Claudia Agudelo

Doelen van de workshop:

- Selectie van de scenario's
- Bepalen van de beoordelingscriteria voor de scenario's
- Definitie van eisen aan de voorbeeldcases
- Vaststellen van tijd/activiteiten voor het projectvoorstel

Agenda

- Inleiding / Kennismaking deelnemers
- Brainstorm over de scenario's
- Discussie en selectie van de scenario's voor de studie
- Discussie en selectie van beoordelingscriteria en eisen aan de cases
- Planning (maart t/m september)
- Begin september technische discussie en eind september bredere workshop over uitkomsten en discussie over vervolgvragen
- Wrap-up

Ouput

1. Er is een korte inleiding over de vorige vergadering en korte kennismaking.

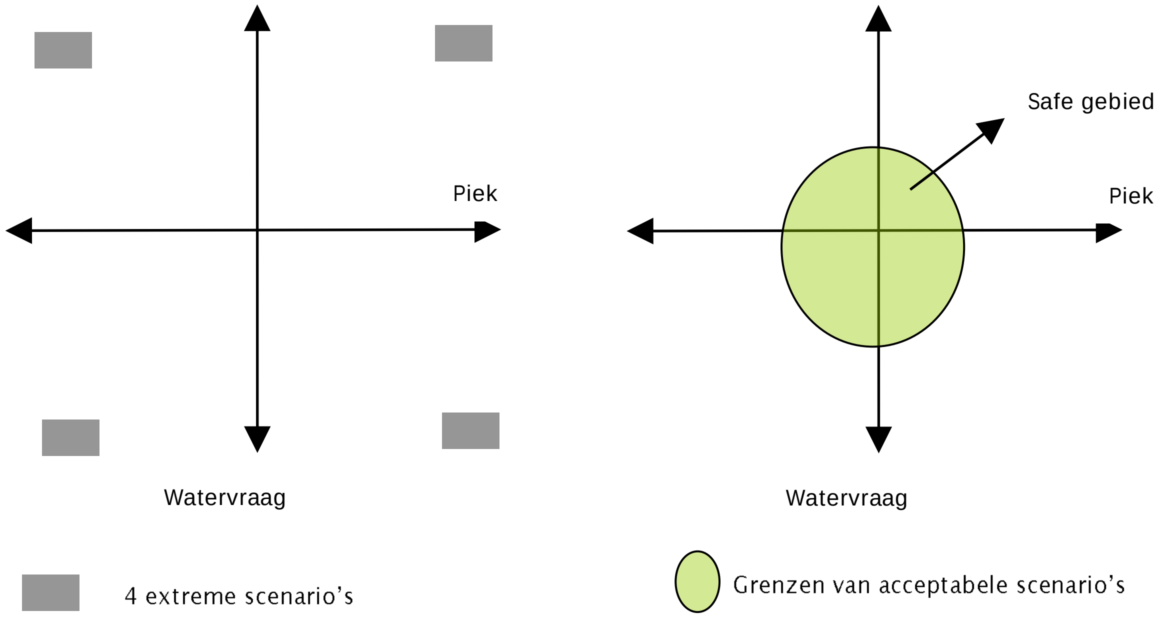
Jan Peter van der Hoek	Waternet
Sanne Hillegers	Waternet
Marc Balemans	WML
Tim Bongard	WML
Henk Vogelaar	WML
Mirjam Blokker	KWR
Jan Vreeburg	KWR
Andreas Moerman	KWR
Claudia Agudelo	KWR

2. De eerste stap van de brainstorm was om verschillende factoren te identificeren (noemen) die een rol spelen in de toekomstscenario's. Er is een lijst met de factoren gemaakt. In de tweede stap is elke factor uitgelegd als dat nodig was.

Factoren	Opmerkingen
Nieuwe sanitatie	Invloed op watervoorziening
Ondergrens van het systeem	Schatten wanneer er een probleem is. Wanneer is het systeem te groot geworden (als dat ooit gebeurd) – Operationeel (Kwantitatief).
Waterkwaliteit	Gerelateerd aan waterkwantiteit
Waterbesparing	
Eco-design	Trends of regel vanuit EU (Brussel). Minder elektriciteit, water en materialen.
Afhaken industrie	Zelfproducent (bedreigen, als een grote gebruiker is)
Off the grid	Autarkisch wonen – mensen die zelf controle willen
Rol van waterbedrijf	Proactief vs. reactief, of vragen aan de consumenten wat zij willen en meedoen
Nieuwe luxe en waterbeleving	Trend waterketen
Waterketen / samenwerking	Ook met andere netbeheerders
Decentraal	Technische oplossingen
Oude infrastructuur	Kansen voor renovatie
Nieuwe technologie	In het algemeen
Klimaatveranderingen	
Regelgeving	Nationaal en internationaal, normen bv. Lekverliezen.
Organisatieschaal	
Demografisch	Regionale krimp
Snelkoppeling	Losse componenten
Politieke invloed	Belasting, waterketen
Druk in de ondergrond	Onderhoud, beheer, andere netwerken. Als er transitie is, moet je rekening houden met de gevolgen voor de ondergrond
Privatisering	
Klant verwachting 365 dagen/24 uur /	Voorspelbaarheid
Normen	
Aantal drinkwaterbedrijven	
Duurzaamheid, milieu	
Kosten	Niet met kosten beginnen, maar als laatste.
Internationalisering	Voor VML: invloed van de grenzen met België of Duitsland
Vakmanschap	Kwaliteitsnormen, kwaliteit van werk
Sociale media	2-way info
IT	Monitoren, sensoren
Gevaar van buiten af kansen/innovatie	

Na de brainstorm was er een korte presentatie van Mirjam Blokker over “wat is al gedaan aan analyse van toekomstscenario’s”. (zie bijlage)

3. Voor de selectie van de scenario’s werd eerst gediscussieerd over te verwachten resultaten. Er is gekozen voor een benadering, waarbij de grenzen van de flexibiliteit worden gezocht door in een case studie de toelaatbare combinaties van verbruikspatronen te bepalen. Een verbruikspatroon wordt bepaald door de pieken en het totaal. Als volgt ontstaan de volgende figuren, waarbij het nulpunt wordt bepaald door de huidige patronen.



Er is besloten om de grenzen te bepalen, en daarna met backcasting de scenario's te construeren.

Als casestudy worden per bedrijf twee gebieden gebruikt max. 1000 aansluitingen. Vier opties per bedrijf zullen geanalyseerd worden: Conventioneel en zelfreinigend, beide nu en in de toekomst.

1. Conventioneel (vermaasd) net
2. Zelfreinigend (vertakt) net: bestaand of constructie

Andere factoren, zoals bluswater zullen in kaart worden gebracht tijdens de backcasting. In een scenario wordt bepaald welke levering mogelijk is (bijvoorbeeld ook een scenario met woningsprinklers)

4. Criteria voor de evaluatie van de scenario's zijn:

- Waterkwaliteit waarvoor zogenaamde surrogaatparameters worden gebruikt: in de vorm van Verblijftijd (Gemiddeld en maximaal)
- Maximale snelheid / druk
- Mediaan snelheid
- Leveringszekerheid
- Leveringscontinuïteit


Case studies
Criteria
Tot waterweg
Case studies
Regionale ontwikkeling
Zelfreinigend net
Transitie trajecten
onzekerheden
Sec

Appendix II Minutes meeting on 2nd meeting July 2013

Vergadering: SPO Toekomstbestendigheid drinkwaterinfrastructuur

Vergadering nummer: 2

Secretaris: Mirjam Blokker

Datum: 1 juli 2013

Stuknummer:

Aanwezig: Marc Balemans, Tim Bongers (WML), Jan Peter van der Hoek, Sanne Hilligers, Job Rook (Waternet), Claudia Agudelo, Andreas Moerman, Jan Vreeburg, Mirjam Blokker (KWR)

CC: Henk Vogelaar (WML)

1. Presentatie van resultaten: scenarioanalyse

Claudia heeft de resultaten gepresenteerd. De presentatie is bijgevoegd.

2. Bespreking van resultaten

Wat valt op?

- Er zijn geen algemeen geldende uitspraken over wat het effect van een bepaald scenario (bijv. ecosanitatie) is; dit moet per wijk worden doorgerekend.

- De netten zijn heel robuust, zelfs een geheel vertakt leidingnet is voldoende robuust om alle verbruiksscenario's "aan te kunnen". Dit is een positief tegengeluid op het "we vervangen niet genoeg"-verhaal.

- Het verschil tussen Sittard vermaasd en vertakt in lengte en leidinginhoud is zeer interessant, misschien wel interessanter dan de verschillen in waterkwaliteit (verblijftijd, zelfreinigende snelheid).

- Het vertakte net is ontworpen voor de situatie van nu, maar kan ook prima een scenario met meer verbruik aan, er zijn geen extra marges nodig (geen grotere diameters). Dat betekent dat je heel goed een blauwdruk kunt maken voor een te saneren net en daar in de loop van jaren naar toe kunt werken tijdens saneringen. Eventueel kan worden gemonitord hoe het waterverbruik veranderd en na 10 jaar kan de blauwdruk worden gefinetuned.

- Het is niet nodig om de toekomstscenario's heel exact te kennen. Met de hele range aan mogelijke scenario's kan de robuustheid van het net worden ingeschat, en over het algemeen is er voldoende marge.

- Een vraag voor Marc was "moeten we ons net anders gaan ontwerpen?". Het antwoord is wat hem betreft tweeledig:

  - o Ja, vertakt aanleggen, en dan geen concessies doen.

  - o Nee, je hoeft geen rekening te houden met alle onzekerheden in toekomstig waterverbruik, het systeem is behoorlijk robuust.

- Een stresstest uitvoeren voor het leidingnet is zinvol. Het geeft antwoord op de vraag of een lokaal leidingnet voldoet voor denkbare scenario's. Het geeft tevens aan waar eventuele aandachtspunten zitten om met een monitoringsprogramma in de gaten te houden.

- "Rekenen is de moeite waard": de leidingen kunnen kleiner en korter en zijn dan nog voldoende robuust/flexibel om de nu denkbare toekomstige ontwikkelingen het hoofd te bieden.

3. Discussie voortgang van het project

De voortgang van het project is goed. De resultaten geven goed antwoord op de vragen van het project.

4. Discussie follow-up activiteiten

- Extra scenario's:

  - o de situatie "nu" met 30% leegstand van woningen, willekeurig verdeeld over de wijk. Reken alleen Sittard door.

  - o Proeftuin Amsterdam-Noord. Hier worden veranderingen voorgesteld die een verandering van watervraag tot gevolg hebben. Voorstel is om eerst te kijken of de veranderingen vallen in de range van de scenario's die al meegenomen zijn, of dat het een toevoeging is. In dat laatste geval wordt dit scenario ook doorgerekend.

  - o Zeeburgereiland. Hier worden aanpassingen gedaan in de afvalwatervraag, welke mogelijk ook een gevolg hebben voor de drinkwatervraag. Voorstel is om eerst te kijken of de veranderingen vallen in de range van de scenario's die al meegenomen zijn, of dat het een toevoeging is. In dat laatste geval wordt dit scenario ook doorgerekend.

  - o In dit kader kan bijvoorbeeld worden gedacht aan de afvoer van groenafval via het riool. Kost wat meer drinkwater, maar is energiezuiniger dan vervoer met vrachtwagens, en beter voor RWZI, en de drinkwaterinfrastructuur kan het prima aan (en wordt mogelijk zelfreinigender bij meer verbruik).

  - o Scenario's die de overgang van bijvoorbeeld NU naar 100% luxe douches weergeven lijken minder zinvol. De verschillen tussen de scenario's zijn niet zo groot dat de overgangen meer inzicht opleveren dan de extremen die we nu kennen.

- Wat is het effect op het riool? Kunnen we een project opzetten dat daar naar kijkt? De ideeën voor hoe een riool beter ontworpen kan worden (zelfreinigend, met pompen aan begin in plaats van zuigers aan het eind, etc.) en methodiek (afvoerpatronen door SIMDEUM, leidingnetberekeningen voor vrijvervalsystemen) zijn zeker binnen handbereik. Mogelijkheden zijn speerpuntonderzoek, BTO, DPW, TKI. Binnen Waternet is wellicht een proefproject mogelijk om ook de ontwerpregels voor riolen kritisch te beschouwen. Een renovatieproject waarbij zowel 30% bespaard kan worden op de lengte als de inhoud van het waterleidingnet wordt nog interessanter als eenzelfde besparing kan worden bereikt op de riolering.

- Grenzen stellen aan de parameters (verblijftijd, druk, zelfreininging, ...) kan relatief (maximaal x% erger dan nu) of absoluut (maximaal y uur verblijftijd). Hoe kunnen we dat bepalen?

    - Wettelijk is er alleen een eis aan druk. Meest kosteneffectief is eventueel te lage druk op te lossen door een bovenstroomse drukverhoging dan door leidingen te vervangen door een met een grotere diameter.

    - Je zou ook kunnen denken aan een schakering van groen (veilig) naar oranje (monitoren wat er gebeurt) naar rood (waar je niet terecht wilt komen).

    - In het DPW-project (van de duinwaterbedrijven) naar datamining van waterkwaliteitsdata in combinatie met leidingnetmodellen komt een methodiek naar voren om per voorzieningsgebied (waterkwaliteit af pompstation is namelijk een belangrijke randvoorwaarde) te bepalen wat de maximale verblijftijd is.

- Beschrijf hoe de waterbedrijven de stresstest moeten doen, waar moet je wel en niet rekening mee houden? Met behulp van de Simdeum Patronengenerator (SPG) kunnen de bedrijven zelf de scenario's doorrekenen, KWR kan de SPG-scripts meeleveren. Wanneer ontwikkelingen gemonitord worden, wanneer is dan de tijd (wanneer is het zinvol) om een stresstest te gaan doen? Bijvoorbeeld om de vraag "kan het net het aan als iedereen een powerdouche neemt?" te beantwoorden. Daarbij komt ook de vraag om de hoek kijken hoe je eventueel gedrag van klanten kunt beïnvloeden.

- Een andere waterkwaliteitsparameter die interessant kan zijn, is de temperatuur. We besluiten deze niet verder te bekijken in dit project.

    - De temperatuur in het tertiaire net wordt bepaald door de temperatuur die uit het secundaire net komt (ongeveer gelijk aan de bodemtemperatuur op 1 m diepte) en de bodemtemperatuur van het tertiaire net. In het speerpuntonderzoek van Brabant Water (Tertiaire net van de toekomst) wordt gekeken naar het effect van leidingen minder diep (60 cm) leggen, met name de temperatuur in de zomer wordt hier meegenomen.

    - In het TKI-project Calorics (waar Waternet ook in deelneemt) wordt gekeken naar de mogelijkheid om de transportleiding te koelen en zo te zorgen dan het water het secundaire en tertiaire net koeler binnenkomt. Het effect op temperatuur, maar met name ook het effect op temperatuurafhankelijke nagroei wordt hier gemodelleerd.

- Een andere parameter die iets zegt over de prestatie (en mogelijk robuustheid) van het leidingnet is OLM. Deze is echter niet afhankelijk van de (verandering in) watervraag en valt daarmee buiten de scope van dit project. Tussen het vertakte en vermaasde ontwerp van Sittard zal wel een verschil in OLM optreden, o.a. door de kortere lengtes en mogelijk grotere secties.

- Rapportage: we willen de methodiek graag internationaal publiceren. We mikken op “Water Research”.

- We willen de resultaten graag delen met een groter publiek. Het zou mooi zijn om dat ook te doen in het licht van de resultaten van aanverwante onderzoeken, zoals bijvoorbeeld het SPO van Brabant Water naar het tertiaire net van de toekomst en het project Calorics. Een datum voor zo een “minisymposium”, bijvoorbeeld in november, moet wel zo snel mogelijk worden vastgelegd.

5. Rondvraag

De meeste items van de rondvraag zijn hierboven al opgenomen in het verslag. Daarnaast nog de melding dat Jojanneke Dirksen op 5 juli haar proefschrift verdedigt dat gaat over verzakkingen van riolen.

Appendix III Input data for SIMDEUM

Table 1 Forecasted household statistics in future scenarios in the Netherlands. In grey the differences with 2004 (Blokker et al. 2010).

			One person households				Two person households				Families with children			
			RC	SE	GE	TM	RC	SE	GE	TM	RC	SE	GE	TM
Number of people per household			1				2				3.7	3.9 (on average)		
Number of households (%)			35	42	52	48	29	27	22	27	36	31	25	25
Gender division: Male / Female (%)			46 / 54				50 / 50				50 / 50			
Age division (%)	Children (0-12 years old)		0				0				12	24	27	28
	Teens (13 – 18 years old)		0				0				13	14	16	16
	Adults (19 – 64 years old)		38	46	54	51	38	46	54	51	64	61	57	56
	Subdivision: % of adults with out-of-home job	Both persons	n.a.				45	52	68	57	54	56	63	60
		Only male adult	64	65	68	66	28	22	8	15	36	34	31	31
		Only female adult	56	58	65	64	10	9	9	11	5	5	3	4
		Neither person	n.a.				17	16	16	18	6	6	4	5
	Seniors (> 65 years old)		62	52	46	49	62	52	46	49	0			

Table 2 Forecasted penetration rate or occurrence per end use in future scenarios in the Netherlands. In grey are the differences with 2004 (Blokker et al. 2010).

End-use type	Penetration rate (%) in households	End-use subtype	Penetration rate (%) within end-use						
			RC	SE	GE	TM	DP	Eco	Eco+
Bathtub	36	120 litres	100.0						100.0
Bathroom tap	100	Washing and shaving	33.0						33.0
		Brushing teeth	67.0						67.0
Dishwasher	65	14 L per washing cycle	100.0						-
		1 L per washing cycle	-						100.0
Kitchen tap	100	Consumption (drinking water, water for cooking)	100.0				SE		100.0
		Dishes and cleaning	33.0						33.0
		Washing hands	67.0						67.0
		Other (e.g., watering plants)	100.0						100.0
Outside tap	see subdivision	Garden watering by hand	35.0	35.0	20.0	25.0		-	-
		Garden watering by automatic sprinkler system	35.0	35.0	45.0	40.0	RC	-	-
		Washing car	35.0	35.0	65.0	65.0		-	-
		Other	35.0	35.0	65.0	65.0		-	-
Shower	100	Shower w/o water-saving shower head (0.142 L/s)	46.2	27.3	21.4	37.5		-	-
		Shower w/ water-saving shower head (0.123 L/s)	46.2	68.2	68.2	56.3		100.0	-
		Luxury shower (0.2 L/s)	7.7	4.5	14.3	6.3		-	-
		Recirculation shower 25 L (0.123 L/s)	-	-	-	-		-	100.0
Washing machine	99	50 L per washing cycle	100.0	90.0	70.0	80.0		90.0	-
		42 L per washing cycle	-	10.0	5.0	20.0		10.0	-
		35 L per washing cycle	-	-	25.0	-		-	-
		1 L per washing cycle	-	-	-	-		-	100.0
WC	100	Small cistern (6 L), with	95.0	95.0	90.0	95.0		-	-

End-use type	Penetration rate (%) in households	End-use subtype	Penetration rate (%) within end-use						
			RC	SE	GE	TM	DP	Eco	Eco+
		water saving option*							
		Japanese toilet (8 L), with water saving option*	-	-	10.0	-		-	-
		Alternative sanitation toilet (1L)	-	2.5	-	2.5		100.0	100.0
		Grey water toilet	5.0	2.5	-	2.5		-	-

* When a water-saving option is available, it is applied in 80% of the flushes

Table 3 Forecasted statistics for diurnal patterns in future scenarios in the Netherlands. In grey the differences with 2004 (Blokker et al. 2010).

		Weekend day	Weekday							
			Child	Teen	Adult without out-of-home job	Senior	Adult with out-of-home job			
							RC	SE	GE	TM
Time of getting up	μ	9:00	7:00	7:00	8:00		7:10	6:50	7:00	6:50
	σ	1:30	1:00	1:00	1:00		1:00	1:00	1:15	1:00
Time of leaving the house	μ	13:00	8:30	8:15	13:00		8:10	7:50	8:00	7:50
	σ	3:00	0:30	0:30	3:00		0:45	0:45	1:00	0:45
Duration of being away	μ	10.0 h	7.0 h	8.0 h	10.0 h		9.5 h	10.0 h	10.0 h	9.75 h
	σ	4.5 h	2.0 h	2.0 h	4.5 h		2.5 h	3.25 h	3.5 h	3.25 h
Duration of sleep	μ	9.0 h	10.0 h	9.0 h	8.0 h		7.0 h			
	σ	1.5 h	1.0 h	1.0 h	1.0 h		1.0 h			

Appendix IV Identification of non-residential connections – Ijburg

To identify the location of non-residential connections in the IJburg network, cadastral information was used: http://bagviewer.pdok.nl/. Here the results for the query sport and education (onderwijs).

Appendix V – Results for the four network analisys

Table 1 Overview results for Bemenrijk

	Demand m³/dag	peak (m³/h)	Age (dag)	head loss(m)
Now	203,6	16,7	2,9	1,79
Eco	173,5	14,8	3,0	1,74
GE	190,2	17,1	2,9	2,52
GE+	239,2	20,4	2,6	3,24
Lux	230,3	19,8	2,6	4,16
Dual	126,0	13,0	3,0	1,74
RC	155,9	14,1	3,0	1,44
SE	170,9	15,9	3,0	1,60
TM	183,6	16,7	3,0	1,01
Pr	166,6	14,7	3,0	1,74
Pr+leak	203,7	16,3	2,8	1,77
Min	126,0	13,0	2,6	1,0
Max	239,2	20,4	3,0	4,2
Max % increase	17,5	22,0	2,2	131,9
Max % reduction	-38,1	-22,5	-12,2	-43,9

Table 2. Overview results for IJburg

	m³/dag	piek (m³/h)	Age (dag)	head val(m)
Now	117.0	10.3	1.8	0.35
Eco	101.7	9.3	2.5	0.30
GE	112.6	10.4	2.3	0.46
GE+	123.5	11.5	2.2	1.10
Lux	122.5	11.6	2.3	0.49
Dual	73.9	7.3	2.8	0.52
RC	91.3	8.2	2.6	0.78
SE	94.7	8.9	2.6	0.43
TM	103.0	9.3	2.4	0.40
Pr	98.2	9.1	2.5	0.72
Pr+leak	115.6	9.8	2.3	0.73
Min	73.9	7.3	1.8	0.3
Max	123.5	11.6	2.8	1.1
Max % increase	5.6	12.9	53.9	211.6
Max % reduction	-36.8	-28.5	0.0	-15.7

Table 3 Overview results for Sittard Looped

	m³/dag	piek (m³/h)	Age (dag)	head val(m)
Now	358.4	27.6	2.2	0.71
Eco	274.2	22.0	2.4	0.47
GE	308.3	25.1	2.3	0.53
GE+	354.7	30.3	2.0	0.95
Lux	421.8	32.5	1.6	0.89
Dual	170.1	15.8	3.0	0.35
RC	247.8	20.2	2.5	0.43
SE	265.9	21.7	2.6	0.42
TM	276.4	22.9	2.6	0.57
Pr	265.1	22.4	2.5	0.52
Pr+leak	316.1	23.3	2.0	0.70
Min	170.1	15.8	1.6	0.3
Max	421.8	32.5	3.0	1.0
Max % incres	17.7	17.6	36.3	34.7
Max % reduction	-52.6	-42.7	-25.2	-50.4

Table 4 Overview results for Sittard Branched

	Demand m³/dag	peak (m³/h)	Age (dag)	head loss(m)
Now	359.2	28.1	0.9	1.9
Eco	279.1	22.5	1.3	1.1
GE	305.9	25.0	1.1	1.4
GE+	359.8	29.6	1.0	1.6
Lux	416.2	34.6	0.9	1.9
Dual	170.8	15.7	1.9	0.6
RC	245.0	20.2	1.4	1.0
SE	260.9	21.4	1.2	0.9
TM	278.5	23.9	1.3	1.2
Pr	263.7	21.7	1.5	1.1
Pr+leak	311.5	23.2	1.1	1.0
Min	170.8	15.7	0.9	1.9
Max	416.2	34.6	1.9	0.6
Max % increase	15.9	23.1	110.9	4.1
Max % reduction	-52.5	-44.1	-2.7	-69.6