

The climate is right up your street

The value of retrofitting in residential streets

A book of examples

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Hogeschool van Amsterdam



Research programme Urban Technology



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Colophon

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Additional Information

This publication can be downloaded from www.hva.nl/klimaatbestendigestad. Also available as an extended online-version (in Dutch), together with a comprehensive package of background information.

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1. Introduction

In this book of examples we present possible implementations of straightforward and manageable climate-resilient ideas and options for residential streets. Examples from ordinary Dutch street views show how climate resilience can be implemented with simple solutions and how this does not need to be more costly than traditional measures, particularly in flat areas (such as we often find in the Netherlands). This observation is based on comparative studies across various Dutch cities. We hope that the examples will inspire you to find ways to implement climate-resilient measures in your city, because *the climate is right up your street*.

1.1 Climate-resilient design: from knowledge and intentions to everyday practice

People have been building sewer systems for wastewater and stormwater (rain) in cities for more than centuries. There have always been extreme rainfall events that the drainage system could not cope with, causing flooding. Due to climate change, the force and frequency of extreme rainfall events is increasing, and more water will fall in shorter spells of time. This requires a higher water storage capacity of excess water on the ground surface. Moreover, water needs to be conserved to cover dry periods and to reduce excessive groundwater level changes. The design focus is shifting from direct discharge to storing and retaining water.

Today, more and more cities are experiencing extreme situations such as cloudbursts, the associated damage and repairs. Many cities around the world have started investigating the local impact of climate change and particularly of the hazards of extreme weather. Nevertheless, there seem to be structural obstacles to integrating climate-change solutions in all retrofitting and maintenance

operations and to moving from 'knowing' to 'doing'. Changing the infrastructure requires a new perspective on urban planning. One of the problems is that there is no standard definition of what climate resilience actually is.

It is a political issue to decide if and how often disruptive effects of extreme rainfall are considered acceptable. The same goes for urban heat-stress effects and changes in groundwater levels. We may have our opinions on these issues, but they are not the essence of what we want to share with this book of examples. The essence of the book is that urban planning must take heed of the increasing frequency of extreme weather (cloudbursts, drought and heat waves) and its consequences. Urban design must adapt to the changes in extreme weather events. In this book, climate-resilient design means taking initiatives to encourage soft surfacing, greening, and to creating space for water and buffers to store it for dry periods. We do not take a normative approach because the challenge is to get the best out of each unique areas potential.

In order to measure the effects of the proposed variants and to be able to compare them, we have chosen a reference value (in mm) for the concept 'extreme rainfall event'. This reference is accounted for in the online background documentation. The reference value is decidedly not intended to set the norm for 'extremity' as that is considered a political issue. In our view, the chosen reference value gives the best estimation of rainfall in one place in one hour that is expected to be exceeded once per 100 years for the year 2050. We expect that such excesses will occur more frequently as a consequence of climate change.

Currently, there is a lively debate in the Netherlands about a possible standard for an 'extreme rainfall event norm'. With regard to retrofitting public space in built-up areas, we are of the opinion that the extreme-rainfall norm is less consequential than the urgency to consider extreme events in the street design. In the coming years, knowledge of extreme weather events will develop further and therefore, urban design should maintain its adaptability. There will be plenty of opportunities to implement adjustments by piggybacking on, for example, replacement of sewer systems, cables, pipelines, hard surfaces and with the retrofitting of public spaces. Adaptation to climate change is therefore a continuous process, rather than a one-off operation.

Institutions in the field, such as municipalities and consultancies, express the need to move forward and indicate a great need for inspiring practical examples with reliable technical underpinnings, and preferably cost-and-benefit estimates. The examples given in this book are presented to inform designers, technicians, and governors alike. Therefore, it provides examples of illustrative designs and financial substantiation.

Ideally, every case of urban retrofitting or maintenance should consider options for climate resilience when refurbishing streets and when renovating or building new residential areas and business districts. This book of examples offers knowledge and practical information to inspire and convince urban planners to take measures.

In the case of the Netherlands, all cities are required to include climate sustainability in urban development from 2020 onwards. The implementation should be realised in all streets by 2050. This target is set in the National Delta Programme.

1.2 Book of examples

In this book of examples we would like to show (1) how ordinary residential streets can be made climate resilient in practice, (2) the costs involved and (3) the advantages. The cases are from neighbourhoods with typical street designs common to many municipalities. For each case we present a traditional design and three more climate resilient alternatives. Each variant is presented with a cost and benefit balance.

We use neighbourhood typologies to distinguish between cases. Besides this also local area features as surface-level fluctuation, soil permeability, and groundwater levels may influence the designs. These features can vary significantly depending on the location. Furthermore, some of the proposed solutions may not be replicable one-on-one in terms of implementation, operationalisation and costing. This book of examples does not aim to cover all situations but it provides examples for the most common cases.

The investment estimations include maintenance and possible water-damage repairs. All investments have been based on a 100-year period in order to provide a realistic comparison of variants with differences in maintenance costs. This should provide a deeper insight into the financial consequences of various options to allow policy makers, designers, administrators and other experts to make well-informed decisions.

In this book we report on 10 cases and their climate-resilient variants. They include flat and sloping surfaces, and differences in soil permeability and groundwater levels. The Netherlands has a predominantly flat surface with

some sloping areas in the eastern- and southern regions. The soil is predominantly sandy with clay or peat and the groundwater tables are usually high. Possibilities, effects and benefits of greening streets are discussed in detail. Greening has several advantages in terms of resistance to excess water and heat stress, making it an ever more important aspect of street and urban design.

This publication is available in both Dutch and English, in printed and online editions. The Dutch online edition provides additional digital background documentation on the case studies to give a comprehensive presentation of their context, situation and the principles of quantification. All case studies are based on planned or completed refurbishment projects in public spaces where the sewer system needed to be replaced or adapted. In each case the focus is on anticipated extreme rainfall. The examples may include more than one street to represent the scale at which projects, such as road construction and sewer replacement, are generally planned.

1.3 Framework

This publication is one of many publications resulting from the project 'The climate-proof city: Urban refurbishing in practice' (De klimaatbestendige stad: Inrichting in de praktijk).

The content and design of the book was realised in collaboration with a peer group of expert advisors in the field (see the colophon).

1.4 Disclaimer

The case studies presented in this book cover the most common situations in the Netherlands, estimated at 80% of all residential/urban streets. A myriad of exceptions and external reasons may require a different solution from the ones presented in this book. For instance, we have not included the presence of basements nor pollution factors and we are assuming high permeability of sand in the foundation (road construction). Every situation is unique and requires a tailored approach. Therefore, this is not a handbook for urban planning, but the intention is to inspire climate-resilient practice.



Lowered curbstone for easy drainage of water to a meadow (Photo Ronald Wentink).



2. The approach

We have selected streets and neighbourhoods that are typical and representative of the Dutch infrastructure (e.g. the urban city block, post-war garden cities and community neighbourhoods). We believe this selection will provide fairly uncomplicated suggestions for climate-resilient design in a variety of situations. A comparison of traditional design with climate-resilient variants shows that the variants are not necessarily costlier and that they are relatively easy to implement when piggybacking on planned retrofitting and maintenance operations.

We have compared variants for the costs of maintenance and implementation as well as the benefits of reduced or prevented flood damage and greening. Benefits that we have so far not been able to quantify sufficiently have not been included.

The focus is on rainwater-resilience. Heat stress and drought are secondary in these case studies, because the effects of climate-resilience methods and public opinion were unknown at the time of writing. As a consequence, it is impossible to indicate what measures would be necessary and sufficient to combat heat stress and drought. However, we have included greening variants because greening always contributes to prevention of heat stress and drought.

2.1 Characteristic typologies

Street design in the Netherlands is often based on a particular philosophy of its time. Ideas and technologies that were available at the time of constructing are captured in the authentic details of these streets, such as the size of the houses, gardens, public space for greens and playgrounds, the width of the streets and the architecture

of the buildings.

Characteristic features that were found across the country were used to distinguish neighbourhood typologies. The set of neighbourhood typologies that we have applied is listed in the table on the following page and is based on Kleerekoper (2016).

The typological variants give direction to the approach to handle more extreme climate effects. For instance, the abundance of public space in post-war neighbourhoods can easily be employed for climate adaptation, whereas in the dense urban housing blocks and pre-war blocks underground solutions are more important. The structure of garden cities offers space for swales to absorb heavy rainfall locally. The opportunities for climate-proof measures will be more or less the same for cities (around the world) in streets of the same typology. Nevertheless, specific characteristics, such as the slope, type of soil and groundwater level, may affect local solutions.

Knowledge of the neighbourhood typology, gradient (flat or sloping), type of soil, and the groundwater level enables us to give a reliable projection of the possibilities and effectivity of local climate adaptation. They apply to many of the streets and neighbourhoods across the Netherlands. In every country common typologies can be determined to present climate adaptations that generally fit in. Throughout Europe typologies will vary strongly, especially from North to South due to difference in climate. Northern countries tend to have more spacious streets to allow sunlight entering the houses during winter. It would be interesting to expand this book of examples to other European neighbourhood typologies.

Table with neighbourhood typologies based on Kleerekoper (2016)

Dutch neighbourhood typology	Period	Features
Urban city block	before 1930	No front garden nor green skirting, 4-5 layers
Pre-war city block	1900-1940	Occasional front garden, 3-4 layers, wider streets than urban blocks and occasional green skirting
Garden village	1910-1930	Spacious front and back garden, 2-3 layers, ample parking space, 1930s architecture, limited public green and rarely street trees
Working-class neighbourhood*	1930-1940	No front garden, little public green, 2-3 layers, single-family units
Low-rise post-war garden city	1945-1955	Open building block with ample green, 2-3 layers, single-family units
High-rise post-war garden city	1950-1960	Open building blocks with ample green, 4-6 layers, apartments, storage on the ground level
Post-war neighbourhood	1940-1990	Front and back garden, 2-3 layers, single-family terraced houses, semi-detached or detached
Community neighbourhood	1975-1980	Single-family unit with front- and back garden, meandering street pattern, courtyards, wide green skirting around the neighbourhood
High-rise city centre*	1960-present	More than 10 layers in grid formation
Suburbanisation - Vinex	1990-2005	Single-family unit, terraced, semi-detached or detached apartments

* Not included in this book of examples are case studies of working-class and high-rise city centre typologies.

2.2 Costs

An often-heard argument against retrofitting public spaces is the assumption that climate-resilient measures are more costly. Therefore, we have created a methodology to estimate the costs and benefits of the variants. This methodology includes construction and maintenance costs of, for example, sewer systems and permeable paving. Furthermore, it includes variation in the lifespan of particular retrofittings. Calculations were based on the cost ratios of the Dutch Sewer Guidelines (Leidraad Riolerend D1100, Stichting Rioned, 2015) as well as empirical evidence provided by individual municipalities (cf. the background documentation).

All investments have been based on a 100-year period in order to provide a realistic comparison of variants with differences in maintenance costs. This should provide a deeper insight into the financial consequences of various options to allow policy makers, designers, administrators and other experts to make well-informed decisions.

The annual cost for each variant were calculated based on investments, periodical reinvestments, maintenance and expected benefits, over a period of one hundred years, assuming that sewer systems have a lifespan of sixty years and streets require major reconstruction every thirty years. A sensitivity analysis of the costs to variation in these periodical assumptions can be found in the online Dutch background documentation.

Costs due to flooding were also expressed in cost per annum based on estimated frequency and the magnitude of the disruption.

2.3 Benefits

Climate-resilient retrofitting of public space has certain benefits. We have included the quantifiable cost-effective measures, such as lower repair costs and valorisation of drainage water for wastewater treatment. Other benefits were less quantifiable, such as reduced or delayed drainage to surface water, groundwater recharge, heat stress reduction, and increased water availability for urban green. In addition to advantages to the water system (such as increased infiltration), greening public space improves public comfort and health, water quality, reduction of energy consumption and it increases biodiversity. These benefits were studied and quantified with the TEEB-city-method ('The Economics of Ecosystems and Biodiversity' [Buck consultants international, 2016]).

We have limited ourselves to a rough description of the benefits of greening because an exact description of the background factors and uncertainties would not fit within the scope of this book of examples.

2.4 Variants

In this book we present ten case studies in detail. They cover a mix of flat and sloping locations. The table on the following page shows eight representative neighbourhood typologies and their characteristics. Two typologies are presented twice: for a sloping and for a flat situation.

It is important to note that the solutions we present are based on street and pavement constructions using a sand sub-base as foundation. Following Dutch standard requirements for sand bedding ('RAW-systematicity for contract documents') we assume that the foundations have good permeability. This allows for temporary stormwater

storage in the foundation (via an infiltration system) when subsoil permeability is insufficient. In order to empty the foundations and swales in the cases with insufficient subsoil permeability we provided (in the designs) drainage facilities in the foundations and below the swales. Based on the standard, solutions in this book of examples are therefore independent of the exact composition of the subsurface or the groundwater level. This principle can be applied almost everywhere. However, there are exceptions in practice when the extra storage of water in the cunnette is not desirable or even impossible.

The next chapter provides a detailed account of the first five cases (see table below). The other five cases are very similar and therefore discussed here in less detail to avoid repetition. The details for all ten cases can be found in the Dutch online background information at www.hva.nl/klimaatbestendigestad.

For each of the selected neighbourhood typologies we compare one traditional design with three climate-resilient variants. Variant 0 is the traditional design, whereas variants (1 - 3) are more climate resilient to extreme rainfall. Some cases include a particularly green variant. Variants were tested on their sensitivity to flooding, assuming that water damage occurs when water enters the houses. For that purpose we calculated for different volumes of extreme rainfall events in one hour if water would enter the houses. These different extreme volumes of rainfall are linked to estimations of frequency of occurrence.

All variants were designed in such a way that a rainstorm of 20 mm in one hour would not cause flooding in the street.

Old statistics predicted that this 'extreme rainfall' threshold would be reached once every other year. By the year 2050, it is expected that, due to climate change, this amount of rainfall in one hour will occur once a year on average (Kluck et al., 2013).

The premise for design variants (1-3) is that rainfall of 60mm in one hour does not result in water entering the houses. This rainfall volume in one hour is our best estimate of an extreme rainfall event in one place expected to occur

Overview of neighbourhood typologies

Case study	Neighbourhood typology	Incline	Paragraph
1	Pre-war city block	flat	3.1
2	Urban city block	flat	3.2
3	Post-war neighbourhood	sloping	3.3
4	Low post-war garden city	flat	3.4
5	High-rise post-war garden city	sloping	3.5
6	Suburbanisation - 1990-2005	flat	3.6
7	Urban city block	sloping	3.7
8	High-rise post-war garden city	flat	3.8
9	Community neighbourhood	flat	3.9
10	Garden village	sloping	3.10

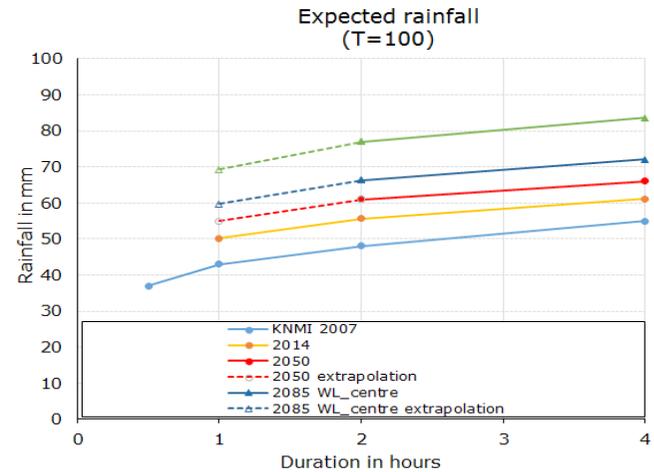
once per 100 years for the year 2050 (Beersma et al., 2015; Kluck et al., 2013), see the graph on the right. The background documents provide more information on the choice of this extreme rainfall event. If more rain should fall in a short time span (one hour) water will enter the houses. The variants differ in the techniques and ratios applied for storing, infiltrating or discharging.

In flat areas the focus should be on retention and the creation of local storage spaces to avoid flooding of houses. Sloping areas are more complicated. Climate resilience of sloping areas depends on the vulnerability of its downstream area. Investment in sloping areas are therefore highly dependent on flooding effects downstream. The gradient, length, and the permeability of the surface affect the extent of a possible downstream flooding. The strategy for such areas aims to:

- delay the water flow where possible, or to store it (temporarily) in available spaces, such as level areas;
- make sure that stormwater is directed into the street and discharged via the street in between the curbs.

Investment in directing water downhill are feasible when there is substantial green or surface-water space downstream. However, the higher the estimated disruptive effect is, the more investment is needed to retain water on the incline. As the need for measures (storing water) depends on the downstream situation, we decided to define three climate proof variants for sloping areas, which differ in ability to cope with extreme rainfall events of 20, 40 and 60 mm in one hour.

¹ This 20 mm of rainfall is based on the size of the paved area and the assumption that in this condition the unpaved surface will not discharge water onto the paved surface. With more than 20 mm of rainfall in one hour we assume that water can flow from the unpaved onto the paved surface.



Extreme rainfall events plotted against extrapolated rain-duration lines based on studies by Beersma et al., (2015) and Buishand en Wijngaard (2007) from Kluck et al. (2017).



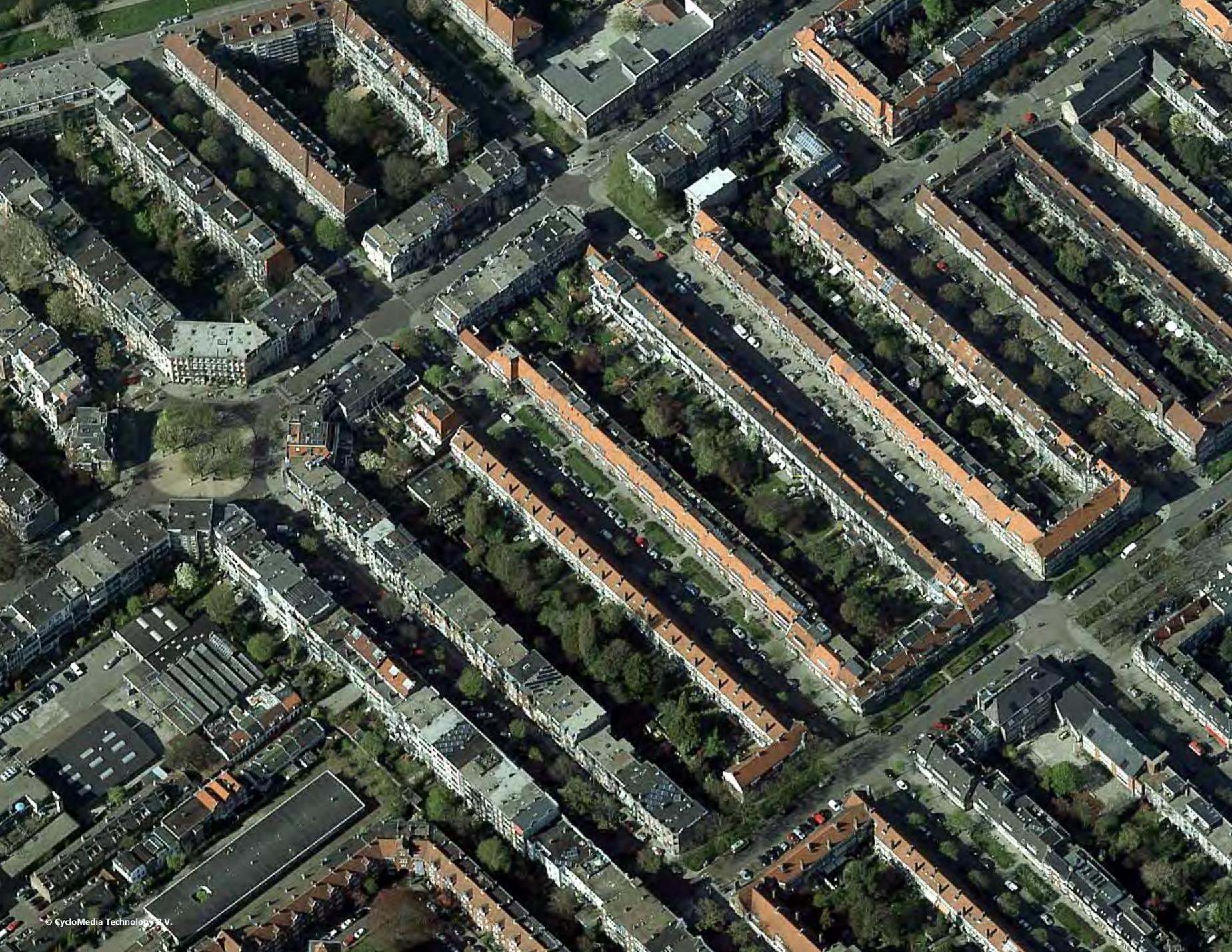
Surface drainage in Arnhem (Photo Floris Boogaard)

Simple climate resilient refurbishing in Deventer (Photo Tauw bv)



3. Real world examples

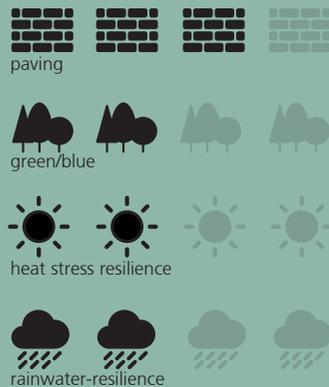
In this chapter we will present the 10 case studies. They are spread out across eight neighbourhood typologies in flat and sloping areas. A comparison is made between climate-resilient variants and traditional refurbishments for each of the cases. This is done on the basis of accurate design and a cost and benefit estimation.



3.1 Pre-war city block

Neighbourhood typology characteristics

The pre-war city block typology was established step-by-step between 1900 and 1940. It characterises itself by geometric street patterns, relatively spacious street profile, and uninterrupted green spaces that make it seem more spacious than the urban city block. The lay out offers opportunities to either store stormwater temporarily on the spacious streets or to diverge it to the green spaces for temporary storage. Pre-war houses sometimes have basements with flood risk. The closed blocks prevent water discharge from the back gardens onto the street. Solutions to this risk are left to the private sector.



Based on Kleerekoper (2016)

Case study of a pre-war city block (flat)



362 m street length



55 ground floor homes

%



Approximately 90% of the public space is paved



Paving consists of bricks and pavement of concrete stones

%



The street level has no slope



37 trees in the street



Approximately 25 m distance between facades

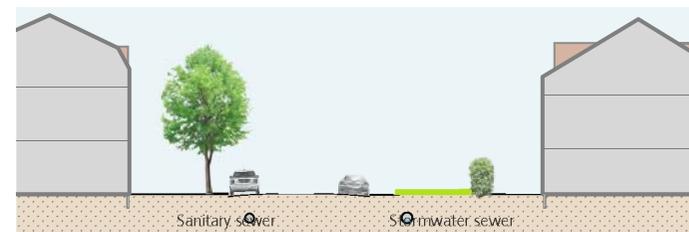


Local Situation

This particular location lies in a flat area with poorly permeable soil and a separate sewer system (sanitary sewer and stormwater sewer). There are trees on one side of the street and a green area on the opposite side. The municipality is going to replace the sewer system and the pavement. This would be a perfect opportunity for retrofitting in a more climate-resilient way.

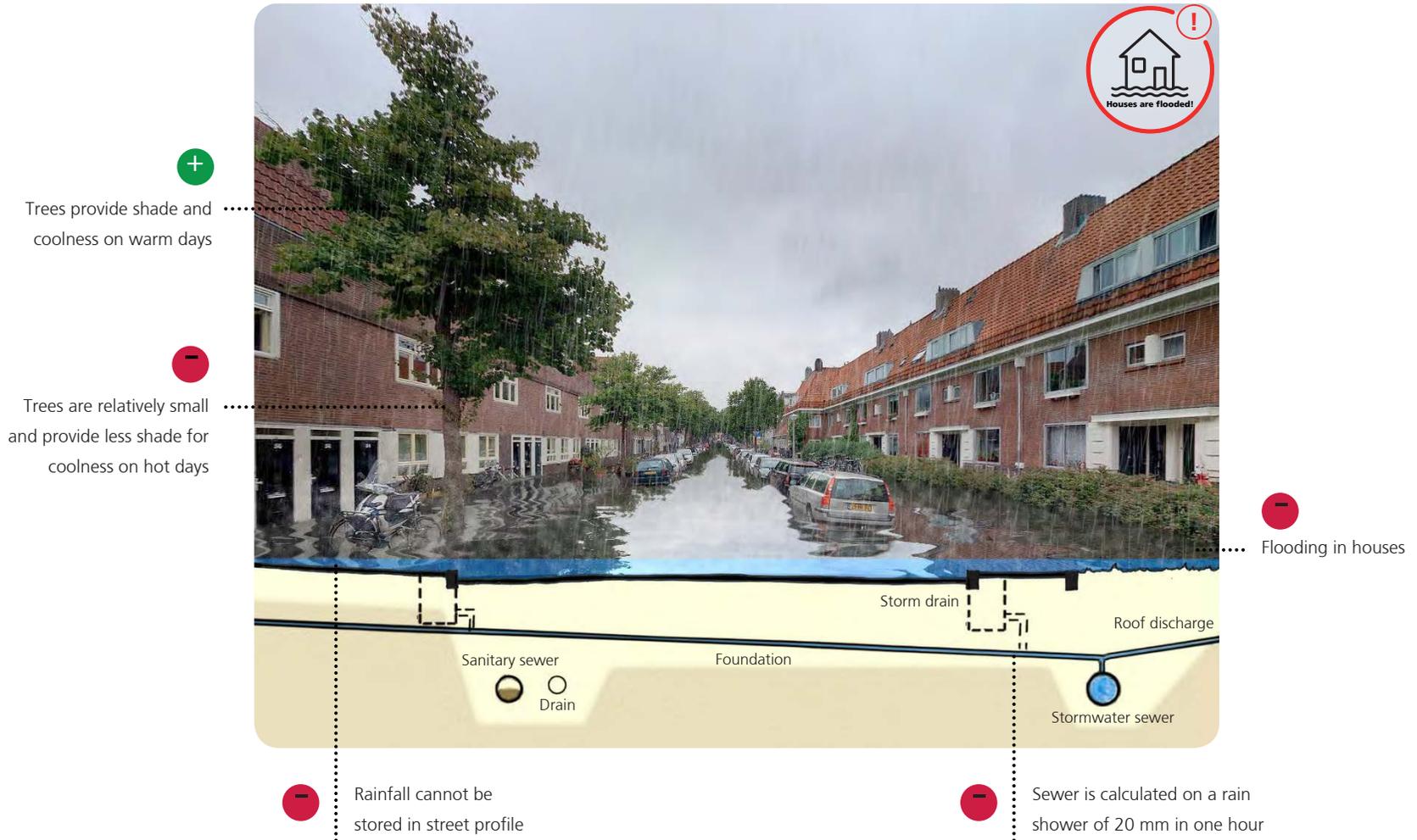
Flat terrain

With a traditional refurbishment, we expect flooding of houses and buildings at rainfall intensity rates of approximately 40 mm in one hour. This image illustrates the traditional refurbishment.



Traditional refurbishment

With a traditional refurbishment, we expect flooding of houses and buildings at rainfall intensity rates of approximately 40 mm in one hour. This image illustrates the traditional refurbishment.



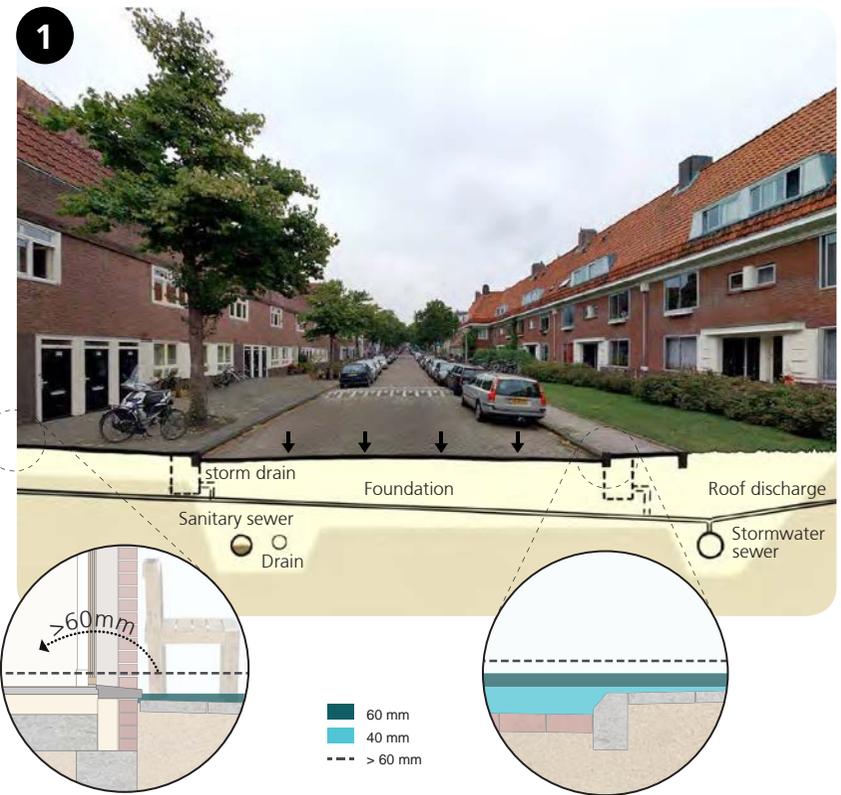
Variant 0: traditional refurbishment

The municipality raises the subsided public space to its original construction height. The existing separate sewer system (sanitary sewer and stormwater sewer) and paving are renewed. The sewer system can cope with heavy rainfall once per one or two years on average. There is some space for stormwater storage in the street, but it has not been designed for that purpose. With extreme rainfall (40 mm or more in one hour), stormwater can flood the buildings. The green area is situated at a higher level than the road.



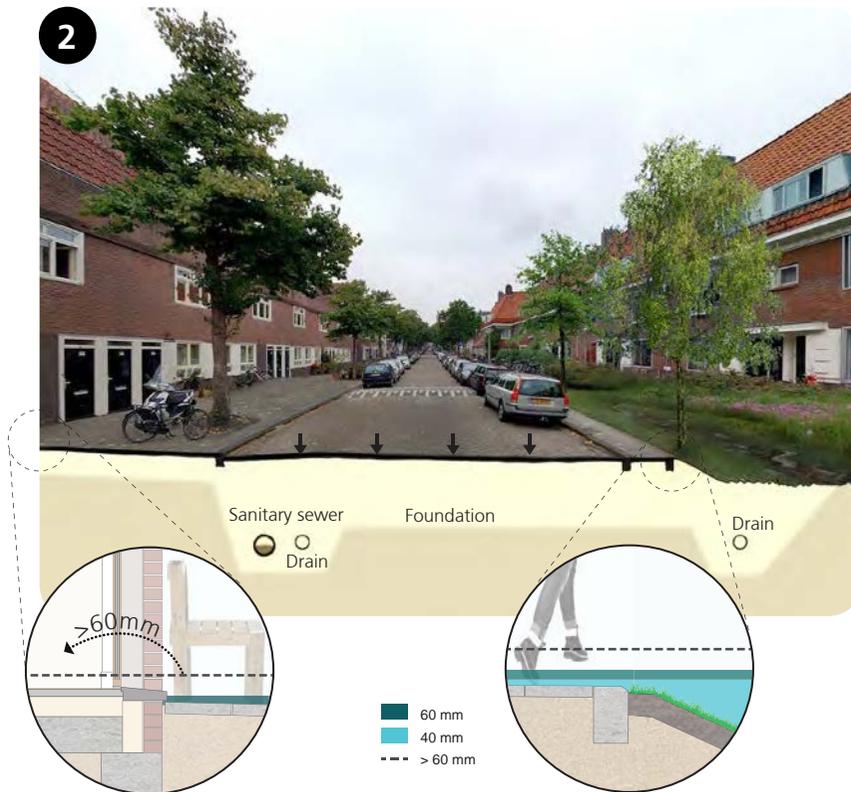
Variant 1: retention in the street

The municipality lowers the road level to 9 cm lower than the level of variant 0. The pavements are then adjusted accordingly, providing storage space in the streets. When a cloudburst exceeds 60 mm in one hour water will flood buildings. The existing sewer system and paving are replaced. The sewer system can cope with a rainstorm once per one or two years on average. The green area is situated at a higher level than the road.



Variant 2: retention in the swale

In this case there is no stormwater sewer system. The municipality builds a swale in the green area. This swale can deal with 20 mm of rain in one hour. The road slopes towards the swale and is 4 cm lower than variant 0, which means that in an area with soil subsidence there is no need to raise the ground as much as in variant 0. Finally, because the swale is positioned at such a low level, flooding of the houses will only occur in case of a cloudburst larger than 60mm in one hour.



Details show water levels of 40mm, 60mm and more than 60mm in one hour

Variant 3: storage in the foundation via permeable paving

In this case there is no stormwater sewer system. Instead, the municipality refurbishes the road with permeable paving that can cope with 20 mm of rainfall in one hour. The road is situated 12 cm lower than in variant 0 and the pavement are adjusted accordingly and slopes towards the street. This creates space for water storage during heavy rainfall. Water will only enter houses with a cloudburst of more than 60 mm in one hour. Consequently, the ground does not need to be raised much in areas with soil subsidence.



Conclusions for pre-war city block

Cost-benefit of rainwater

The graph shows the annual costs for each variant, including construction, maintenance and flooding costs. The annual costs are based on estimates over a period of one hundred years.

The annual costs for variant 1 (retention on the street) are approximately 7% lower than those for the traditional . The variants with infiltration (2 and 3) are more expensive than the traditional variant. However, variants 2 and 3 have the advantage that rainwater is stored underground and either is slowly infiltrated (good permeability) or slowly discharged by a drainage system (low permeability). In the latter case the drainage system in the foundations also drains water when the natural groundwater level is high.

When variants with infiltration (2 and 3) are disconnected from the stormwater system, they will delay drainage onto the surface water and alleviate stress on the surface water system. The possible benefits of this have not been taken into account.

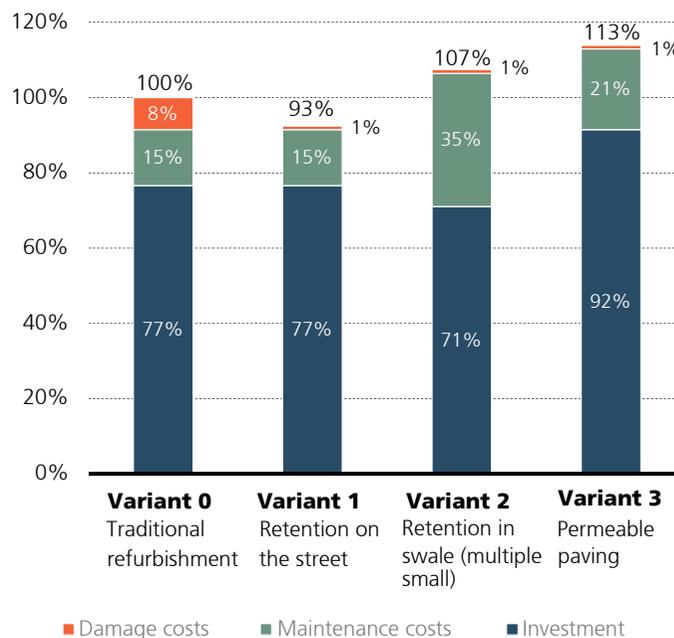
Green Benefits

More green in the city contributes towards the reduction of heat stress and the prevention of drought. According to our calculations the benefits to health, comfort, economic value and energy use are many times higher than the annual costs of refurbishing the entire street. Moreover, the benefits are considerably higher than the additional costs (investment, management and maintenance) of the green areas.

Conclusions

In the typology of pre-war city blocks in a flat area, residential streets might as well get a climate-resilient redesign at no extra cost by lowering the street level. Furthermore, piggybacking on planned operations such as renewing the sewer system or periodical redesign is cost effective. The variants with a swale (variant 2) and with permeable paving (variant 3) appear to require a little more investment. Nevertheless, the benefits are that they retain water locally and cause a reduction in water discharge. The climate resilient designs cause less inconvenience and flood damage and can be combined with more vegetation in the street.

Costs for pre-war city block



“Green increases property value” (Daams, 2016)





3.2 Urban city block

Neighbourhood typology characteristics

Urban city blocks are characterised by multilevel stories and an organic street pattern. The paved streets leave little space for public green, although there are a few large trees. The closed building blocks prevent water discharge via the back gardens. Solutions to this problem are left to private initiative.



Case study of an urban city block (flat)



299 m street length



40 ground floor homes

%



Approximately 90% of public space is paved



Paving consists of bricks and concrete paving stones

%



The street level has no slope



43 trees in the street



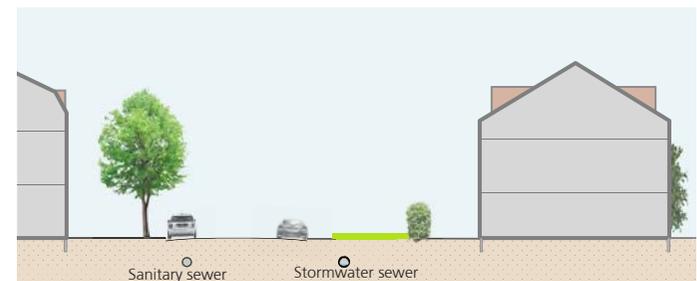
Approximately 15 m distance between facades

Local situation

The researched location is on flat terrain and consists of poorly permeable soil. The street foundation has good permeability and there is a separate sewer system (sanitary sewer and stormwater sewer).

Flat terrain

Flat terrain has the benefit of relatively easy water retention. With extreme rainfall events the water will not flow freely but it will be collected at the lowest points.



Traditional refurbishment

With a traditional refurbishment, we expect flooding of houses and buildings at rainfall intensity rates of approximately 40 mm in one hour. This image illustrates the traditional refurbishment



Variant 0: traditional refurbishment

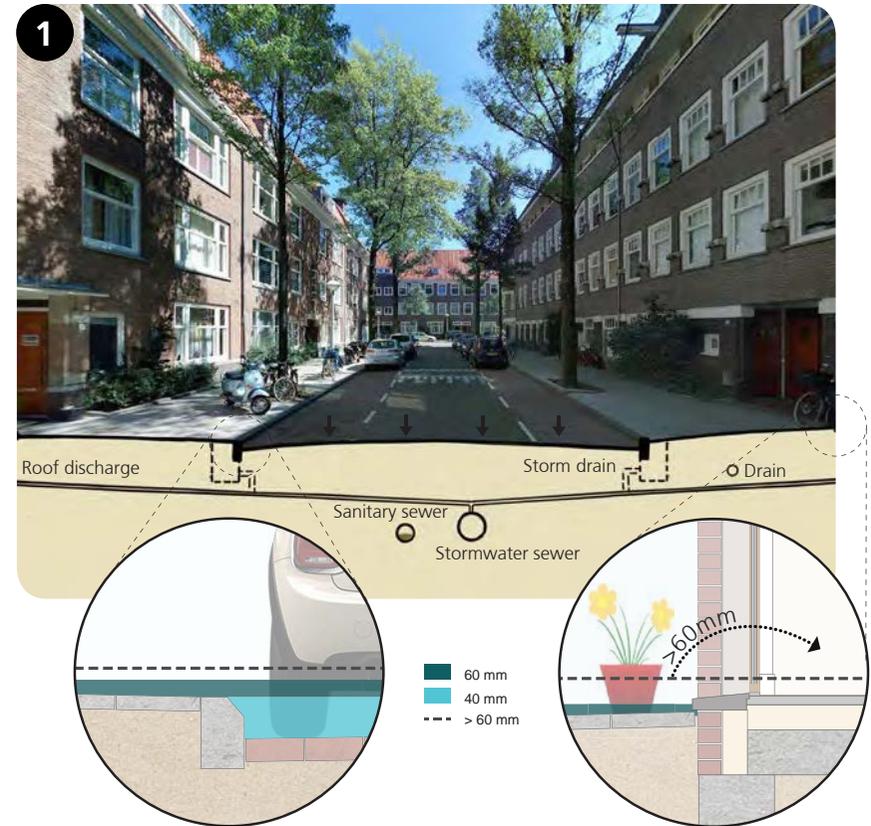
The municipality raises the level of the public space to its original construction height to correct for the soil subsidence. The existing separate sewer system (sanitary sewer and stormwater sewer) and the pavement are renewed. The sewer system can cope with heavy rainfall once per one or two years on average. The street is not specifically designed to retain water, but it can hold a small amount. Water may enter the buildings with extreme rainfall of 40 mm or more in one hour.



Details show water levels of 40mm, 60mm and more than 60mm in one hour

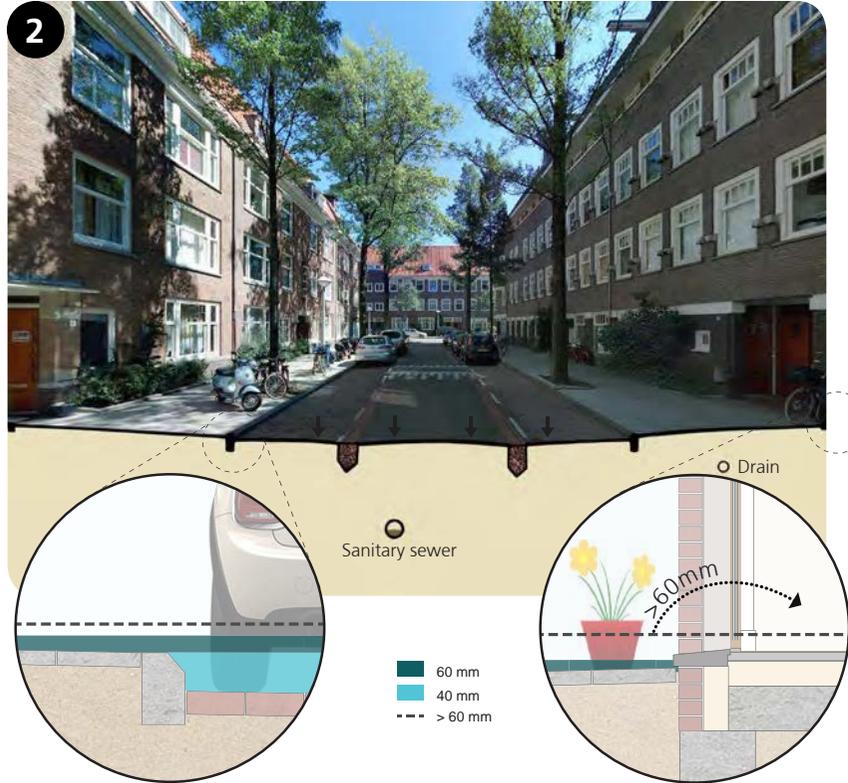
Variant 1: retention in the street

The municipality rebuilds the road level 10 cm lower than the level of variant 0. Therefore, in case of soil subsidence, the costs for raising the street are lower. The pavement is adjusted accordingly and slopes towards the street. Consequently, it provides water-storage space in the streets. A cloudburst of more than 60 mm in one hour may cause water to enter the buildings. The existing sewer system and paving are replaced. The sewer system can cope with rainfall once 1-2 years on average.



Variant 2: retention in the foundation via infiltration gullies

In this case, there will be no separate stormwater sewer system. Instead, infiltration gullies are added to the road paving, allowing stormwater to flow into the foundation. These infiltration gutters have a capacity of up to 20 mm of rainfall in one hour. The municipality builds the road 10 cm lower than in variant 0. Therefore, in case of soil subsidence, the costs for raising the street are lower. The pavement is adjusted accordingly and slopes towards the street. The lower street level creates space for heavy rainfall to be stored in the street. Water will enter the houses only with a cloudburst causing more rainfall than 60 mm in one hour.



Details show water levels of 40mm, 60mm and more then 60mm in one hour

Variant 3: storage in the foundation via permeable paving

There is no stormwater sewer system. Instead, the road has permeable paving that can cope with 20 mm of rainfall in one hour. The municipality builds the road 10 cm lower than in variant 0. Therefore, in case of soil subsidence, the costs for raising the street are lower. The pavement is adjusted accordingly and slopes towards the street. The lower street level creates space for heavy rainfall to be stored in the street. Water will enter the houses only with a cloudburst causing more rainfall than 60 mm in one hour.



Green opportunities

Green benefits

More green in the city contributes to the reduction of heat stress and the prevention of drought. According to our calculations, the benefits to health, comfort, economic value and energy use are many times higher than the annual costs of refurbishing the entire street. Moreover,

the benefits are considerably higher than the additional cost (investment, management and maintenance) of the green areas. Besides green benefits, additional green areas provide opportunities for stormwater drainage.



Additional façade plants reduce the absorption of heat through the façade and lowers the temperature



Additional vegetation provides more shade and coolness



A combination of bike racks, vegetation and permeable paving

Conclusions urban city block

Cost-benefits of rainwater

The graph shows the annual costs for each variant, including construction, maintenance and flooding costs. The annual costs are based on estimates over a period of one hundred years.

The annual costs for variant 1 (retention in the street) are approximately 9% lower than the costs for traditional refurbishing. Variants with infiltration are more expensive. However, the advantage is that these variants have a capacity to store stormwater in the ground when it is permeable. Or, if the ground is poorly permeable, stormwater drainage will be delayed. Drainage in foundations can also work for higher natural groundwater levels as they delay stormwater drainage (see background documents).

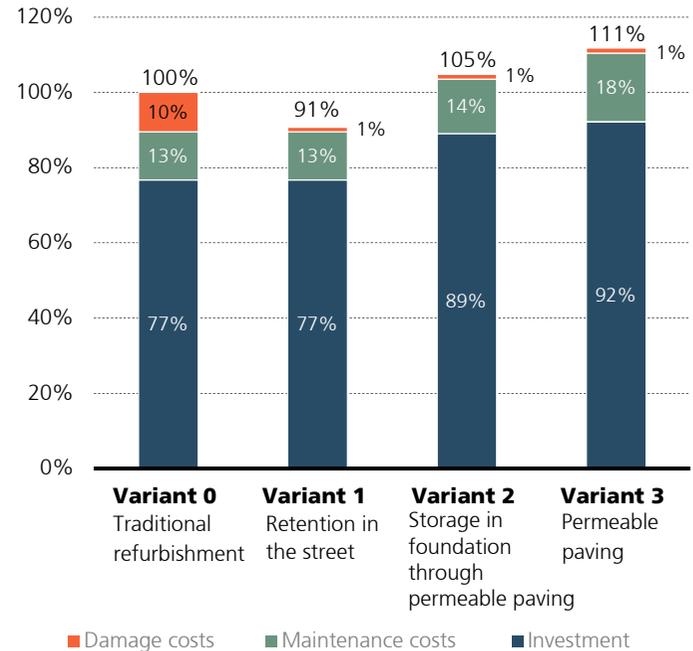
When variants with infiltration (2 and 3) are disconnected from the stormwater system, they will delay discharge onto the surface water and alleviate stress on the system. The possible benefits of this have not been taken into account.

Conclusions

In the flat urban city block typology, residential streets can be made climate-resilient at no extra cost by lowering the surface level. To achieve this, it is important to piggyback on planned operations, such as replacing the sewer system and periodical redesign operations.

The climate resilient designs cause less inconvenience and flood damage, and can be combined with more green in the street.

Costs for urban city block





3.3 Post-war neighbourhood

Neighbourhood typology characteristics

The post-war neighbourhood is characterised by low-rise buildings with a front and back garden. In this typology the density of green space relies predominantly on private gardens. Demands for parking space varies according to the population density. This neighbourhood is designed spaciouly with a wide road and parking space on either side. Possibilities for creating space for water are straightforward and will reduce flooding in the lower areas.



Case study of a post-war neighbourhood (sloping)



229 m street length



27 terraced houses

%



Approximately 100% of public space is paved



Paving consists of bricks and concrete paving stones

%



The street has an incline of approximately 7 m



There are no trees in the street



Approximately 20 m distance between facades

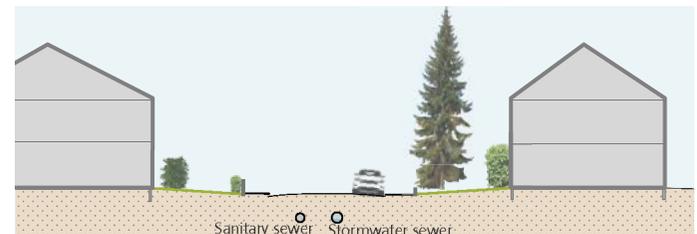


Local Situation

The case study location is characterised by large front gardens and relatively wide streets with semi-detached houses. The street profile consists of a hard surface with pavements on both sides and parking space along the pavement. The ground is permeable. There is a separate sewer system (sanitary sewer and stormwater sewer).

Sloping area

The slope and the elevation of each of the houses in this area varies. Water can be drained on the slope by using the difference in height. If drainage problems are likely to occur downhill it is important to retain water on the slope.



Traditional refurbishment

With traditional refurbishment, water is expected to enter the houses at rainfall intensity rates of approximately 40 mm in one hour. This picture illustrates the situation.



Front gardens offer a chance to plant additional vegetation. This provides coolness in the summer



Rainfall cannot be stored in street profile



Flooding in houses



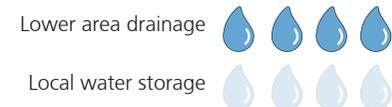
Lack of shade increases heat stress in summer



Sewer is designed for discharge of rain showers of 20 mm in one hour

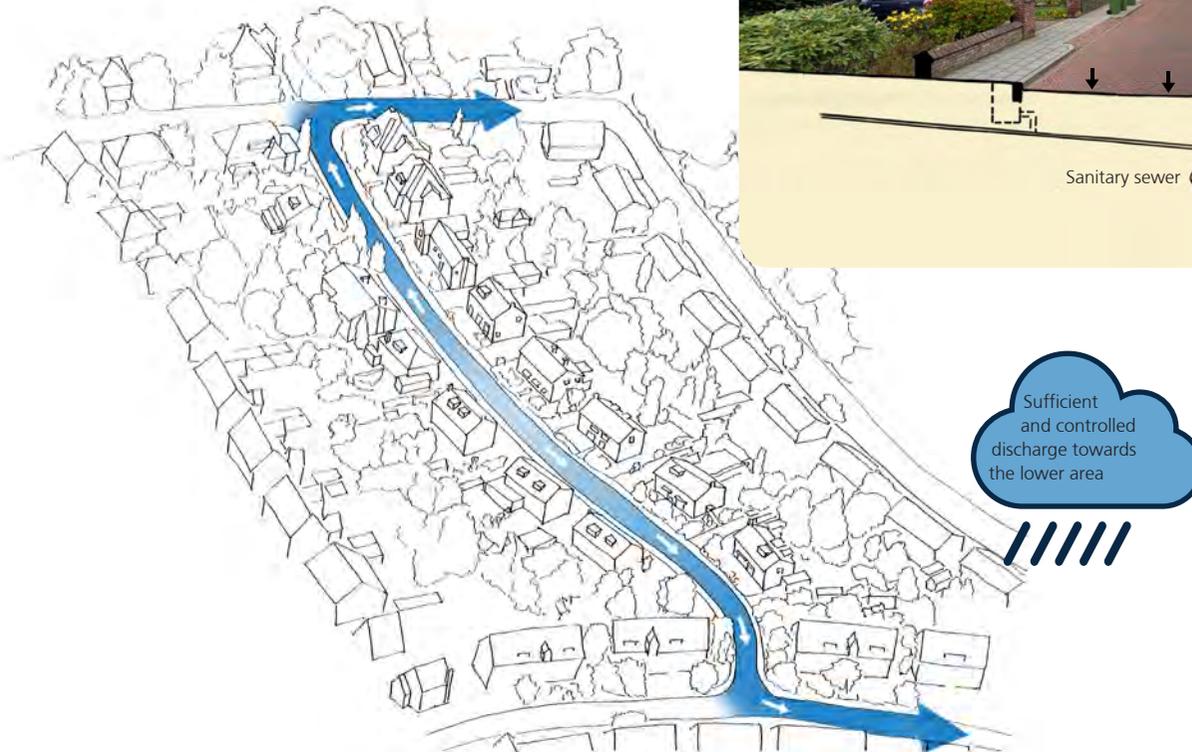
Variant 0: traditional refurbishment

The refurbishment of public space follows the existing profile. The sewer system and the paving are renewed. The sewer system can process a rainstorm once in 1-2 years on average. There is some space for water retention in the street, although the street has not been designed for this purpose. Heavy rainfall can lead to considerable water flow downhill due to the slope. Water may enter the houses at the bottom of the street and could cause significant disruption.



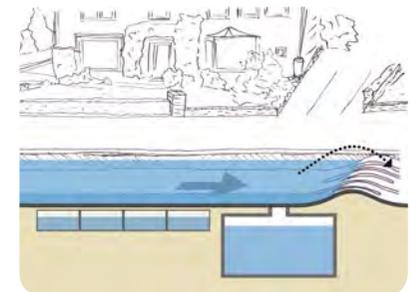
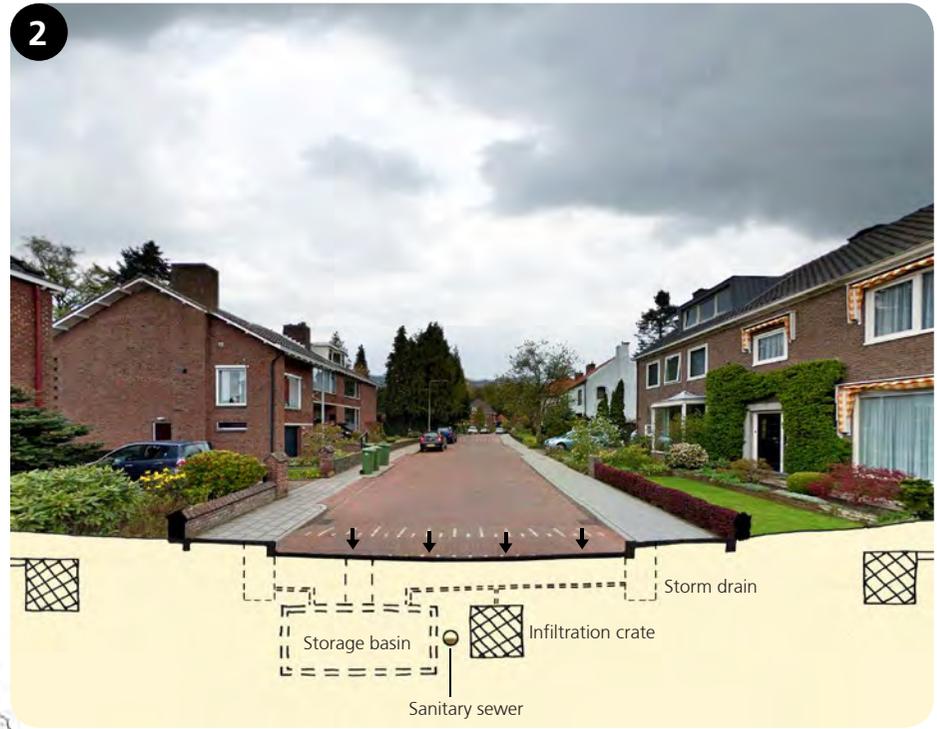
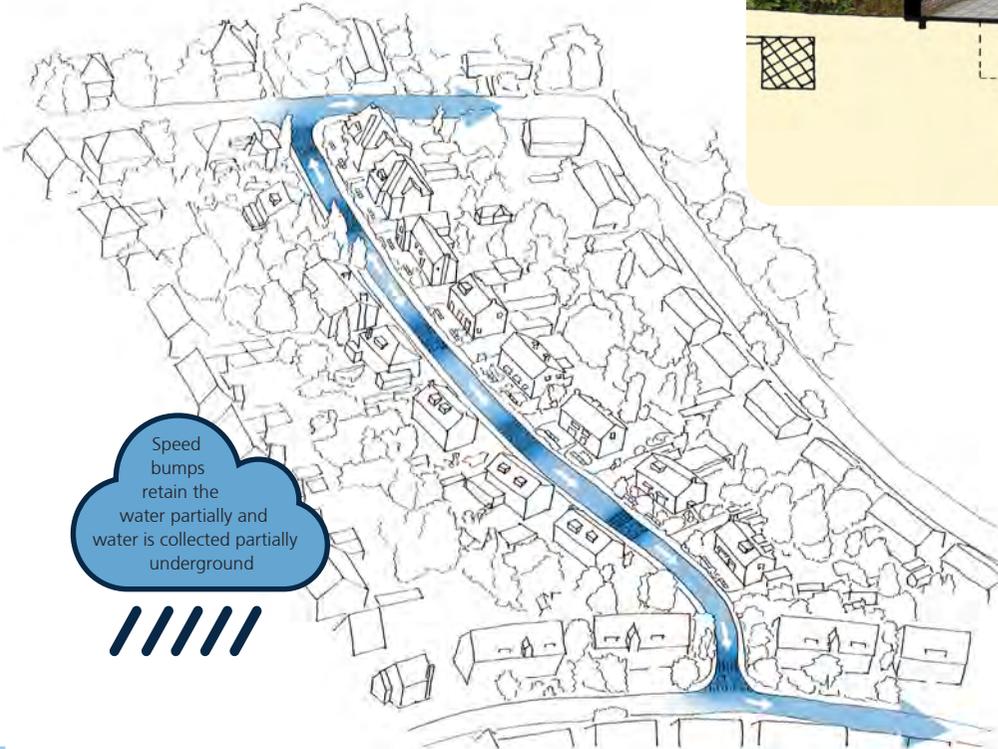
Variant 1: guiding the water in the street

The slope prevents water storage in the street. The municipality lowers the road by 10 cm in comparison to variant 0, which means that the water flow will concentrate on the street itself. The existing sewer system and paving are replaced. The road is made hollow so that the road and stormwater sewer system together can cope with 60 mm of rainfall in one hour without water entering the houses. The assumption is that there will be no disruption downstream.



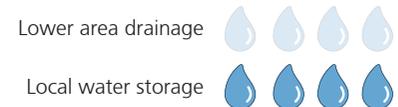
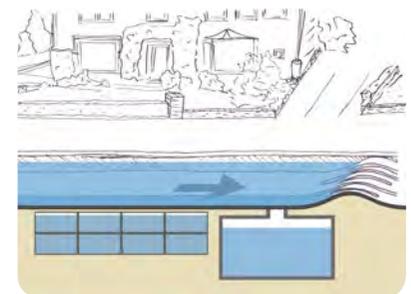
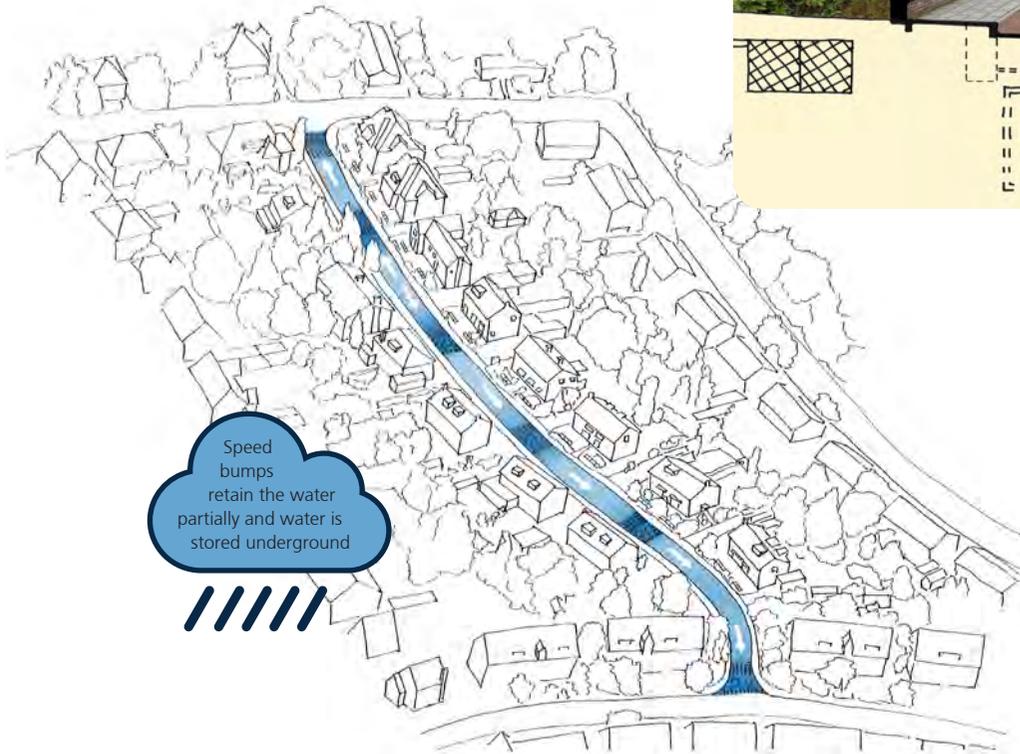
Variation 2: underground storage

The municipality does not install a new water-sewer system, but lowers the road by 10 cm in comparison to variation 0. Infiltration facilities (e.g. crates), which are located under the road, can store water and drain into the soil. Thresholds in the road retain water so it can flow into the infiltration facilities. These thresholds should be lower than the pavement. Additionally, infiltration crates are placed in the front gardens and in the road. The two systems can retain 40 mm of rainfall in one hour. The other 20 mm in the hour finds its way down the hollow street profile. The assumption is that in this variation there will be no disruption downstream at 40 mm of rainfall in one hour.



Variation 3: underground storage (large)

The municipality does not install a new stormwater sewer system, but lowers the road by 10 cm in comparison to variation 0. Infiltration facilities (e.g. crates) are implemented underneath the road. These facilities store water and release it into the ground. Thresholds in the road retain water so it can flow into the infiltration crates. These thresholds should be lower than the pavement. Additionally, crates are placed in the front gardens and in the road. The two systems combined can cope with 60 mm of rainfall in one hour. Only when there is more than 60 mm of rainfall in one hour would the water flow into the downstream area.



Green opportunities

Green benefits

More green in the city contributes to the reduction of heat stress and the prevention of drought. According to our calculations, the benefits to health, comfort, economic value and energy use are many times higher than the annual costs of refurbishing the entire street. Moreover, the benefits are considerably higher than the additional costs (investment, management and maintenance) of the

green areas. Besides green benefits, additional green areas provide opportunities for stormwater drainage. In this case, the individual household plays an important role in the struggle against flood risks.



Large trees provide protection against radiation of the sun on hot days.



Vegetation on the street provides additional infiltration capacity and coolness.

Conclusions for post-war neighbourhood

Cost-benefit of rainwater

The graph shows the annual costs for each variant, including construction and maintenance costs. The annual costs are based on estimates over a period of one hundred years.

Flood damage costs were not included in the graph because they depend on the downstream situation. For example, if there would be a large green area or surface water downstream, the flood damage would be much less than if there would be a built-up area. Street length and gradient are other factors that affect the risk of flood damage.

The annual costs are lowest for variant 0 (traditional) and for variant 1 (guiding the water). The variants with water storage and infiltration on the slope seem to be more expensive, but they have the advantage that they bring more water into the ground or delay (peak) discharge and reduce downstream flood risk.

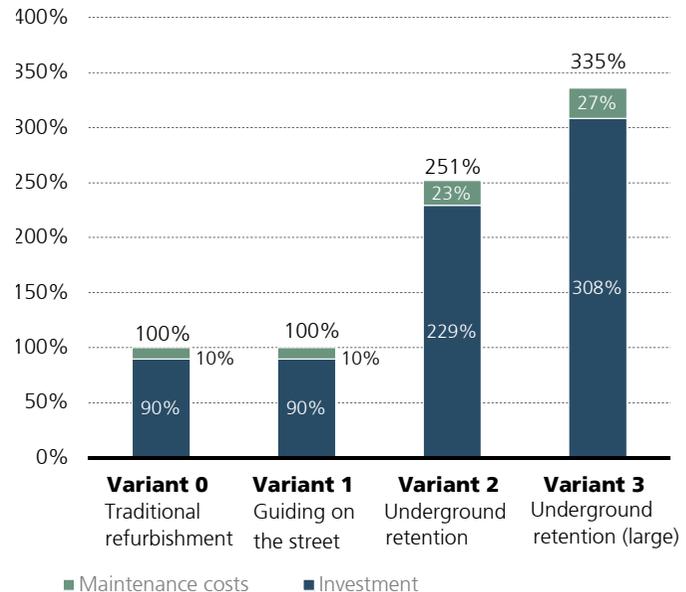
Whether or not the infiltration of rainwater is cost effective depends largely on the potential damage at the bottom of the gradient. Each situation is unique and must be observed and evaluated individually.

When variants with water storage and infiltration on the slope (2 and 3) are disconnected from the stormwater system, they will delay drainage onto the surface water and alleviate stress on the system. The possible benefits of this have not been taken into account.

Conclusions

For the sloping post-war neighbourhoods, measures to channel the water flow and to (partly) infiltrate it into the streets, are an option. They offer a clear improvement to the current situation. The amount of money and effort that needs to be invested highly depends on the (water) damage that could occur downstream and needs to be tailored to the situation. From a financial perspective, the cost of implementation can be reduced by piggybacking on planned construction, such as the renewal of the sewer system and periodical redesign.

Costs for post-war neighbourhood



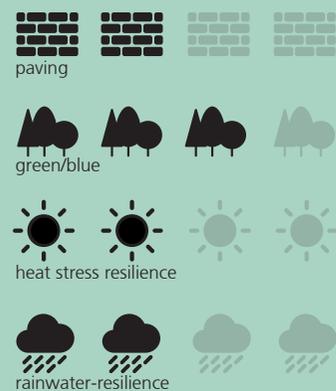
² The effectiveness of infiltration depends on the permeability of the soil.



3.4 Low-rise post-war garden city

Neighbourhood typology characteristics

The flat post-war garden city with low-rise buildings is characterised by a relatively large public space between the houses. The houses are either bungalows or terraced houses with private gardens. They occur in residential areas that have a green public space in each block that allows for local water storage and infiltration. The preservation of green space in these areas is under pressure. However, when green space is made to be part of the water system, there will be more reason to preserve it.



Case study of a post-war garden city with low-rise buildings (flat)



44 m street length



12 ground floor homes

%



Approximately 68% of the public space is paved



Paving consists of bricks and concrete paving stones

%



The street level has no slope



3 trees in the street



Approximately 30 m distance between facades

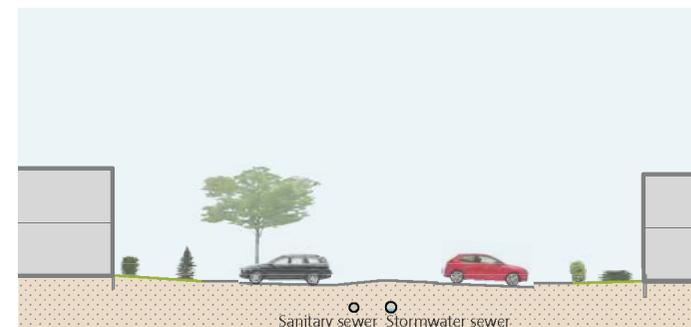


Local situation

The area is flat. It has a low groundwater level and good permeable soil. There is a combined sewer system, which is going to be replaced by a separate sewer system.

Flat terrain

The flat terrain contributes to the relative ease of water storage. During extreme rainfall events, the water will not flow away freely but will accumulate in the lowest area.



Traditional refurbishment

With traditional refurbishment, we would expect water to enter houses after rainfall with of approximately 40 mm in one hour, as illustrated in the picture.



Rainfall cannot be stored in street profile



Trees provide shade and coolness on warm days



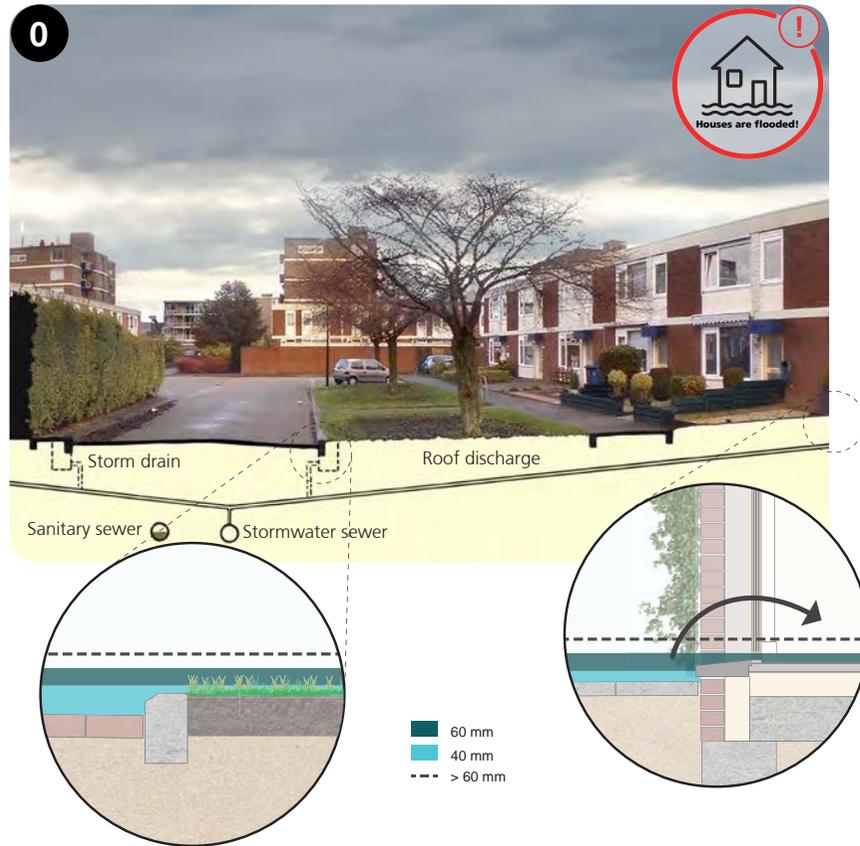
Flooding in houses



Sewer is designed for discharge of rain showers of 20 mm in one hour

Variant 0: traditional refurbishment

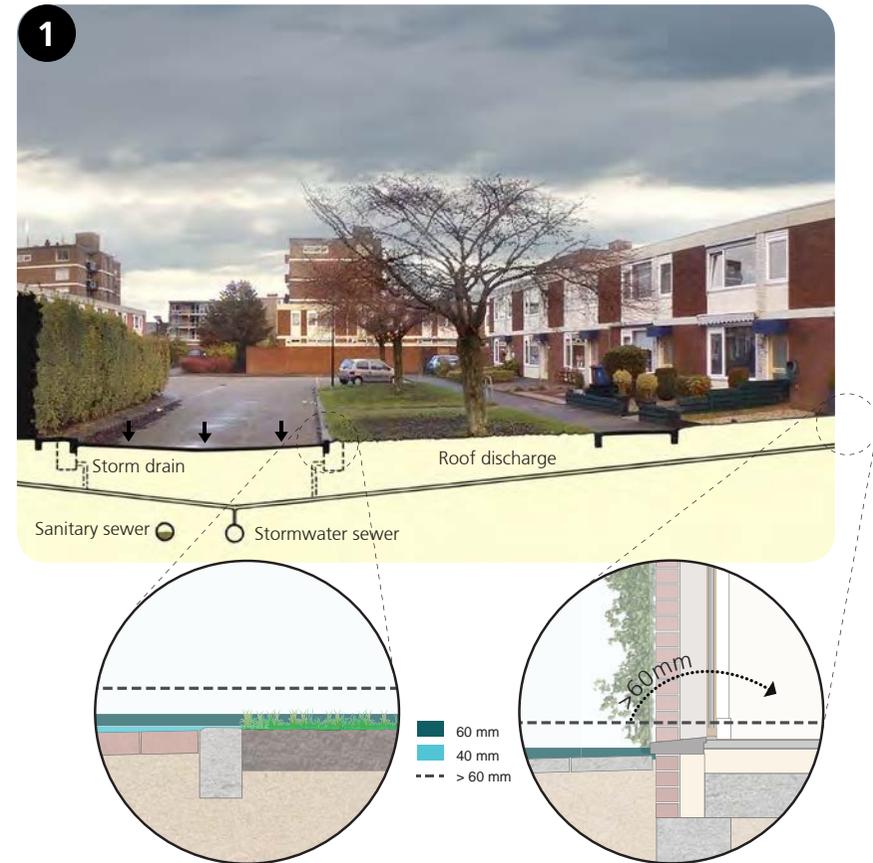
The existing combined sewer system is replaced by a separate sewer system, followed by the renewal of the paving. The sewer system can process heavy rainfall once every 1-2 years. There is some space for water in the street. However, the street is not particularly designed for this purpose. Extreme rainfall can lead to water entering the houses (it is assumed that this will happen when there is more than 40 mm rainfall in one hour).



Details show water levels of 40mm, 60mm and more than 60mm in one hour

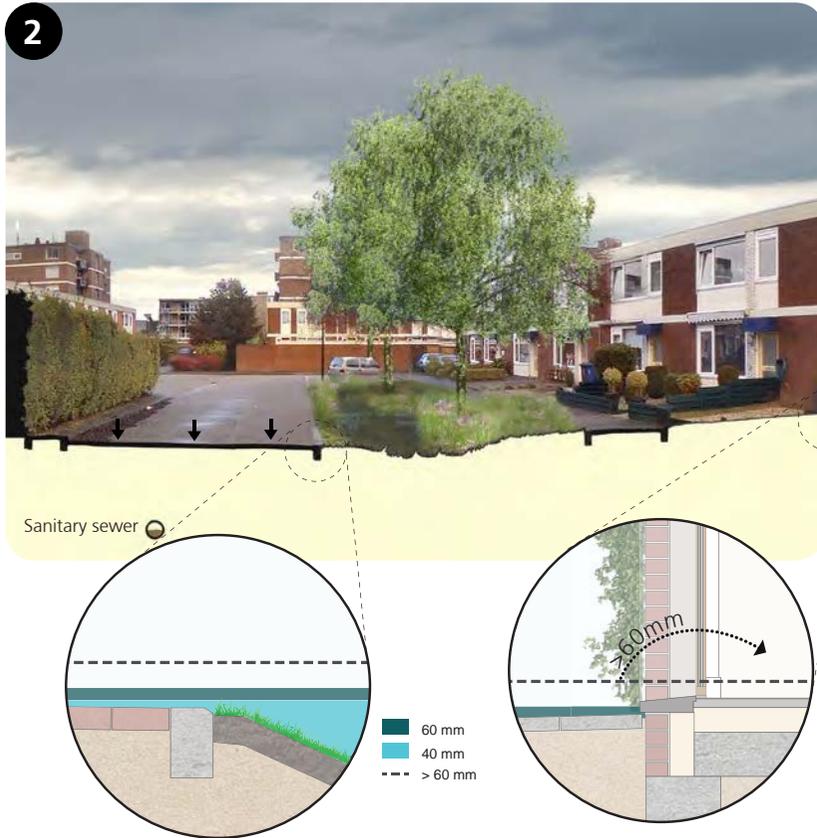
Variant 1: retention in the street

The current convex road surface is replaced by a hollow surface at 10 cm lower than the road in variant 0. This change leads to more space to store water from extreme rainfall events in the street. Water can only enter the houses with a cloudburst of over 60 mm in one hour. A separate sewer system replaces the combined sewer system, and the paving is refurbished. The stormwater sewer system can process heavy rainfall once every 1-2 years.



Variant 2: storage in a central swale

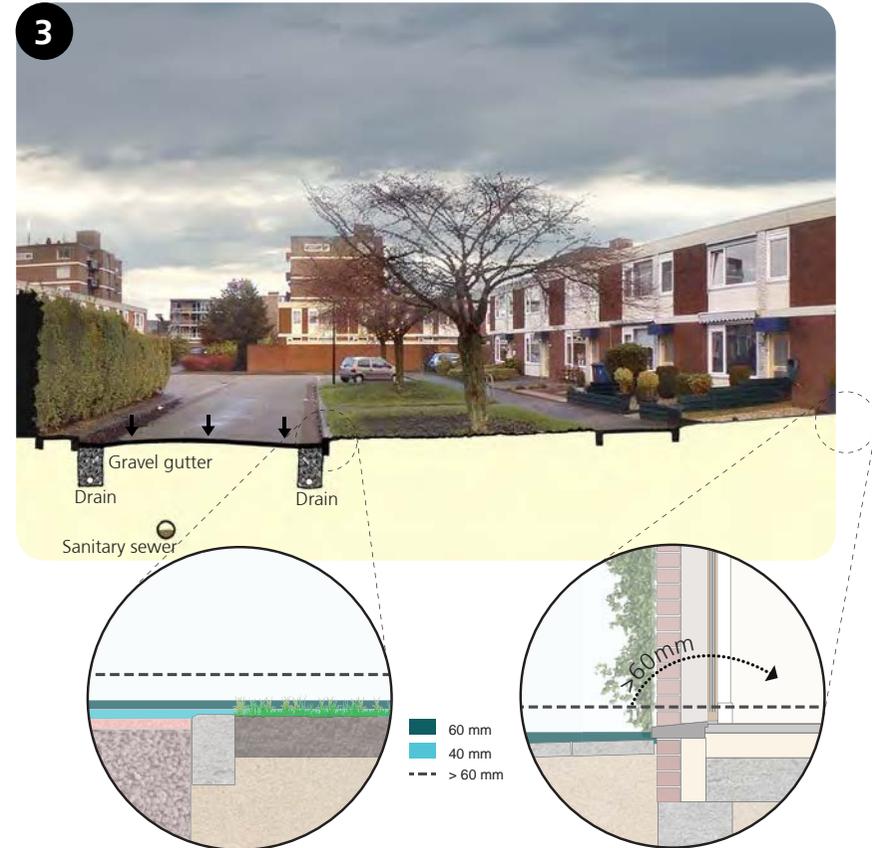
The municipality only installs a wastewater sewer system, so there is no stormwater sewer system. The road inclines towards a swale or a brick street gutter. The gutter conducts the water towards the swale, which is located in an existing green strip. The road is 4 cm lower compared to variant 0. The swale can process 20 mm rainfall in one hour, which creates space to store the water in the street during extreme rainfall events. Only when the rainfall exceeds 60 mm in one hour will water enter the houses.



Details show water levels of 40mm, 60mm and more then 60mm in one hour

Variant 3: storing in the foundation via an infiltration trench

The municipality only installs a wastewater sewer system and no stormwater sewer system. The road keeps the same profile as in variant 0, but it is lowered by 10 cm. A gravel trench is placed in the deepest areas, parallel to the road for infiltration. The water flows into the gravel trench via a sandtrap. The gravel trenches can process 20 mm of rainfall in one hour. Only when the precipitation rate is larger than 60 mm in one hour will water enter the houses.



Conclusions low-rise post-war garden city

Cost-benefit of rainwater

The graph shows the annual costs for each variant, including construction, maintenance and flooding costs. The annual costs are based on estimates over a period of one hundred years.

The annual cost for variant 1 (retention in the street) is 10% lower in comparison with traditional refurbishment. However, variant 2 is even cheaper with its infiltration capacity and central swale. The variants without stormwater sewer (variant 2 and 3) have the additional benefit that rainwater is stored in permeable soil, or drainage is delayed where the ground is poorly permeable. The foundations help delay the drainage of rainwater when higher natural groundwater levels are reached (see background documents online).

The variants with infiltration (2 and 3) that lead stormwater away from the combined sewer system relieve the pressure on the entire wastewater system. This may save approximately 10% of the annual sewer treatment costs. Variants that are disconnected from the stormwater sewer system will delay drainage onto the surface water and alleviate stress on the system. The possible benefits of this have not been taken into account.

Green benefits

More green in the city contributes towards the reduction of heat stress and the prevention of drought. According to our calculations, the benefits for health, comfort, economic value and energy use are many times higher than the annual costs of refurbishing the entire street. Moreover, the benefits are considerably higher than the additional costs

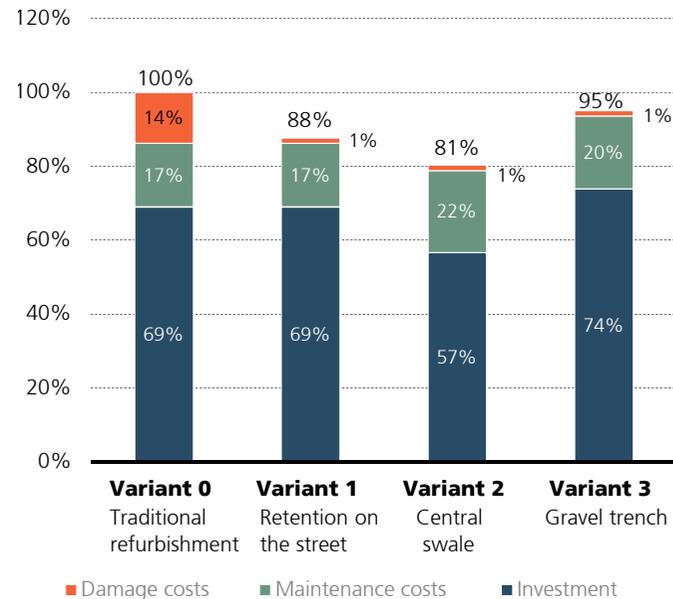
³ Beneficial on long term for the complete water cycle

(investment, management and maintenance) of the green areas.

Conclusions

Flat residential streets in the typology 'low-rise post-war garden city' can have a climate resilient retrofitting at the same price as traditional refurbishment. It is important to piggyback on planned construction work such as the replacement of sewer systems and periodical redesign. The climate resilient designs cause less inconvenience and flood damage, and can be combined with more green in the street.

Costs for low-rise post-war garden city



***“A grown tree evaporates
(transpires) some 400 litres of
water each day” (Kravcik et al., 2007)***



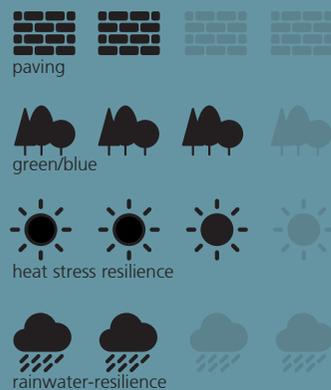
Water storage and greening in the city (Photo Tauw bv)



3.5 High-rise post-war garden city

Neighbourhood typology characteristics

This typology is characterised by its (semi) high-rise buildings in a spacious setting. Much of this space is green (meadows). Water storage and infiltration is relatively easy to realise. The housing blocks in this area are less sensitive to flooding as the ground floor is mainly used for storage. When the area is at a higher level than its surrounding areas, it is preferable to take action at this higher level to relieve the surrounding areas.



Based on Kleerekoper (2016)

Case study: high-rise post-war garden city (sloping)



300 m street length



0 ground floor homes

%



Approximately 53% of public space is paved



Paving consists of bricks and concrete paving stones

%



Approximately 7 m incline at street level



27 trees in the street



Approximately 25 m distance between facades

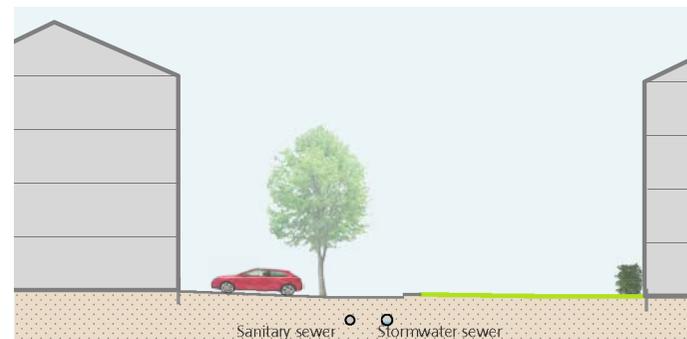


Local situation

The studied area is located on a slope. Green areas in the side streets are almost flat and parallel to the contour. There is a separate sewer system.

Sloped area

The slope can be used to drain water. It is important to provide storage space on the slope to prevent water damage downstream.



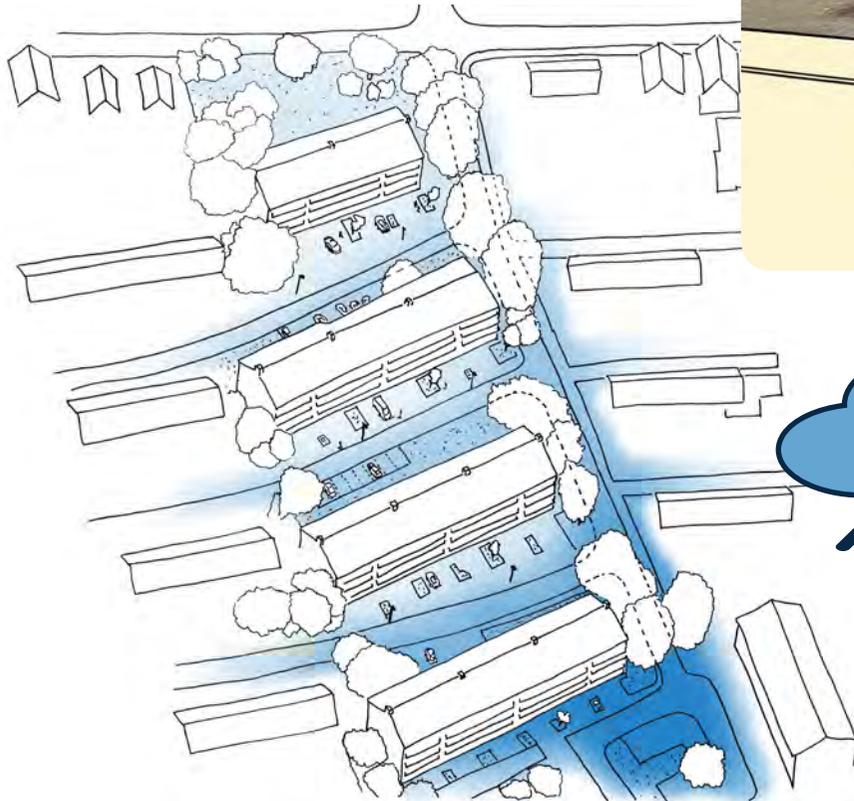
Traditional refurbishment

With traditional refurbishment, it is expected that water will enter the buildings at approximately 40 mm of rainfall in one hour.



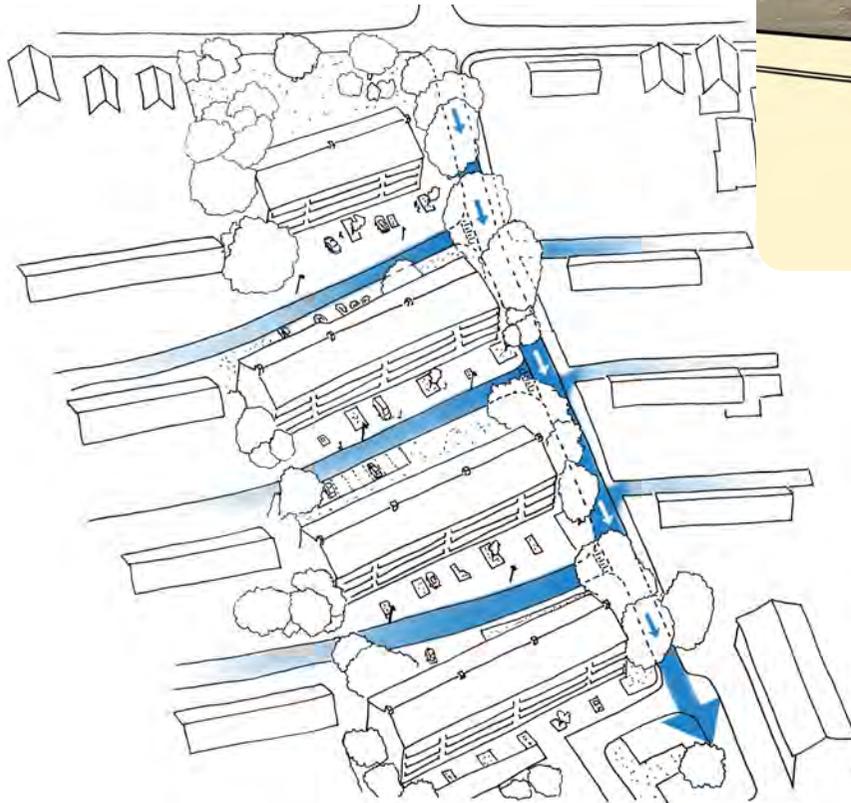
Variant 0: traditional

Public space maintains the original profile. The existing sewer system is replaced and can cope with a rainstorm once every 1-2 years. There is some space for water in the street, though the street has not been designed for that purpose. Due to the slope, extreme rainfall can cause considerable flooding. Water can flood the houses in the lower part of the street and can do substantial damage.



Variant 1: guiding the water onto the street

Storing water on a slope is problematic. The municipality lowers the road by 10 cm in comparison to variant 0, which causes most of the water to flow downstream. The existing sewer system and the paving are replaced. By making a hollow road, water can flow downstream without entering the houses if there is less than 60 mm rainfall in one hour. In this variant, it is assumed that there are no flooding issues downstream.



Sufficient and controlled discharge to lower-lying area



Lower area drainage



Local water storage

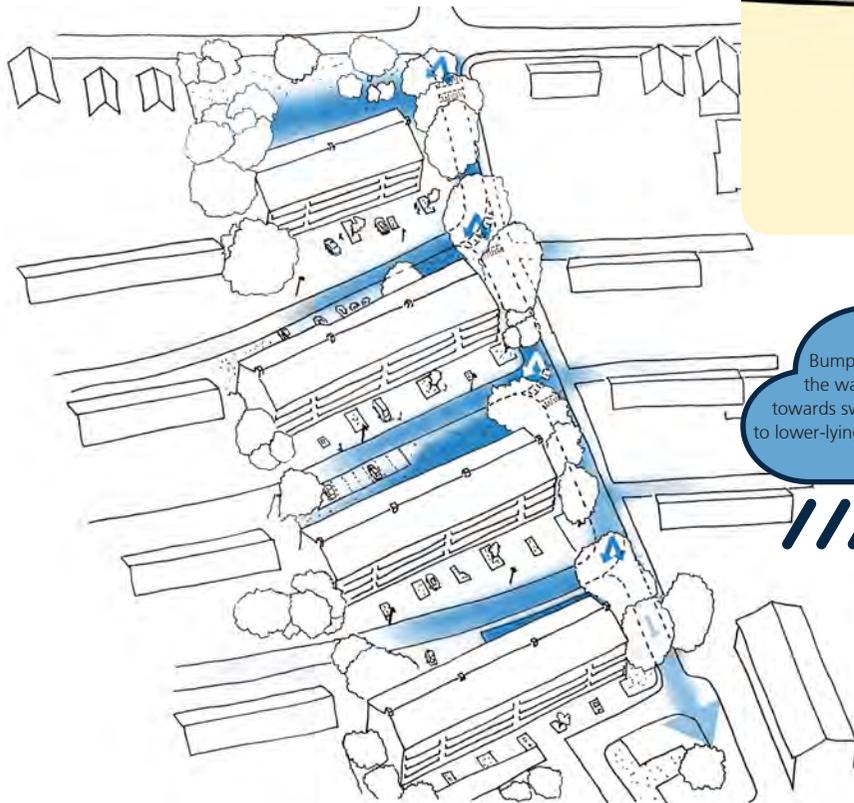


Variant 2: swale and storage in the street

Rather than providing a stormwater sewer system, the flat layout of the side-streets is used to create space for water storage. The municipality creates swales in the green strips of the side streets. These swales can process 20 mm of rainfall in one hour. The side streets are lowered by 8 cm in comparison to variant 0. This provides 20 mm of water storage. The water is stored between new curbstones and thresholds. The total storage capacity is up to 40 mm of rainfall in one hour. When this limit is exceeded, the rest of the water is directed downstream, which is assumed not to cause any flood problems.



Bumps guide the water partially towards swales and partially to lower-lying area



Variation 3: swale and a significant increase in street water storage

Rather than creating a stormwater sewer system, the flat layout of the side streets is used to create space for water storage. The municipality creates swales in the green strips of the side streets that can store and process 20 mm of rainfall in one hour. In the side streets, the road is lowered by 13 cm in comparison to variation 0, which leaves storage space in the street for 40 mm of rainfall. The water will be stored between the new curbs and thresholds. In total, 60 mm of rainfall can be processed in one hour. When the limit is exceeded, the surplus is directed downstream, which is assumed not to cause any flood problems.



Bumps guide the water (partially) towards swales to retain the water in the area



Lower area drainage 
Local water storage 

Green opportunities

Green benefits

More green in the city contributes towards the reduction of heat stress and the prevention of drought. According to our calculations the benefits to health, comfort, economic value and energy use are many times higher than the

annual costs of refurbishing the entire street. Moreover, the benefits are considerably higher than the additional costs (investment, management and maintenance) of the green areas.



Perennials increase infiltration capacity of the swale



A swale is a great opportunity to add valuable green to public areas



Trees provide shade on warm days

Conclusions high-rise post-war garden city

Costs and benefits of rainwater

The graph shows the annual construction and maintenance costs for each variant. The annual costs are based on estimates over a period of one hundred years.

The cost of flooding damage is not included in the graph as this is strongly dependent on the downstream situation. If there is plenty of green and surface water downstream, flood damage costs are much lower than when there are buildings. Furthermore, the length of the street and the gradient affect the risk of water spreading and flooding buildings.

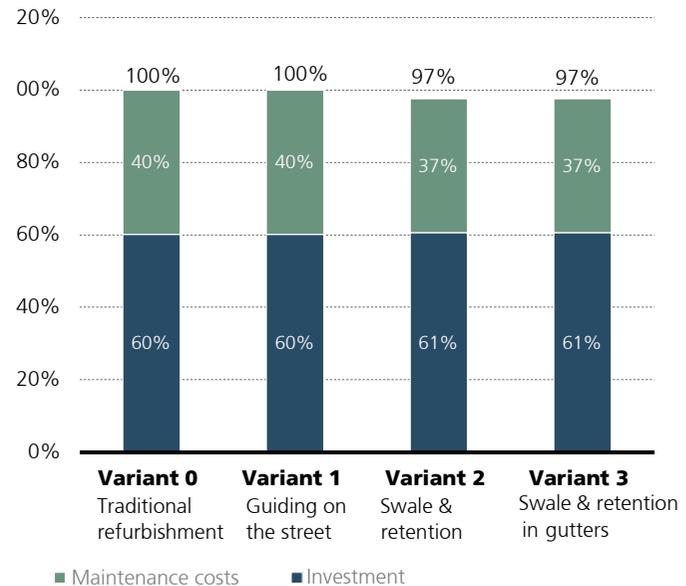
The annual costs for the variants are practically the same. This is fascinating as the other three case studies show a significant increase in the costs as more water needs to be stored in sloping areas. This is due to the characteristic features of this neighbourhood typology and the specific situation: a lot of room for green and, in this case, level side streets that can easily retain and store water.

Variants 2 and 3 (with infiltration) have the advantage that rainwater is stored in the ground when the soil is permeable, or delayed when soil-permeability is poor. Flood damage at the bottom of the slope will be reduced when more water is stored and kept upstream on the slope. When the variants with infiltration (2 and 3) are disconnected from the stormwater sewer system, this will lead to a delay in drainage to the surface water. This relieves the strain on the water system. The benefits have not been calculated.

Conclusions

For residential streets in high-rise post-war garden cities in a sloping area, simple measures can be taken to ensure that water is channelled and retained. Moreover, it is possible to store up to 60 mm of rainfall in one hour without any additional cost in comparison with traditional refurbishment. This is a clear improvement, compared to the current situation, which pays itself back. The amount saved on water damage control will depend on the local situation.

Costs for high-rise post-war garden city



This case study shows that it makes sense to choose a sizeable project area. The options for climate resilient refurbishing in sloping streets are limited, but elements in the vicinity, such as side streets, offer more solutions. From the perspective of costing at decision time, costs can be minimised by piggybacking on planned construction work, such as renewing the sewer system.

`Cooling with green is more effective than adjusting the colour of facades or widening the streets for better ventilation (cf. Shashua-Bar et al., 2012)

3.6 Suburbanisation - 1990-2005 (flat)

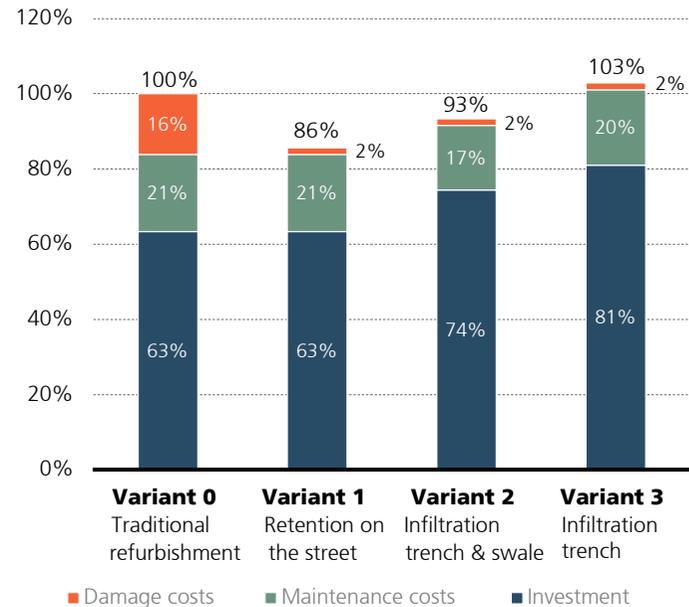


-  297 m street length
-  70 ground floor homes
-  Approximately 82% of public space is paved
-  Paving consists of bricks
-  The street level has no slope
-  18 trees in the street
-  Approximately 15 m distance between facades

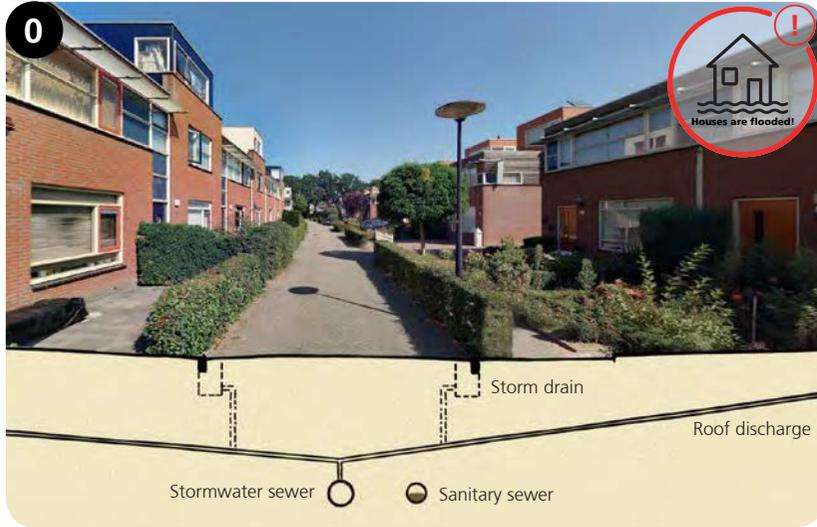
This case study will not be discussed here in as much details as the five cases above. A more detailed description (in Dutch) can be found in the online documentation at www.hva.nl/klimaatbestendigestad.

The case study for suburbanisation in the period 1990-2005 in a flat area shows a straightforward way of making streets climate resilient at no extra expense. As shown in previous examples, the lowered and hollow street design is the most cost-effective variant. When taking into account the reduced damage costs, variants without stormwater sewer systems (variants 2 and 3), can be implemented at the same cost as the traditional refurbishment.

Costs for suburbanisation



Variant 0: traditional refurbishment



Variant 1: retention on the street



Variant 2: infiltration trench and swale



Variant 3: infiltration trench



3.7 Urban city block (sloping)

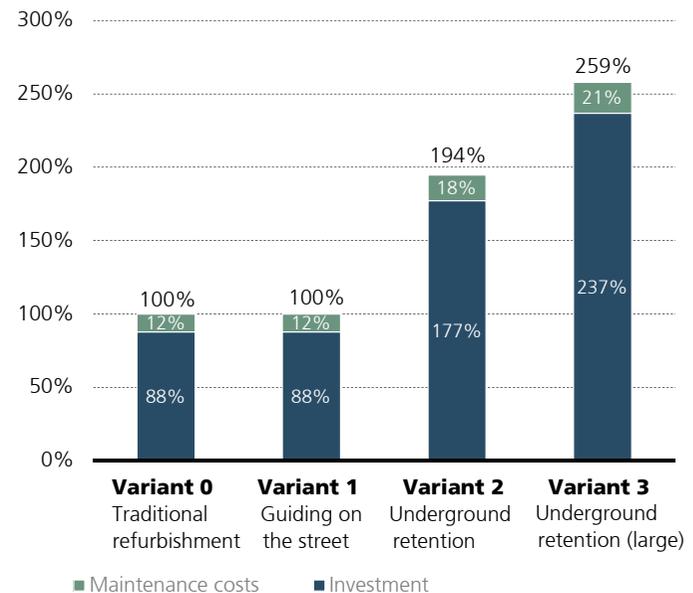


-  110 m street length
-  30 ground floor homes
-  Approximately 100% of public place is paved
-  Paving consists of bricks and concrete paving stones
-  The street has an incline of approximately 4 m
-  8 trees in the street
-  Approximately 20 m distance between facades

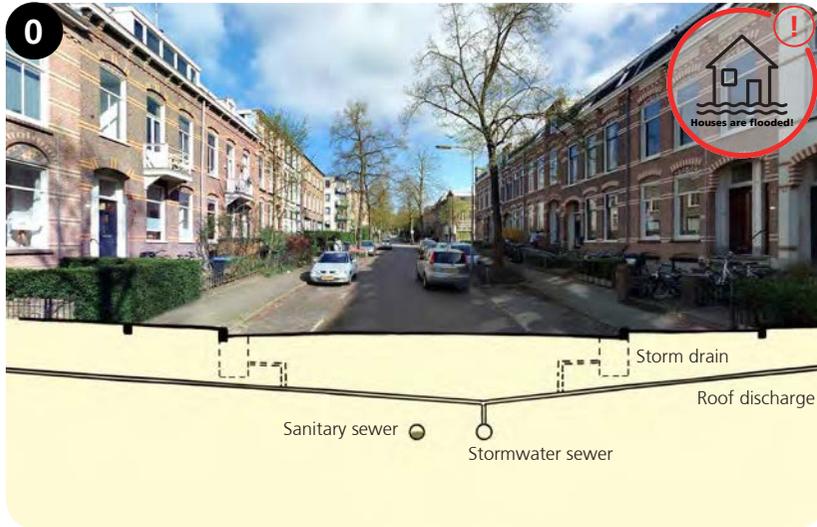
The case study of urban city blocks in a sloping area shows that costs increase with the need for more water storage. There is little public space, and no space for water storage above ground. Choices need to be made between storing water on the slope itself and possible damage downstream.

A more elaborate description (in Dutch) of this case study is available from the online documentation at www.hva.nl/klimaatbestendigestad.

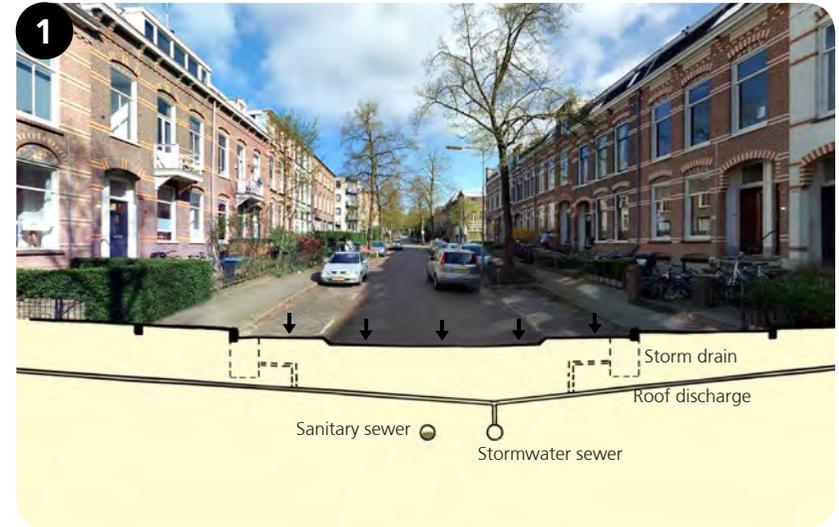
Costs for urban city block



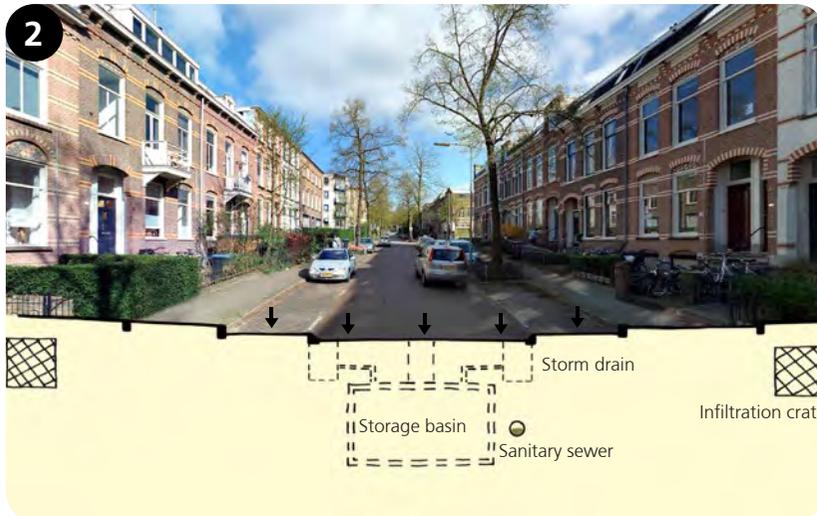
Variant 0: traditional refurbishment



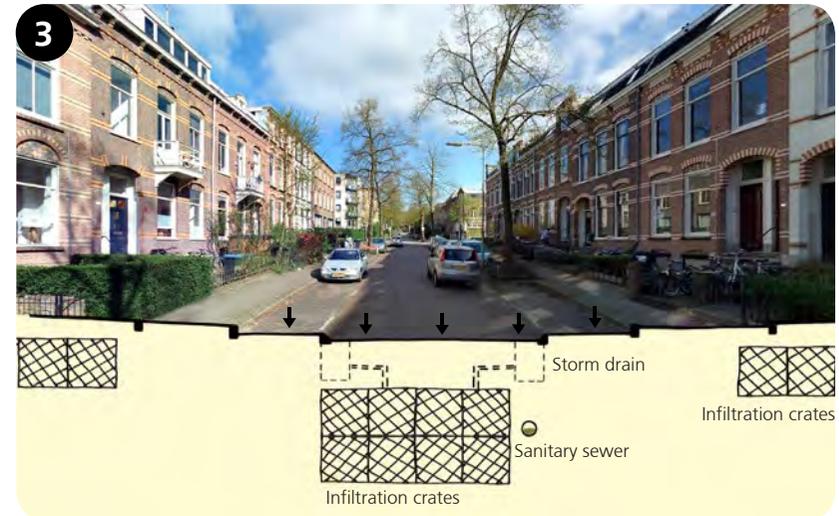
Variant 1: controlled flow on the street



Variant 2: underground storage



Variant 3: underground storage - large



3.8 High-rise post-war garden city (flat)



217 m street length



0 ground floor homes

%



Approximately 50% of public space is paved



Paving consists of bricks and concrete paving stones

%



The street level has no slope



16 trees in the street

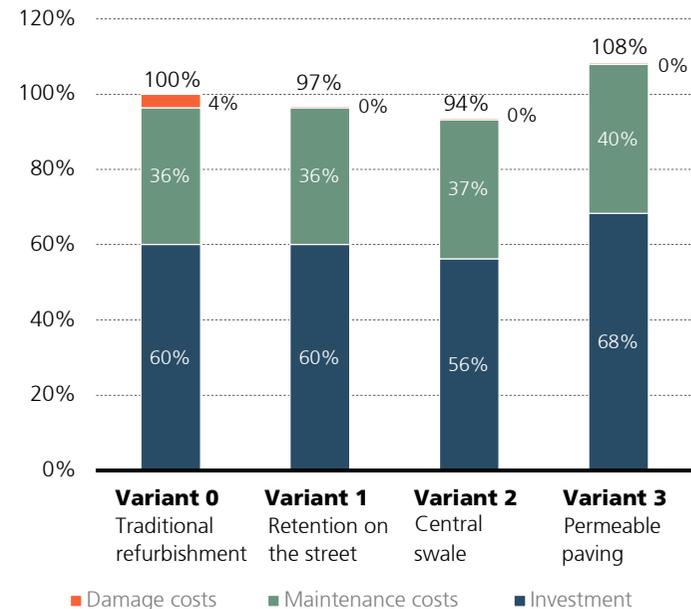


Approximately 30 m distance between facades

This high-rise post-war garden city case in a flat area shows that water storage in a public area is uncomplicated and ensures that retrofitting can be climate resilient at the same price as traditional refurbishment. Public space provides sufficient storage space for large quantities of water.

A detailed description (in Dutch) of this case study is available in the online documentation at www.hva.nl/klimaatbestendigestad.

Costs for high-rise post-war garden city



Variant 0: traditional refurbishment



Variant 1: retention on the street



Variant 2: central swale



Variant 3: permeable paving



3.9 Community neighbourhood (flat)

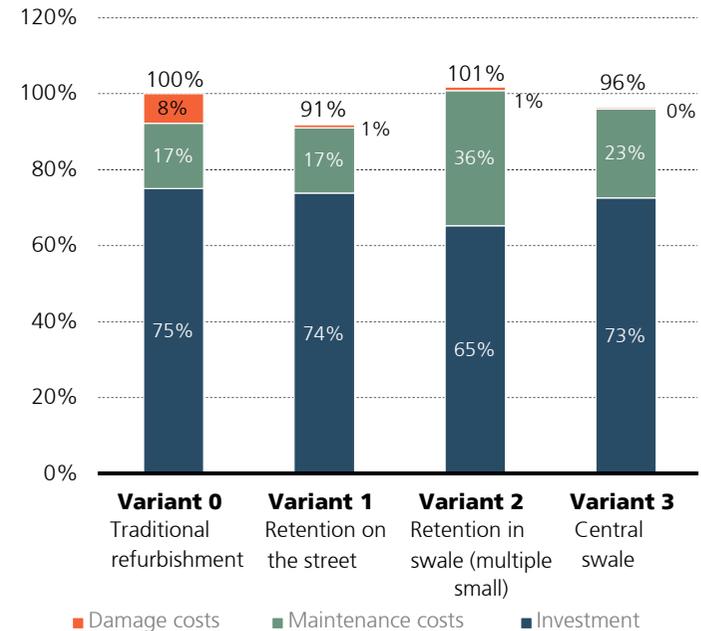


-  89 m street length
-  13 ground floor homes
-  Approximately 90% of public space is paved
-  Paving consists of bricks and concrete paving stones
-  The street level has no slope
-  12 trees in the street
-  Approximately 20 m distance between facades

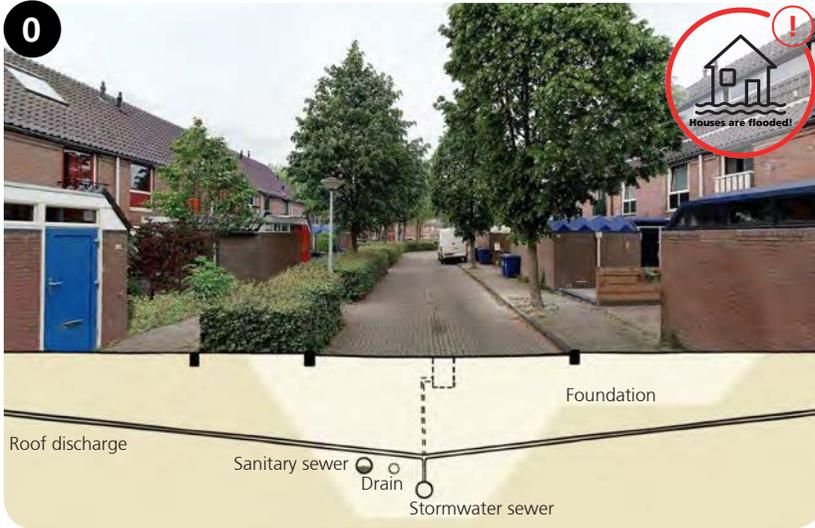
The study results of this community neighbourhood in a flat area are straightforward. It requires no extra investment compared to traditional refurbishment. Water damage is not particularly high. It is worth mentioning that the costs for the general retrofitting are relatively high due to the small number of houses per hectare.

For a more detailed description (in Dutch) of this case study please see www.hva.nl/klimaatbestendigestad.

Costs for community neighbourhood



Variant 0: traditional refurbishment



Variant 1: retention in the street



Variant 2: swale (multiple, small)



Variant 3: central swale



3.10 Garden village (slope)



154 m street length



48 ground floor homes

%



Approximately 100% of public space is paved



Paving consists of bricks and concrete paving stones

%



The street level has an incline of approximately 4 m



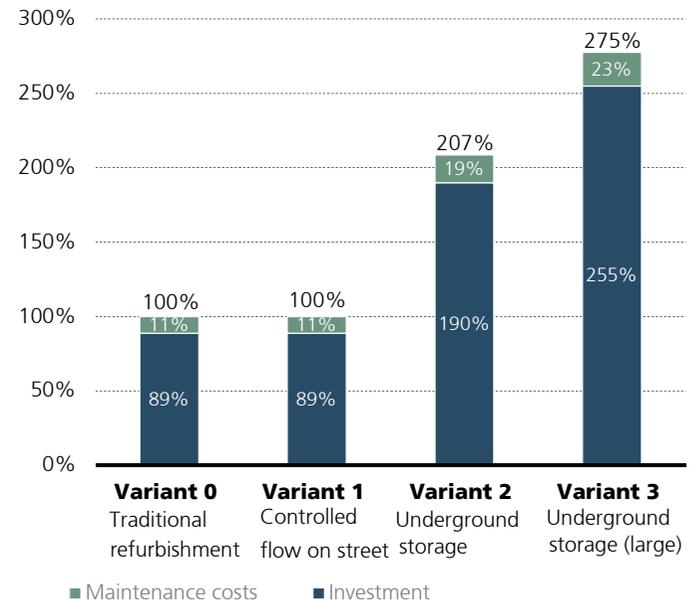
There are no trees in the street



Approximately 20 m distance between facades

The studied street is sloping, and there are large front gardens. Furthermore, the street has a relatively narrow profile with parking space on either side along the entire street. There is little public space and no space for water storage above ground. Due to the slope and the limited public space, the costs of this case study increase with more water to be retained underground. Choices need to be made between water storage on the slope itself and the possible water damage downstream. For a more detailed description (in Dutch) please see www.hva.nl/klimaatbestendigestad.

Costs for garden village



Variant 0: traditional refurbishments



Variant 1: controlled flow on the street



Variant 2: underground storage



Variant 3: underground storage - large





Photo: Laura Kleerekoper

4. Conclusions

In this book of examples, we have presented ten case studies (representing eight neighbourhood typologies) with climate-resilient retrofitting variants for residential streets and the accompanying costs and benefits. The premises for the design included:

1. Increasing the sponge capacity of the street (retaining and storing more water);
2. Guiding surplus water above ground;
3. Greening the street.

It is important to retain water in order to delay drainage and to avoid downstream problems. Water retention can either be achieved by storage on the surface or by infiltration into the soil. Water storage and retention is needed as stormwater sewer systems are not designed to cope with extreme rainfall events. Greening contributes to infiltration in the soil and in this way contributes to flood risk reduction of streets and houses and, since there is a subsurface water buffer, to better cope with drought and heat stress. We have indicated which measures would apply to process a maximum of 60 mm of rainfall in one hour without risking house flooding. Of course, heavier rainstorms can occur and still cause flooding.

The case studies reveal that climate resilience measures can be quite easy, as demonstrated by the comparison of the variants. Climate-resilient retrofitting is not necessarily more costly than traditional refurbishment practices, especially in flat areas. Lowering the street level is a particularly easy and cheap solution as it does not affect maintenance and management costs, while at the same time flood damage costs are reduced significantly. Variants without stormwater sewer system are not much more expensive than the

⁴ 60 mm rainfall in one hour on the total surface (including both unpaved and paved surface, and private and public ground).

traditional variant and the extra costs are about equal to the savings on flood damage.

The situation is more complicated for sloping areas as it is harder to retain water on the slope itself than it is in flat terrain. The need to retain water on slopes depends very much on the downstream situation. If there are vulnerable buildings downstream, water retention is essential. The risk of flooding in sloping areas should be taken into careful consideration as it varies significantly from one situation to another, and predominantly occurs downstream. Because disruptive effects vary per case, we have limited ourselves to illustrate the possibilities of water retention in these sloping areas and compared them with traditional refurbishment.

Retaining approximately 20 mm of water underground in sloping areas roughly doubles the retrofitting costs. However, if the area has a lot of public space (for example in the high-rise post-war garden city) with green areas along the elevation contours, it is very well possible to retain water more economically. This brings climate-resilience into the picture at no extra expense.

The case studies presented in this book reveal that neighbourhood typologies help to order the possibilities for climate-resilient retrofitting. The more spacious typologies with more public space -- as we find for example in post-war garden-cities and community neighbourhoods -- leave plenty of room to store water in the green areas. Even in neighbourhoods of these typologies in sloping areas water retention in green areas is often possible. More densely built-up city centres (such as historic- and pre-war

⁵ 20 mm of rainfall on the total surface, including the paved surface.

city blocks) have little space in the streets. Nevertheless, lowering the street level creates a lot of water-storage space in the streets and reduces the risk of flooded houses. Furthermore, permeable pavement and other infiltration measures are an option to make these areas more climate-resilient.

The presence of trees and their shadow effect is essential to reduce heat stress in the streets. However, so far there is no clear goal for urban heat management nor is there a norm for the desired amount of shading. This makes it difficult to picture a completely 'heat-proof' street. Some of our case studies that were based on the TEEB-city methodology show that the benefits of green generously compensate for the additional cost (investment, management and maintenance). The annual benefits (including an estimate for health and comfort) would be a multiple of the annual retrofitting costs. The profit would not benefit the municipality that bears the costs directly, but it would benefit the community as a whole. However, additional local-tax revenues can be generated from increasing property value due to attractive greening. On average, those benefits are good for 60% (with a wide margin of 10 to 140%) of the annual retrofitting costs.

Infiltration variants that divert stormwater away from the combined sewer system relieve the pressure on the entire wastewater system. This may save approximately 10% of the annual sewer treatment costs.

The difference in maintenance costs between the variants are relatively high. Permeable pavements and small swales have relatively high maintenance costs. We therefore recommend more research into those costs (for example

mowing swales and maintaining the storage capacity of permeable surfaces), and into better designs of these features (e.g. selection of suitable plants for swales and alternative ways to direct water from the pavement into the underlying subsoil).

Summary

- In flat areas climate-resilient retrofitting is perfectly possible;
- Lowering the street level is the cheapest option;
- Greening is multifunctional (it benefits the infiltration capacity and reduces heat stress and wastewater treatment costs);
- The choice for no stormwater sewer system, but local storage of rainwater is somewhat more expensive. However, such solutions are attractive from a holistic point of view because, in the case of flooding, prevented flood costs will equal the extra investment. Water retention also relieves the water system and sewer treatment plant.



Gutter on the street to drain rainwater in Enschede (Photo Ronald Loeve).

We hope that this book of examples will inspire municipalities and contractors to include climate-resilient variants in their maintenance and retrofitting projects at an early stage. Our advice is to examine the local characteristics of the existing stormwater drainage in view of extreme rainfall events, to check whether water can be retained above ground, and (if this is desirable) to consider whether more space can be created for water and green areas. This is how we can make all our streets climate resilient, one at a time.

A full water square in Den Bosch (Photo Floris Boogaard)



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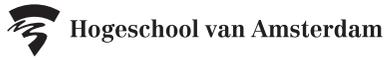
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This book of examples suggests a variety of options for easy and accessible climate-resilient retrofitting of residential areas. The case studies for a set of common streets in the Netherlands will match urban settings in other countries. The examples show that effective climate-resilient retrofitting is usually quite simple and does not necessarily incur higher costs than traditional approaches, particularly in flat areas. An examination of typical Dutch urban street designs shows how climate resilience can be incorporated under different conditions while keeping costs down with retrofitting. We have investigated the effects of four retrofitting variants and specified their cost and benefits, applying a typology of common residential street characteristics. We sincerely hope these case studies inspire you to get started in your own town, city and country, because the climate is right up your street.