Design criteria,
Flooding of sewer systems in ‘flat’ areas.

Ir Harry. Van Luijtelaar

Tauw bv, P.O. box 830, 7400 AV Deventer, The Netherlands,
Telephone +31570699304, Fax +31570699666, E-mail hlj@tauw.nl.

ABSTRACT

In the Netherlands, a very simple criterion for flooding is used to check the hydraulic behaviour of a drainage system. The European approach is more strict but not applicable. Therefore, an alternative approach is presented to eliminate hydraulic bottlenecks in drainage systems in flat and moderately sloped areas.

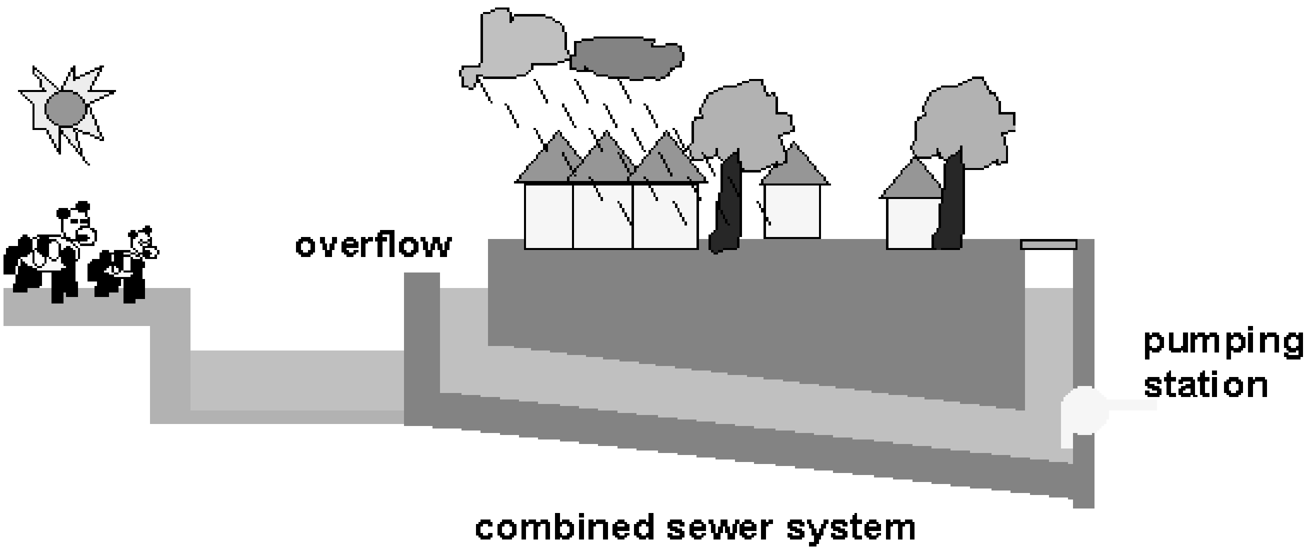
KEYWORDS

Flat and sloped area, hydrodynamic simulations, runoff, rainfall, surcharge, flooding, overflow, pumping station, guidelines, European standard.

INTRODUCTION

The Netherlands is for almost 80% a flat country, which is situated in the Rhine, Meuse and Scheldt delta. More than half of the country consists of a system of polders below sea level. The highest hill in the province of Limburg has a maximum elevation of more than 300 m above sea level. In many towns and cities, the maximum difference in ground elevation is less than a few meters over a distance of several kilometres.

More than 95% of the houses are connected to a combined or separate sewer system. Most of the systems are combined. In areas with much surface water, the sewer system often has many overflow locations to reduce the transport distance to an overflow.



In the Netherlands, combined and improved separate sewer systems can be compared with a reservoir (bath) filled by rain and drained by a pump to transport the wastewater under pressure to the treatment plant. The storage capacity is about 7-10 mm for combined baths and 4 mm for separate systems, the corresponding pumping capacity is 0,7 and 0,3 mm/h. Once the storage capacity of a system is used, the water is transported to a number of overflows, mostly located at the edge of the system.
A remarkable difference with sewer systems in most parts of Europe is the acceptance of frequently surcharged pipes during moderate rain conditions. During severe rain events, the main discharge is transported through the big pipes towards the overflows under pressurised flow conditions. In this circumstances the discharge direction in pipes may change. During the filling of the system the flow is directed to the pumping station, in the filled system the flow-direction often reverses to the overflow.

Traditional design criteria
The traditional hydraulic design of sewer systems in The Netherlands is based on simple rules and criteria. They are characterised by permanent flow simulations, a design rainfall intensity of 60 $l.s^{-1}.ha^{-1}$ in flat area's and 90 $l.s^{-1}.ha^{-1}$ in inclined area's and a freeboard of 0.2 m between maximum water level and ground level.

New guidelines show a modern approach with dynamic flow simulations, 10 different design storms with a return period from 0,25 to 10 years and a runoff model. Over the years, the criteria in accepting maximum water levels have become less strict. One has forgotten the 0.2-m freeboard. The main reason is a quick transformation to a new generation (computer) designer and the fact that flooding frequency of systems in flat areas was very low.
As an effect of new regulations to obtain a limitation of CSO discharges, almost all the available storage capacity in systems is used. In addition, the proceeding limitation of the number of overflow locations causes longer transport distances through bigger pipes. The building density of towns is growing but there are poor regulations in determining the real contributing catchment area. More contributing area means higher investments in improving systems. In shopping areas, the difference between the entrance level and the street profile level has decreased over the years, systematically. The extra safety in storage capacity of water on the street level has reduced substantially. The practical effect of the mentioned developments is an increasing risk of flooding of the system although theoretical the design criteria are met. The result is a growing number of insurance claims.

European standard
European guidelines are aimed at a limited surcharge and flooding frequency depending on the type of area: shopping centres, rural area's, industrial area's etc. Application of the European design rules and criteria in Dutch circumstances is impossible, due to the small difference between the ground elevation and the surface water. The existing theoretical design criteria are not tuned in on real processes and circumstances. The existing way of analysing and checking the dynamic hydraulic behaviour of the system needs to be adapted to get a better view on hydraulic bottlenecks.
In this paper, a method is presented to analyse the hydraulic behaviour of sewer systems in flat areas. Examples of new design criteria are proposed for frequently surcharged systems based on a more realistic design storm approach.

SEWER SYSTEM HYDRAULICS

In the Netherlands, a sewer system is checked on two aspects: the discharge capacity of the system under extreme rainfall conditions and the storage capacity of the system in a long-term simulation with a continuous rainfall series (1955-1979).

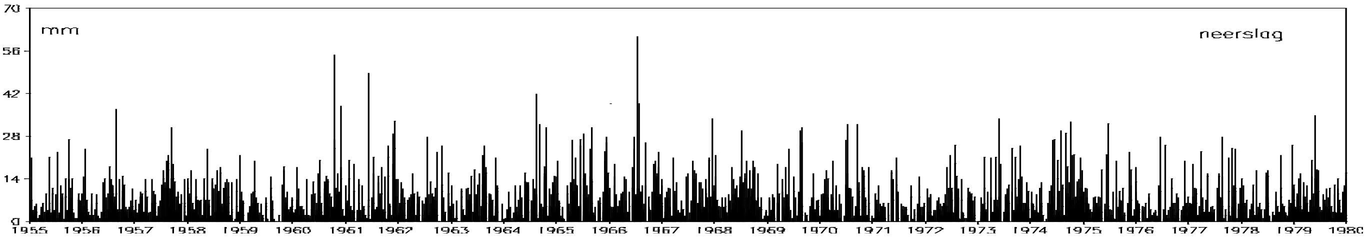


Figure 1 Rainfall series De Bilt, 1955-1979, daily volumes.

Sufficient discharge capacity is needed to prevent flooding situations in buildings. Sufficient storage capacity is needed to limit the emission of polluted water from the system to the surface water.

The discharge capacity of a system is checked with rainfall event 08, as shown in figure 2. A maximum rainfall-intensity of 110 $l.s^{-1}.ha^{-1}$ implies a return period of 2 years.

The hydraulic behaviour of the system is simulated with a hydrodynamic model. Generally, the hydraulic discharge capacity of the system is found acceptable if the simulated water levels in a manhole remain just below ground elevation. In some situations, especially in flat areas, also water levels above the ground elevation are accepted.

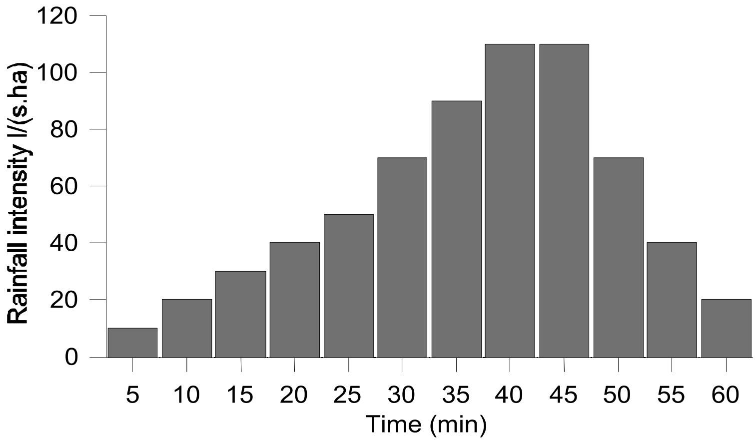


Figure 2 Inflow hydrograph 08, Dutch guidelines.

Traditionally sewer systems are designed on a stationary rainfall intensity of 60 $l.s^{-1}.ha^{-1}$ for flat areas and 90 $l.s^{-1}.ha^{-1}$ for inclined areas. Because of model limitations, a minimum freeboard of 20 cm was maintained, between the maximum water level and the ground elevation at a manhole.

EUROPEAN STANDARD (CEN TC 165)

The European standard is established by the CEN, Comité Européen de Normalisation, technical committee TC 165. In this standard, the principles are set out for the hydraulic design and considerations of environmental impact of drain and sewer systems that essentially operate under gravity. In this standard, the essential requirements of good practice in the various engineering activities related to the planning, design and operation are discussed. The following matters are raised in the European standard:

- sources of additional information,
- definitions;
- protection from surcharge and flooding, protection from pollution, protection from septicity;
- self cleansing velocities;
- hydraulic calculations, velocity equations, head losses, sewers with steep gradients;
- wastewater design flows, water consumption, sewer systems, drain systems;
- surface water and combined drains and sewer design flows, rainfall - performance criteria, design flows, flow balancing;
- environmental considerations, impact of drain and sewer systems, control of pollution, storm-water overflows, outfall design requirements, groundwater protection, residues for maintenance.

Our attention is especially directed to the protection from surcharge and flooding and the rainfall - performance criteria. Surcharging is said to be undesirable in waste water and sewer systems because frequent surcharge of defective sewers can result in structural damage. No statements are made about the undesirability of flooding.
Design of a system should provide protection against flooding and surcharging from storms of predetermined intensities and frequencies, where backwater levels have to be taken into account.

It is accepted that it is impracticable to avoid flooding from severe storms. A balance has to be drawn between costs and the level of protection provided. If the relevant authority has specified (local) performance criteria for protection against surcharge and flooding, these shall be adhered to the standard.

An overview of European design frequencies is given in Table 1. For small schemes the "design storm frequency" (no surcharge) criteria should be used in the absence of any specified by a relevant authority.

Table 1 Recommended design frequencies in Europe

	Design Storm No surcharge Frequency* (1 in n years)	Design Storm Flooding Frequency (1 in n years)
Rural areas	1 in 1	1 in 10
Residential areas	1 in 2	1 in 20
City centres/Industrial/Commercial areas	1 in 2 or 1 in 5	1 in 30 where no flooding check
Underground railway underpasses	1 in 10	1 in 50

* For these design storms no surcharge shall occur.

For larger schemes, design should be undertaken to limit the frequency of surcharge using a sewer flow simulation model recognised by the relevant authority. The design should be checked to ensure that an adequate level of protection would be provided at specific sensitive locations. These design checks are especially important on steeply sloping catchment areas. Any requirements from the relevant authority shall be followed, but in their absence, the design flooding values given in Table 1 should be used.

NETHERLANDS SEWER AND DRAINAGE PRACTICE

A combined sewer system in the Netherlands has an average storage capacity of 7 – 9 mm rainfall.
In a flat areas a system can have more than one sewer overflow with equal crest levels. Most of the volume in the system is located below the crest level of the lowest weir in the system so that most of the volume can be used as storage capacity.

A system with 9,0 mm storage capacity and 0,7 mm.h^{-1} pumping capacity corresponds with a theoretical sewer overflow frequency of nearly 10 times per year. Waterboards require limited overflow volumes and frequencies tuned to the desired water quality.

The last 10 years additional storage capacity is required to achieve a far-reaching reduction of combined sewer overflow frequencies and -volumes. The additional storage is realised in different ways:
- realising storage detention tanks at the combined sewer overflow locations;
- reduction of the contributing catchment area;
- optimising to use the available volume in the system as storage capacity by extra internal weirs in the system.

Especially the use of extra internal weirs in the system can lead to higher water levels in the system not only in extreme weather conditions. Most of the sewer pipes are completely filled nearly a 20 times per year when a rainfall volume of approximately 10 mm is exceeded.

In the Netherlands the European standard surcharge criteria are not applicable.

In most cases, the difference in the ground elevation doesn't exceed 1 or 2 meters over a distance of several kilometres. In a flat area, the street offers a great storage volume on the ground level. This is the reason that flooding problems relatively seldom occur. Most of the flooding problems appear in (steeply) sloped catchment areas.

The north-western part of the country lies below sea level. In the south-east the ground elevations reach until more than 300 meters above sea level. The high-low map is shown in figure 4.

Figure 4 Netherlands 'high' -low map

Flooding problems due to an insufficient capacity of the sewer system are relatively rare in the Netherlands. It only occurs in a few relatively sloped areas and under extreme weather conditions. This is also the reason that the traditional (local) design criteria are not very strict. If water appears on the ground level, it can spread out over a wide area. On the ground level, generally there is an additional storage capacity of about 80 mm rainfall. Probably, this volume is exceeded once in 100 years.

In this situation, possible-flooding problems might not be treated seriously enough.

Flooding suddenly can become a very topical subject. Due to the limited extend and attention for flooding, the limitations and developments in simulation techniques, the changes in street-profile, the non-development in traditional design criteria and a relatively rapid change in a generation of computer designers.

Dynamic simulations
In a dynamic simulation to check the hydraulic behaviour of a sewer system, simulation of storage on the ground level and possible flows over the street are relatively inaccurate. A flooding problem shown because of a simulation and that is not experienced in practice generally doesn't lead to measures.

Street profile
A traditional road street in the Netherlands generally has sidewalks and kerbs on both sides. The average ground level of the house along a street lies about 0,2 m (200 mm) above street level. Since the introduction of pedestrian areas, the sidewalks have disappeared in the 80's especially in shopping areas. The last decade the central drain was introduced.
The effect of recent changes in the street profile is a decreasing storage volume and flow profile on the ground elevation. In sloped areas, the street has the function of a shallow open channel.
A reduction of the difference between housing and street levels also leads to a reduction of the flow capacity of the street profile. In extreme weather conditions, the risk of flooding problems in houses has increased.

The system has become more sensitive for flooding, particularly on locations with a ground elevation that is slightly lower than its surrounding area.

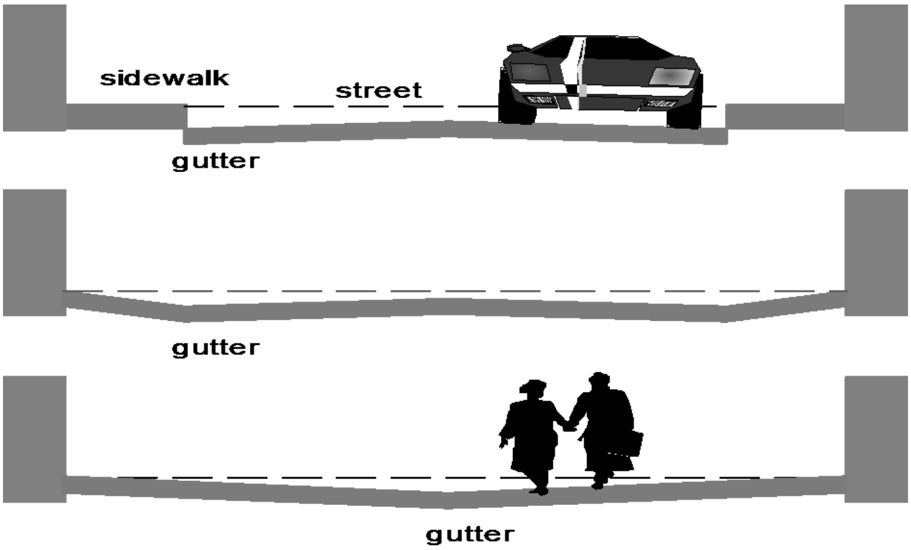


Figure 5 Development street profile since 1980.

Design criterion flooding
The hydraulic capacity of a combined sewer system is checked on a rainfall event with a theoretical return period of T = 2 years (shown in figure 2). The simulated hydraulic gradients are shown in figure 6 (situation A).

The criterion is that a system can cope with this rainfall event without any simulated water level above the ground elevation. A variation of the system (situation B) under the same rainfall conditions is shown in figure 7.

The hydraulic gradient simulated with the T= 5-year storm clearly breaks the ground elevation in situation B. Both systems meet the required limited water level based on a rainfall event with a return period of T = 2 years. In more extreme conditions, it is clear that system in situation **A** offers more protection against flooding than the system in situation **B**.

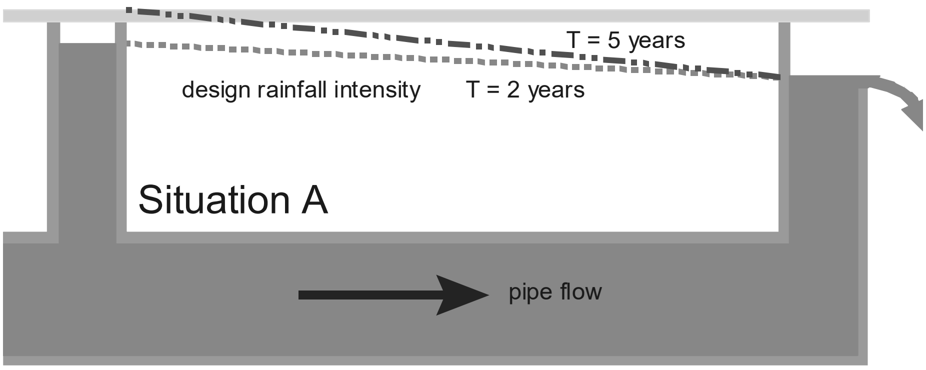


Figure 6 Simulated hydraulic gradient, T = 2 and 5 years.

In the Dutch guidelines, this quality of the system is not taken into account. The reason is that the design criterion is directed at a water level in a manhole, in stead of the discharge capacity of a pipe. Therefore, the traditional design criteria may not be adequate to judge the hydraulic behaviour of a system in relation to protection against flooding. The European standard doesn't offer a solution because the surcharge criterion is not applicable and the flooding criterion is based on (too) extreme design storms. If a general

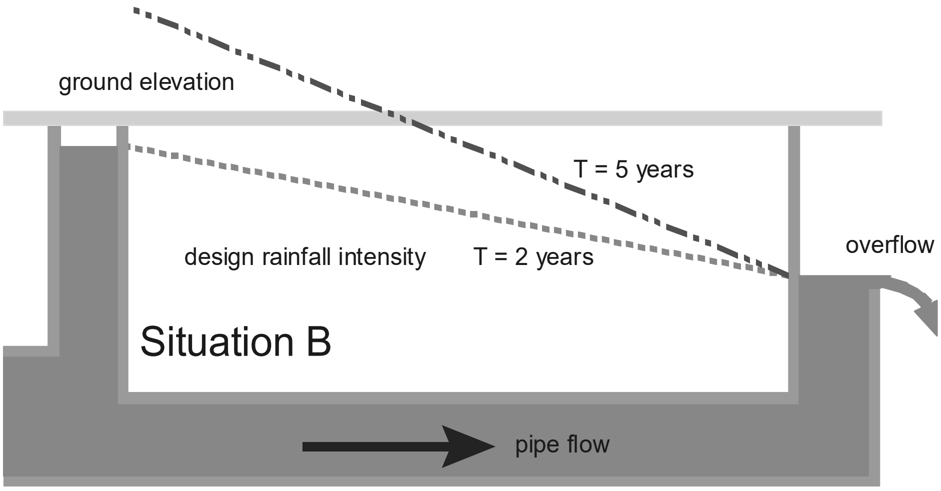


Figure 7 Simulated hydraulic gradient, T = 2 and 5 years.

Dutch sewer-system is simulated with a 10-year design storm, almost the whole system is theoretically drowned, while there are no actual problems.

DESIGN CRITERION (alternative approach)

An alternative approach to judge the hydraulic behaviour of a sewer system in flat areas should be based on sufficient flow capacity instead of maximum water levels in manholes. From the example given in the figures 6 and 7 we can derive that the hydraulic gradient simulated as an effect of a certain design-storm should be limited. In the Dutch situation it is impossible to design the hydraulic capacity of a system on a rain event with a return period of 10 or more years, as directed in the European standard.

A long-term experience shows that a system designed on a 2-year design storm offers sufficient protection against flooding in a flat area. Important is to realize that a local depression in the ground elevation as collection point of a large area should be avoided. These locations should be drained by an isolated (local) collection system, with sufficient storage capacity. To reduce the load of contributing area, a barrier in the ground elevation can be a very effective measure.

In (moderately) sloped areas the hydraulic gradient simulated with a 2- and 5-year design storm should be limited. A relation can be drawn to the gradient of the ground elevation. A hydraulic bottleneck appears if a simulated hydraulic gradient is much greater than the gradient of the local ground elevation. In the Netherlands the maximum runoff of a 2 and 5-year storm can vary from 90 $l.s^{-1}.ha^{-1}$ to 150 $l.s^{-1}.ha^{-1}$. Translated to hydraulic gradients it means that:

$$\frac{hydraulic\ gradient(T = 5\ year)}{hydraulic\ gradient(T = 2\ year)} \approx \frac{150^2}{90^2} \approx 3$$

If a system is checked with a 2-year storm, the available freeboard should be enough to cushion an increase in the hydraulic gradient by at least a factor 3.

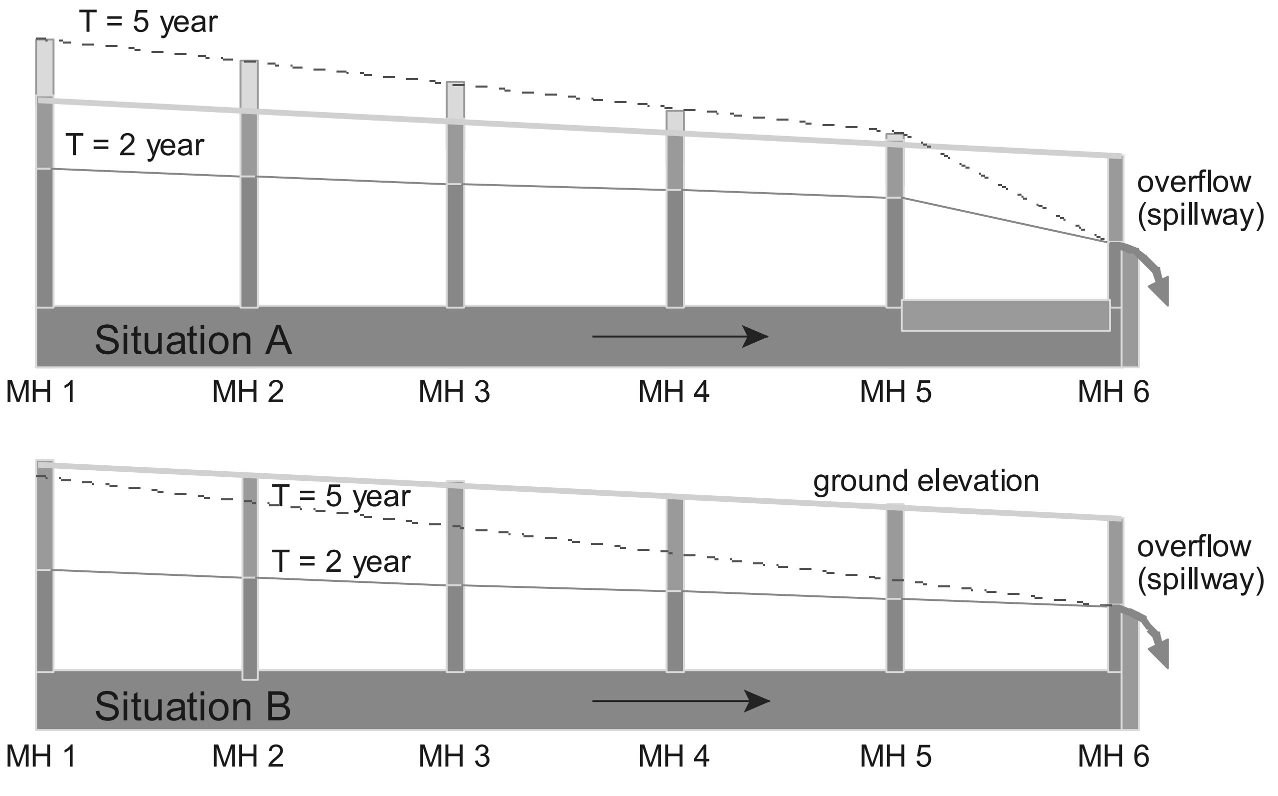


Figure 8 (Part of a) Drainage system simulated with a 2 and 5-year storm.

In figure 8 it is shown that the capacity of pipe MH5-MH6 is theoretically insufficient to discharge a 5-year storm without flooding. The hydraulic gradient in the 2-year storm simulation is much steeper than the corresponding gradient of the ground elevation. In situation B the capacity of pipe (MH5-MH6) is fitted so that the hydraulic gradient is reduced to a value in the same order than the gradient of the ground elevation.
Now the system can discharge a 5-year storm without serious flooding problems. The hydraulic bottleneck of the system is removed and the discharge capacity is more balanced (spread out) over the system.
To relate the maximum hydraulic gradient to the gradient of the ground elevation one can look at the local gradient of the ground elevation between the manholes and the average gradient of the area.
This method is also applicable in situations that hydraulic simulations show the system cannot handle the 5-year storm without flooding. By improving the hydraulic bottlenecks in the system where the 'maximum' hydraulic gradients are shown, the protection against flooding will increase substantially.

CONCLUSIONS

In a flat country like The Netherlands the European approach to look at the surcharge and/or flooding criteria with 5,10 and 50-year storms is not applicable. Most of the protection against flooding in a flat area is found in the large storage capacity on the ground level. Due to changing concepts to arrange the public space, the storage capacity on the ground level will reduce. Therefore, the traditional design criterion in the Netherlands may not offer enough protection against flooding. In the new Dutch Guidelines, the discharge capacity of a drainage system should be sufficient to handle a 2-year storm, without the occurrence of flooding (a water level above ground elevation). A long-term experience shows that a 2-year storm sufficiently shows the hydraulic bottlenecks of the system. Additional protection against flooding is found in balancing the hydraulic capacity of the system. Pipes with a maximum hydraulic capacity greater than the (average or local) gradient of the ground elevation are potential bottlenecks in a system, which should be avoided or removed. In stead of checking the surcharge or flooding frequency of a system, the attention should be directed at the maximum simulated hydraulic gradient in relation to the ground elevation.

REFERENCES

Buishand, T.A., Acker, J.B.M. van, Luijtelaar, H. van, Analyse van kwartiersommen van de neerslag, H2O, 11 (24), 1991.

Mameren van, H.J. and Clemens, F.H.L.R (1996): `Guidelines for hydrodynamic calculations on urban drainage in The Netherlands: overview and principles'; paper in the proceeding of the 7th ICUSD, Hannover, Germany.

Ministerie van Volksgezondheid, Ruimtelijke Ordening en Milieu (1995): `Rioleringsberekeningen, hydraulisch functioneren; module C2100 of the Leidraad Riolering'.

Nationale Werkgroep Riolering en Waterkwaliteit (1989): `Neerslag, inloop, overstort-model, beschrijving en analyse; NWRW publicatie 4.3'.

Van Luijtelaar H. and Rebergen E.W. (1996): `Guidelines for hydrodynamic calculations on urban drainage in The Netherlands: backgrounds and examples'; paper in the proceeding of the 7th ICUSD, Hannover, Germany.