Heavier Rainfall Due to Climate Change
How to deal with effects in urban areas

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ABSTRACT
Heavier rainfall due to climate change may be the explanation for the public's increasing concern with flooding in urban areas. August 2006 was a very wet period in the Netherlands, where many flooding problems were reported due to heavy rainstorms after a very hot, dry period in the previous month.
Do we have a problem with the hydraulic capacity of our urban drainage system or do we have a problem with the public's perception as they experience temporary water storage on the road surface? This paper is about four aspects of flooding in urban areas:
1. What do we expect in terms of heavier rainfall due to climate change?
2. What are the real problems underlying recent cases of flooding in the Netherlands?
3. What is (is not) acceptable nuisance due to flooding of urban areas?
4. How can we act now in light of a future with more frequent, heavier rainstorms?

KEYWORDS
Climate change, heavier rainfall, hydraulics, nuisance, flooding, measures, future, risks

INTRODUCTION
After a very hot, dry period in the previous month, August 2006 was a very wet period during which many flooding problems were reported due to heavy rainstorms. The following questions being investigated by RIONED:
- What is the real cause of the flooding problems: excessive amounts of rainfall, lack of stewardship in urban drainage management, or special local circumstances?
- What can be done to prevent unacceptable nuisance and damage?

The results of this investigation, which involved questions to 203 Dutch municipalities about flooding problems, will be presented to the conference. 90% of Dutch municipalities have to deal with minor flooding problems, while 10% have to cope with greater flooding problems.

This is the first time an investigation on this subject, at this scale and level of detail has been conducted in the Netherlands. This research has allowed RIONED to develop a view of climate change and rainwater nuisance in urban areas. The drainage system has a limited storage and discharge capacity, so it is inevitable that severe downpours will often result in the temporary storage of water in the streets. Water in streets is more part of a solution than a symptom of a problem. It is important that municipalities aim for a water-aware layout of their aboveground infrastructure, to cope safely with extreme quantities of rainfall

CLIMATE SCENARIOS FOR THE NETHERLANDS

Based on the most recent results of climate research, KNMI (Royal Netherlands Meteorological Institute) has presented four new climate scenarios for the Netherlands. These represent a "moderate" increase of the global temperature of +2°C in 2100 relative to 1990, and a "strong" increase of +4°C in 2100.

The new climate scenarios are consistent and plausible pictures of possible future climates. These scenarios are intended for use in studies exploring the impacts of climate change, and are used to formulate possible adaptation strategies.

The wet circulation scenario shows an increase in T = 10 yr daily precipitation of up to 50% during severe storms in the summer period. In 2006 the combination of a wet circulation in august after a dry circulation in the previous months possibly had a bigger effect than the official scenarios assumed.

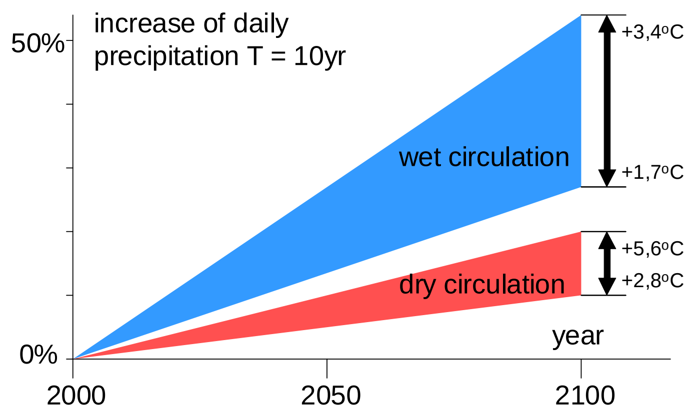

Figure 1. Increase in T = 10 yr daily precipitation until 2100, summer period, distinguished according to a wet and dry circulation scenario and a moderate or strong increase in global temperature

Climate models differ considerably in their calculation of global temperature rise. This is caused by uncertainty regarding future emissions of greenhouse gases and aerosols, which, in turn, depend on factors such as future population growth, and economic, social and technological developments. Nevertheless, our understanding of the complex processes in the climate system is still limited.

A number of key characteristics of climate change in the Netherlands and surrounding areas are common across all the scenarios:

- Temperature will continue to rise. Mild winters and hot summers will become more common;
- On average, winters will become wetter and the number of extreme precipitation events will increase; the intensity of extreme rain showers in summer will increase, but the number of rainy days in summer will decrease;
- The calculated change in wind is small compared to the natural fluctuations;

Climate models show an increase in total annual precipitation for the temperate regions and a decrease in the subtropics. For southern Europe nearly all climate models calculate a decrease in summer precipitation and an increased likelihood of drought. For northern Europe the change in precipitation is less consistent. For Europe as a whole, calculations show an increased probability of prolonged, heavy precipitation and short, intense showers.

RESEARCH

In spring 2007, RIONED conducted a survey among all 443 municipalities in the Netherlands in order to asses the nature and causes of and potential solutions to rainwater nuisance in urban areas. One reason for the survey was climate change, coupled with publicity about failures of the urban drainage systems during the heavy downpours of August 2006.

The survey was intended to gain an up-to-date view of the actual situation throughout the country. An extensive questionnaire was used, which was completed and returned by 203 municipalities, representing almost 50% of the population of the Netherlands. RIONED considers that the results are representative of the situation in the Netherlands.

Rainwater nuisance in practice

More than 90% of all municipalities experience rainwater nuisance, mostly at a few locations.

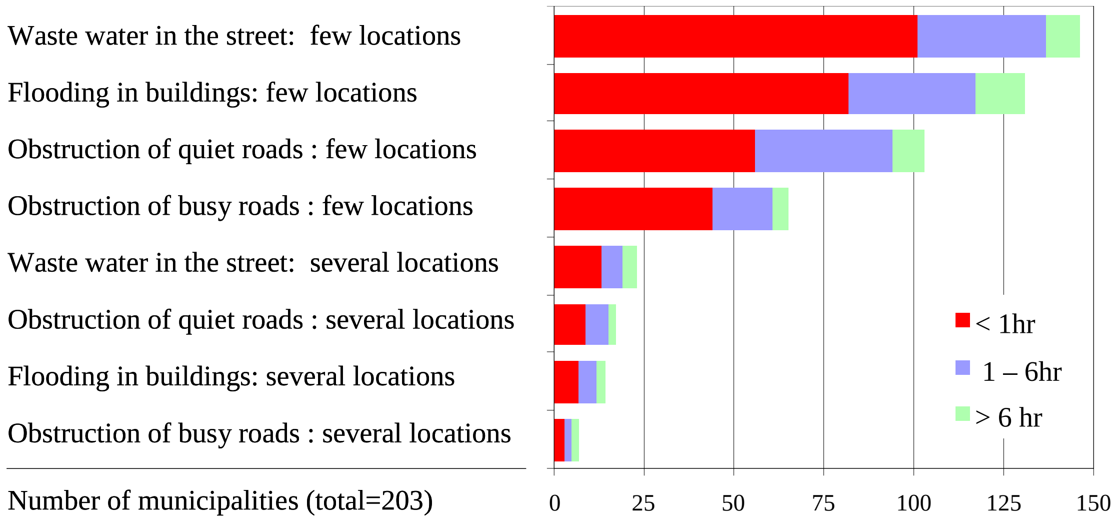

Figure 2. Rainwater nuisance experienced in practice; 4 types and 3 ranges of duration

The main types of nuisance are wastewater from the sewerage system in the street and water flooding into buildings. To a lesser extent the respondents encounter obstructions in both quiet and busy roads. In most municipalities the flooding lasts for less than an hour. One quarter of the municipalities have to deal with flooding lasting more than one hour. About 10% of the municipalities have to deal with flooding at a large number of locations, mainly in the form of wastewater in the street. In 6% of the municipalities rainwater entered buildings in many locations.

What do municipalities regard as rainwater nuisance?

The drainage system has a limited discharge capacity, so it is inevitable that severe downpours will (often) result in water in the streets. During extreme downpours, this water in the street can pose a genuine nuisance. The majority of the municipalities consider that the most significant forms of rainwater nuisance are water flooding into buildings and rising manhole covers. Many municipalities also consider that there is a problem in such cases as overflowing toilets; wastewater in the street; flooded traffic routes; flooded tunnels; inundated shopping areas; and flooded basements. A minority of municipalities consider the following to be problems: flooded residential streets; flooded loading docks on industrial premises; flooded gardens or paths behind a dwelling.

Developments in rainwater nuisance

About 50% of the municipalities have experienced relatively frequent, extreme downpours in recent years. Over half of the municipalities have had to deal with repeated incidents at some locations in recent years. More than 60% of the municipalities stated that they had problems more than once every five years.

In the summer of 2006 almost 20% of the municipalities were confronted with unexpected problems. In retrospect, more than 30% said that many problems could have been foreseen. Approximately 16% said that new, previously unknown locations had been flooded. About 30% of the municipalities stated that flooding appeared to be on the increase. The number of reports and complaints is increasing in 40% of the municipalities.

Causes of rainwater nuisance

An inventory was made of the causes of rainwater nuisance, both in terms of the quantity of water in the street (a lot, medium or a little) and the number of locations. The causes can be classified in five categories:

1. design of the urban drainage system (design);
2. management of the urban drainage system (management);
3. flood pathway design in built up areas (layout);
4. discharge and storage capacity of the water system (water);
5. rainwater drainage in buildings and on private land (private).

The following causes appear to be most significant, based on a combination of the size and effect and the number of locations where there is a problem:

- Water mainly flows over the surface into depressions below ground level (layout).
- Insufficient discharge capacity of the urban drainage system (design).
- Absence or inefficient operation of ventilation pipes (private).
- Ground floor levels insufficiently raised above street level (layout).
- Air retention in sewerage system: reflux in toilets, rising manhole covers (design, private).
- Drains/gutters frequently blocked by floating litter and falling leaves (especially in the autumn) (management).
- Surface water level is higher than the overflow weir level (water).
- Great increase in the impervious catchment area in recent years (design).
- Sewerage systems originally designed for a relatively low rainfall intensity of 60 litres per second per hectare (design).
- Facilities for keeping areas below ground level dry either do not work at all or work inadequately (private).

The most frequently mentioned causes are:

- blocked gulley pots;
- insufficient or inadequate ventilation of systems;
- sewers with insufficient discharge capacity.

The causes having the most significant effect are:

- water collecting in local depressions;
- absence of discharge points of buildings;
- a recent large increase in the impervious catchment area.

No clear relations could be found between rainwater nuisance and the physical features of an urban area. Flooding occurs all over the country, in both in hills and flat areas, in both wet areas with much open water and dry areas with little open water, and with both permeable and impermeable soils.

Completed and planned measures in existing areas

About 90% of municipalities have planned measures and 70% have recently completed measures. The most common measures for countering flooding in existing areas are:

1 diverting rainwater towards an additional system (more discharge capacity);
2 creating additional capacity in open waters (storage and discharge);
3 diverting rainwater toward small-scale, local facilities (around dwellings);
4 creating additional discharge capacity (enlarge mains);
5 water-aware layout of the built environment (profiling above ground level).

Creating additional discharge capacity in a rainwater system has several advantages: less rainwater is discharged to a waste water treatment plant; less pollution of surface water via combined sewer overflows; less polluted waste water in the street.

More than 60% of the municipalities are taking measures in anticipation of the effects of more frequent, heavier downpours due to climate change. About 20% state that they have taken measures, but that they have not achieved sufficient impact in practice.

Completed and planned measures for new building areas

About 90% of the municipalities have planned measures and 60% have recently completed measures. The most common measures in newly built areas are:

1 creation of more storage capacity in the water system;
2 separate treatment of rainwater on private land, with overflow to the public system;
3 water-aware design of the infrastructure above ground level;
4 increasing the capacity of rainwater systems;
5 deliberate creation of storage capacity for water at ground level.

In the case of new construction the emphasis is on processing rainwater separately, combined with planning measures. It is often easier and more cost effective a to build new installation with overcapacity than to change one afterwards in an existing area.

Knowledge level

Most urban drainage managers have an understanding of locations that are vulnerable to rainwater nuisance and of potential problems in the functioning of the urban drainage system. More than 50% of the municipalities record complaints systematically in some form, while more than 60% keep rainfall records.

More than half of the municipalities have recently compiled digital inventories of their contributing catchment areas. Careful record keeping is an important basis for determining and testing the operation of rainwater systems.

Liability

About 50% of the municipalities have been held liable one or more times for damage caused by flooding. Over 30% of the municipalities have had claims made against them for more than € 1,000. Nearly 15% have paid compensation. Half of the municipalities expect that there will be less scope for invoking force majeure in future.

Urgency and experience of rainwater nuisance

Rainwater nuisance has become a much more pressing political issue in recent years, as witness the way it is reported in the local press. More than half of the municipalities have paid special attention to flooding in their municipal urban drainage plan (GRP). Half of the municipalities state that there is less and less scope for invoking force majeure.

About 40% of municipalities say that public acceptance of water in the street has clearly declined. It is necessary to supply adequate information on the controlled storage and discharge of water in the street and the prevention of damage. Buffering water in the street is especially necessary to cope with extreme quantities of rainwater in urban areas.

Conclusions

- Almost all municipalities regard water in buildings and wastewater from the urban drainage system in the street as the most undesirable forms of flooding.
- Almost all municipalities have to deal with flooding, but almost always at only a few locations and for brief periods. About 10% of the municipalities are confronted with flooding at a large number of locations.
- In more than half of the municipalities flooding recurs at least once every five years. This is consistent with the fact that more than half of the municipalities have experienced flooding in recent years.
- Municipalities consider the main causes of flooding to be: sewers with insufficient discharge capacity; blocked gulley pots; water flowing into depressions below the ground level; improper operation of ventilation pipes in dwellings; floor levels insufficiently raised above ground level.
- No clear relations could be found between flooding and the physical characterization of an urban area.
- Urban drainage managers admit that political and public concern about flooding is increasing and that acceptance of water in the street seems to be decreasing.
- 90% of the municipalities have planned measures in existing areas and for new building areas, while 70% have recently completed measures.
- 50% of the municipalities stated that there is less and less scope for invoking force majeure. In addition, the rainwater nuisance could have been foreseen in a relatively large number of recent cases (32%). Flooding has occurred repeatedly in 65% of the municipalities in recent years.

WHAT IS ACCEPTABLE?

The hydraulic discharge capacity of Dutch sewerage systems is traditionally designed to cope with a model storm having a return period of 2 years. This approach is based on the limitations of hydraulic models and available data to simulate the storage and discharge of storm water above ground level.

It is therefore accepted that the system cannot handle every severe storm. In a largely flat urban environment the storage capacity above ground level is relatively large. The effect of temporary storage of water on roads is generally accepted by the public.

Flooded streets are mostly a very local phenomenon, generally restricted to a single road, square or tunnel. Even after measures have been taken, some sites will be vulnerable to flooding simply due to their location. These include isolated, low-lying areas, often at the foot of a slope. Sites with a limited surface water capacity where the drainage system cannot cope are also vulnerable.

Water in the streets can be a nuisance, but it can also cause damage. In general, it is acceptable if the water remains in the streets for a few hours after heavy rainfall. The nuisance is comparable to snowfall: travel on the roads is more difficult. Water on the road between the kerbstones every now and then is annoying, but it does no harm. In situations like this the local authorities weigh the costs of (expensive) measures against the nuisance and specific interests, such as accessibility and the convenience of such public road users as pedestrians, cyclists and the elderly.

Generally speaking, unacceptable incidents of flooding in the streets are:

- rainwater draining from the road and flowing into buildings (material damage);
- large quantities of waste water exiting the sewers and flowing onto the road (public health hazard);
- floods blocking major traffic routes (hindrance to emergency services, economic damage).

The local authority determines the threshold between nuisance and damage and decides which measures are to be taken. Damage cannot be totally ruled out, though, no matter what measures are taken. The rainfall can always be even more severe than we expected when we framed our measures.

There must be general acceptance that the streets can be flooded. All levels of government must continually inform their constituencies to achieve such agreement. The local authorities and the water authorities have to adopt appropriate measures, as will building owners. Real estate owners can contribute by restricting the paved area and by allowing rainwater infiltration on their own land. Building design will have to focus more on such matters as the presence of sloping kerbs and thresholds, drainage facilities in cellars, and adequate height differences between the ground floor and ground level.

The costs of tackling flooding in the streets are not yet known with any precision. They depend among other things on the level of protection envisaged, the degree to which flooded streets are accepted, and the possibility of combining measures to counter water damage with other operations in the public space, such as drain replacement, road reconstruction or urban renewal. Nor is it desirable that a strict application of standards should lead to unnecessary measures. Our concern, after all, is tackling the genuinely vulnerable areas. It must be made very clear that any measures will cost extra money. If water damage is to be prevented, then a certain degree of local nuisance has to be accepted.

MEASURES

If it is decided that measures should be taken, then a choice can be made from a number of options for coping with water in the streets. The measures chosen will depend on: frequency and quantity of water in the street, damage, natural conditions, present drainage and buildings, development plans, cost, and the degree to which the hazard of flooded streets is accepted.

Bigger drains

One obvious way to cope with more severe rainfall is to increase the size of the drains. In existing systems, however, any effective solution would involve upgrading relatively large areas of the system. This might involve years of work and would be very expensive in urban situations. High-capacity drainage can be installed right away in areas under construction.

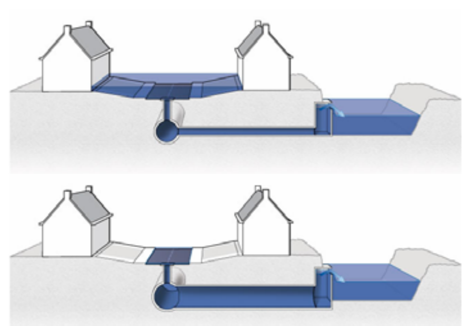

Figure 3. Effect of bigger drains.

Kerbs and lowered street levels

The street actually functions as a rainwater storage basin. This can be deliberately harnessed by, for instance, building sloping kerbs and lowering the street level. This is an effective and relatively inexpensive measure for the controlled storage of large quantities of water for brief periods. If they are well and cleverly designed, such facilities should not form an obstacle for invalids, the elderly and children, while preserving access to shops. If well managed, water in the streets is not a major problem; it is actually part of the solution.

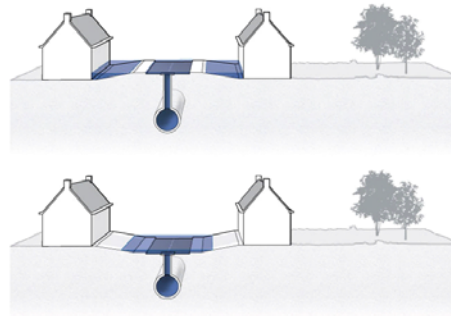

Figure 4. Effect of lowered street level

Rainwater storage in the public space

Public parks, gardens and children's play areas can be used as buffers during heavy downpours. The water drains into the ground or flows on into the ditch or drainage system.

The use of public areas for temporary water storage is extremely common in countries such as those with monsoon climates, which experience far heavier showers than The Netherlands. It might take a change of public opinion here to accept that extreme weather will be accompanied by some degree of nuisance.

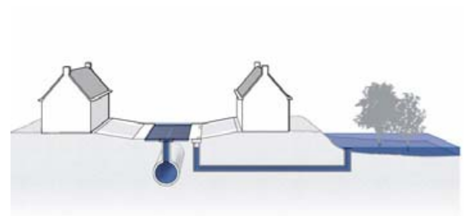

Figure 5. Storage in public space

Underground rainwater storage

Rainwater is permanently separated from polluted sewage water. The water infiltrates the soil from the underground storage or drains away through a pipe to open water. This disconnection and separation, as it is called, is already implemented in many places to reduce the incidence of waste water flowing from the sewers. As a measure for countering severe rainfall it is effective only if substantial storage capacity is created.

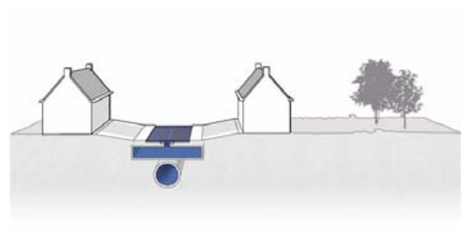

Figure 6. Extra storage underground

More open water

The streets can be flooded because the receiving open water bodies are maintained at too high a level. The solution here is to increase the storage and drainage capacity of the open water by increasing the area or upgrading the discharge capacity of the pumping stations.

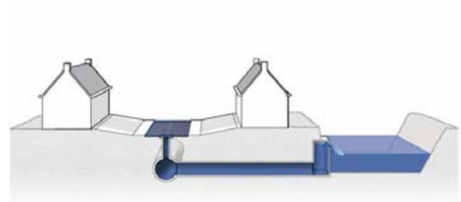

Figure 7. More open water capacity.

Protect buildings against water

To a degree, buildings must be protected against flooding by rainwater. Drainage facilities on private property (vents, weirs) must be present and must work properly. Keeping low-lying areas dry needs special facilities. One way to offer greater protection is to increase the height of the kerbs.

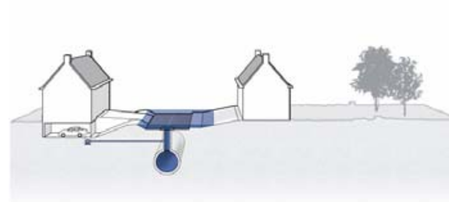

Figure 8. Protection of buildings

FUTURE

Until now the hydraulic capacity is the standard in the design of urban drainage systems. To control the effects of excessive rainfall we have to direct our attention on the construction of the urban infrastructure above ground level. At the same time and especially in The Netherlands, this is a major opportunity and challenge. In a largely flat urban area there is a potentially large storage capacity on roads and in green areas. The development of Digital Terrain Modelling may be the solution to seize this opportunity. In a flat environment the challenge is to distinguish the vulnerable locations, where small errors in differences of ground elevation could be fatal, causing or preventing serious damage (costs).

The Urban Flood Risk Landscape can be seen as an instrument to present knowledge and local experience. Information about the possible causes and effects of flooding in the urban environment could be presented as a multi-layer map, on which all kinds of related aspects are brought together. Some of these aspects include: location of local depressions in the ground level, location of accessible basements under buildings, roads functioning like an open channel, observations of residents, etc.. This approach is much broader than the usual presentation of the results of a hydrodynamic model. This combination of information could lead us to a better understanding of the mechanisms of flooding and how to take precautionary measures. The urban flood risk landscape could also play an important role in stimulating public awareness, feeding back relevant information about possible threats and allowing the public to protect their properties.

Computer models for designing drainage systems are not suitable for the analysis of flooding in the urban area. The drainage system models do indicate where and when flooding will start, but not its depth nor where it will flow. It is difficult to simulate, partly thanks to degree of detail needed, including many small differences in ground level, the presence of all kinds of obstacles (such as traffic bumps), and flow paths (such as drive-in garages without up-sloping kerbs). The modelling of flooding in urban areas still needs to be refined. Such a model will not be available in the near future, thanks to the complexity of the problem and the limited amount of data available.

It is necessary to direct efforts first of all to those areas that regularly experience problems. If research reveals that certain areas are most vulnerable to water damage, then that’s where measures will be needed. One has to take a longer-term view of new building estates: the assumptions about the frequency and degree of flooding must be re-examined with an eye to societal need and effectiveness.

Measures taken at existing hot spots will also have to be climate proofed if further development is planned. On the other hand, fixing a general level of protection may lead to excessive measures being taken. The effective balance must be found.

CONCLUSIONS

- The intensity of extreme rain showers in summer will increase, but the number of rainy days in summer will decrease. In urban areas we may have to deal with substantially heavier rainstorms, with an increase in rainfall of up to 50%.
- Research among all Dutch municipalities has shown that almost all municipalities have to deal with flooding, but almost always at only a few locations and for brief periods. About 10% of the municipalities are confronted with flooding at a large number of locations. 50% of the municipalities stated that there is less and less scope for invoking force majeure. In addition, the rainwater nuisance could have been

foreseen in a relatively large number of recent cases (32%). Flooding has occurred repeatedly in 65% of the municipalities in recent years.

- Stichting RIONED thinks it is important to communicate to the society that the handling of extreme rainfall is more than realizing sufficient drainage capacity. There must be general acceptance that the streets can be flooded. All levels of government must continually inform their constituencies to achieve such agreement. The local authorities and the water authorities have to adopt appropriate measures, as will building owners.
- Until now the hydraulic capacity is the standard in the design of urban drainage systems. To control the effects of excessive rainfall we have to direct our attention to the construction of the urban infrastructure above ground level.
- The modelling of flooding in urban areas still needs to be refined. Such a model will not be available in the near future, thanks to the complexity of the problem and the limited amount of data available.
- If it is decided that measures should be taken, then a choice can be made from a number of options for coping with water in the streets. The measures chosen will depend on: frequency and quantity of water in the street, damage, natural conditions, present drainage and buildings, development plans, cost, and the degree to which the hazard of flooded streets is accepted.

ACKNOWLEDGEMENT

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