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PREDICTING THE IMPACT OF CLIMATE CHANGE ON PIPE FAILURE IN DRINKING WATER DISTRIBUTION SYSTEMS.

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Underground water infrastructure can be vulnerable towards climate change. In previous research, correlations between weather parameters and pipe failure rates in the drinking water distribution systems (DWDS) of the Netherlands were found. Using the statistical relations between pipe failure frequencies and weather conditions, a methodology is proposed to assess the effect of climate change on the integrity of DWDSs. As the time scales of climate change are in the order of 50 years, the methodology has been set up to also incorporate the evolution of the DWDS.

INTRODUCTION

Underground water infrastructure is designed to withstand a variability of forces during its lifetime before failure occurs. As a result of variations in loads on and deterioration of the pipe, early failures may occur. Climate change may accelerate or decelerate these processes, and is therefore relevant for maintenance decisions on the drinking water distribution system (DWDS). There is a lack of knowledge on quantitative relationships between climate change and asset deterioration (UKWIR, 2012). Recently, we performed a statistical analysis of the effects of weather parameters on pipe failure (Wols and van Thienen, 2014). The weather parameters temperature and drought were recognized as most influential on pipe failure. Based upon failure data of a large part of the Dutch drinking water network, a weather parameter dependent pipe failure frequency could be determined. A model has been introduced to predict future pipe failure rates under changing weather conditions. In the current work, these results are used to assess the impact of climate change (long-term weather variations) on pipe failure. A clear graphical presentation of the impact of climate change on a distribution network is proposed that also considers the evolution of the drinking water distribution network (changes in material composition). Also, the effect of ageing of the pipes is considered in the modelling.

METHODOLOGY

Weather data was collected from KNMI (Royal Netherlands Meteorological Institute), for the weather station De Bilt located in the center of The Netherlands. Data was collected on a daily basis. Future weather data under various climate scenarios were also obtained on a daily basis using the climate explorer tool developed by KNMI (Trouet and Van Oldenborgh 2013). Four different climate scenarios defined by KNMI (van den Hurk et al. 2006) were considered in this study: moderate (G), moderate plus changes in wind circulations (G+), warm (W) and warm plus changes in wind circulation (W+). The historical weather pattern of 1976-2005, which is representative for the climate of 1990 was used as a reference. For the different climate scenarios these historical patterns were transformed (online tool KNMI climate explorer) into a pattern representative for the climate of 2050 (daily pattern over the period 2036-2065) and 2100 (daily pattern over the period 2086-2115). We used these daily patterns to obtain a probability density function of a weather variable for the different climate scenarios in 2050 and 2100 (Figure 1).

The failure frequency as a function of a weather variable (e.g. temperature) has been determined in Wols and van Thienen (2014). This weather dependent failure frequency is combined with the expected weather variable distribution to predict pipe failure for a specific climate scenario.

Next to the effects of climate change, ageing will also influence pipe failure. Ageing of the pipes is modelled as an exponential increase in pipe failure as a function of age, which was fit to historical failure data. The evolution of the network is determined from a specific replacement strategy (for example in The Netherlands, a replacement strategy is assumed according to a triangular distribution: the replacement starts at an age of 80 years, with a peak at an age of 100 years, and all material should be replaced at 140 years. In addition to that, also every year 0.5% of the pipes are replaced irrespectively of age.). The climate specific effect is combined with the evolution of the network to make predictions of pipe failures in future distribution networks.

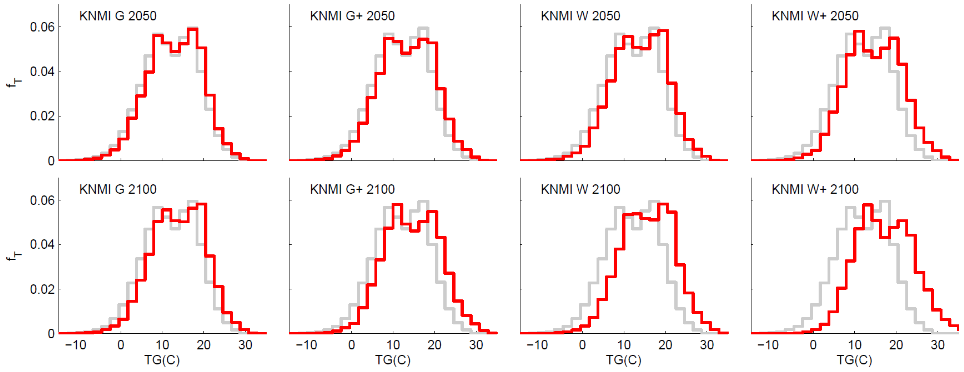

Figure 1. Distribution of daily mean temperature (calculated over a 30 year periods) for different climate scenarios in the year 2050 (daily pattern over the period 2036-2065) and 2100 (daily pattern over the period 2086-2115). The reference distribution (1976-2005) is shown by the grey line

RESULTS

Previous research showed that ambient temperature is the most influencing weather parameter, followed by antecedent precipitation index (drought) (Wols and Van Thienen, 2014). Since drought is also strongly correlated with temperature, the predictive model developed here only considers the expected change in ambient temperature.

Different pipe materials react differently towards climate change. We considered the three most commonly used pipe materials in the Netherlands, namely PVC, AC (asbestos-cement) and GCI (grey cast iron). Table 1 shows the predicted change in pipe failure rates in 2050 and 2100 as a result of climate change for the different pipe materials for the four climate scenarios. The largest increase in pipe failure can be observed for AC pipes, which show a strong increase at high ambient temperatures (hot summers). PVC and GCI are most vulnerable to low temperatures. Therefore, as a result of climate change, a slight decrease is observed for PVC pipes, and a larger decrease is observed for GCI pipes due the lower incidence of cold periods. The changes are most severe for the W+ scenario, which is the scenario with the strongest increase in temperature. The effects seem to become stronger in the period 2050-2100 than the period 2010-2050, probably due to an expected acceleration of climate change in this period.

Table 1. Current and predicted failure frequency (#/km/year) under different climate scenarios in 2050 and 2100.

	Current	G 2050	G+ 2050	W 2050	W+ 2050
AC	0.064	0.065 (+2%)	0.066 (+4%)	0.067 (+5%)	0.069 (+9%)
PVC	0.013	0.013 (-2%)	0.013 (-2%)	0.013 (-3%)	0.013 (-4%)
GCI	0.032	0.030 (-7%)	0.029 (_9%)	0.028 (-13%)	0.027 (-16%)
	Current	G 2100	G+ 2100	W 2100	W+ 2100
AC	0.064	0.067 (+5%)	0.069 (+9%)	0.072 (+13%)	0.078 (+23%)
PVC	0.013	0.013 (-3%)	0.013 (-4%)	0.013 (-6%)	0.012 (-9%)
GCI	0.032	0.028 (-13%)	0.027 (-16%)	0.025(-23%)	0.024 (-26%)

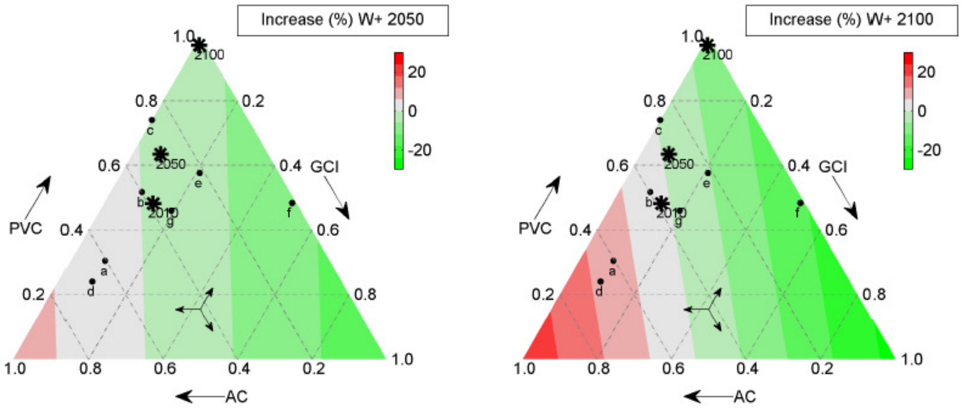

Figure 2. Ternary plots of joint (left) and pipe (right) failure: the three sides show the fraction of each pipe material in the distribution network. The colors show the increase in failure due to climate change for the different scenarios. The stars show the Dutch drinking water distribution network of today and the future.

Assessment of drinking water distribution system

From the results of the individual pipe materials, ternary plots are constructed (Figure 2). In these plots, the increase in pipe failure as a result of climate change can be read for an arbitrary drinking water distribution network that is composed of these three materials. This has been done for the most severe climate change scenario (W+) expected in the Netherlands in 2100. Pipe and joint failure frequencies increase if the AC amount in the network increases, the opposite occurs for GCI. Climate change will result in higher failure frequencies for networks with high AC amounts, and lower failure frequencies for networks with high GCI amounts. Lowest failure frequencies will occur for networks with high PVC amounts, which will even slightly decrease due to climate change.

The model is applied to about half of the Dutch drinking water distribution network. Using the above mentioned replacement strategy, the evolution and age of the network is determined (Figure 3). Evolution and age is combined with climate change to model future pipe failure in the Dutch network. The expected failure frequencies for the different climate scenarios are shown in Table 2. Failure frequencies increase up to 2050 due to ageing of the remaining AC and GCI pipes, and the effect of climate change on AC pipes. In 2100 failure frequencies will decrease as most of the network will consist of PVC, which has a lower absolute failure frequency and is almost insensitive towards climate change.

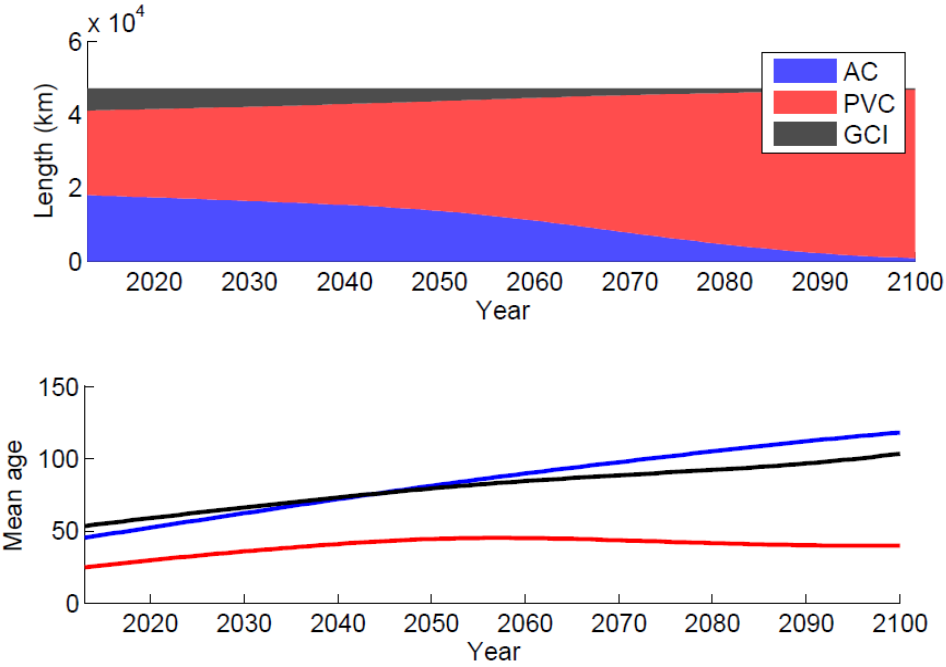

Figure 3. Evolution (upper panel) and mean age (lower panel) of the considered DWDS.

Table 2. Current and predicted failures in Dutch distribution network, if the network remains the same (current network) or if most of the AC and GCI pipes are replaced by PVC (future network)

Scenario	Frequency (#/km/year)	Difference with current climate (%)
Current 2010	0.0294	-
Current 2050	0.0630	-
Current 2100	0.0407	-
G 2050	0.0632	0.3
G+ 2050	0.0636	1.0
W 2050	0.0638	1.4

W+ 2050	0.0649	3.1
G 2100	0.0400	-1.8
G+ 2100	0.0398	-2.1
W 2100	0.0396	-2.6
W+ 2100	0.0394	-3.1

CONCLUSIONS

The presented analysis points out the vulnerability of existing and future DWDSs towards climate change. This analysis can be conducted for any DWDS, for which historical failure registrations and weather parameters are available. The proposed methodology can therefore assist in the construction and maintenance planning of DWDSs, particularly in the context of climate change adaptation. In this work, the methodology has been worked out for and applied to the Dutch drinking water distribution network.

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