

The efficiency of asset management strategies to reduce urban flood risk

J. A. E. ten Veldhuis and F. H. L. R. Clemens

ABSTRACT

In this study, three asset management strategies were compared with respect to their efficiency to reduce flood risk. Data from call centres at two municipalities were used to quantify urban flood risks associated with three causes of urban flooding: gully pot blockage, sewer pipe blockage and sewer overloading. The efficiency of three flood reduction strategies was assessed based on their effect on the causes contributing to flood risk. The sensitivity of the results to uncertainty in the data source, citizens' calls, was analysed through incorporation of uncertainty ranges taken from customer complaint literature. Based on the available data it could be shown that increasing gully pot blockage is the most efficient action to reduce flood risk, given data uncertainty. If differences between cause incidences are large, as in the presented case study, call data are sufficient to decide how flood risk can be most efficiently reduced. According to the results of this analysis, enlargement of sewer pipes is not an efficient strategy to reduce flood risk, because flood risk associated with sewer overloading is small compared to other failure mechanisms.

Key words | asset management, sewer blockage, urban flooding

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INTRODUCTION

In recent years, increased media attention for urban flood incidents and uncertainties in climate change predictions, have inspired discussions among urban drainage managers about the need for investments in sewer systems to improve urban flood prevention. The objective of the study presented in this paper is to evaluate asset management strategies for urban flood reduction based on risk assessment. Thus, the efficiency of strategies to reduce flood risk can be assessed. This paper focuses on three asset management strategies: gully pot cleaning, sewer pipe cleaning and sewer enlargement. First, existing asset management strategies are briefly described. Then urban flood risks are quantified for two case studies, based on data from call centres reporting flooding incidents. The results for the two case studies are compared and the effects of differences in asset management strategies between the two case studies are evaluated. Finally, the effects of investments to reduce flood risk are quantified for three asset management strategies based on a decision making example for one of the two case studies.

Current strategies to control urban flood risk

Sewer overloading is commonly dealt with by defining a design standard for flooding frequency, usually once per year or per 2 years in The Netherlands (RIONED 2004). Compliance with this standard is checked by mostly unvalidated model calculations conducted in the design stage. Calculations are repeated approximately every 10 years. If according to these calculations sewer flooding frequency exceeds the design standard, an improvement measure is designed and implemented following a preventive approach. If model results are not trusted or if insufficient budget is available, improvements are postponed or cancelled. Besides the preventive approach, complaints from citizens about flooding may form a reason to react and implement structural improvements. Sewer blockage is tackled in two ways: by sewer cleaning following inspection and upon citizens' complaints. Sewer inspection frequencies are usually of the order of once every 10 years, therefore the potential detection rate of blockage by inspection is low.

When blockages occur in the period between inspections and lead to flooding, these are resolved only if citizens complain about the flooding. Since most sewer systems in the Netherlands are looped networks, pipe blockage normally leads to flooding in the main transport routes and where local transport capacity is critical. Gully pots are sewer inlets placed along street gutters that collect runoff from streets and pavements into a small chamber that has a connection to the main sewer system. Some settlement of sand and leaves that are transported with the runoff water takes place in the chambers. The gully pot chambers are usually cleaned once a year; vulnerable locations like market places and shopping streets are often cleaned 2 or 4 times yearly. In addition, gully pots are cleaned upon complaints, usually within a maximum period of 1 or 2 weeks after the complaint was made.

METHODS

Urban flood incident data

Data on urban flood incidents were obtained from municipal call centres that register information from citizens' calls about observed flood problems and ensuing information from technical staff after on-site investigation. Sewer inspection data were not used, since data sets were small and inspection data have proved to be unreliable (Dirksen *et al.* 2007). Call data from the cities of Haarlem and Breda were analysed to detect characteristics of failure processes for the three failure mechanisms described in the introduction. Table 1 summarises characteristics of the sewer systems and maintenance regimes for the two cities. A detailed account of the characteristics and processing of call data and rainfall data and influence of data uncertainty can be found in ten Veldhuis (2010).

Probabilistic risk analysis

Occurrence of flooding was evaluated in terms of flooding frequencies and flood risk related to various groups of consequences: flood risk associated with flooding in buildings, flooding of roads and the total of all flooding consequences, including the former two and flooding of parking lots, sidewalks, gardens, etc. Flooding frequencies were drawn from incident occurrences over the period of available data. Flood risk was quantified by multiplication of incident occurrence probability by average number of locations per incident. The average number of locations per incident was assumed to be equal to the average number of calls

Table 1 | Summary of data for the cities of Haarlem and Breda

	Haarlem	Breda
<i>Data case study</i>		
Number of inhabitants	147,000	170,000
Length of sewer system (% combined)	460 km (98%)	740 km (65%)
Diameter range of sewer pipes	200–1,500 mm	200–1,850 mm
Total surface connected to sewer system	1,110 ha	1,800 ha
Total number of gully pots	42,500	80,000
Gully pot	0.05–0.2 m ³	0.05–0.2 m ³
Maximum ground level variation	20 m	10 m
Rainfall data (min–max, mm/ day)	0.1–51.5 mm	0.1–108 mm
<i>Maintenance regime</i>		
Gully pot cleaning	1 × /year + upon calls	1 × /year + upon calls
Sewer cleaning (% of total sewer length)	62 km/yr (13%)	65 km/yr (6%)

per incident; this generalisation holds for 95% of all incidents.

$$R = P(\text{flooding}) * \bar{C} \quad (1)$$

where R : risk of flooding in amount of flood locations in period of time t ; $P(\text{flooding})$: probability of flooding in period of time t ; \bar{C} : average consequence of flooding incidents expressed as the number of locations per incident: total number of calls divided by total number of flooding incidents.

Efficiency of asset management strategies for flood risk reduction

Quantitative risk analysis results for the case of Breda were used to assess the efficiency of asset management strategies for flood risk reduction. Additionally, the reliability of the results was analysed to evaluate whether call data can be used to draw reliable conclusions as to what asset management strategy is most efficient. Three possible strategies to reduce flood risk were compared: increasing sewer capacity to reduce sewer overloading, increasing sewer cleaning frequency to reduce sewer blockage and increasing gully pot cleaning to reduce blockage. Based on van Wiechen *et al.* (2002) and Devereux & Weisbrod (2006), the expected percentage of citizens who make a call out of the total

number of citizens who observe unsatisfactory conditions was estimated between 2 and 30%. These percentages were used to establish a bandwidth of true flood incidents based on received call data. The effects of flood risk reduction actions were estimated based on available data for the two case studies and expert judgment where insufficient data were available to quantify the effect of actions, as is the case for gully blockage.

RESULTS AND DISCUSSION

Urban flood risk derived from call data reporting flood incidents

Tables 2 and 3 give the results of call data analysis for 3 failure mechanisms: 'gully pot blockage', 'sewer pipe blockage' and 'sewer overloading', for the cases of Haarlem and Breda. Classification results are shown for all types of flooding consequences combined and for flooding in buildings separately. Tables 2 and 3 show that calls which explicitly report flooding-related consequences make up 25% of all calls for Haarlem and 38% for Breda. A small portion of these calls report flooding in buildings. The results for

flooding in buildings were analysed separately, because these are severe consequences compared to flooding of streets and parks. According to the call texts, flooding of roads never caused traffic disruption or damage, probably because both case study areas are more or less flat. For both cases, gully pot blockages occur far more often than the other two failure mechanisms. The amount of calls per incident is also higher for gully pot blockages, indicating that more locations are affected per incident. Sewer overloading rarely leads to flooding in buildings. The same applies for sewer blockage in Haarlem; in Breda, blocked sewers are a frequent cause of flooding in buildings. The relatively high blockage rate of gully pots compared to sewers may indicate that most sediments are trapped in gully pot chambers, leading to a low blockage rate for sewer pipes. Besides sediments, intruded roots are an important cause of flooding in the investigated cases. Further research is needed to confirm a relation between gully pot blockage, sediments trapped in gully pots and sewer pipe blockage.

Comparison between cases

To allow for comparison between the two cases, the results in Tables 2 and 3 were divided by the total sewer length and the total length of the measurement period for each case. This results in incident frequencies per 100 km sewer length per year for the 3 failure mechanisms. Figure 1 shows incident frequencies for Haarlem and Breda per 100 km of sewer length and per year. The graph shows that incident frequencies of gully pot blockages are similar for Haarlem and Breda: 4.2 and 3.9 per 100 km sewer length per year, for the total of all flood-related consequences. Gully pot blockages cause about one incident of flooding in buildings per 100 km per year, for both cases.

Incident frequency of sewer pipe blockages is approximately eight times higher for Breda compared to Haarlem, for all flood related consequences. A possible explanation is that the two cities have different sewer cleaning strategies: sewer cleaning frequency in Haarlem is two times higher than in Breda (see Table 1). In addition, a recent evaluation report of urban drainage management in Breda (Gemeente Breda 2008) mentions that in 2004 and 2005 many sewers were cleaned that hadn't been cleaned for a long time. This was not reflected in a reduction of the amount of 'sewer blockage' calls for 2006 and 2007, which may indicate a remaining backlog in maintenance work. Ages of sewer pipes cannot account for the difference in blockage frequency; the distribution of pipe lengths over pipe ages is similar for both cities.

Table 2 | Results of call data analysis Haarlem, 3 failure mechanisms for sewer flooding. Call data for Haarlem cover a period of 10 years; in this period 566 independent rain incidents occurred

Haarlem Failure mechanisms	# of incid.	# of calls	# of incid.	# of calls
	Flood-related conseq. classes		Flooding in buildings	
Gully pot blockage	202	897	55	110
Blocked sewer pipe	6	6	0	0
Sewer overloading	10	15	5	6
Total	218	918	60	116

Table 3 | Results call data analysis Breda, 3 failure mechanisms for sewer flooding. Call data for Breda cover a period of 5 years; in this period 251 independent rain incidents occurred

Breda Failure mechanisms	# of incid.	# of calls	# of incid.	# of calls
	Flood-related conseq. classes		Flooding in buildings	
Gully pot blockage	137	978	40	66
Blocked sewer pipe	28	36	14	14
Sewer overloading	18	25	4	6
Total	183	1,039	58	86

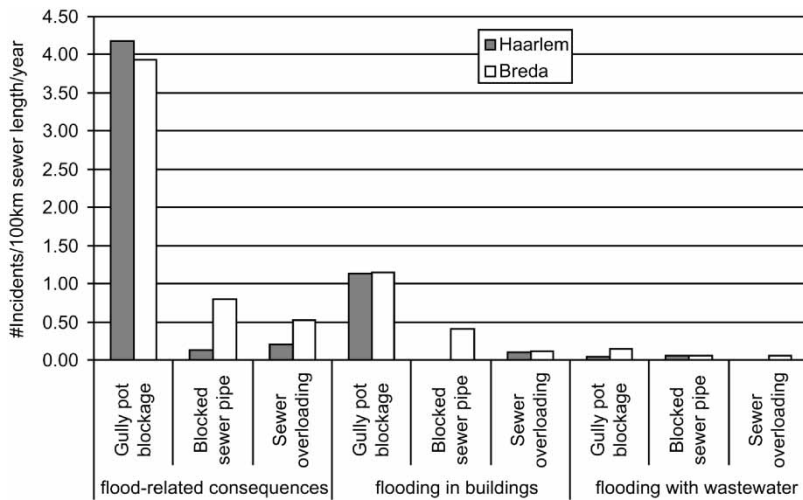


Figure 1 | Comparison of the number of incidents per kilometre sewer length per year between Haarlem and Breda for 3 different selections of flood consequence classes.

Incident frequency of sewer overloading is three times higher for Breda compared to Haarlem. A possible explanation is that older parts of the system in Breda were designed according to a lower design standard and that system capacity was not adjusted at a later stage. Recent hydrodynamic calculations for four subcatchments in Breda have indeed shown that system capacity in three of these areas does not comply with the design standard (Gemeente Breda 2008). Other areas will be evaluated in the coming years. Also, the frequency of occurrence of rainfall incidents in Breda could have been higher over the study period compared to Haarlem. This could not be confirmed, since only daily rainfall data were available for Haarlem and sewer overloading is mainly influenced by peak intensities over short durations.

Probabilities of occurrence of incidents were quantified as well as average consequences per incident. Average consequences were expressed in terms of the number of reported locations per incident. These values were used to quantify flood risk. Table 4 gives the results of probabilities and quantified risk for all flooding-related consequences and for flooding in buildings. The accumulated risk of flooding incidents for 3 failure mechanisms is 0.19 locations/km sewer length/year for Haarlem and 0.29 locations/km/year for Breda, for all flood-related consequences. The accumulated risk of flooding in buildings is less than 10% of risk for all flood-related consequences. In both cases, gully pot blockages contribute most to flood risk.

Table 4 | Summary of flooding risks for case studies of Haarlem and Breda: probabilities of flooding incidents and average risk per failure mechanism per year. All values are calculated per year and per kilometre of sewer length

	Prob. of incid. ($\text{km}^{-1} \text{yr}^{-1}$)	Flood risk (locations $\text{km}^{-1} \text{yr}^{-1}$)	Prob. of incid. ($\text{km}^{-1} \text{yr}^{-1}$)	Flood risk (locations $\text{km}^{-1} \text{yr}^{-1}$)
	Flooding-related consequences		Flooding in buildings	
<i>Haarlem</i>				
Gully pot blockage	0.041	0.180	0.010	0.020
Blocked sewer pipe	0.001	0.001	0.000	0.000
Sewer overloading	0.002	0.003	0.001	0.001
Total		0.19		0.024
<i>Breda</i>				
Gully pot blockage	0.039	0.280	0.010	0.019
Blocked sewer pipe	0.008	0.010	0.004	0.004
Sewer overloading	0.005	0.007	0.001	0.002
Total		0.29		0.025

Estimated efficiencies of flood reduction strategies

The obtained quantitative risk values were used to assess the efficiency of asset management strategies to reduce flood risk for the Breda case study. The urban drainage policy plan for the city of Breda states the following maximum acceptable flooding frequencies for roads: once or twice per year for residential areas, once per two years for commercial areas and the city centre (Gemeente Breda 2008). Flooding of buildings is not explicitly distinguished from flooding of roads.

Table 5 summarises the quantified risk results of call data analysis for the case of Breda, for flooding of roads and of buildings separately. This table shows that flooding frequencies amount to 0.2 flooded road locations per km per year or 152 road floodings

Table 5 | Quantified flood risk in numbers of flooded locations/km sewer length/year, city of Breda, period 2003–2007, total sewer system length 740 km

Flooded Locations/km/yr	Roads	Buildings
Sewer overloading	0.003	0.002
Sewer blockage	0.003	0.004
Gully blockage	0.2	0.02
Total	0.206	0.025

per year at city level. Flooding of buildings occurs at 0.025 locations per km per year or 18.5 locations at city level. These frequencies exceed maximum values prescribed in the policy plan and indicate a need for flood reduction.

Under the assumption that calls represent 2 to 30% of all real flood occurrences (van Wiechen *et al.* 2002; Devereux & Weisbrod 2006), the uncertainty range in real flood risk in terms of the number of calls per km sewer length per year is summarised in Table 6.

If, based on these results it is decided that flood risk should be reduced, various actions can be taken to address these flooding causes. Table 7 summarises actions that can be undertaken to reduce flood risk for three individual causes of flooding: sewer overloading, sewer blockage and gully pot blockage. The effects were estimated for the same investment level of 0.05 M€/km/year. The effect of maintenance related actions was estimated based on the results of the two Dutch case study analyses, complemented with expert judgment where data were lacking, especially for the effect of gully pot cleaning frequency. Details on assumptions underlying the cost estimates can be found in ten Veldhuis (2010, chapters 5 and 6).

Sewer overloading is reduced by implementation of a structural measure: enlargement of a sewer pipe. Blockages are handled by increasing maintenance

Table 6 | Uncertainty range of quantified flood risk in no. of calls/km sewer length/year, city of Breda, under the assumption that calls represent 2 to 30% of real flood occurrences

Flooded Locations/km/yr	Roads			Buildings		
	# calls	Min real occur	Max real occur	# calls	Min real occur	Max real occur
Sewer overloading	0.003	0.01	0.15	0.002	0.007	0.10
Sewer blockage	0.003	0.01	0.15	0.004	0.013	0.20
Gully blockage	0.200	0.67	10.00	0.020	0.067	1.00
Total	0.206	0.69	10.30	0.025	0.087	1.30

Table 7 | Actions to reduce flood risk, for three causes of flooding. Costs were estimated based on investment and maintenance costs for 2 case studies; effect was estimated based on expert judgment

Flooding cause	Action to reduce associated flood risk	Estimated cost M€/km/year	Estimated effect: flood risk reduction outcome (locations/km/yr)
Sewer overloading	Enlarge sewer pipe	0.05 ^a	Reduction by 16.67% of sewer overloading-related events
Sewer blockage	Increase cleaning frequency	0.05	Reduction by 14% of sewer blockage-related events
Gully blockage	Increase cleaning frequency	0.05	Reduction by 10% of gully pot blockage-related events

^aBased on €1,000/m sewer length replacement, 40 years amortization, interest rate 0.04.

Table 8 | Assumptions underlying estimates of the costs and effects of measures to reduce flood risk

Flood reduction	Cost assumptions	Effect assumptions
Enlargement of sewer pipe to reduce flooding due to sewer overloading	1 location at a time: 1,000 m pipe enlargement by replacement with larger diameter; Investment cost: €1,000,000 or €50,000 per year.	Reduction of 1 flooded location per year (where capacity is enlarged) out of average 6 flooded locations per year: reduction 1/6 or 16.67%
Increase sewer cleaning frequency	Yearly costs of sewer cleaning are €180,000. Increase cleaning costs with €50,000/yr: cleaning frequency increases by 28%	Comparison of 2 cases with different cleaning frequencies shows that 2 times higher cleaning frequency corresponds with half the number of calls/year (50% reduction). It is assumed that 28% increase of frequency results in 14% reduction in the number of calls/year
Increase gully pot cleaning frequency	Yearly costs of gully pot cleaning are €150,000. Increase cleaning costs with €50,000/yr: cleaning frequency increases by 33%	No data are available to estimate the effect of increased gully pot cleaning. The expected bandwidth of reduction induced by 33% frequency increase is 0–33%. It is assumed that 33% increase in cleaning frequency leads to 10% reduction in the number of calls

frequencies. Similar yearly investment levels are used for comparison between the three actions. The following assumptions were made with respect to the effects of measures in relation to investment costs (Table 8).

The relationship between actions and reduction of call numbers is summarised in Table 9. Comparison of the results in Table 9 with those in Table 6 shows that increasing gully pot cleaning frequency is the most effective of the three strategies to reduce flood risk. Sewer pipe enlargement and increasing sewer cleaning frequency have only marginal effect on total flood risk. This follows from the small

number of calls, thus flooded locations, related to sewer overloading and sewer blockage compared to gully pot blockage.

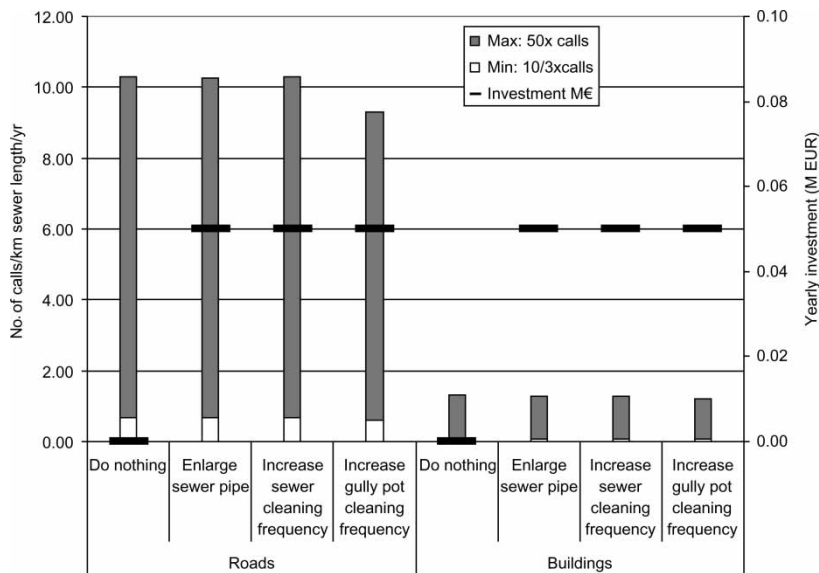
Table 10 summarises investment costs and minimum and maximum flood risk estimates in terms of the number of flooded locations per year for the current situation and after execution of each of the three flood reduction measures. Figure 2 gives a graphical representation of the data in Table 10. It shows that for the same investment level, increasing gully pot maintenance is the most effective measure to reduce flood risk. The effect of increased gully pot cleaning frequency is about 10 times higher than

Table 9 | Uncertainty range of quantified flood risk in nr of locations/km sewer length/year, city of Breda, as a result of 3 different flood reduction measures, for road flooding and for building flooding

	Enlarge sewer pipe		Increase sewer cleaning frequency		Increase gully pot cleaning frequency	
	Min occur.	Max occur.	Min occur.	Max occur.	Min occur.	Max occur.
<i>Locations/km/yr Road flooding</i>						
Sewer overloading	0.008	0.125	0.010	0.150	0.010	0.150
Sewer blockage	0.010	0.150	0.009	0.129	0.010	0.150
Gully blockage	0.667	10.000	0.667	10.000	0.600	9.000
Total	0.685	10.275	0.685	10.279	0.620	9.300
<i>Locations/km/yr Building flooding</i>						
Sewer overloading	0.006	0.083	0.007	0.100	0.007	0.100
Sewer blockage	0.013	0.200	0.011	0.172	0.013	0.200
Gully blockage	0.067	1.000	0.067	1.000	0.060	0.900
Total	0.086	1.283	0.085	1.272	0.080	1.200

Table 10 | Summary of yearly investment costs and resulting flood risk in terms of the number of flooded locations/km sewer length/year, for 3 flood reduction measures. Uncertainty margins are based on estimated representation of flood-related calls compared real number of flooded locations

Effect of investments; nr. of flooded locations/km/yr	Do nothing	Enlarge sewer pipe	Increase sewer cleaning frequency	Increase gully pot cleaning frequency
<i>Investment</i>	€0/yr	€50,000/yr	€50,000/yr	€50,000/yr
<i>Road flooding</i>				
Min (calls represent 30% of real occurrences)	0.687	0.685	0.685	0.620
Max (calls represent 2% of real occurrences)	10.300	10.275	10.279	9.300
<i>Building flooding</i>				
Min (calls represent 30% of real occurrences)	0.087	0.086	0.085	0.080
Max (calls represent 2% of real occurrences)	1.300	1.283	1.272	1.200

**Figure 2** | Yearly investment costs and estimated flood risk in terms of the number of flooded locations/km sewer length/year, for 4 scenarios: do nothing and 3 different asset management strategies for flood reduction.

that of enlarging sewer pipe capacity or increasing sewer cleaning frequency. Uncertainty in flood risk results derived from call data does not influence this conclusion. It only influences absolute values of quantitative flood risk outcomes.

CONCLUSIONS

Data from call centres at two municipalities were analysed in order to quantify flooding frequencies and

associated flood risks. Call data consist of reports of problems related to urban drainage. The data were analysed for three main failure mechanisms that can lead to flooding. The results were used to evaluate current operational strategies for flood prevention. The aim was to find out whether current operational strategies based on practical experience are efficient and if directions for improvement could be found. Quantified flood risk for the two cases was estimated at 0.19 flooded locations per km sewer length per year and 0.29 locations per km per year. This is well above the standard, which is defined as a flooding

frequency of once per year. The analysis pointed out that gully pot blockages are the main cause of flooding.

It was shown that based on call data analysis, effective strategies for flood risk reduction can be identified. Currently, information about the effect of flood reduction measures is lacking to adequately assess the effect of actions for flood risk reduction. Based on the available data it could be shown that increasing gully pot blockage is the most efficient action to reduce flood risk, given data uncertainty. Reduction of sewer overloading by increasing sewer capacity was shown to be less efficient, because flood risk related to sewer overloading is small. If differences between cause incidences are large, as in the presented case study, call data are sufficient to decide how flood risk can be most efficiently reduced. If differences are small, call data do not provide sufficient accuracy to distinguish between causes. Additional data must be collected to assess flood risk more accurately and to estimate the effect of flood reduction measures.

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