U.PORTO
FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

U.PORTO
FACULDADE DE ARQUITECTURA UNIVERSIDADE DO PORTO

DESIGNING MORE PERMEABLE URBAN AREAS BASED ON GREEN SOLUTIONS

Comparing practices in Copenhagen and Porto

MARTA MARINO

Dissertation submitted for partial satisfaction of the requirements for the degree of

MASTER IN SPATIAL PLANNING AND URBAN PROJECT

Supervisor: Professora Doutora Sara Maria dos Santos Rodrigues da Cruz

JUNE 2024

MASTER IN SPATIAL PLANNING AND URBAN PROJECT 2023/2024 - FEUP / FAUP

CIVIL ENGINEERING DEPARTMENT

Tel. +351-22-508 1901

✉ mppu@fe.up.pt

Edited by

FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO

Dr. Roberto Frias Street

4200-465 PORTO

Portugal

Tel. +351-22-508 1400

Fax +351-22-508 1440

✉ feup@fe.up.pt

http://www.fe.up.pt

Partial reproductions of this document will be authorised on condition that the Author is mentioned and reference is made to *Master in Urban Planning and Project - 2023/2024 - Department of Civil Engineering, Faculty of Engineering of the University of Porto and Faculty of Architecture of the University of Porto, Porto, Portugal, 2024.*

The opinions and information included in this document represent only the respective Author's point of view, and the Publisher cannot accept any legal or other responsibility in relation to errors or omissions that may exist.

This document was produced from an electronic version provided by the respective Author.

This document was written in English (UK).

To my family

Ubi tu, ibi ego

Acknowledgemnts

I take this moment to thank all the people who have accompanied me during this journey. From my professor Sara Maria dos Santos Rodrigues da Cruz, who supported me throughout the thesis year, to all the teaching staff of the Master's in Spatial Planning and Urban Project who conveyed their passion during the classes.
I thank the entire MASU Planning studio in Copenhagen for all the knowledge I have gained, for their kindness, and for all the help I have received throughout this year. It has been inspiring to work alongside all of you.
But above all, I want to thank my family, without whom I could not have reached this point. I am fortunate to have received all this love during these two years.
Thank you to Michele, without whom I could not have done any of this, who always believed in me even when I didn't believe in myself.
I want to thank my parents, Nicoletta and Roberto, for always helping me achieve every milestone, for never doubting that I could make it.
Thanks to my sister Valentina, who always understands me, whatever the problem may be.
Thanks to my Aunt Bebe and Uncle Daniele, Aunt Chichi and Uncle Caio, who have always been by my side.
You are a wonderful family, and I am thankful every day to have you with me.

Resumo

O aumento da precipitação intensa devido às alterações climáticas está a causar, e continuará a causar, problemas significativos nas cidades. Inundações, problemas de drenagem e a incapacidade dos solos para reter a água, resultando numa perda da capacidade de retenção de água, são apenas alguns dos danos causados por este fenómeno. Estes problemas estão principalmente relacionados com o elevado número de superfícies impermeáveis nas zonas urbanas, que alteram tanto o ambiente como o ciclo da água nestas regiões. Na procura de soluções para este problema, está a ganhar terreno o conceito de "cidade esponja", que permite reter as águas pluviais e não sobrecarregar a rede de drenagem que, na maioria dos casos, já não tem capacidade para lidar com volumes tão grandes de água.

As intervenções de infraestruturas verdes e azuis estão atualmente a ser realçadas pela União Europeia, entre outros, para resolver estas questões. Incluem-se aqui todos os métodos que visam aumentar a superfície permeável das cidades, desde o asfalto permeável aos jardins de chuva e às bacias de retenção de águas pluviais. Este trabalho procura perceber que tipos de intervenção podem ser mais viáveis e porquê, tendo em conta vários critérios antes de fazer uma escolha e comparando essas intervenções com algumas que já foram implementadas para perceber os seus potenciais problemas ou pontos fortes. Através da análise dos aspetos territoriais, sociais, ambientais e económicos, foi criada uma visão geral das técnicas mais utilizadas, com o objetivo de compreender como a sua importância vai para além do bem-estar dos habitantes de uma determinada rua ou bairro e representa una melhoria da qualidade de vida.

Keywords: superficìe permeável, adaptação climática, cidade esponja, soluções sensíveis à água, infraestrutura verde-azul.

Summary

The increase in heavy rainfall due to climate change is causing, and will continue to cause, significant problems in cities. Flooding, drainage problems and the inability of soils to retain water, resulting in a loss of water retention capacity, are just some of the damages caused by this phenomenon. These problems are mainly related to the high number of impermeable surfaces in urban areas, which have altered both the environment and the water cycle in the area. In the search for solutions to this problem, the concept of the sponge city, which allows rainwater to be retained and does not burden the drainage network, which in most cases is no longer able to cope with such large volumes of water, is gaining ground.

Blue-green infrastructure interventions are currently being emphasised by the European Union, among others, to address these issues.

This includes all methods aimed at increasing the permeable surface area of cities, from permeable asphalt to rain gardens and stormwater retention basins. This text seeks to understand which types of intervention might be more feasible and why, considering various criteria before making a choice and comparing these interventions with some that have already been implemented to understand their potential problems or strengths. By analysing the territorial, social, environmental and economic aspects, an overview of the most used techniques has been created, with the aim of understanding how their importance goes beyond the well-being of the inhabitants of a specific street or neighbourhood and represents an improvement for all citizens.

Keywords: permeable surface, climate adaptation, sponge city, water sensitive solutions, blue-green infrastructure

General Index

Acknowledgemnts I

Resumo III

Summary V

General Index VII

Index of Figures IX

1 INTRODUCTION 1

2 LITERATURE REVIEW 3

2.1. CLIMATE CHANGE AND URBANISATION 3

2.1.1. CONTEXTUALISATION AND MAIN PROBLEMS ASSOCIATED WITH CLIMATE CHANGE AND URBANISATION 3

2.1.2. PROBLEMS RELATED TO CLIMATE CHANGE AND URBANISATION 6

2.1.3. IMPORTANCE OF CLIMATE CHANGE ADAPTATION IN CITIES 7

2.2. CLIMATE CHANGE ADAPTATION IN CITIES – FROM POLICIES TO ACTION 8

2.2.1. RESPONSABILITY AND POLICY AT DIFFERENT LEVELS 8

2.2.2.THE LIMITATION OF PUBLIC SECTORS 9

2.2.3. TRANSFORMING MINDSET FOR CLIMATE ADAPTATION 10

2.3. ADAPTATION MEASURES AND SOLUTIONS FOR WATER MANAGEMENT 12

2.3.1. CITY WATER MANAGEMENT CHALLENGES 12

2.3.2. CLIMATE ADAPTATION MODELS 14

2.3.3. GREEN INFRASTRUCURES SOLUTIONS 14

2.3.4. PAVEMENT SOLUTIONS FOR WATER MANAGEMENT 16

3 REFERENCE CASE: COPENHAGEN 20

3.1. URBAN CONTEXT IN COPENHAGEN 20

3.1.1. URBAN DEVELOPMENT TRANDS 20

3.1.2. CLIMATE SCENARIO AND IMPACTS ON THE URBAN ENVIRONMENT 21

3.2. COPENAGHEN´S CLIMATE ADAPTATION PLAN 23

3.2.1. OVERVIEW OF THE CLIMATE ADAPTATION PLAN 23

3.2.2. ANALYSIS OF THE GOALS, OBJECTIVES, AND TARGETS OF THE ADAPTATION PLANS 25

3.2.3. EFFECTIVNESS OF IMPLEMENTATION OF THE ADAPTATION PLANS 25

3.3. CLIMATE ADAPTATION INITIATIVES AND PROJECTS IN COPENHAGEN 26

3.3.1. REVIEW OF SPECIFIC INITATIVES AND PROJECTS AIMED AT CLIMATE ADAPTATION IN COPENHAGEN 26

4 THE CASE STUDY 44

4.1 METHODOLOGY 44

4.2 CONTEXT OF PORTO 45

4.3. CLIMATE PLAN ADAPTATION PORTO: A GENERAL REVIEW AND COMPARISON WITH THE COPENHAGEN PLAN 46

4.3.1 OVERVIEW OF THE CLIMATE ADAPTATION PLAN 46

4.3.2 STRUCTURE OF PORTO´S CLIMATE ADAPTATION PLAN 47

4.3.3 COMPARISON WITH COPENHAGEN´S CLIMATE ADAPTATION PLAN 48

4.4. DATA COLLECTION AND DATA ANALYSIS 49

4.4.1. RAINFALL DATA 49

4.4.2. DATA ON HYDROGEOLOGICAL CONFIGURATION 52

4.4.3 DATA ON URBAN CONFIGURATION 56

4.5. STUDY OF URBAN FLOODING 62

4.6 SYNTHESIS 65

5 ANALYSES OF RIBEIRA DA GRANJA 67

5.1 CASE STUDY 67

5.1.1 CARVALHIDO AND JARDIM ARCA DÁGUA. TWO STUDY AREA 68

5.1.2 STUDYING THE ISSUES AND POTENTIAL SOLUTIONS 73

5.1.3 DISCUSSION OF RESULTS 80

6 CONCLUSIONS 82

6.1 MAIN CONCLUSION 82

6.2 MAIN RECOMMENDATION 84

6.3 FURTHER RESEARCH 84

7REFERENCES 85

8APPENDIX 93

8.1 Climate indices for the 16 climate hazards 93

8.2 Aggregate potential impact of climate change on Europe's regions 94

8.3 Example of a specific branch of the Copenhagen climate adaptation plan 95

8.4 Example of a specific branch of the Copenhagen climate adaptation plan 96

8.6 Climate adaptation plan in the Klimakvarter Neighbourhood Area 98

Index of Figures

Figure 1: 32 Climate indices for the 16 climate hazards, grouped into six hazard types, as identified by the Intergovernmental Panel on Climate Change (IPCC) in its Sixth Assessment Report (Source: EEA report 2021). 4
Figure 2: Graph Disaster Risk (IPCC report 2023) 5
Figure 3: Aggregate potential impact of climate change on Europe's regions (Source: climatepolicyinfohub). 8
Figure 4: Examples of permeable pavements (Source: Personal elaboration).....17
Figure 5: Table with different runoff coefficients 19
Figure 6: The Copenhagen Metropolitan 'Finger Plan (Source: denishdesignreview.com) 21
Figure 7: Example Copenaghen Masterplan (Source:Climate Change Adaptation Statement, 2015).....23
Figure 8: Example of Climate Adaptation Plan Implementation (Source: Climate Change Adaptation Statement, 2015). 27
Figure 9: Example a specific example of a localized area (Source: Climate Change Adaptation Statement, 2015). 27
Figure 10:Enghaveparken today, 2019 (Source: Tredje Nature Architect Firm).....28
Figure 11:Enghaveparken today, 2019 (Source: Tredje Nature Architect Firm).....29
Figure 12:Water collection solution in Enghaveparken, 2019 (Source: Tredje Nature architect Firm) 29
Figure 13:Water collection solution in Enghaveparken, 2019 (Source: Tredje architect Firm).....29
Figure 14: Climate Adaptation Plan in the Klimakvarter Neighbourhood Area (Source: Climate Change Adaptation Statement, 2015). 30
Figure 15 : Sankt Kjeld's Square Transformation, 2018 (Source: SLA architect firm). ...31
Figure 16: Sankt Kjeld's Square Transformation; 2018 (Source: SLA architect firm). 31
Figure 17: Sankt Kjeld's Square Transformation; 2018 (Source: SLA architect firm). 31
Figure 18: Sankt Kjeld's Square, Specific solutions for water drainage, 2018(Source: SLA architect firm). 32
Figure 19: Sankt Kjeld's Square, Specific solutions for water drainage, 2018 (Source: SLA architect firm). 32
Figure 20: Sankt Kjeld's Square, Specific solutions for water drainage, 2018 (Source: SLA architect firm). 33
Figure 21: Climate Tile project in Norrebro, 2018 (Source: Tredje Nature Architect Firm) 34
Figure 22: Climate Tile project detail, 2018 (Source: Tredje Nature Architect Firm).....34

Figure 23: Climate Tile detail, 2018 (Source: Tredje Nature).....35
Figure 24: Climate Tile detail, 2018 (Source: Tredje Nature).....35
Figure 25: Example of a water drainage channel, 2017 (Source: MASU Planning Architect Firm).....36
Figure 26: Example of a water drainage channel, 2017 (Source: MASU Planning Architect Firm).....36
Figure 27: Example of a rain garden for collecting rainwater, 2017 (Source: MASU Planning Architect Firm) 37
Figure 28: Depressions in the ground created for rainwater collection, 2017 (Source: MASU Planning Architect Firm) 37
Figure 29: Depressions in the ground created for rainwater collection, 2017 (Source: MASU Planning Architect Firm) 37
Figure 30: Details of permeable pavement, 2017 (Source: MASU Planning Architect Firm).....38
Figure 31: Details of permeable pavement, 2017 (Source: MASU Planning Architect Firm).....38
Figure 32: Figure 31: Details of permeable pavement, 2021 (Source: MASU Planning Architect Firm).....39
Figure 33: Details of permeable pavement, 2021 (Source: MASU Planning Architect Firm).....40
Figure 34; Details of permeable pavement, 2021 (Source: MASU Planning Architect Firm).....40
Figure 35: Details of permeable pavement, 2021 (Source: MASU Planning Architect Firm).....41
Figure 36: Roadside rain garden (Source: personal elaboration.....41
Figure 37: Rainwater entry points to the rain garden (Source: personal elaboration).....42
Figure 38: Detail of tree solutions (Source: personal elaboration) 42
Figure 39: Rainwater entry points to the rain garden (Source: personal elaboration).....42
Figure 40:Raingarden detail (Source: personal eleboration) 42
Figure 41: Rain uses in a playground (Source: Personal elaboration). 43
Figure 42: Photos of the event in São Bento (Source: today.rtl.lu, 2023).....46
Figure 43: Study of the frequency of annual precipitation exceeding 50 mm between 1971 and 2000 (Source: Portal do Clima, 2024). 50
Figure 44: Study of the frequency of annual precipitation exceeding 50 mm between 2011 and 2040, RCP 4.5 scenario (Source: Portal do Clima, 2024). 50
Figure 45: Study of the frequency of annual precipitation exceeding 50 mm between 2011 and 2040, RCP 8.5 scenario (Source: Portal do Clima, 2024). 50

Figure 46: Study of the frequency of annual precipitation exceeding 50 mm between 2041 and 2070, RCP 4.5 scenario (Source: Portal do Clima, 2024) 51
Figure 47: Study of the frequency of annual precipitation exceeding 50 mm between 2041 and 2070, RCP 8.5 scenario (Source: Portal do Clima, 2024). 51
Figure 48: Study of the frequency of annual precipitation exceeding 50 mm between 2071 and 2100, RCP 4.5 scenario (Source: Portal do Clima, 2024). 51
Figure 49: Study of the frequency of annual precipitation exceeding 50 mm between 2071 and 2100, RCP 8.5 scenario (Source: Portal do Clima, 2024). 52
Figure 50: Hydrogeological configuration map (Source: geoportale.lneg.pt.,2024) 53
Figure 51: Permeability potential map (Source: PDM Porto, 2018) 54
Figure 52: River and streams map (Source: PDM Porto, 2017). 54
Figure 53: River and streams map (Source: PDM Porto, 2017). 55
Figure 54: Flood-prone areas map (Source: PDM Porto, 2018). 56
Figure 55: Land use map (Source: PDM Porto, 2017). 56
Figure 56: Green spaces in the city of Porto map (Source: PDM Porto, 2017). 57
Figure 57: Heritage sites and waterways map (Source: PDM Porto, 2017). 57
Figure 58: Green space types map (Source: PDM Porto, 2017). 58
Figure 59: Vegetation types map (Source: PDM Porto, 2017). 58
Figure 60: Species richness classification map (Source: PDM Porto, 2017). 60
Figure 61: Urban flood susceptibility areas map (Porto Municipal Council, 2015) 60
Figure 62: Identification of premises at risk of flooding (Porto Municipal Council, 2011) 61
Figure 63: Frequency of urban floods between 1974 and 2014 (Source: PDM Porto, 2018). 62
Figure 64: Frequency of urban floods and soil permeability map (Source: Personal elaboration) 62
Figure 65: Frequency of urban floods and presence of waterways map (Source: Personal elaboration) 63
Figure 66: Frequency of urban floods and land use map (Source: Personal elaboration) 63
Figure 67: Example of comparison between land use map and Google Maps satellite image (Source: Personal elaboration) 64
Figure 68: Frequency of urban floods and species diversity map (Source: Personal elaboration). 64
Figure 69: Frequency of urban floods and types of green areas (Source: Personal elaboration) 65
Figure 70: Frequency of urban floods and types of vegetation map (Source: Personal elaboration) 65

Figure 71: Ribeira da Granja map (Source: Personal elaboration) 67
Figure 72: Location of the Study Areas Map (Source: Personal Elaboration). 68
Figure 73: Identification of the Study Areas (Source: Personal Elaboration).....69
Figure 74: Overlay of the Two Areas with the Ribeira da Granja Stream (Source: Personal Elaboration). 69
Figure 75: Overlay with Flooded Areas (Source: Personal Elaboration). 70
Figure 76: Carvalhido Map and Identified Main Issues (Source: Personal Elaboration). 71
Figure 77: Jardim Arca D'Água Map and Identified Main Issues (Source: Personal Elaboration). 72
Figure 78: Urban Composition Modification Diagram (Source: Personal elaboration)....74
Figure 79: Intersection of Rua de Nove de Abril and R. de São Dinis (Source: Personal elaboration). 75
Figure 80: Addition of Green Space (Source: Personal elaboration). 75
Figure 81:Intersection Transformed by Rain Gardens, Before and After (Source: Personal elaboration). 76
Figure 82: Idea of channels along the road (Source: Personal elaboration).....77
Figure 83: Rainwater harvesting in private courtyards (Source: Personal elaboration). .78
Figure 84: Raingardens in roundabouts (Source: Personal elaboration).....79
Figure 85: Transformation of Jardim Arca d'Água (Source: Personal elaboration).....80

1

INTRODUCTION

The climate changes occurring during this historical period are having effects on all European cities. One of the most prevalent issues, expected to increase in the coming years, is intense rainfall. Often hitting urban areas that are unprepared to absorb these amounts of water, such rainfall causes significant damage to buildings and infrastructure and poses potential danger to citizens. For these reasons, it is important to begin applying practices today that make cities more resilient and adapted to climate changes.

Nature-based solutions are among the most frequently cited and considered when discussing the topic, both in scientific texts and within urban climate adaptation plans. These solutions harness natural processes and provide ecosystem services to mitigate the effects of climate change, for example by enhancing green spaces, creating rain gardens and restoring wetlands. Such measures not only help manage stormwater but also provide additional benefits like improving air quality, enhancing biodiversity, and offering recreational spaces for communities. Starting from this premise, this text analyses two different situations: the cities of Copenhagen and Porto, both increasingly affected by intense precipitation. By examining their approaches, we can draw insights for effective urban climate resilience strategies. Copenhagen, for example, has developed comprehensive climate adaptation plans that include a series of blue-green infrastructure projects. These projects are designed to manage excess water through the integration of parks, ponds and green roofs, transforming the urban landscape to better manage heavy rainfall and implement drainage systems. By comparing the two-climate adaptation plans and subsequently examining the interventions carried out in Copenhagen in recent years, an attempt has been made to identify which solutions would also be suitable for certain areas of Porto. The two chosen areas are in the northern part of the city: the *Carvalhido* area and the *Jardim Arca D'Água* area, which often experience flooding issues during intense rainfall events. The two areas were examined from different perspectives, analysing the zone and comparing certain situations with the Copenhagen ones, to determine which of the possible solutions might be most appropriate for the location. The challenge, especially when dealing with an already built urban environment, is to find ways to integrate blue-green structures without necessarily implementing large-scale interventions, both for logistical or resource and economic reasons. For this purpose, efforts have been made to investigate where the implementation of such structures could be more easily achieved or how existing structures can be adapted to current issues.

The ongoing climate changes force everyone to acknowledge their actions and contributions. To overcome this urban challenge, the efforts of institutions alone are not enough; support from private citizens is also necessary, though they must be well-informed about the issues. Involvement of residents not only ensures the success of adaptation measures but also fosters a sense of shared responsibility and community resilience. Ultimately, the integration of nature-based solutions and collaborative approaches represents a holistic way to build urban resilience. By learning from successful examples like Copenhagen and applying tailored strategies in cities like Porto, we can better prepare for the increasing challenges posed by climate change. As intense rainfall becomes more common, it is through such innovative and

cooperative efforts that cities can safeguard their futures, protect their residents, and thrive in the face of environmental changes.

2

LITERATURE REVIEW

2.1. CLIMATE CHANGE AND URBANISATION

2.1.1. CONTEXTUALISATION AND MAIN PROBLEMS ASSOCIATED WITH CLIMATE CHANGE AND URBANISATION

The growing threat posed by climate change is becoming increasingly evident today. It is now recognized that these changes are indeed a direct result of human behaviour, primarily due to the increasing amount of greenhouse gas (GHG) emissions in the atmosphere and the unconditional use and exploitation of land, natural resources, and environmental resources (UN, 2023).

The climate's responses to this ongoing exploitation are beginning to be felt more and more, especially in recent years, causing extensive damage, particularly in areas already considered vulnerable and unstable (IPCC, 2023).

In Europe alone, in 2023, a high rate of extreme weather events was recorded, both in terms of precipitation, which caused extensive damage, including fatal outcomes, in Croatia, Italy, Austria, and Slovenia, and due to very high temperatures. In fact, 2023 was recorded as one of the hottest years, with 50% of days surpassing 1.5°C above the pre-industrial average (1850-1900), leading to numerous wildfires, especially in Greece, Spain, and Portugal (EC, 2023).

The consequences of extreme weather events are numerous, so much so that the European Environment Agency website depicts them through a diagram (Fig.1) that attempts to summaries and group the different types, resulting in 6 main hazard types: heat and cold, wet and dry, wind, snow and ice, coastal, and open ocean (EEA, 2021).



Figure 1: 32 Climate indices for the 16 climate hazards, grouped into six hazard types, as identified by the Intergovernmental Panel on Climate Change (IPCC) in its Sixth Assessment Report (Source: EEA report 2021).

As can be seen from Figure 1, the categories that certainly attract the most attention are those related to temperatures, especially regarding high temperatures, and those concerning the presence of heavy precipitation alternating with periods of aridity.

These two main issues are also recognized in the "European Climate Risk Assessment: executive summary 2024," where it is stated that intense precipitation and catastrophic floods, as well as heatwaves and prolonged periods of drought, are increasing in all European states and are recognized as the main challenges that will need to be addressed in the coming years (European Climate Risk Assessment: executive summary 2024).

Addressing these issues, however, is very complex, as they involve various aspects ranging from logistical to economic, raising many challenges.

From an economic standpoint, for example, repairing environments after extreme events is costly. Just in 2023, the entire EU solidarity fund was used, given to regions where these events were most catastrophic. It is also interesting to note that in the "Supporting Disaster Recovery 2002-2022," which helps to provide a general overview of the main disasters that have occurred in Europe over the last 20 years and therefore received funds, it is shown that about 50% of the disasters can be attributed to flood-related issues (Supporting Disaster Recovery 2002-2022).

Today, hindering these events is no longer possible, not until the causes that are leading to climate change are at least partially counteracted. For this reason, to reduce the damage and danger of events, it is important to look for solutions to minimise risks, making territories safer even in the event of climate damage.

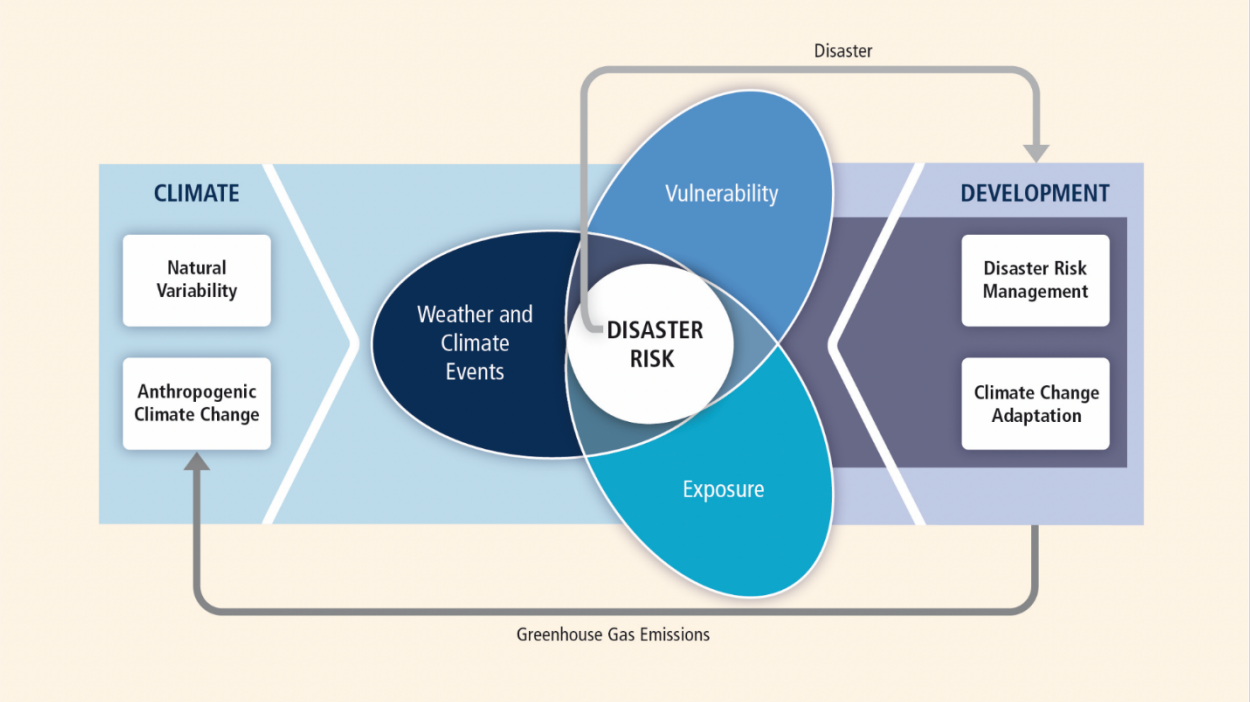


Figure 2: Graph Disaster Risk (IPCC report 2023)

In the IPCC report of 2023, a new version of the scheme was presented to explain how risks emerge from the interlink between climate hazards, vulnerability and exposure (Figure 2). Natural disasters are influenced not only by extreme climatic conditions but also by the exposure and vulnerability of the environment. Given that it is not currently possible to directly act on extreme weather events themselves, except by trying to reduce the presence of greenhouse gases in the atmosphere, a condition that will inevitably take time to have effects, what can be addressed is necessarily the vulnerability and exposure of environments through the development of risk management plans and climate change adaptation elements (IPCC, 2023).

Urban centers are undoubtedly the places where the impacts of climate change are becoming more evident. The rapid urbanisation witnessed in recent decades has altered the structure and organisation upon which many European States were previously built. In 2008, the urban population surpassed the rural population for the first time in history, and this trend in the growth of urban agglomerations is expected to continue rising. According to UN-Habitat, about three-quarters of the European population currently resides in urban agglomerations, a figure projected to increase to approximately 80% by 2050. Additionally, the number of residents is expected to grow by 73 million annually (UN, 2023).

The concentration of large numbers of people in relatively confined spaces, along with the rapid growth and the array of services that urban areas must provide, such as transportation and infrastructure, have made urban zones among the most polluting. It is estimated that emissions from cities accounted for between 62-72% of global emissions between 2015 and 2020 (IPCC report 2023).

With the rapid population growth, cities have, on average, increased their size by 78% from the 1950s to the present (EEA, 2024). This has led to alterations in land use and land cover (LULC), such as rapid urbanisation, deforestation, or de-vegetation, and the expansion of agricultural territories, all activities that have and continue to influence hydrological and ecological aspects (Giglou, et al., 2024).

By combining these two aspects - highly polluted environments and a lack of green and natural spaces - cities are currently struggling to counteract the effects of climate change.

2.1.2. PROBLEMS RELATED TO CLIMATE CHANGE AND URBANISATION

The uncontrolled and rapid growth of cities in recent decades has not only led to consequences in terms of greenhouse gas emissions or soil degradation but has also often made the urban environment difficult to manage during extreme weather events.

Instances of intense heat, including heatwaves, have intensified in cities, exacerbating episodes of air pollution and compromising the functioning of key infrastructure. Urban facilities such as transportation, water sanitation, and the energy system have been affected by extreme and slow-onset events, resulting in economic losses, service disruptions, and impacts on people's well-being (IPCC report, 2023).

Some of the main problems in cities today are related to heat waves, often associated with increased humidity, which can pose significant health risks, affecting mortality rates and hospital admissions, as well as influencing the well-being and productivity of workers. The elderly are particularly affected by heat waves due to their weaker physical condition and lower awareness of health risks (EEA, 2023).

The number of very hot days, with temperatures exceeding 30°C, has increased across Europe and will continue to rise, especially in southern Europe, by the end of the century, considering the highest emissions scenario (European Climate Risk Assessment, 2024).

Situations like heatwaves are particularly intensified in urban environments, causing a phenomenon known as the urban heat island effect, mainly due to various intrinsic factors of the urban environment. Materials such as concrete and asphalt, which absorb and retain heat, contribute to temperature rise by heating up during the day (Ferguson, Woodbury, 2007). Additionally, the limited presence of vegetation, which helps cool the air by providing shade and through transpiration processes, anthropogenic activities that produce pollution, such as vehicle traffic or industrial activities, and urban geometry, often not designed to ensure better air circulation, contribute to making the urban environment hotter than rural areas (Kabano, et. Al., 2021).

Another issue increasingly prevalent in urban environments is related to alternating periods of drought and heavy rainfall. Climate change is exacerbating the disparity between these two weather conditions. Prolonged dry periods are often followed by heavy rainfall, causing damage to agricultural or industrial activities, which suffer from inconsistent water availability in some cases, and posing challenges in managing these extreme events (EEA, 2023).

In cities, rainwater management is usually directed towards sewers and culverts, which, due to changes in land use or because they are designed to retain a different amount of rain, may not be efficient today. Today, we find ourselves with a water network unable to cope with the demands of such large water accumulation, leading to situations such as flooding of public and/or private areas, malfunctioning of the

water network, and problems with return period. Furthermore, surface water runoff can increase pollutants, thereby affecting the deterioration of water quality. Oil, fuels, and solid waste are collected on surfaces and transported into drainage systems, risking direct transportation into seas or groundwater. The presence of numerous impermeable surfaces in urban areas only increases the hydrological risk in certain areas, causing significant damage to homes, buildings, and infrastructure.

As stated on the EEA Europe website, "between 1980 and 2017, floods have taken some 4,300 lives and cost Europe's economy more than € 170 billion, representing nearly a third of the total damage from natural hazards" (EEA, 2023).

2.1.3. IMPORTANCE OF CLIMATE CHANGE ADAPTATION IN CITIES

The rapid urban growth poses one of the most pressing challenges of our time. Cities must confront a range of issues, including poor air quality, the impacts of heat islands, increased flood risk, and the frequency/intensity of extreme weather events (such as droughts and heatwaves), as well as social problems such as rising crime, social injustice, poverty, and urban environmental degradation (Lafortezza, Sanesi, 2019).

Improving urban spaces is crucial for reducing global greenhouse gas emissions, and there are significant benefits to be gained from upgrading urban areas. These benefits include improved mobility, more reliable energy sources, and reduced vulnerability to disasters as we transition to a low-carbon economy. Engaging local communities and adopting nature-based approaches to adaptation in urban and peri-urban areas can lead to sustainable development of cities (Greenwalt, et. al. 2018).

There can be various types of possible interventions and useful urban planning practices, which is why these should be studied according to the specific location where they need to be applied. Sustainable urban planning practices would also help implement all aspects related to liveability, promoting innovation, and maximising economic and social benefits.

To understand how interconnected these benefits are, the EEA has developed an analytical model that, through six different lenses, analyses the role of cities in transitioning to more sustainable urban development: through the scheme in Figure 3, it is possible to emphasise how, to achieve the goal of having more sustainable cities in Europe, it is necessary not only to focus on different processes but also to have the capacity and tools to observe and develop them from different perspectives.

One of the strategies to be implemented in the coming years at the European level is, for example, to increase blue-green infrastructure within urban areas. Although starting from the desire to create more natural, interconnected environments that bring benefits in terms of environmental characteristics and biodiversity within urban areas, does not imply that they cannot also bring improvements in other areas such as social justice and cohesion, public health and well-being, and economic aspects such as more job opportunities or urban regeneration (Raymond et. Al. 2017). The interconnections created in these environments can be of great richness within the urban context.

Blue-green infrastructures are systems mainly designed for managing urban flood risks through integrated systems within the urban context that provide a network, through water basins and open green spaces, where water can be collected without causing harm to people or property. Some examples include green roofs, detention basins, the renaturation of riverbeds, rain gardens, or permeable pavements (Lamond, Everett, 2019). They have been recognized by the European Parliament within the EU Biodiversity Strategy for their value as ecosystem services and for maintaining biodiversity (European commission, 2013).

2.2. CLIMATE CHANGE ADAPTATION IN CITIES – FROM POLICIES TO ACTION

2.2.1. RESPONSABILITY AND POLICY AT DIFFERENT LEVELS

Within the European Union, the signs of climate change are becoming increasingly evident, impacting cities and countries alike. The European Environment Agency (EEA) has recognized the aspects posing the greatest risks to the territory and has particularly identified potential future risks. This is crucial because, by identifying these phenomena, it becomes possible to study and anticipate which areas will be most at risk in the coming years.

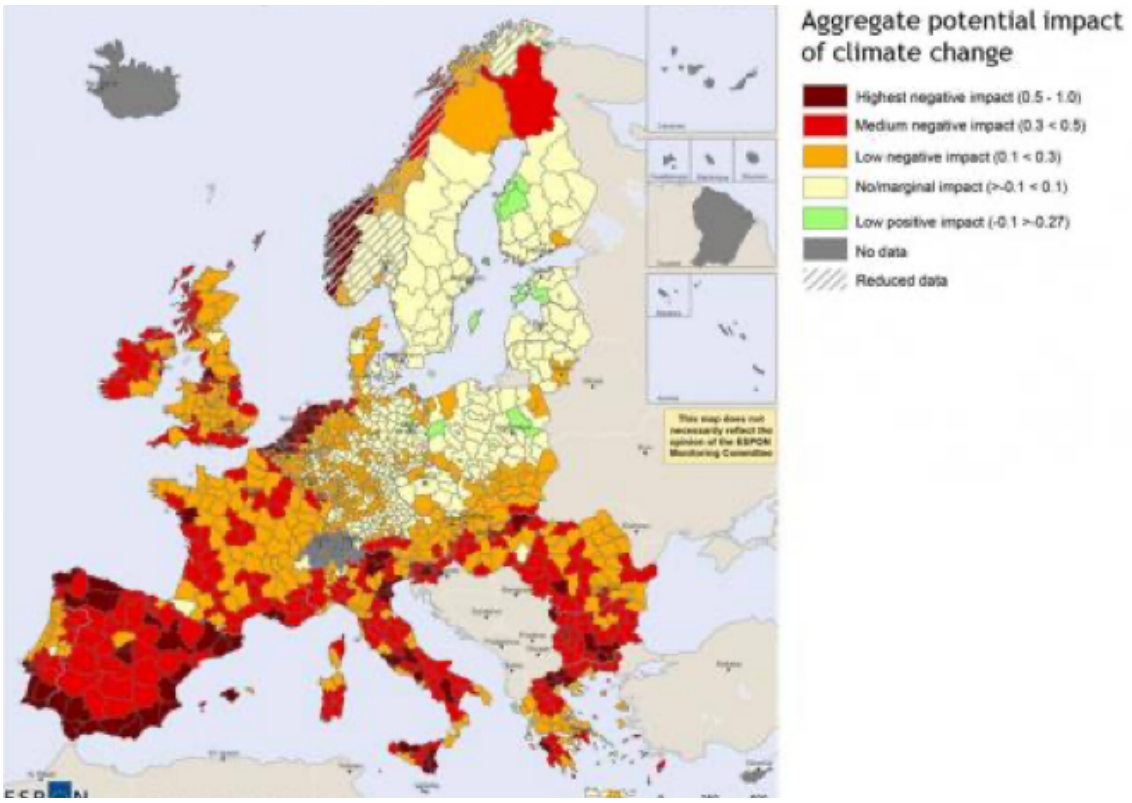


Figure 3: Aggregate potential impact of climate change on Europe's regions (Source: climatepolicyinfohub).

Through Figure 3, it can be observed which regions will be most affected, as identified by the EPSON in four main categories:

1. Coastal regions with high population;
2. Mountain regions with high dependence on tourism;
3. Urban areas with high population density (where urban heat islands might become a problem);
4. Regions exposed to river flooding.

For these reasons, Europe is promoting sustainable development policies to establish a common strategy in strengthening territories and preparing them for the increasingly extreme conditions in the coming years. The long-term goal is set for 2050, aiming to become "a climate-resilient society, fully adapted to the unavoidable impacts of climate change" (European commission, 2021).

On February 24, 2021, the European Commission formulated the Climate Change Adaptation Strategy. In addition to the goal of becoming climate resilient by 2050, the new strategy focuses on informational and data collection aspects, making the gathered data available to anyone interested. This approach aims to facilitate the study of faster and more intelligent strategies, better understanding all possible implications, and tailoring solutions specifically to each territory. Much of the information and data collected are accessible on the Climate ADAPT website, which has been and continues to be increasingly encouraged to become a more significant tool for data collection and processing (European commission, 2021).

Additionally, all initiatives for implementing plans and strategies are encouraged and supported, with a particular focus on three main aspects: "integrated adaptation into macro-fiscal policy", "nature-based solutions for adaptation," and "local adaptation action" (EU, 2024).

However, despite the presence of common goals and various strategic plans covering various areas related to climate change, the practical implementation of measures often occurs at a subnational level. All member states, along with Iceland, Liechtenstein, Norway, Switzerland, and Turkey, have national adaptation plans, and 22 member states have also adopted an adaptation action plan. In some states, adaptation plans have been integrated at the regional level (EEA, 2021).

Regional-level policies are supported at the European level through the Cohesion Policy 2014-2020, which has allocated 8 billion euros. The fund also promotes measures and strategies for climate adaptation, as well as risk prevention (Climate ADAPT, 2012).

The implementation of green infrastructure is part of this aid package, considering it highly important at the urban level. The combination of these ecosystem-based strategies is regarded as the most effective, easily achievable, economically valid, and impactful approach to combat the impacts of climate change. While the execution of these projects is entrusted to the local level, much of their value lies in their connection and interdependence. Therefore, neighbouring entities often need to collaborate on a common project. It is impractical to have a European directive involving all member states since territories can vary significantly and have different specific needs. However, it is essential to remember that certain important features, such as mountain ranges like the Alps and the Pyrenees, river basins, or forests, traverse various regions and states. Hence, strategies should always be coordinated to work together towards the same objective (European commission, 2013).

2.2.2.THE LIMITATION OF PUBLIC SECTORS

The European directive is based on close cooperation between the member states, through the European Climate Law, but it will then be put into practice by the states themselves through the drafting of Climate Adaptation Plans (European Commission, 2023). This plan is primarily determined by the states themselves, which, in turn, base many practical decisions and the actual implementation of adaptation plans on the regions.

This organisational structure has some positive aspects, as the development of plans involving individuals closely tied to a specific territory is a crucial step to ensure that subsequent actions are effectively targeted. However, this high level of fragmentation could also pose some problems. Firstly, there is a lack of

harmonisation among different areas, losing some focus on the overall picture. Especially in a situation like climate change, where each element is often closely related to others, this fragmentation could result in a loss. Another aspect to consider is related to practical implementation. Small municipalities or economically disadvantaged regions are economically vulnerable, influencing the number and quality of possible interventions (Fünfgeld, et. al. 2023).

It can be deduced that while adaptation actions are necessary everywhere, greater urgency should be considered, especially in these more at-risk and often more vulnerable areas with lower adaptive capacity (Nina Knittel, 2016). Following these characteristics, it becomes evident that, at the local level, a closer correlation between different realities, especially private ones, is increasingly crucial to ensure successful adaptation. Private entities should actively participate in public management (Wamsler, Brink 2014).

The two actions should be complementary; public action is necessary as it operates on larger territories and infrastructures, playing a vital role in resource management. On the other hand, private action can afford more targeted interventions that, if well-coordinated, can positively influence the overall adaptation of a specific area.

Private actions encompass any type of climate adaptation initiated by citizens themselves, or by a private entity or association, not directly by the public administration. These actions address one or more of the following hazards: floods, sea-level rise and increasing water levels, windstorms, low temperatures, snow and ice, high temperatures, dry spells and water scarcity, water contamination distaste, energy shortage and outage, and landslides (Wamsler, Brink 2014).

Although this type of adaptation is increasingly evident, in many instances, citizens' behaviours are influenced by the perception of a lack of institutional support (Wamsler, Raggers, 2018). Therefore, they often take on specific conditions without real recognition from the institutions themselves. The lack of regulations, in this case, could also contribute to a general state of inactivity, thereby achieving an opposite effect (Wamsler, Brink 2014). Nowadays, it is increasingly urgent to find a way to enhance collaboration between public and private entities, to increase and encourage the involvement of private companies and citizens in a process of redeveloping territories. This would help both the social aspect, fostering stronger connections between people and the places they inhabit, and incentivise greater attention, responsibility, and awareness of the ongoing climate changes, leading to increased actions for the proper adaptability of locations.

The complex and varied interactions between citizens and city administrations in climate management involve not only the legal responsibility of citizens to protect their property but also individual adaptation choices capable of positively or negatively influencing societal climate resilience (Wamsler, Raggers, 2018).

2.2.3. TRANSFORMING MINDSET FOR CLIMATE ADAPTATION

To instil positive behaviours in the population through the implementation of initiatives to adapt cities to climate change, it is necessary to introduce a mindset shift in the current context. Effectively addressing this emergency requires a fundamental reconsideration of the approaches, habits, and perspectives adopted so far. The traditional way of conceiving the relationship between humanity and the environment must evolve into a more sustainable perspective that is attentive to global interconnections. This mindset shift not only involves awareness of the impact of individual actions on the climate but also the willingness to adopt innovative and responsible solutions.

Some studies are beginning to explore how a specific mindset may or may not influence citizens to take private actions to counteract the effects of climate change and how this mindset may be partially influenced by public organisation. Several important factors influencing citizens' decisions to take concrete actions on the ground have been recognised.

A study conducted in Sweden at Lund University highlights how the ability to develop a certain type of mindfulness can aid in taking actions related to climate change. During the study, participants were given different scores based on their responses to how they would react to severe climate events. It was observed that high mindfulness scores are associated not only with a less fatalistic and more proactive attitude in taking adaptive measures but also with numerous social inclinations, such as greater solidarity with neighbours and encouragement for others to take pro-climate actions (Wamsler, Brink 2014).

The correlation between social and environmental aspects is evident in this research, and though the topic remains complex, it is inspiring to think that the challenges posed by climate change may influence social choices and stimulate the growth of more cohesive and mutually supportive communities.

To develop this level of cooperation, it is necessary to start by creating a relationship between citizens and municipal institutions, emphasising that authorities should consider and make room for aspects that are not entirely rational. This is because cooperation is often driven by motivations that do not necessarily follow a logical thread, and at the municipal level, these motivations may not be understood or considered. Therefore, it is important to build suitable spaces for discussion, places where there can be meetings for clarification or to resolve doubts, to explore together all the different aspects of interactions necessary for adaptation actions. This model could work well, as public support is often motivated more by empathy or charity than by reason (Wamsler, Raggers, 2018).

Consequently, the development of norms regarding private actions for climate change adaptation or public support should somehow take this emotional aspect into consideration.

It is also crucial to develop safe spaces where citizens feel protected and can establish trust with authorities. Actions and inactions related to climate issues are supported for various reasons, making the topic complex and at times ambivalent. While public participation can be encouraged by municipalities, it can be a double advantages in some cases. Trusting competent authorities can, in fact, also encourage opposing behaviours, making citizens less inclined to make changes in their lives, believing that someone they trust will take care of the problem. On the flip side, very active behaviours are often observed from individuals who have little trust in public authorities. They take matters into their own hands, seeking to solve problems themselves or implementing social actions (Wamsler, et. al. 2022).

On the other hand, a low level of awareness can also influence one behaviour over another, such as not realising the social and environmental impact of certain individual choices. "If we adopt the position that people can, individually and collectively, influence the future, there will be a need for policies that create related opportunities and provide support" (Wamsler, et. al. 2022).

There is no simple answer, as the presence of different types of thinking makes finding a solution to this puzzle difficult if not impossible.

Social innovation involves changes in social relations and practices, typically bringing new approaches to understanding, thinking, acting, and organising. It is a process that brings about profound transformations at both individual and collective levels, emphasising the importance of awareness, autonomy, and citizen action as fundamental conditions and desired outcomes.

In a study conducted on a group of activists (Guerra, Syed, 2024), three specific psychological profiles were identified: The Sceptical Activist, characterised by a strong community vision but a low esteem for government actions; The Optimist Technocrat, with strong social values and a more positive view of government and urban planning actions; and The Bystander with Mixed Feelings, exhibiting a lower openness to climate change and a significant presence of a fatalistic worldview (Guerra, Syed, 2024).

Although these three perspectives are sometimes contradictory, it is in their differences that their true strength lies. Each influences the others, encouraging positive environmental actions.

The research is still in its early stages, and the field remains open to drawing conclusions. However, some articles suggest that choices made not only by municipalities but also by citizens can impact broader social dynamics. Changes in this area are undoubtedly complex and take time to implement, but there is already greater awareness of climate issues today.

However, a notable gap exists between competent authorities and the population, leading some individuals to distrust or believe that their actions won't make a difference. Regions or municipalities must initiate social engagement actions that help everyone understand why certain behaviours or choices are important. These actions should also be economically supported, possibly through incentives or tax benefits.

The sense of community, perhaps somewhat lost in previous decades, should be rediscovered. It is from such feelings that more concrete actions can be obtained, considering both the emotional and rational aspects of human behaviour.

2.3. ADAPTATION MEASURES AND SOLUTIONS FOR WATER MANAGEMENT

2.3.1. CITY WATER MANAGEMENT CHALLENGES

The speed at which the effects of climate change are manifesting and the rapid urbanisation of recent decades have significantly impacted the ability of cities to manage weather events (Koop, Leeuwen,2017).

The main issues are primarily related to extreme weather events, which are becoming increasingly frequent, such as heavy rainfall, surface runoff, but also droughts and heatwaves that affect the quality and quantity of water resources in many European countries today (Özerol, et. al. 2020).

All these factors can exacerbate various water stress phenomena in many cities, both in terms of high temperatures, and because of droughts and lack of rainfall that could increase, but also with changes in river regimes and more saltwater intrusion through river mouths flowing into the sea, dramatically increasing environmental problems related to habitats in areas that are usually already very fragile (Kirshen, 2018).

Many of the problems related to these issues can be attributed to the way cities have evolved and been built, effectively transforming the natural landscape into a built environment and influencing the normal water cycle and the resilience capacity of a territory to withstand extreme events.

Studying a natural and unaffected soil, one might notice how most of the water that falls would be "lost" through evapotranspiration (about 40%) and infiltration (about 50%), enriching groundwater and remaining in place. Only 10% of the total would instead end up in surface runoff (Moretti, et. al. 2015).

Following rapid urbanisation, however, the increase in surfaces such as roofs, roads, and other impermeable surfaces has drastically changed the balance between impervious and pervious surfaces,

causing significant changes both in the quality and quantity of rainfall runoff, with subsequent degradation of the urban water system (Huang, et. al., 2015).

In fact, the high percentage of impermeable surfaces covering more than half of the territory means that the percentage of water capable of infiltrating into the ground drops to about 15%, while that lost to surface runoff reaches 55% (Moretti, et. al. 2015).

Although they may seem of opposite nature, water scarcity and its abundance during heavy rains are two events closely related to each other. The modification in the pattern of climatic precipitations will lead more and more to situations of this type, where periods with heavy and intense rains will give way to more drought months, and the inadequacy of cities to retain water will cause difficulties in ensuring its availability during the summer months, a situation that may be worse in those countries characterised by a hotter and more humid climate, and therefore, in our case, especially in southern Europe (Conte et al, 2012).

To date, however, it is the floods events that have caused, in European countries, the most damage, with estimated costs of 4.9 billion euros in the decade between 2000 and 2012, but which are estimated to grow to 23.5 billion by 2050 (Koop, Leeuwen,2017).

To prevent the water crisis that could hit cities, they should aim to think about how ecosystem services could be an added value in the fight against climate change and begin to integrate practices of this integration both in development plans and in other related sectors (Özerol, et. al. 2020).

It is therefore a good practice to increasingly aim for an integrated water management system, through a "holistic management of urban water supply, sanitation, stormwater, and wastewater to achieve sustainable economic, social, and environmental objectives" (Kirshen, et. al., 2018).

The construction of cities has led to a substantial modification in the water cycle, causing a distinction between a natural water cycle and a man-made one, but today it is necessary to become aware of how it is precisely between the integration of these two cycles that the solution to restoring a systemic balance and improving the resilience of territories could be found (Kirshen, et. al., 2018).

One of the major problems regarding the management of weather events today lies in traditional methods of rainwater drainage. Currently, rainwater is treated according to the principle of the fastest possible removal, collected on the surface through runoff, and swiftly discharged through underground pipes often connected to nearby water basins (Ji, Bai, 2021). This model presents several issues that require further investigation. Firstly, in numerous European urban centres, the pipes that collect rainwater and those of the sanitary system are frequently combined into a single network. As a consequence, following a period of intense precipitation, the accumulated rainwater, which is rapidly discharged into watercourses, is also carrying pollutants from household and commercial drainage systems (Ashley et al., 2020). Secondly, the rainwater itself, particularly when collected through surface runoff, carries a multitude of pollutants that have accumulated on urban surfaces. The reintroduction of this water into water bodies can result in pollution, which presents a significant challenge to human health and the natural habitats that support animal and plant life (Ji, Bai, 2021). In addition, as previously stated, this approach presents challenges in retaining water on-site, thereby exacerbating water supply issues during periods of low precipitation. The creation of permeable surfaces can therefore have several beneficial effects, including the elevation of groundwater levels, the provision of this resource during drier seasons, the enhancement of soil absorption and water storage capacity, and the improvement of green space quality. Furthermore, the reuse of

wastewater through various techniques could reduce water stress and improve water quality (Kirshen, et al., 2018).

2.3.2. CLIMATE ADAPTATION MODELS

In recent years, some climate adaptation models for cities have been developed, which revisit the concept of reintroducing more space dedicated to water in urban environments. The objective of these models is to restore certain areas to return the land to its previous capacity to store rainwater through practices implemented in urban settings, where the increase in impermeable surfaces has significantly altered the natural water cycle (Griffiths et al. 2020). This strategy is reflected in models such as the sponge city or the water-sensitive city. These models overlap and are based on implementing practices to make the city more efficient in terms of urban water supply, ecological water management, green infrastructure, and permeable urban paving. The objective of these practices is to enhance the city's capacity to absorb water, thereby improving environmental conditions, restoring the water cycle, and mitigating the heat island effect (Nguyen et al. 2019).

The concept is not merely about modifying specific urban areas; it also encompasses the investment in climate adaptation interventions, even on a small scale. This emphasises the importance of cooperation between professionals, public officials, and citizens (Nieuwenhuis, et al. 2023). The types of interventions are based on interdisciplinary knowledge, encompassing engineering, environmental sciences, and social sciences, with the objective of improving not only water management in the urban environment but also its liveability (Geert, et. al. 2023).

These models demonstrate the plastic capacity of the territory. Modifying it and reducing the percentage of impermeable pavements would restore some natural rules that would allow greater water absorption by the territory. These developments have been informed by considerations of not only the practical aspects of rainwater management but also aesthetic and social values, with the result that these spaces are able to fulfil multiple functions (Wong, 2000).

The concept of the sponge city is expansive, suggesting a general nature-based approach that can transform the urban landscape. This approach is essential for the coming years, when cities must be prepared to manage heavy rains due to increased precipitation. The topic was also addressed at the last G20 meeting, where this type of approach to cities was deemed necessary. The report also establishes that this approach is required across the entire urban area, not just selected parts, and should be considered as a new way of seeing the future of cities, integral to their growth and transformation (Kumar, et al. 2024).

2.3.3. GREEN INFRASTRUCURES SOLUTIONS

Despite the difficulties posed by climate change and urban environments, some solutions have been introduced to improve the management of stormwater through best management practices (BMPs), low impact development (LID), and green infrastructures (GI) (Wan, et. al. 2022). All these aspects are parts of the same problem, namely solutions that seek to enhance the resilience capacity of cities by restoring some natural processes related to stormwater.

Some LID solutions have become very important in urban stormwater management and, where implemented, have established positive effects on excessive rainfall treatment and water pollution (Chui, et. a. 2016). Assessing cost-effectiveness of specific LID practice designs in response to large storm events.

Examples of LID practices include preserving undeveloped open space, rain gardens, green roofs, porous pavement, and biofiltration. (EPA, 2009). All these practices, with some additions, are also found within

blue-green infrastructures, which encompass all practices inspired by and utilising nature to solve urban problems, as mentioned earlier. From the European Commission's website: "Green infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation" (EEA Glossary). One of the characteristics emphasised when discussing green infrastructure is that it is not a singular solution but rather bases its strength on the interconnectedness within its network. The urban environment must increasingly serve ecological functions to facilitate hydrogeological processes such as evaporation, transpiration, infiltration, and detention (Liu,Jensen 2018).

However, one of the major challenges regarding the development of these solutions concerns their implementation in already developed urban environments, where finding ample space is not always possible. For this reason, some solutions, such as storage features, are not easily integrable.

Preferable solutions are instead small-scale distributed GI/LID elements, which can be combined with larger storage elements at the regional level (Hettiarachchi, et.al. 2022).

The drainage systems formed in this way, through greater use of natural solutions, should provide two important functions, structural and hydrological. Implementing the capacity and return of water to underground aquifers, through a greater presence of permeable soils, while ensuring it does not carry pollutants or contaminants, is the first important aspect. The second aspect is the reduction of runoff and, especially in the case of waters that collect many pollutants, the collection in detention basins where they will be treated for suspended solids and pollutants (Moretti, et. al. 2015).

The benefits regarding the development of an urban ecosystem are many and well-documented. In fact, in addition to better water management, they will bring benefits to the entire urban environment, improving air quality, helping to reduce temperature, positively influencing potential problems related to water stress, but also implementing a social aspect of cohesion and increasing, from an economic point of view, the value of real estate (Özerol, et. al. 2020). The concept of green infrastructure can mean different things, including networks of green areas designed to provide multiple ecosystem services and green technologies that offer benefits especially in urban environments. The European Commission views green infrastructure as a strategic tool to integrate ecosystem services into spatial planning, addressing social, economic, and environmental issues, and supporting ecological resilience and climate change adaptation (Lai, Zoppi 2024). Additionally, BGIs can play an important role in mitigating the biodiversity crisis, especially in cities. Global biodiversity is continuously declining due to climate change and the loss of natural land, and international organizations are calling on cities to contribute to its conservation and restoration. Although urbanization is one of the main causes of biodiversity loss, urban areas can provide valuable habitats for species, including those of conservation importance (Perrelet, et al., 2024).

However, all these sustainable water management practices should not only be supported by those who technically operate in the sector but also by all stakeholders, including public administration, NGOs, and property owners (Conte, et. al. 2012). One of the problems concerning sustainable development and the implementation of these practices is precisely related to the various difficulties, especially managerial ones, due to the large number of stakeholders involved during the various phases which, due to the lack of adequate criteria and difficulty in monitoring ecosystem services, often lead to deficiencies in connections, which as we have seen are necessary for green solutions to work (Özerol, et. al. 2020).

It is therefore necessary to focus on future sustainable development by seeking the inclusion of all involved parties. Better stormwater management encompasses more challenges than merely those related to water management itself, but it is an important first step for cities to become pioneers in a change of approach to the territory different from the current one. Better stormwater management does not only mean assistance during severe weather events due to climate change but also signifies creating spaces where a more correct and natural balance in the ecosystem can be restored, placing importance on all social and economic aspects as well.

2.3.4. PAVEMENT SOLUTIONS FOR WATER MANAGEMENT

Although many solutions within those proposed as blue-green solutions are commendable, this text focuses more in-depth on permeable pavements to transform the urban environment and make it more resilient to problems related to heavy rainfall. Permeable pavements are solutions that do not require extensive modifications and can be easily implemented even in small spaces and at a relatively low cost. Additionally, they do not necessarily require a change in land use, allowing for climate adaptation to begin even in areas that are more challenging to modify. Additionally, this feasible solution helps resolve issues not only related to runoff and flooding but also in retaining water on-site, promoting the restoration of the urban water cycle, reducing traditional needs due to extreme rainfall events, and may also contribute to filtering pollutants and suspended solids that could be transported (Huang, et. al. 2015).

Furthermore, thanks to the ability to absorb water into the soil, permeable pavements not only address surface water accumulation issues but also help during heat waves by aiding in the evapotranspiration of water present within the structure (Wang, et. al. 2022) thereby improving air quality and humidity, which helps lower temperatures by mitigating the urban heat island effect (Wei, et. al. 2015). Compared to regular impermeable surfaces, permeable pavements have better characteristics in other aspects as well, aiding in managing the urban heat island effect, such as lower reflectance, higher volumetric heat capacity, thermal conductivity, and the ability to absorb additional heat (Vujovic, et. al. 2021).

There are two main types of pervious pavements: permeable pavements and porous pavements. Permeable pavements include all surfaces made through impermeable modular elements but leaving infiltration space between one piece and another. Porous pavements, on the other hand, are made using evenly grated inert bound by a permeable binder (Fini, et. al. 2017).

Having multiple solutions available, especially in urban spaces, where it is necessary to implement various types of pavements according to multiple needs, is excellent.

Permeable pavements are usually used to cover pedestrian surfaces or places where asphalted are not necessary, such as parking lots (both public and private) or pathways. In cases where green spaces cannot be implemented, permeable pavements can help. Elements like white stones, reinforced lawns, soil, paving grids for grass parking lots, light stones, cobblestones, gravel, or permeable self-locking blocks can be utilised (Moretti, et. al. 2015).

Some examples can be found in the following figures:



Figure 4: Examples of permeable pavements (Source: Personal elaboration)

In general, replacing regular pavements with permeable ones would be an excellent solution to increase the water-absorbing capacity of cities, especially considering that pavements cover about 20-40% of the total built area (Wang, et. al. 2022). In this perspective, the network of pedestrian areas and sidewalks in urban areas could have considerable importance in managing extreme weather events (Moretti, et. al. 2015).

Since a study on various types of Low Impact Development (LID) practices feasible in urban areas to contain surface runoff included permeable pavements, and this study demonstrates that, compared to bioretention basins and green roofs, permeable pavements are among the most effective solutions for reducing peak flow at a low cost (Chui, et al. 2016), it is crucial to implement changes where possible, replacing traditional pavements with permeable ones. Another important aspect that should influence the choice of this type of pavement is its filtration capacity for pollutants. Water pollution is, as seen earlier, one of the major problems when it comes to surface runoff, substances found on the streets and sidewalks of urban areas that, if transported to natural habitats, can contribute to the spread of pollutants and small insoluble particles, widening the pollution problem well beyond urban centres, as is already happening. This is why the filtering capacity of permeable pavements is another very important aspect to consider.

Through a study, in the document by Wei Jiang et al., the filtering capacity of permeable asphalt pavement was measured based on 16 different pollutant substances. The results are positive, showing significant filtration and removal of substances such as copper (Cu), zinc (Zn), lead (Pb), and sodium (Cd), and a relative, albeit lower, removal of substances such as petroleum pollutants (PP), animal and vegetable oil (AVO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and ammonia nitrogen (CH4-N) (Wei, et. al. 2015).

The ecosystem changes that have led to the current situation, with an increasingly difficult management of some phenomena in urban areas, be they heat waves or difficult stormwater management, have also originated from incorrect land use and rapid urbanisation. The increasing presence of impermeable soils is currently a growing problem in Europe, and a change is necessary. Improving the impact that the urban ecosystem has on the soil-atmosphere interface is one of the priorities that should be established as a future goal. The increasing urbanisation, which has brought and still brings destruction of natural processes and the water cycle, is a loss not only for the ecosystem as a whole but also affects the mechanisms of self-sustainability, resistance, and resilience of a territory that, now more than ever, with a climate presenting increasingly severe events, are important attributes (Fini, et. al. 2017).

A significant consideration in the selection of materials for pavements is the runoff coefficient, which quantifies the proportion of precipitation that contributes to surface runoff relative to the total amount of precipitation that falls on the material. This aspect is of paramount importance in the design of urban pavements, as it has a significant impact on the management of water during and after rainfall.

To illustrate, an impermeable material such as asphalt exhibits a markedly high runoff coefficient, reaching 0.95, as evidenced in the table below. This indicates that only a minor proportion of precipitation is absorbed by the material, with the remainder lost as surface runoff. Consequently, asphalt is an appropriate choice for locations where the reduction of water accumulation is a priority.

In contrast, materials with a lower runoff coefficient are more permeable, thereby facilitating the absorption of water into the ground. These materials, such as permeable pavements or gravel, are optimal for locations where water accumulation is desired, as they facilitate the absorption of water into the soil, rather than contributing to surface runoff.

In conclusion, the selection of pavement material should consider its runoff coefficient to either control or facilitate water absorption, depending on the specific requirements of the area and the objectives of urban water management.

Typical Runoff Coefficients

MATERIAL	NOTES	COEFFICIENT
pavement types		
asphalt		0.95
concrete		0.95
brick		0.85
gravel		0.75
porous concrete unit pavers	<5% slope	0.50
porous concrete	<5% slope	0.30
porous asphalt	<5% slope	0.40
roofs		
asphalt		0.95
green roof 1	depth <4 inches	0.50
green roof 2	depth 4 inches – 8 inches	0.30
green roof 3	depth 9 inches – 20 inches	0.20
green roof 4	depth >20 inches	0.10
turf		
flat	0 – 1% slope	0.25
average	1 – 3% slope	0.35
hilly	3 – 10% slope	0.40
steep	>10% slope	0.45
vegetation		
flat	0 – 1% slope	0.10
average	1 – 3% slope	0.20
hilly	3 – 10% slope	0.25
steep	>10% slope	0.30
filtration basin		0.00

Figure 5: Table with different runoff coefficients

3

REFERENCE CASE: COPENHAGEN

3.1. URBAN CONTEXT IN COPENHAGEN

3.1.1. URBAN DEVELOPMENT TRANDS

The city of Copenhagen is the capital of Denmark and the most populous city in the entire country. It is located on the islands of Zealand and Amager, with its origins dating back to the 10th century as a Viking fishing village. Urban development began in the seventeenth century when King Christian IV encouraged the growth of what is now considered the city centre. Following numerous epidemics and fires during the same century, the city began to flourish again, leading to urban development outside the fortifications for the construction of new neighbourhoods and housing.

However, the first building law was not established until 1856 when, due to the rapid expansion of the Danish capital, there was a need to regulate land use both within the city and in the surrounding areas. Growth continued into the next century with the development of neighbourhoods surrounding the historic centre to the north, west, and south (Vesterbro, Nørrebro, and Østerbro). This period was significant for the city as, for the first time, a proper plan for the development of new neighbourhoods was implemented following an architectural competition, culminating in the issuance of the first national urban planning law in 1925. The new laws aimed to ensure development that provided adequate health and sanitation services, transportation, and recreational facilities but did not completely halt the chaotic growth of housing and industries.

To partially contain the phenomenon, a new planning law was applied, which partially inspired the subsequent and better-known "Finger Plan", where local authorities were asked to divide the territory into three different zones: land, urban, and intermediate. It was established within the plan that it was prohibited to build anything within the designated land zones, thereby ensuring that some areas were recognised as inviolable. But it was especially after the end of the Second World War that, thanks to the Danish wartime planning-for-peace movement, planning began to be considered a real tool for reconstruction (Lager 2004).

Following the war's extensive losses and the destruction the city suffered from bombings, there was a great need for housing, transportation, and green areas. However, it soon became clear that without adequate planning and strong collaboration among different stakeholders, the city would soon become a congested puzzle. This phenomenon was already occurring, and it was evident to all how it would lead to issues of access to green areas and public services for the entire population. Therefore, a plan had to be agreed upon to ensure rational development of housing, commercial activities, services, transportation, and green corridors.

The plan, which would later become famous as the "Finger Plan" (Figure 5) was based on the development of a central city from which fingers extended, providing housing and transportation through a new metro development. The fingers would be divided by green wedges, ensuring both easy access to green areas and rational city expansion. Additionally, the railway lines developed longitudinally along the fingers ensured rapid connection to the centre, developing a highly efficient public service model (Sørensen,Torfing 2019).

Unlike other realities, therefore, in the city of Copenhagen, there has long been an interest in this integration and interaction between green spaces and the built environment and how to enhance urban efficiency.



Figure 6: The Copenhagen Metropolitan 'Finger Plan (Source: denishdesignreview.com)

3.1.2. CLIMATE SCENARIO AND IMPACTS ON THE URBAN ENVIRONMENT

Like many other European cities, the Danish capital, Copenhagen, has experienced rapid development since the end of the Second World War. Although there has been attention to urban development in the area, the implementation of urban planning has become necessary considering the ongoing climate changes. One of the city's main issues in recent years is the increase in heavy and torrential rainfall, which has altered the precipitation profile of the city (Copenhagen Climate Adaptation Plan, 2011). One event that sounded an alarm was in 2011 when Copenhagen experienced one of the most destructive rainfall events on record. On June 2 of that year, a torrential downpour hit the city, recording up to 200 mm of rainfall in the hardest-hit areas in just 30 minutes. This event caused extensive damage, ranging from public infrastructure, especially to one of the city's largest hospitals, to flooded basements in residential

areas. In total, those 30 minutes of rain caused the city damage of over 1.6 billion euros, making it the costliest weather-related event in Europe that year (State of Green, 2024).

The Danish Meteorological Institute (DMI) expects an increase in these extreme weather events in the future. The intensity of rainfall could increase by 20 to 50%, leading to changes in both surface runoff and the water load received by sewer systems and watercourses. This means that the sewer system will have to cope with a greater volume of water, about 30% by 2100, and the increased intensity of rainfall will result in water accumulation on surfaces, thereby increasing surface runoff (Copenhagen Climate Adaptation Plan,2011).

Currently, rainwater infiltration into the city mainly occurs through the sewer system, which collects both domestic wastewater and rainfall. However, the pipes, often built more than 150 years ago, are not sized according to current standards and cannot handle the quantity of water during heavy rains. Consequently, water can overflow from the pipes and accumulate on the surface, especially in low-lying areas. The primary goal of the sewer company is to ensure that domestic wastewater is safely discharged from ground level of buildings. However, protecting basements is not among their service objectives and must be managed privately, for example, through the installation of backflow valves (Copenhagen Climate Adaptation Plan,2011).

The service objectives of the sewer company are established in the municipal wastewater plan, considering historical, technical, and economic aspects. Since sewer systems have a limited lifespan, between 50 and 100 years, it is necessary to begin considering the expected climate changes in the coming decades. With the increase in intense precipitation, it will be necessary to adapt sewer infrastructure or reduce the volume of wastewater conveyed to ensure the maintenance of service standards. In Denmark, standards for sewer sizing in view of climate change have been developed under the supervision of the Water Pollution Committee of the Danish Society of Engineers (IDA) (Copenhagen Climate Adaptation Plan,2011).

Furthermore, even in the vicinity of watercourses, driven by heavy rainfall, water could overflow from the channel and flood nearby land. Another problem is related to the safety valves in the sewer system, which, in the case of a large accumulation of water, release wastewater into nearby seas, rivers, or lakes where there is no more space. With the increase in precipitation, this phenomenon is destined to increase, causing damage also from an environmental point of view (Cloudburst management plan 2010). The second calamity that could bring more difficulties to the city of Copenhagen is the rising oceans because of global warming. The ocean height, which around Copenhagen could increase by about 1 metre in the next 100 years according to the Danish Meteorological Institute, could determine how severe the storm surges that hit some areas of the city during bad weather events will be. Storm surges could cause a lot of damage, especially to buildings near the coast (Copenhagen Climate Adaptation Plan, 2011). These two issues are the ones to which the municipality of Copenhagen has begun to pay more attention, also following extreme events that have occurred in recent years. The effects of climate change are also becoming apparent in other areas, such as generally warmer temperatures in summer compared to the past and the phenomenon of the urban heat island, emphasised especially by the large amount of impermeable and asphalted surfaces.

3.2. COPENAGHEN´S CLIMATE ADAPTATION PLAN

3.2.1. OVERVIEW OF THE CLIMATE ADAPTATION PLAN

After the torrential rainfall that hit the city in June 2011, the municipality of Copenhagen drafted a climate adaptation plan to address the new challenges that will need to be faced in the coming years but also to lay the foundations for creating a more liveable city for its citizens. The plan is divided, focusing on the two main problems related to this territory: the increasing frequency of torrential rains causing damages such as flooding, overload of the sewer system, and consequent discharge of wastewater into nearby water basins. And, as a second important issue, the rising oceans and the possible storm surges that would result. The document was drawn up in 2011 by the municipality of Copenhagen, based on the latest IPCC report and taking as a case study scenario A2, i.e., one with the highest CO2 emissions, studying the impacts that these changes could have for the next 50 or 100 years. The plan will also be readapted following the new IPCC reports subsequently issued, thus remaining always up-to-date following possible changes. The foundations on which the plan is based start precisely from this concept of flexibility for readjustment in relation to the implementation of IPCC plans but also focus on aspects such as being in synergy with other plans adopted by the city itself, characterised by a high technical level, making the city not only efficient from a climate point of view but also attractive for inhabitants, especially using blue and green elements, and finally, obtaining a climate of cooperation both among neighbouring municipalities and internationally.

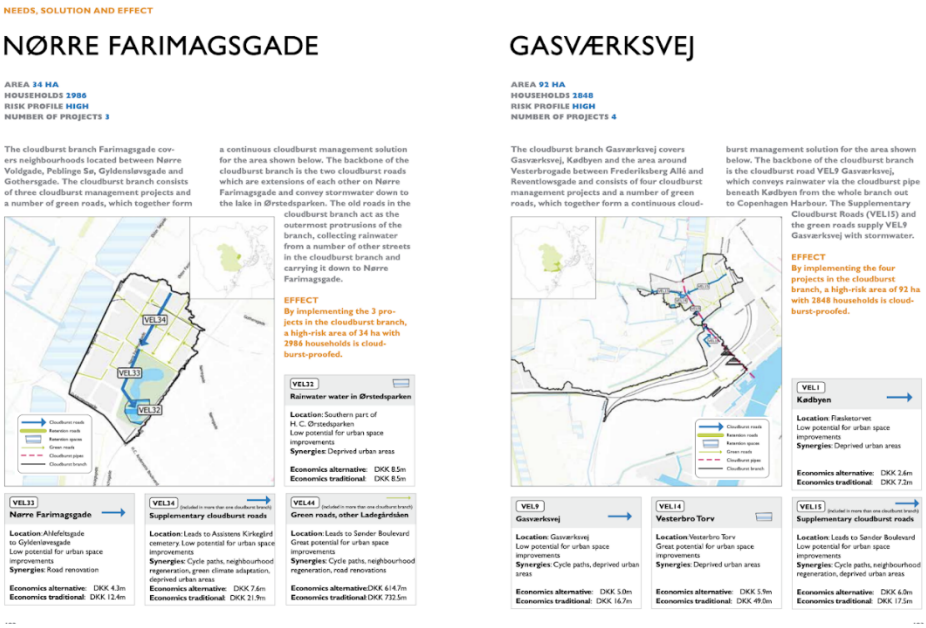


Figure 7: Example Copenaghen Masterplan (Source:Climate Change Adaptation Statement, 2015)

For the municipality of Copenhagen, it is not only important to set up a climate adaptation plan that works, but, realising how necessary it is today to find solutions that can both make a city more resilient to climate challenges but at the same time implement urban liveability.
Copenhagen's Climate Adaptation Plan focuses on a series of strategies to address the impacts of climate change. It is recognised that it is not possible to fully protect the city from extreme weather events, but the aim is to reduce the likelihood and extent of incidents and decrease vulnerability. The plan provides for three levels of adaptation calculated on risk assessment: prevention, reducing the extent of events, and post-event management. The goal is to protect priority public assets and improve citizens' quality of life. Flexible solutions and synergies with other planning initiatives are emphasised.
The climate adaptation plan is also associated with other plans, first and foremost the Cloudburst Management Plan of 2012, which pays more attention to rainwater management in the city and takes into account new data following the heavy precipitation of 2011. Furthermore, in 2015, a new document, The Climate Change Adaptation Statement, was drafted, tasked with analysing storm management projects implemented up to that point.
These projects are organised into hydraulic branches, which constitute continuous rainwater management systems. Each hydraulic branch is designed to manage the runoff of rainwater from specific collection areas, considering the natural water runoff patterns on the city's surface. Moreover, the hydraulic branches are designed to operate synergistically so that the effectiveness of one project depends on collaboration and coherence with the other projects in the branch.
This approach allows for holistic rainwater management in the city, ensuring fair distribution of resources and optimising system efficiency. Additionally, it allows for better assessment of the impact of storm management initiatives, as each project is part of a broader and interconnected context.
Understanding hydraulic branches is fundamental for assessing the overall effectiveness of sudden storm management. Projects are divided into branches based on hydrographic basins, which facilitate management and evaluation of results. This allows for constant monitoring and improvement of system performance by identifying any critical areas or optimisation opportunities.
Sudden storm management projects are designed to ensure that rainfall is managed safely and efficiently, minimising the risk of flooding and damage to urban infrastructure. This includes the use of temporary retention spaces, drainage channels, and underground tunnels to divert water away from inhabited areas and towards safe discharge areas, such as ports and rivers. However, it is important to note that sudden storm management requires a flexible and adaptable approach, as meteorological and hydrological conditions can vary significantly over time. Therefore, sudden storm management projects must be constantly monitored and updated to effectively respond to changing needs and environmental emergencies.
Furthermore, the effectiveness of sudden storm management projects also depends on the active participation and collaboration of local communities and competent authorities. Public awareness and participation in decision-making processes are crucial to ensure the long-term success and sustainability of sudden storm management initiatives.

3.2.2. ANALYSIS OF THE GOALS, OBJECTIVES, AND TARGETS OF THE ADAPTATION PLANS

As previously noted, Copenhagen's climate adaptation plan primarily focuses on two issues: those related to heavy rainfall and those related to rising sea levels. The problem of flooding during extreme rainfall events is caused by the large amount of rainwater collected from roofs and streets, which flows into watercourses. This overloads the watercourses, causing them to overflow downstream, resulting in damage. With the dual problem of projected sea level rise by 2110, the ability of watercourses to discharge water will be further reduced. The solution requires collaboration with other municipalities in the watershed. Rainwater collection occurs through the sewer system, but once the system's capacity is exceeded, water begins to flow on the surface, causing extensive damage. To protect public assets, two strategies are proposed: disconnecting rainwater from the sewer system and methods to channel excess water where it does not cause damage, known as "Plan B."

Disconnecting rainwater from the sewer system occurs through separation or using Sustainable Urban Drainage Systems (SUDS), which include elements that delay and treat water before discharge. These elements, recognisable as blue-green and low-tech, help reduce the load on the sewer system by collecting rainwater during intense rainfall, allowing it to infiltrate the ground instead of being transported into the sewer system. Plan B includes various methods to channel rainwater on the surface, using raised sidewalks and gutters, and utilising underutilised spaces such as parking lots or parks, thus avoiding overloading the sewer system. It is important that these waters avoid mixing rainwater and wastewater, so separation before discharge is essential. Areas for Plan B must be designated considering the city's diverse needs. Protecting basements is not the municipality of Copenhagen's objective, so protective measures must be adopted privately. Installing a back-flow valve can prevent basement flooding, and an awareness campaign can educate the public and businesses on the importance of this solution. Critical points in the sewer system should be addressed, and it is specified that further studies will be conducted with the preparation of a new sewer plan. One of the suggested ideas is to increase system basins to collect wastewater so that it is not released directly into watercourses, lakes, or the sea, stored for a certain period, and then transported to treatment facilities. Regarding the issue of rising sea levels, it is also very complex and could cause significant economic and cultural heritage damage. Furthermore, the increasing valorisation of areas threatened by flooding due to urban development makes it essential to intervene with preventive measures, such as building small levees. However, there are no specific areas that can be protected to prevent extensive flooding. One possible solution would be to create barriers at Nordhavnen and Kalveboderne and raise the coast towards Øresund. Protecting new constructions against flooding and groundwater penetration is more cost-effective at the construction stage. West Amager is also at risk of flooding due to its low altitude. A levee along the coast has been raised to protect these areas, considering the sea level rise. A 0.5-meter increase is expected in the next 100 years. Nordhavn and Kalveboderne could be protected with mobile barriers, but further studies need to be conducted at this point to understand their effectiveness and actual needs.

3.2.3. EFFECTIVNESS OF IMPLEMENTATION OF THE ADAPTATION PLANS

During the initial years of Copenhagen's climate adaptation plan implementation, the city has embarked on a solution to address torrential storms, with over 300 specific projects scattered throughout the city.

This new infrastructure aims to divert rainwater from the sewer system, utilising a combination of surface solutions and underground pipelines for managing torrential rainfall. The project involves constructing four extra-large cloudburst pipes that will discharge water into lakes and the harbour, along with additional conduits in various areas of the city. The implementation of these projects will span the next 20-30 years, with an initial phase dedicated to independent solutions preceding the completion of the large cloudburst pipes. Each cloudburst pipe will play a crucial role in ensuring that water is efficiently conveyed, with the construction of a pipeline network connecting various parts of the city to the main water basins. For instance, one pipe will be installed in Vesterbro to channel rainwater and discharge to the harbour basin, while another in Østerbro will handle runoff from surrounding areas to the Nordhavn basin. These projects will have a significant impact on Copenhagen's ability to manage torrential rains and reduce the risk of flooding. Although the implementation of this infrastructure will take several decades, it is considered a vital solution to protect homes, cultural heritage, and commercial properties from future intense rainfall. However, this will require patience from the citizens of Copenhagen, as the full benefits of these projects will not be immediately visible. Additionally, approximately 300 blue-green infrastructure projects are being developed across the city, divided within the various hydraulic branches, to increase water infiltration capacity into the soil throughout the city's territory. These projects are selected annually, focusing not only on the characteristics of the location but also on the potential for integration with other initiatives within the same hydraulic branch, thus creating a network within them and increasing the capacity of these tools. However, a step backward has been taken regarding the Plan B mentioned in the Climate Adaptation Plan. Originally, the Climate Adaptation Plan recommended that rainwater from extreme storms be drained to places where flooding would cause minimal disruption: parks, sports fields, open spaces, and lakes. The idea was to store rainwater in these buffer areas until the drainage system restored its capacity. The extreme rainfall event on July 2, 2011, and subsequent calculations have now unequivocally shown that this method is inadequate in preventing rainfall flooding in much of the city. In fact, estimates show that the storage method - known as 'Plan B' in the Climate Adaptation Plan – would only cover a small portion of the need for rainwater drainage. New studies show that storage should be complemented by measures where water is conveyed to the sea through roads, urban canals/watercourses, and underground tunnels. Therefore, the preferred solution will be drainage to the sea via new flow paths (Cloudbuster management plan, 2012).

3.3. CLIMATE ADAPTATION INITIATIVES AND PROJECTS IN COPENHAGEN

3.3.1. REVIEW OF SPECIFIC INITATIVES AND PROJECTS AIMED AT CLIMATE ADAPTATION IN COPENHAGEN

Example of cloudburst branch

The Cloudburst Branch Åboulevarden stretches from Fuglekvarteret in the north to Skt. Jørgens Sø in the south, comprising eight cloudburst management projects and several green roads, forming a continuous cloudburst management solution. The backbone of the branch is the cloudburst pipe beneath Åboulevarden, conveying water from the projects to the retention space in Skt. Jørgens Sø.

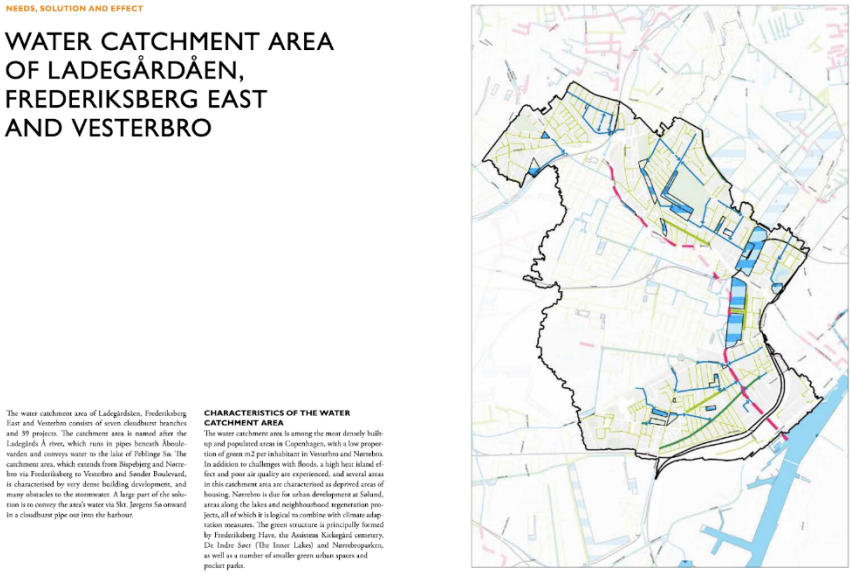


Figure 8: Example of Climate Adaptation Plan Implementation (Source: Climate Change Adaptation Statement, 2015).

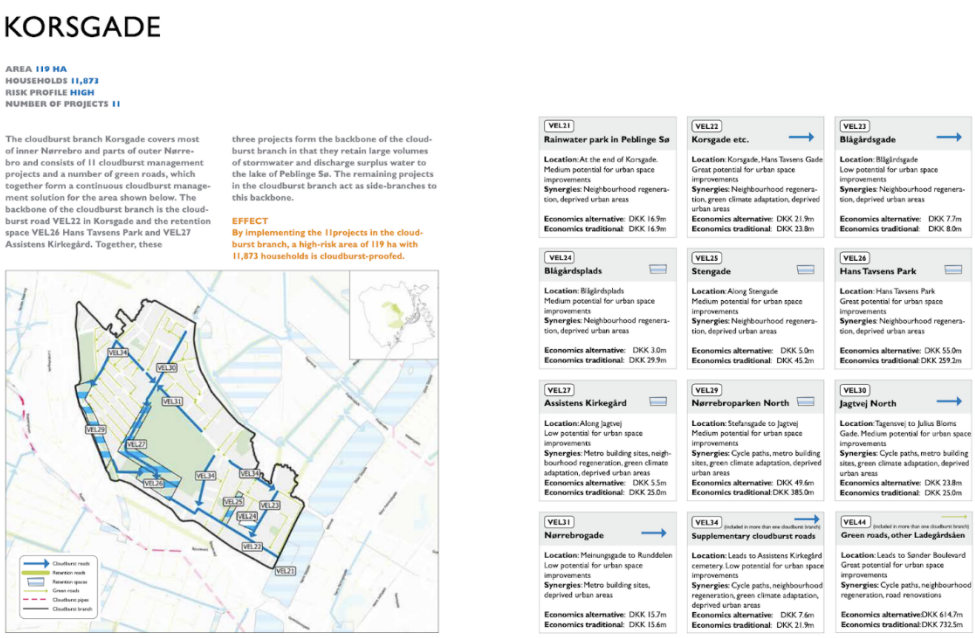


Figure 9: Example a specific example of a localized area (Source: Climate Change Adaptation Statement, 2015).

Enghaveparken

Enghaveparken, inaugurated in 1928, exemplifies the early welfare state in Denmark by providing light, fresh air, and green spaces to Vesterbro's population living in small apartments. In the 1950s, it became a popular venue for outdoor dancing. However, with increased indoor spaces, its significance waned. In the early 2010s, torrential rains affected Copenhagen, leading to flooding and costly damage. Enghaveparken,

located lower than a hill, has become crucial in managing torrential rains. During moderate rains, rainwater from surrounding roofs flows into the park, serving as a 2000 cubic meter retention basin. It is stored for irrigating plants during dry periods and street cleaning. Rainwater is managed above ground, allowing usage in a fountain garden. Reusing rainwater and groundwater is typically used for recreational purposes. The park closes during extreme rain to protect surrounding buildings. With rich biodiversity, Enghaveparken offers recreational activities, cultural gatherings, and opportunities for street sports and concerts, making it accessible to all Copenhageners.

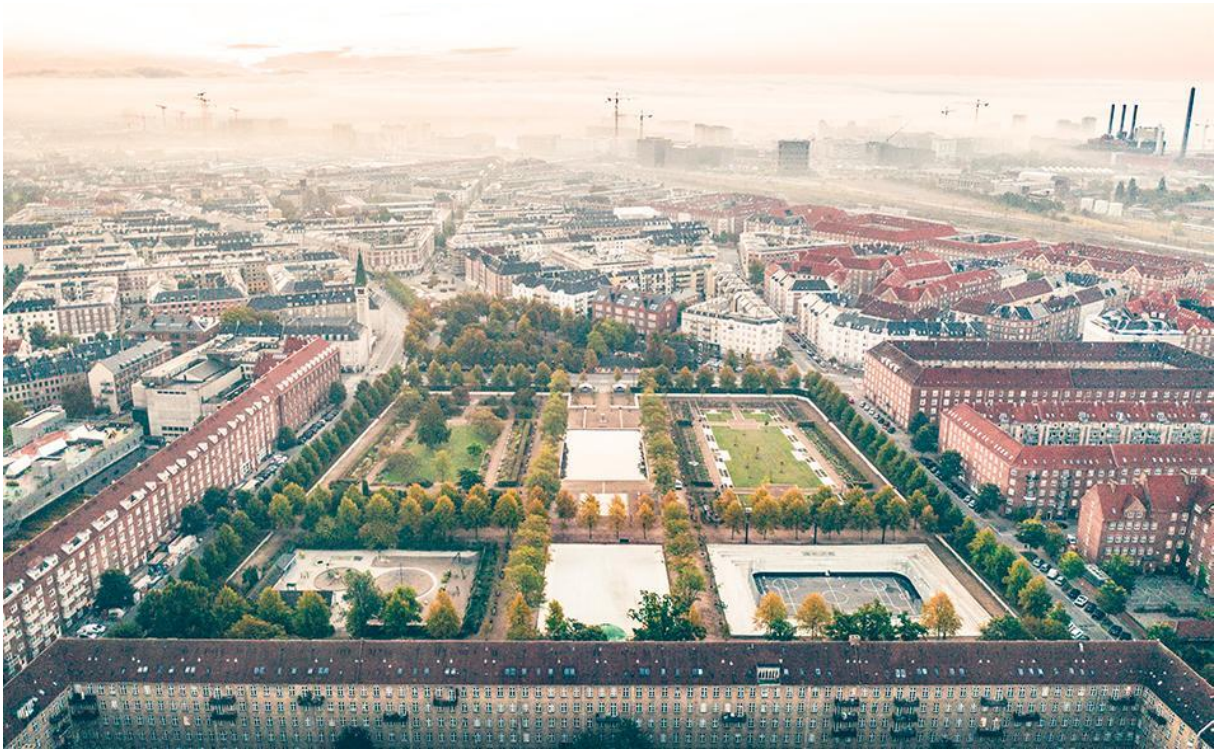


Figure 10:Enghaveparken today, 2019 (Source: Tredje Nature Architect Firm)



Figure 11:Enghaveparken today, 2019 (Source: Tredje Nature Architect Firm)



Figure 13:Water collection solution in Enghaveparken, 2019 (Source: Tredje architect Firm)



Figure 12:Water collection solution in Enghaveparken, 2019 (Source: Tredje Nature architect Firm)

Klimakvarter

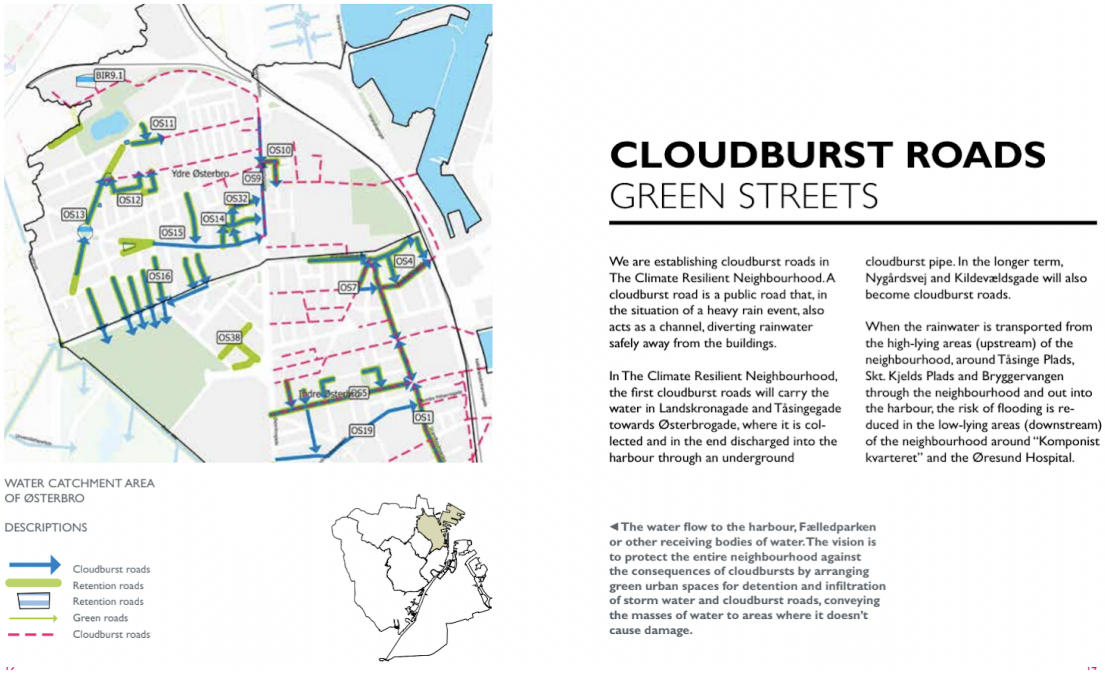


Figure 14: Climate Adaptation Plan in the Klimakvarter Neighbourhood Area (Source: Climate Change Adaptation Statement, 2015).

Copenhagen's Østerbro district pioneers the city's first Climate Resilient Neighbourhood, aiming to mitigate climate change impacts, particularly extreme rainfall events. Traditional sewer systems prove inadequate, leading to overflow and damage. The initiative disconnects rainwater from the sewer system through green streets, urban squares, and cloudburst streets, utilising natural elements for absorption and diversion. Skt. Kjelds Plads and Bryggervangen will transform into vibrant green spaces. Cloudburst roads like Landskronagade and Tåsingegade divert rainwater safely during storms. Future Green Courtyards collect rainwater to support vegetation and improve aesthetics. The transformation aims for climate adaptation, urban revitalisation, and community cohesion. By integrating green infrastructure, Copenhagen strives for a liveable, sustainable, and resilient urban environment. The initiative's success garners international recognition, inspiring innovative approaches to climate change adaptation. As can be seen in Figure 15 and subsequently in the two images in Figures 16 and 17, the transformation of the roundabout has led to a noticeable change in the space.

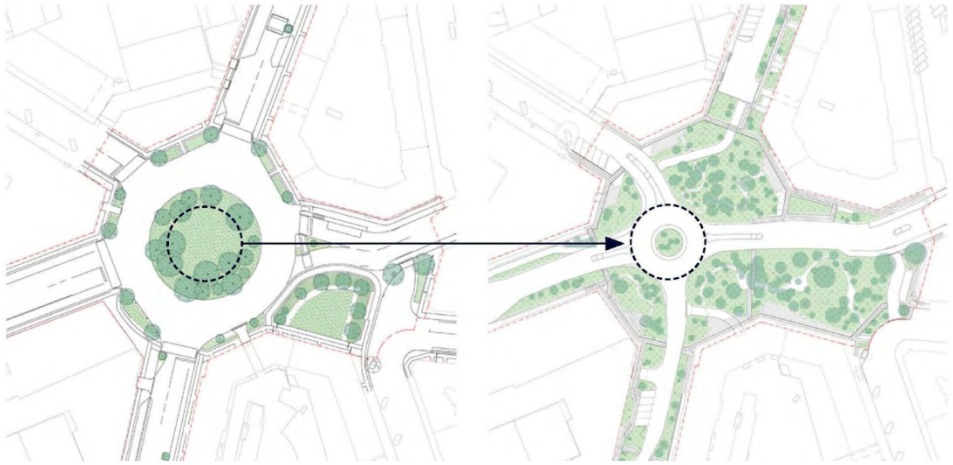


Figure 15 : Sankt Kjeld's Square Transformation, 2018 (Source: SLA architect firm).

In summary, Copenhagen's Climate Resilient Neighbourhood initiative represents a holistic approach to climate adaptation, leveraging nature-based solutions, engaging residents, and reimagining urban spaces. It leads towards a resilient and sustainable future amidst climate uncertain.



Figure 16: Sankt Kjeld's Square Transformation; 2018 (Source: SLA architect firm).



Figure 17: Sankt Kjeld's Square Transformation; 2018 (Source: SLA architect firm).



Figure 18: Sankt Kjeld's Square, Specific solutions for water drainage, 2018(Source: SLA architect firm).



Figure 19: Sankt Kjeld's Square, Specific solutions for water drainage, 2018 (Source: SLA architect firm).



Figure 20: Sankt Kjeld's Square, Specific solutions for water drainage, 2018 (Source: SLA architect firm).

Climate Tile

The Climate Tile is a climate adaptation project developed to offer solutions even in case of limited space available in cities. Constructed with vertical and horizontal pipes, the Climate Tile allows for various functions to be added, making it adaptable to any situation or activity on the sidewalk. The project took shape in the Norrebro district, with a length of 50 m, and was installed in 2018 to observe and collect data on its effectiveness. One of the positive features of this system, and why it is heavily studied, is that it is placed using the same working procedure as pipe replacement or restoration, resulting in time and cost savings. Through these specific tiles, it is possible to restore the water cycle in the city, collecting water not only from the sidewalks but also from the rooftops. The water is directed to the surrounding plant holes for irrigation and evaporation. Some is absorbed by the plants, while the rest seeps into the soil. The Climate Tile manages rainwater from rooftops and sidewalks by channelling water through holes in the tiles and integrated pipes to a water management system. Water from the roof is directed to water banks for percolation, avoiding contact with salt during sidewalk salting.



Figure 21: Climate Tile project in Norrebro, 2018 (Source: Tredje Nature Architect Firm)

As of now, the Climate Tile has surpassed expectations regarding its durability and water retention over a span of 6 years.

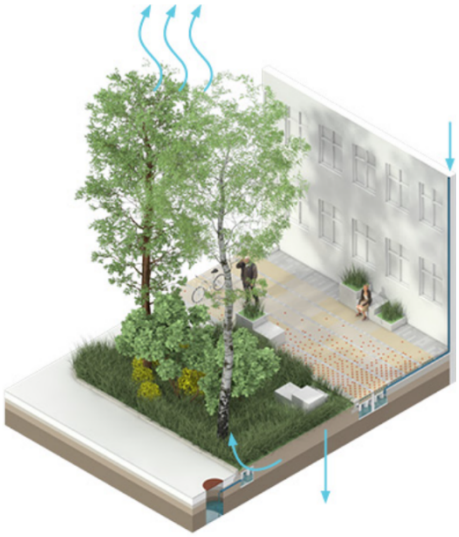


Figure 22: Climate Tile project detail, 2018 (Source: Tredje Nature Architect Firm).

Assessment by the Municipality of Copenhagen suggests it as a viable approach for handling rising rainfall in urban settings. Calculations indicate that installing the Climate Tile in areas initially slated for pavement restoration could yield cost savings up to 10 times. This underscores its dual benefit as both an environmentally sound and economically efficient solution.



Figure 23: Climate Tile detail, 2018 (Source: Tredje Nature)



Figure 24: Climate Tile detail, 2018 (Source: Tredje Nature)

The climate courtyard on Nattergalevej

The project represents one of three pioneering initiatives in the Municipality of Copenhagen, actively managing rainwater within the courtyard instead of directing it to the sewer system. It is a step in the city's overall climate adaptation and an incentive to renew and improve the humanitarian value of the courtyard.



Figure 25: Example of a water drainage channel, 2017 (Source: MASU Planning Architect Firm)



Figure 26: Example of a water drainage channel, 2017 (Source: MASU Planning Architect Firm)

In the two photos (Figures 25 and 26), we can see an example of a drainage channel designed to collect rainwater from paved areas and rooftops, directing it into the grassy area, where certain sections are intended to be periodically submerged.

Another solution adopted to collect water from the rooftops was to place rain gardens directly under the final outflow of the gutter (Figure 27). Moreover, all pavements incorporated into the project are permeable to further increase the total absorbent surface area (Figure 30 and 31).



Figure 27: Example of a rain garden for collecting rainwater, 2017 (Source: MASU Planning Architect Firm)



Figure 28: Depressions in the ground created for rainwater collection, 2017 (Source: MASU Planning Architect Firm)



Figure 29: Depressions in the ground created for rainwater collection, 2017 (Source: MASU Planning Architect Firm)



Figure 30: Details of permeable pavement, 2017 (Source: MASU Planning Architect Firm)



Figure 31: Details of permeable pavement, 2017 (Source: MASU Planning Architect Firm)

The Beethovensvej housing Block

The Beethovensvej housing complex integrates surface rainwater management by collecting water from rooftops and other surfaces, channelling it through open channels into a system of green ditches and small ponds that frame the central green spaces. In this case as well, solutions such as permeable pavements have been used (Figures 31 and 32), and water from the gutters has been directed to collection points within the green area (Figures 33 and 34).



Figure 32: Figure 31: Details of permeable pavement, 2021 (Source: MASU Planning Architect Firm)



Figure 33: Details of permeable pavement, 2021 (Source: MASU Planning Architect Firm)



Figure 34; Details of permeable pavement, 2021 (Source: MASU Planning Architect Firm)



Figure 35: Details of permeable pavement, 2021 (Source: MASU Planning Architect Firm).

Street rain gardens and solutions for tree plantings

The presence of permeable surfaces has also been increased with the addition of rain gardens along the sides of roads, where possible. An example is the rain garden located on Glentevej, shown in Figure 35.



Figure 36: Roadside rain garden (Source: personal elaboration

These rain gardens are designed to accumulate water from nearby houses, typically via a channel that carries rainwater from the gutter (Figure 36) to the rain garden, and from the street through ground depressions (Figure 37). The rain gardens also feature drainage solutions for overflow situations (Figure 38).

In cases where there is limited space, one solution has been to increase the permeable surface near trees by using simple grates, allowing for car parking while still providing benefits in terms of rainwater collection (Figure 39).



Figure 37: Rainwater entry points to the rain garden (Source: personal elaboration).



Figure 39: Rainwater entry points to the rain



Figure 38: Detail of tree solutions (Source: personal elaboration)



Figure 40:Raingarden detail (Source: personal eleboration)

Other solutions for collecting rainwater

It can also be an idea to not only use rainwater to benefit vegetation but to transform it into something new. In this case, the playground has been positioned in the centre of a ground depression that, when it rains, collects water, thus changing the play experience for the children who use it (Figure 41).



Figure 41: Rain uses in a playground (Source: Personal elaboration).

4

THE CASE STUDY

4.1 METHODOLOGY

The objective of this text is to provide an analytical and conceptual understanding of the phenomenon of flooding due to heavy rainfall in urban areas. To this end, data pertaining to the city of Porto were collated, commencing with a comprehensive overview and subsequently focusing on two areas of particular interest. Initially, precipitation data for the region were analysed across three distinct time intervals: 2011-2040, 2041-2070 and 2071-2100. For these time intervals, the most favourable scenario (RCP 4.5) and the least favourable scenario (RCP 8.5) were analysed to ascertain whether intense rainfall events would increase in the future in the city and, if so, whether this could present a challenge for future urban management.

Subsequently, hydrogeological data were analysed, including soil composition and the possible presence of watercourses or flood zones. The data were useful for understanding the territory, its formation, and whether there might be difficulties in water absorption by the soil. Finally, data on the urban environment were collected and analysed. This included land use data, the presence or absence of green areas and their type (public gardens, historical gardens, etc.), the environmental quality of the green areas, species diversity, richness, and vegetation composition. Additionally, data on urban flooding were collected with the objective of identifying the area's most prone to flooding.

Following the collection of the data, a spatial analysis was conducted by overlaying the various maps collected with the map of reported flooded areas. The overlays permitted an analysis of the potential link between the occurrence of floods within the city and specific urban or territorial conditions. Once the data had been analysed, it was possible to identify which solutions could be more effectively implemented in the study area, which aspects should be given greater attention, and how the characteristics of the places (for example, land uses, types of surfaces, etc.) could influence future choices, thus providing a general overview.

The general data collected enabled us to hold a meeting with some representatives from the municipal water and energy company *Águas Do Porto*. This meeting allowed us to comprehend the municipal strategies and discuss some alternative solutions. Through this meeting, we were able to gain a better understanding of the problems within the urban fabric, as well as the solutions that had already been implemented and those that were currently being focused on. It was also interesting during the meeting to understand which areas would be better to focus on for a possible more detailed territorial analysis. A specific area was then selected for more focused reflection, with the objective of identifying and analysing the practical problems that could be recognised and seeking possible solutions.

The second phase of this thesis focused on a more restricted study area. Research was conducted on the area itself and its history. The area was identified as being located within one of the most important riverbeds, which is why the position of the stream and the areas most affected by floods were analysed.

Finally, the urban fabric was analysed in order to ascertain its formation and the main problems related to the area.
Following this initial phase, the collected data were analysed and possible solutions that could be implemented were considered, based on previous research. To confirm these findings, a second meeting was organised with representatives from the municipal water and energy company, where the identified problems were presented and possible solutions were discussed. This meeting was of great importance in order to validate the solutions being proposed.
Following the more comprehensive analysis of the area provided by this meeting, several potential solutions were identified that could be implemented in specific zones. These solutions were designed to improve rainwater management, with the aim of generating value for the urban fabric as a whole.

4.2 CONTEXT OF PORTO

The problem of surface runoff and soil impermeability is an issue found in many European cities, both in the North and the South of the continent. In the city of Porto, the same problem has been identified with several incidents causing significant damage to the city.
A significant event, which may be considered for comparison with the previously studied event that occurred in Copenhagen, is the one that took place on 8 January 2023, in Porto. In approximately 20 minutes, approximately 25 L/m² of precipitation fell on the city, resulting in the formation of extensive surface flows and considerable damage. In less than two hours, around 250 emergency calls were recorded, primarily from the downtown area, reporting hazardous situations in homes or along the streets. (source: portugalresident.com). This type of event is not the norm, but it is illustrative because it gives an idea of the strength and damage that these situations can cause and could cause in the future. It is incredibly challenging, even for a prepared city, to cope with a phenomenon of this magnitude, which is why it is crucial to begin identifying the areas most affected during these events to devise solutions to manage them as much as possible and at least limit the damage. An additional challenge arises from the wide variety of possible solutions, since each city has unique characteristics, both in terms of its morphological structure and the way it has been built. There is no one-size-fits-all solution. It will most likely be the combination of several different approaches that makes a meaningful difference.
This thesis lays the groundwork for finding possible solutions to increase the permeability of pavements in certain areas of Porto. Through the example of Copenhagen, some possible models were studied, drawing on data collection that will take into consideration everything from rainfall amounts to land use, and the quantity of green spaces. Additionally, data regarding the frequency of emergency calls will be analysed to cross-reference information and identify where within the urban fabric there are greater challenges.
This data will be reviewed with representatives from the water company *Águas Do Porto* to closely analyse practical solutions for specific areas.

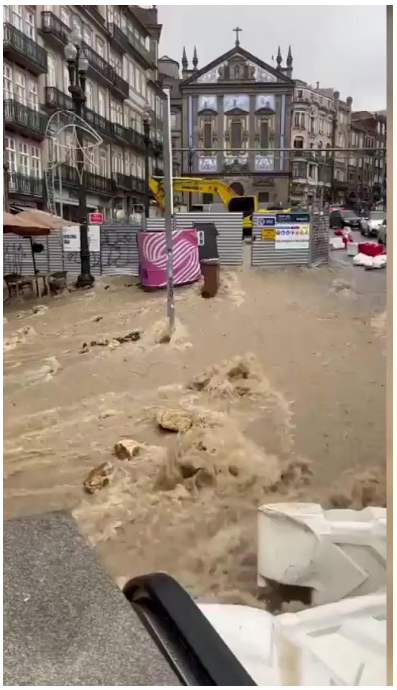


Figure 42: Photos of the event in São Bento (Source: today.rtl.lu, 2023)

4.3. CLIMATE PLAN ADAPTATION PORTO: A GENERAL REVIEW AND COMPARISON WITH THE COPENHAGEN PLAN

4.3.1 OVERVIEW OF THE CLIMATE ADAPTATION PLAN

The municipal council drafted the Climate Adaptation Plan for Porto in 2016. This document, based on the Portuguese climate law, seeks to outline the future steps through which the city can aim to make the right choices regarding the creation of spaces resilient to climate change.

The main points it focuses on are the alteration of certain climatic aspects that could, in the future and, to some extent, even today, negatively impact the lives of citizens, contributing to increased social disparities and creating harmful and dangerous situations for both people and buildings and infrastructure (Porto Climate Adaptation Plan, 2016).

As in the Copenhagen Climate Adaptation Plan, the Porto plan identifies the main difficulties arising from climate change that could significantly impact the city. By analysing climate projections and their potential impacts through the associated risk levels, based on projections for today, mid-century, and a century from now, it emerges that the main challenges will be threefold.

The general decrease in annual precipitation and an increase in potential temperature, especially in the summer period, will lead to a drier and warmer climate, with more frequent heat waves, especially in urban areas. The temperature increases with consequent problems related to soil aridity is one of the main issues in Southern Europe, recognized by European climate institutions, and it is a growing problem that requires more attention.

As in other European regions, studies in the Porto area have shown that changes in precipitation patterns will lead to a decrease in average annual precipitation but increase the likelihood of intense and very intense precipitation events. This increase in rainfall intensity and variability can lead to elevated surface runoff, posing greater risks of flooding and other forms of environmental stress.

This, as also studied in the Copenhagen Climate Adaptation Plan, is certainly influenced by the inefficiency of the rainwater collection system. When it fails to capture all the rainfall, it leads to surface runoff and accumulation of rainwater in lower-lying areas.
Another issue is that, during urban development, about 75% of the waterways were enclosed in pipes, which has led to a reshaping of the territory and made rainwater management more challenging, as there's no longer room for rainwater within the natural basins (iwa-network, 2024).
The third problem, identified in the Climate Adaptation Plan, relates to the rising sea levels and the consequent loss of coastline (Porto Climate Adaptation Plan, 2016).

4.3.2 STRUCTURE OF PORTO´S CLIMATE ADAPTATION PLAN

The structure of Porto's Climate Adaptation Plan primarily addresses these three main risks to develop its action plan.
To understand the future challenges the city will face, projections have been made for the present, 50 years ahead, and 100 years ahead, considering two possible emission scenarios. Additionally, the plan was developed using a methodology called ADAM, based on five different stages:
1. Identification and Data Collection of Previous Events (2000-2014): Data from about 15 years are gathered. All future estimates are based on these collected data.
2. Identification of Future Vulnerabilities: This step is based on the estimates derived from the data analysis. It's important to evaluate not only the primary impacts and risks but also to understand which ones are more problematic through a scoring table. It is also crucial to consider where these events might cause the most damage and which sectors, activities, or social groups could be most affected.
3. Identification of Relevant Adaptation Options: Possible solutions to make the city more resilient are recognized as grey infrastructure, green infrastructure, and non-structural measures, such as municipal incentives, educational activities, or land observation groups.
4. Evaluation of Adaptation Options: The previously identified adaptation options are assessed based on specific parameters, such as effectiveness, efficiency, equity, flexibility, legitimacy, urgency, and synergies.
5. The Final Stage: This phase analyses the adaptation options identified in the previous stage from a land use planning perspective, identifying and characterising planning instruments that could help implement these adaptation measures effectively.

Within the document, there is a list of potential issues, each with an associated action strategy to follow. Among the selected solutions, the implementation of green structures, potentially linked to grey infrastructure, is currently considered the most suitable approach. At present, some initiatives are already underway and are proving their effectiveness, including the *"Defender a linha de costa"* project, the promotion of bioclimatic measures (such as green roofs), and participation in *LIFE-mybuildingsgreen*, an initiative focused on developing school facilities with greater thermal comfort provided by green solutions. Additionally, in the eastern area (Campanhã), initiatives are being developed to create healthy corridors, which are highly used pedestrian corridors that will be enhanced with green solutions. Finally, programs such as *"Respeitar o ciclo da água"* aimed at increasing permeable surfaces and rehabilitating streams, and *"Árvores: mais sombra e menos carbono"* aiming to increase the number of trees, especially native species, both in the city and in private spaces, are in progress (CM Porto, 2024).

Moreover, measures are being implemented to reduce the amount of carbon in the atmosphere, which is a major cause of climate change, through a reduction in the municipality's total emissions.
Through the *"Pacto para o clima"* the city has committed to reducing its carbon emissions by 85% by 2030, seeking collaboration with private entities and the general public.

4.3.3 COMPARISON WITH COPENHAGEN´S CLIMATE ADAPTATION PLAN

Although the two cities are quite different, their climate adaptation plans have some common features. The two cities exhibit considerable variation in their morphological characteristics. The Danish capital is situated on an island with relatively flat terrain and a greater availability of space for roads, squares, and public spaces in general. In contrast, Porto is characterised by significant slopes and a more complex urban fabric, which generally features narrower streets and less pedestrian space. Consequently, the implementation of solutions in Porto is more challenging than in Copenhagen, where the greater availability of space allows for the application of a wider range of solutions. Starting with the issues at hand, and considering geographical differences and their climatic implications, both cities face challenges related to heavy rainfall and rising sea levels. In both plans, green structures are recognized as valuable allies in the fight against climate change, especially in addressing the challenges associated with the increase in extreme events such as heavy rains and heat waves.
In Porto's Climate Adaptation Plan, there is also emphasis on the practical consequences of these events and the social implications. Climate change does not affect the entire population equally; its consequences are often more severe and drastic for those who are already economically or socially disadvantaged. Simply put, the flooding of a basement can be more easily repaired by someone with greater financial resources.
This is an important aspect to consider, as establishing regulations or aid packages for these vulnerable groups ensures they have the same opportunities to recover and adapt. Both cities recognize the importance of incorporating social equity into their adaptation strategies, emphasising the need for inclusive policies that support all citizens in the face of climate change.
In general, neither adaptation plan details the specific actions to be taken. Plans are often designed as general guidelines, providing directions to follow. However, Copenhagen's Climate Adaptation Plan has been supplemented with additional documents in the following years to help implement it. One is the Cloudburst Management Plan, focusing on increased rainfall, and the other is the Climate Change Adaptation Statement, issued approximately every two years, which tracks all progress made over the years and monitors the types of interventions carried out in the territory.
These two documents are of great importance because they help complete and concrete an action plan that is understandable by all. The plans are public and accessible, allowing anyone to know the climate adaptation progress in their neighbourhood. Moreover, these documents consider not only public initiatives, mainly focused on street management or public spaces, but also all private initiatives that add value to the community. Green roofs adapted courtyards with green spaces, or plant-covered walls are all elements considered in the plan for which specific funding is allocated.
Furthermore, the plan considers all those measures aimed at raising public awareness of what is happening and how the city's funds are used for the common good. For example, during the development of the Klimakvarter, the entire community in the district was involved in what would happen, and possible solutions were evaluated together through assemblies. Today, the neighbourhood has numerous private initiatives that have expanded onto those implemented by the municipality.

A common action plan is essential for the success and implementation of climate adaptation plans because municipalities alone cannot face this challenge. Most land is usually occupied by private constructions, whether residential or not, which the municipality cannot directly intervene in, but it can establish an action plan that helps guide private owners to make certain choices over others.
For instance, promoting climate adaptation in private buildings through incentives while also raising public awareness of the reasons behind certain choices is proving to be a successful strategy in Copenhagen, a strategy that could also be implemented in Porto.
Overall, Porto's Climate Adaptation Plan has a solid foundation, similar to that of the Danish capital, but currently lacks a more practical guide and a monitoring body that allows initiatives to develop.
Moreover, a primary municipal approach to the issue remains crucial. The occurrence of heavy rainfall is a real problem that can be addressed through the use of permeable solutions. Therefore, it would be appropriate for every modification or work carried out in the municipal territory to consider this perspective, not only providing incentives but also taking the lead in combating climate change.
An aspect that both cities should consider is the creation of consistent initiatives. One of the criticisms levelled at the Copenhagen municipality is that it sometimes encourages the implementation of an excessive number of initiatives, risking incomplete procedures and starting several that are not connected. This is why it is necessary to implement general action plans but also specific ones for different zones, ensuring consistency across initiatives.

4.4. DATA COLLECTION AND DATA ANALYSIS

The analysed data were gathered from various platforms to better understand different aspects of the urban environment. Data were collected to gain insights into the hydrogeological configuration of the territory, the ecological structure, and the land use patterns.Data on expected rainfall exceeding 50 mm were also analysed, including those based on records collected between 1971 and 2000 and on two future emissions scenarios: RCP 4.5 (a scenario with strong mitigation) and RCP 8.5 (a scenario without any mitigation).

4.4.1. RAINFALL DATA

Rainfall data were collected from the *"Portal do Clima"* a project of the AdaPT program in Portugal aimed at promoting climate change adaptation. The portal offers climate data, historical series, and specific regional indicators to educate and raise public awareness. The data come from the IPCC AR5 and include detailed analyses at the NUTS3 level and indicators like the drought index and fire risk. What is known from observing the data in Southern European regions is that, in general, the average precipitation will decrease over time, but the likelihood of high-intensity events will increase. Unfortunately, it is challenging to estimate the probability and magnitude of these events. This document, therefore, considers statistics on rainfall events exceeding 50 mm for two different scenarios.

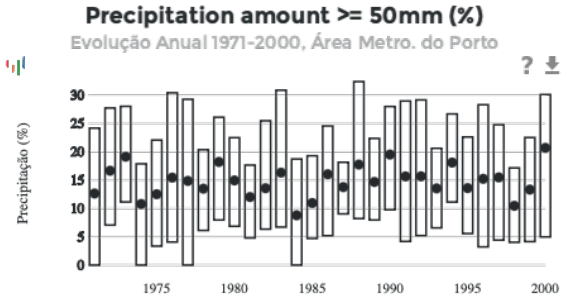


Figure 43: Study of the frequency of annual precipitation exceeding 50 mm between 1971 and 2000 (Source: Portal do Clima, 2024).

First, data on annual precipitation exceeding 50 mm from 1971 to 2000 were collected (Figure 43), which will then be compared with future scenarios to see if there are any differences. The first interval considered is between 2011 and 2040, with both the RCP 4.5 scenario (Figure 44) and the RCP 8.5 scenario (Figure 45).

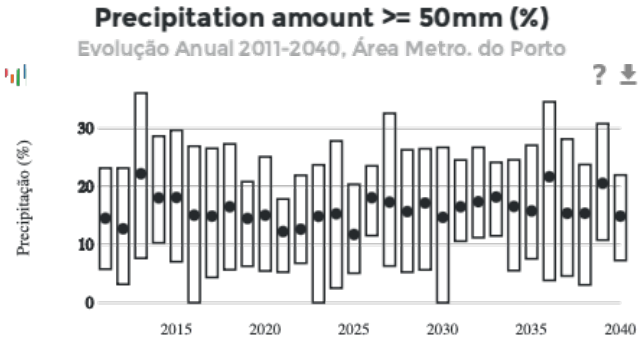


Figure 44: Study of the frequency of annual precipitation exceeding 50 mm between 2011 and 2040, RCP 4.5 scenario (Source: Portal do Clima, 2024).

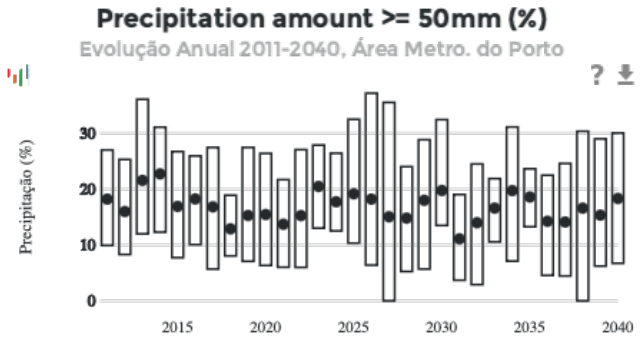


Figure 45: Study of the frequency of annual precipitation exceeding 50 mm between 2011 and 2040, RCP 8.5 scenario (Source: Portal do Clima, 2024).

Subsequently, a second time interval between 2041 and 2070 was considered, analysing the two possible scenarios as before (Figure 46, Figure 47).

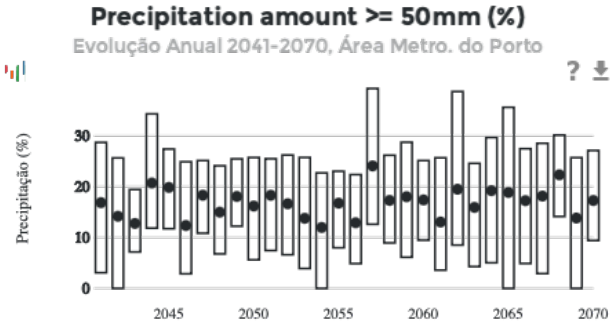


Figure 46: Study of the frequency of annual precipitation exceeding 50 mm between 2041 and 2070, RCP 4.5 scenario (Source: Portal do Clima, 2024)

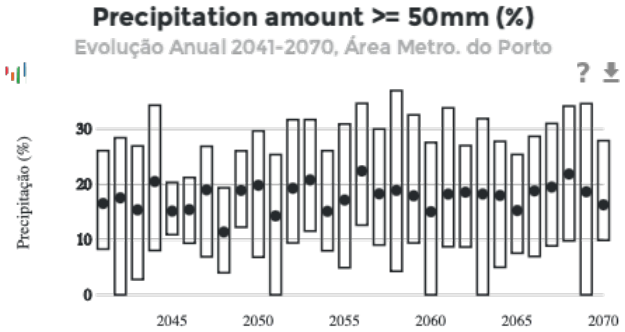


Figure 47: Study of the frequency of annual precipitation exceeding 50 mm between 2041 and 2070, RCP 8.5 scenario (Source: Portal do Clima, 2024).

Finally, the two possible scenarios with the time interval between 2071 and 2100 are analysed (Figure 48, Figure 49).

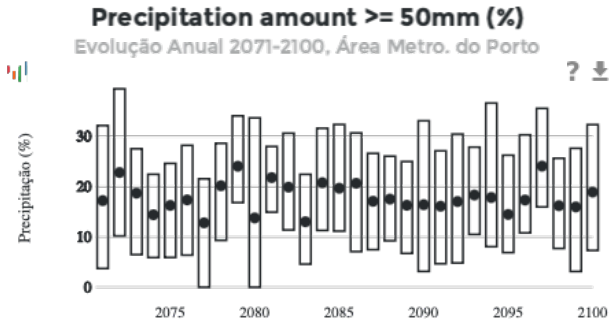


Figure 48: Study of the frequency of annual precipitation exceeding 50 mm between 2071 and 2100, RCP 4.5 scenario (Source: Portal do Clima, 2024).

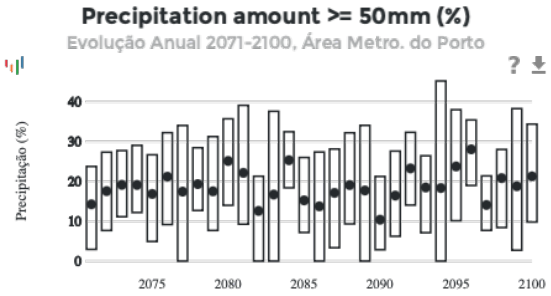


Figure 49: Study of the frequency of annual precipitation exceeding 50 mm between 2071 and 2100, RCP 8.5 scenario (Source: Portal do Clima, 2024).

These data intervals are typically the ones considered in climate adaptation plans to establish subsequent measures to be adopted.

We can observe that, in the case of the RCP 8.5 scenario, which considers the hypothesis of a continued high release of CO2 into the atmosphere without mitigation measures, the frequency of rainfall exceeding 50 mm will increase over the years. This aligns with the scenario predicted in the IPCC report, suggesting an increase in extreme rainfall events in both northern and southern Europe.

4.4.2. DATA ON HYDROGEOLOGICAL CONFIGURATION

Subsequently, some data regarding the hydrogeological configuration of the territory were analysed. This parameter is important for understanding whether a given area is highly permeable or not. The permeability of the ground is a crucial factor when considering suitable measures for a particular location and identifying potential issues with water absorption.

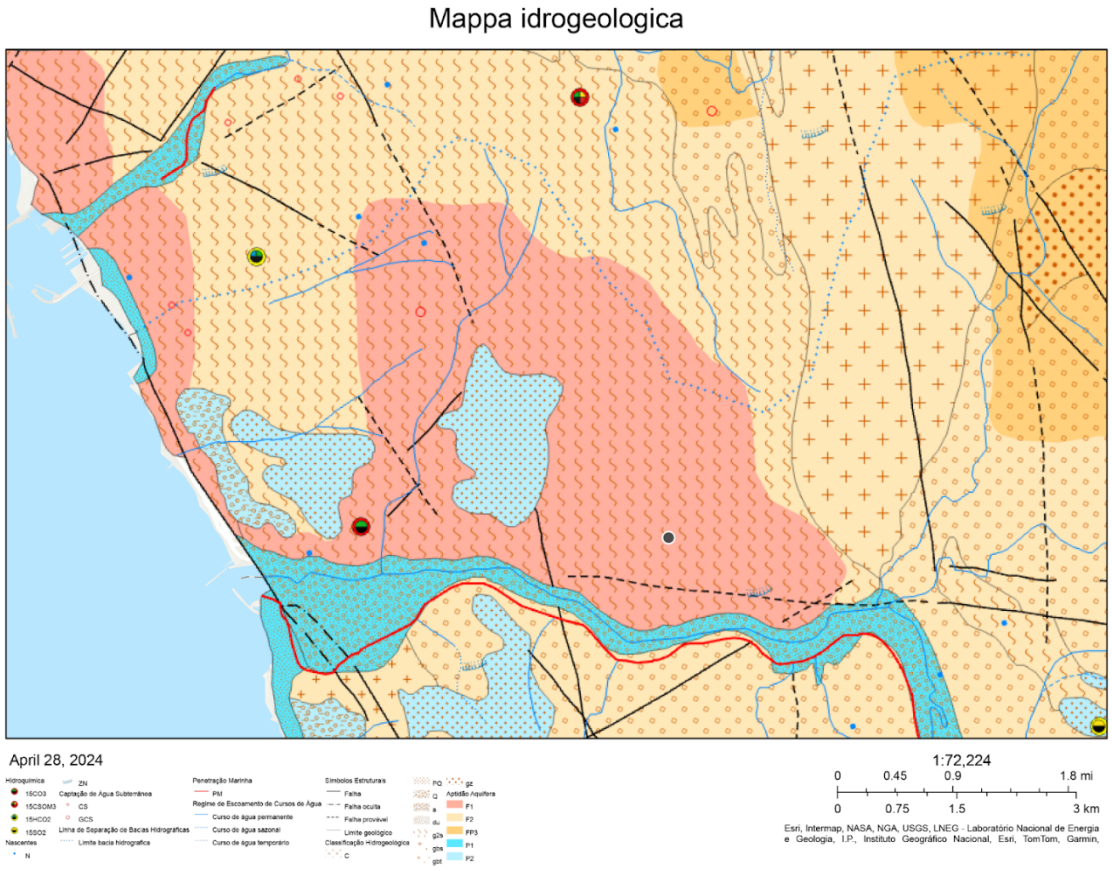


Figure 50: Hydrogeological configuration map (Source: geoportale.lneg.pt.,2024)

Through Portugal's Geoportal, you can observe the geophysical configuration of the soil. Most of the territory consists of fractured granite (g2s) with medium to low permeability (F1 and F2). This characteristic can also be observed in the soil permeability potential map (Figure 50), which allows for a more detailed analysis, identifying variations in permeability along the watercourses where the permeability tends to be higher.

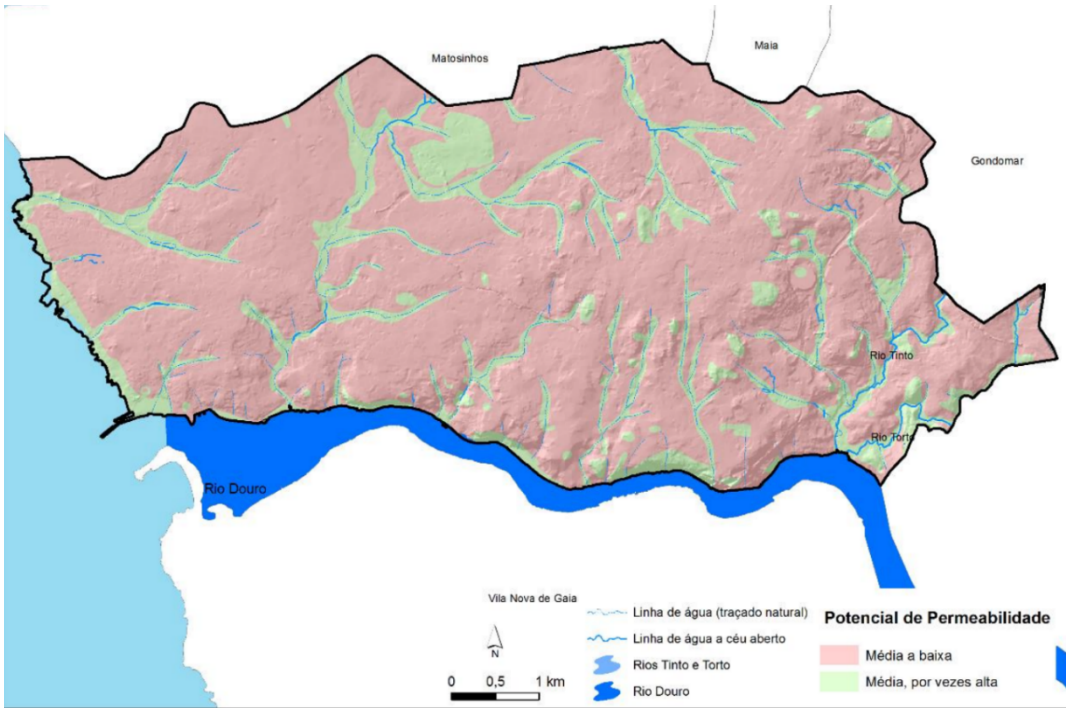


Figure 51: Permeability potential map (Source: PDM Porto, 2018)

The presence of waterways in the territory is quite high, as shown in Figure 51, but it is also true that much of their length is below the surface, channelled into underground conduits during the city's construction for sanitary reasons. Today, however, this represents a loss of permeable surface, leading to difficult water absorption in certain areas.

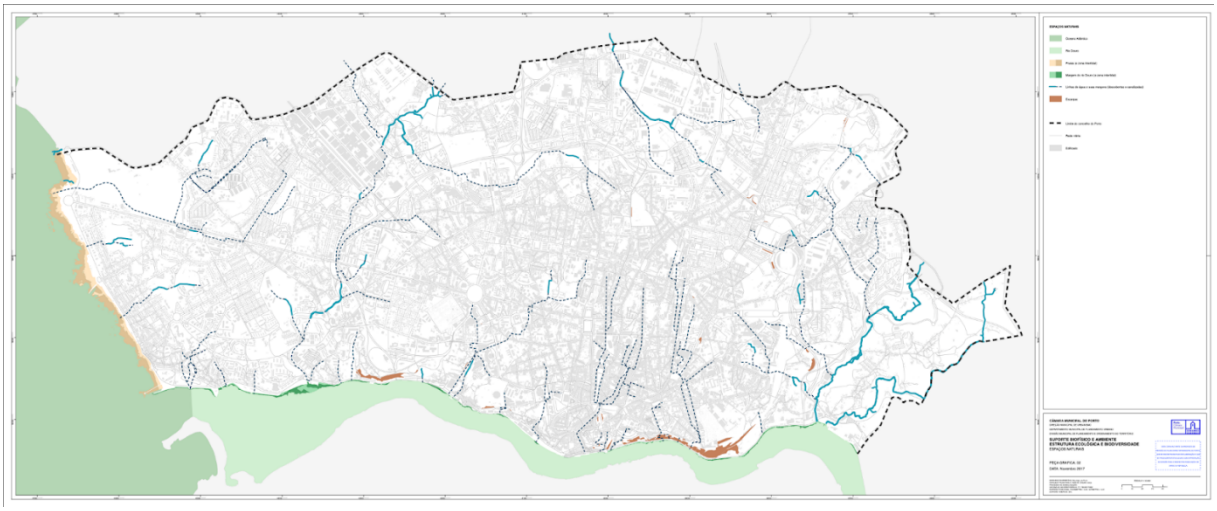


Figure 52: River and streams map (Source: PDM Porto, 2017).

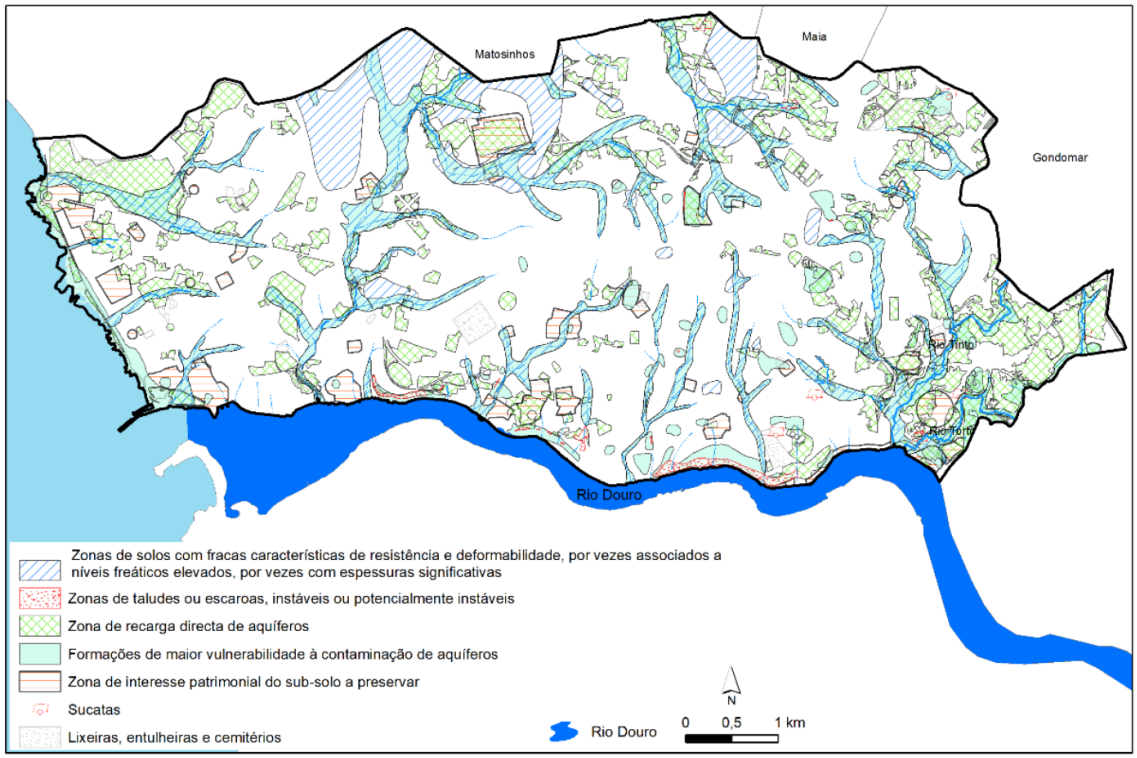


Figure 53: River and streams map (Source: PDM Porto, 2017).

The total floodplain area around these waterways, shown in Figure 53, has also been studied.
Floodplains are low-lying areas along rivers that naturally oscillate between periods of high and low water. These unique ecosystems are crucial because they provide natural resources and act as barriers against flooding, thanks to their high capacity to absorb and retain water, serving as a preventive measure against floods (irks.org).
In this context, it is possibile see from the map showing flood-prone areas that they are located along sections of open rivers, a mechanism that aids in managing and reabsorbing rainwater (Figure 54).

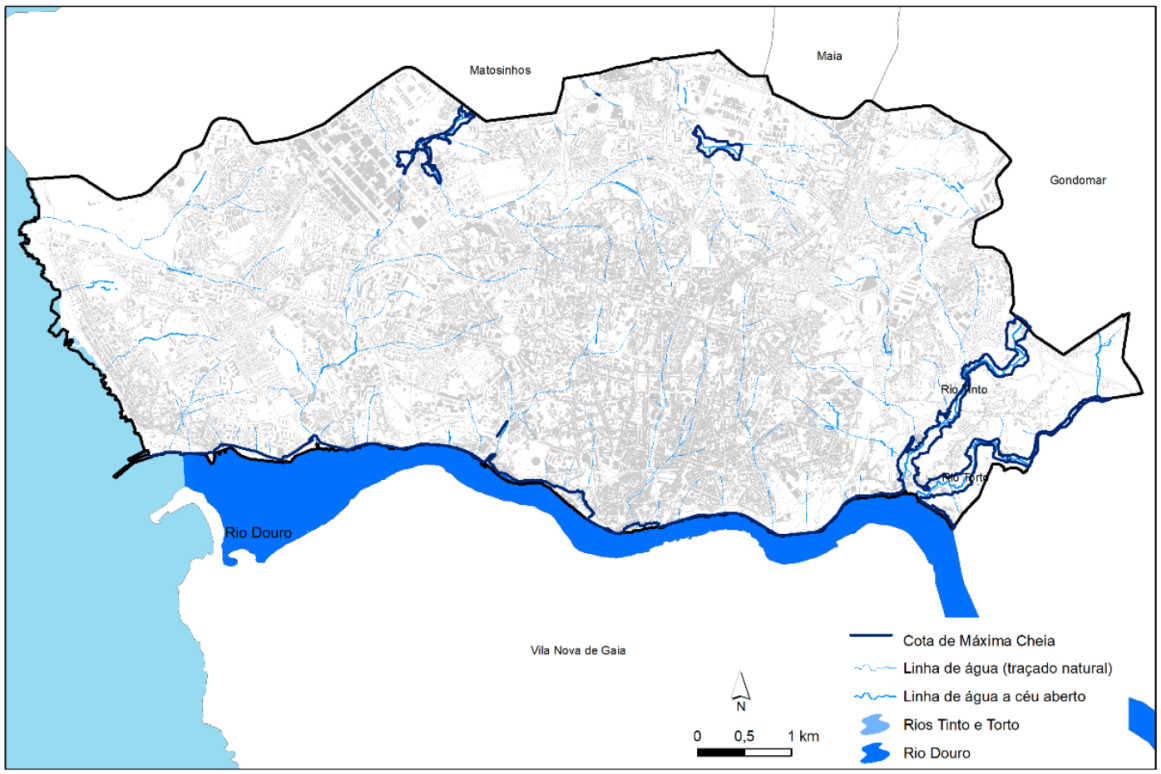


Figure 54: Flood-prone areas map (Source: PDM Porto, 2018).

4.4.3 DATA ON URBAN CONFIGURATION

At this point, it is equally important to study the urban configuration of the city to better understand how different areas might react differently to large amounts of water. The first map to analyse is the one depicting land use (Figure 47).

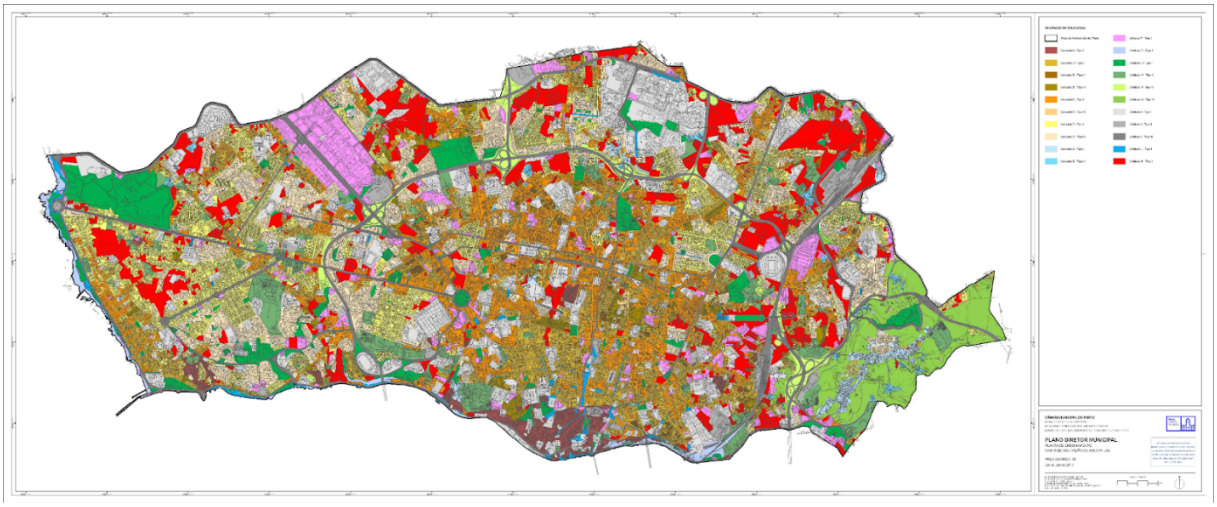


Figure 55: Land use map (Source: PDM Porto, 2017).

The first thing to notice is the presence and fragmentation of green areas, which are found only in certain parts of the city and are less frequent in the central or historic areas. The map also indicates the different land uses, such as building diversity, public and private zones, connections, infrastructure, and roads. Next, a more detailed examination of the existing green areas was conducted, considering their quality, species richness, and type.



Figure 56: Green spaces in the city of Porto map (Source: PDM Porto, 2017).

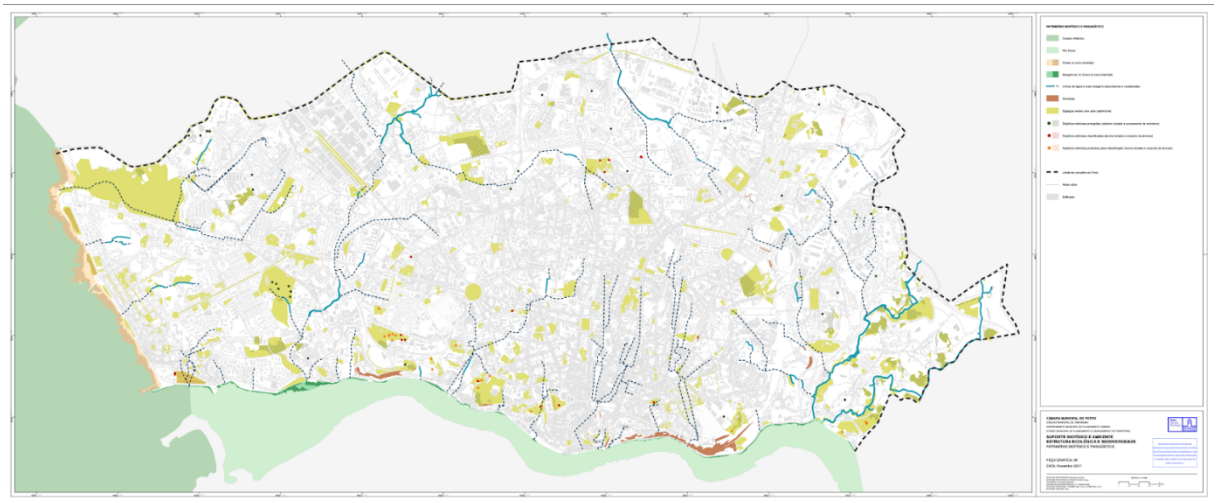


Figure 57: Heritage sites and waterways map (Source: PDM Porto, 2017).

Figures 56 and 57 provide an overview of the green spaces without a more specific classification. It is evident that the distribution of these entities is more concentrated in specific areas of the city, with a notable decrease in density in the central region. It is frequently the case that green spaces are associated with the presence of waterways, particularly in areas where the waterways are open.

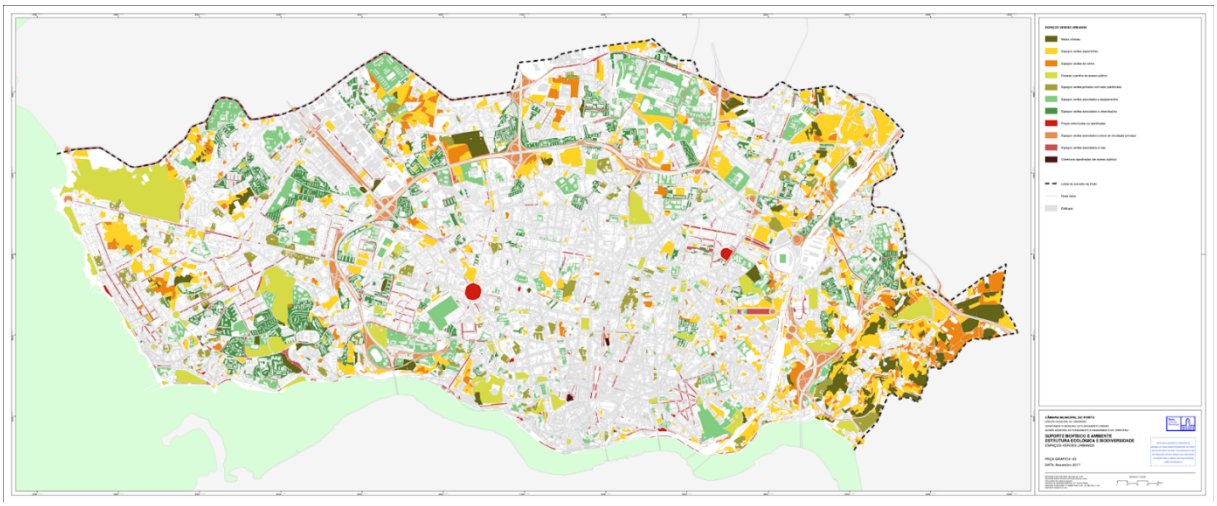


Figure 58: Green space types map (Source: PDM Porto, 2017).

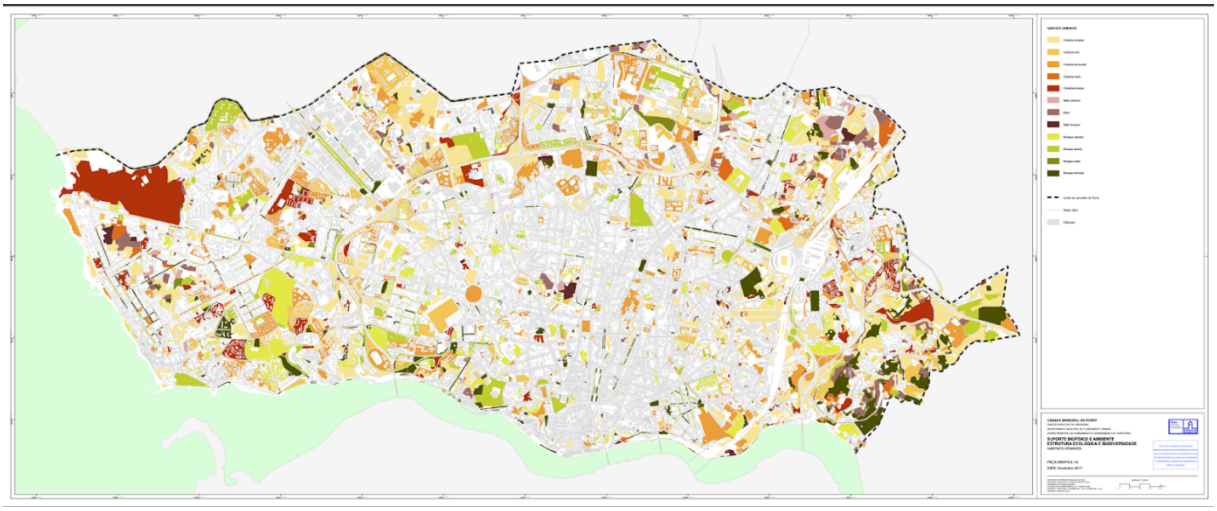


Figure 59: Vegetation types map (Source: PDM Porto, 2017).

Figures 58 and 59 provide further breakdowns on the quality and type of urban green spaces. Figure 58 presents a classification of urban spaces based on their typology, which includes:

- Urban Forests;
- Green Spaces in Waiting: undeveloped or partially developed spaces that have been abandoned and colonised by spontaneous vegetation;
- Cultivation Green Spaces;
- Public Access Parks or Gardens;
- Private Green Spaces with Heritage Value;
- Associated Green Spaces (schools, universities, hospitals, etc.);
- Green Spaces associated with residential developments (residential complexes with public green access);

- Tree-lined Squares: with impermeability over 65%;
- Green Spaces along Transportation Routes (railways, highways, etc.);
- Green Spaces along local traffic roads;
- Public Green Roofs.

This classification can be very useful; the type of green space is crucial to understand whether it's possible to make improvements to the area's soil absorption capacity. A mixed flower bed with herbaceous plants and shrubs will absorb more water than simple grass, and a tree-covered area will absorb more than a mixed flower bed.

Figure 59 illustrates a further subdivision based on the diversity of green cover, whether it is more shrub-like or has tree cover. This classification may also prove useful in facilitating a more nuanced understanding of the city's terrain, which could in turn inform strategies for enhancing water absorption potential. The classification is divided as follows:

- Simple Glade: Tree/shrub cover ≤ 25%;
- Glade-Border: Tree/shrub cover between 26% and 50%, with linear plant positions;
- Glade-Dotted: Tree/shrub cover between 26% and 50%, with dotted plant positions;
- Shrub-Glade: Spaces with tree/shrub cover between 26% and 50%, mainly shrubs;
- Glade-Forest: Open spaces with tree/shrub cover between 26% and 50%;
- Shrub-Forest: Spaces dominated by shrub vegetation with tree/shrub cover between 51% and 75%, interspersed with grass zones;
- Patchy-Forest: Spaces dominated by tree/shrub vegetation with patchy cover between 51% and 75%;
- Open-Forest: Spaces dominated by tree vegetation with cover percentage between 51% and 75%;
- Dense Forest: Spaces dominated by tree vegetation with cover between 76% and 100%.

As can be seen from both maps, areas with tree cover are fewer compared to other types of urban greenery. In Figure 50, there is a high percentage of green areas belonging to the "green spaces in waiting" type or associated green spaces, both public and in residential complexes. This pattern is also observed in Figure 51, where there are few green spaces with a high quantity of tree cover or a significant presence of mixed trees and shrubs.

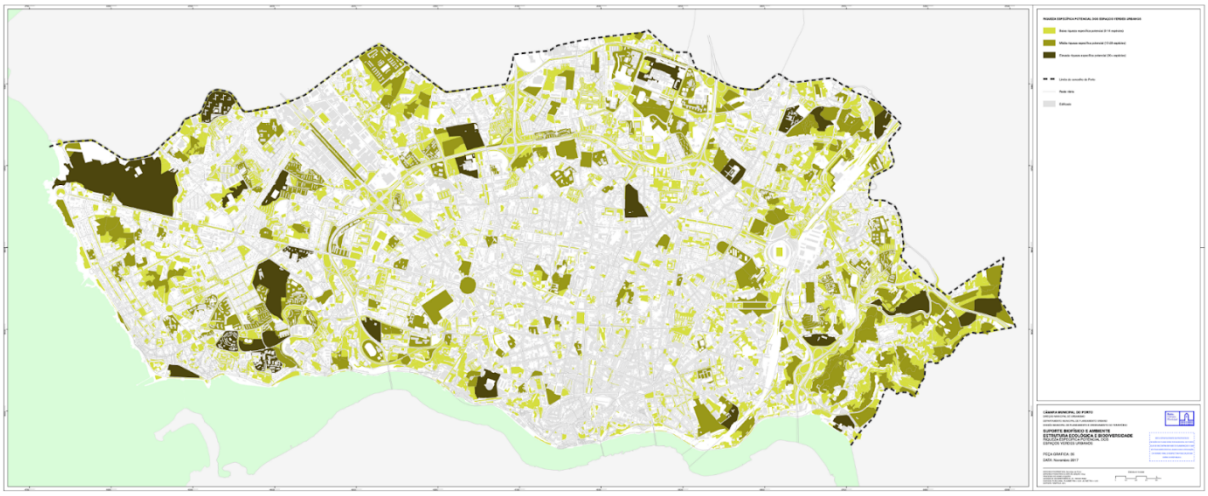


Figure 60: Species richness classification map (Source: PDM Porto, 2017).

An additional analysis is provided in Figure 60, which divides green spaces according to the number of species present. Light green represents areas with 0 to 14 species, intermediate green for those with 15 to 29 species, and dark green for spaces with over 30 species. The variety of species can also influence the soil's water absorption capacity, making it a feature worth considering.

Lastly, some maps are designed to show where the most significant flooding and inundation events have been reported in the city, another critical element that, when correlated with the land use map, helps to better understand how certain types of terrain might impact rainwater absorption. The first map is about the city's flood susceptibility, with zones ranging from yellow to red indicating areas with the highest likelihood of flooding (Figure 61).

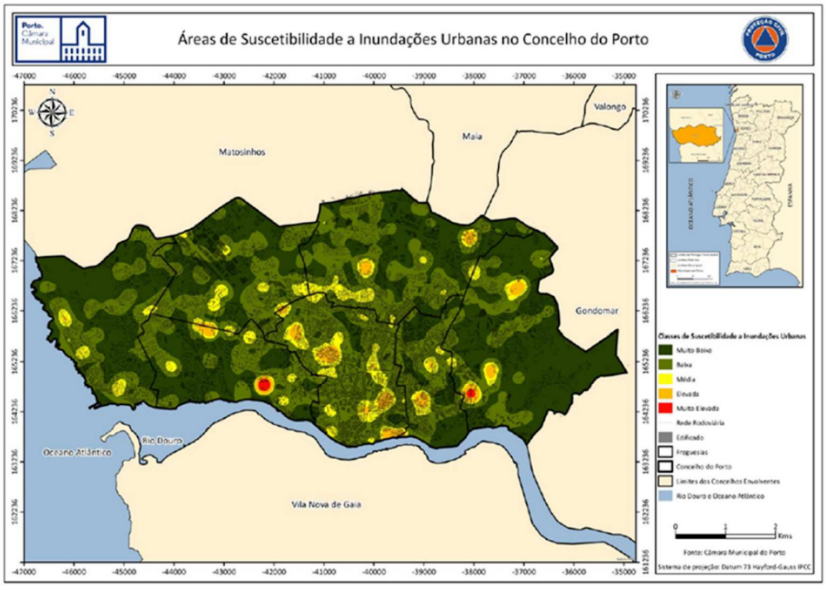


Figure 61: Urban flood susceptibility areas map (Porto Municipal Council, 2015)

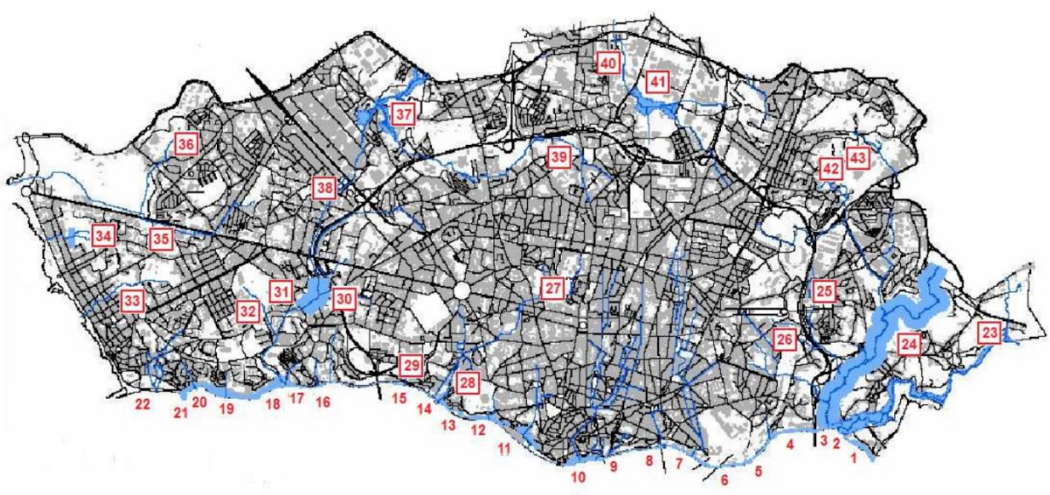


Figure 62: Identification of premises at risk of flooding (Porto Municipal Council, 2011)

The first map is about the city's flood susceptibility, with zones ranging from yellow to red indicating the areas with the highest likelihood of flooding (Figure 61). There are also two other related maps: one showing the identification of premises at higher risk of flooding (Figure 62), and another with the frequency of urban flooding in the city between 1974 and 2014 (Figure 63). It will certainly be interesting to correlate these maps to see if there is a connection between the type of land use, the presence of green areas, and the likelihood of flooding. Although the data set is incomplete, lacking both the frequency of these events and information on all areas where flooding may have occurred but were not reported, these maps were used to gain insight into the general distribution of these situations.

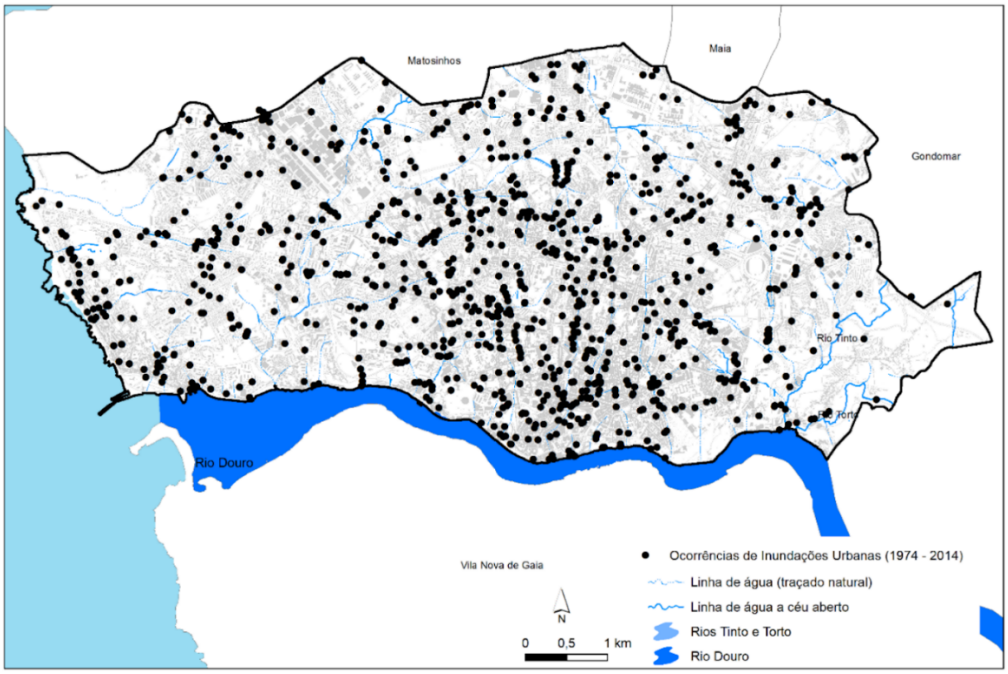


Figure 63: Frequency of urban floods between 1974 and 2014 (Source: PDM Porto, 2018).

4.5. STUDY OF URBAN FLOODING

To gain a clearer understanding of the possible causes of urban flooding in the city of Porto, the maps concerning land use, degree of permeability, and vegetation characteristics were overlaid with the map showing the frequency of urban floods, using QGIS and Photoshop software.

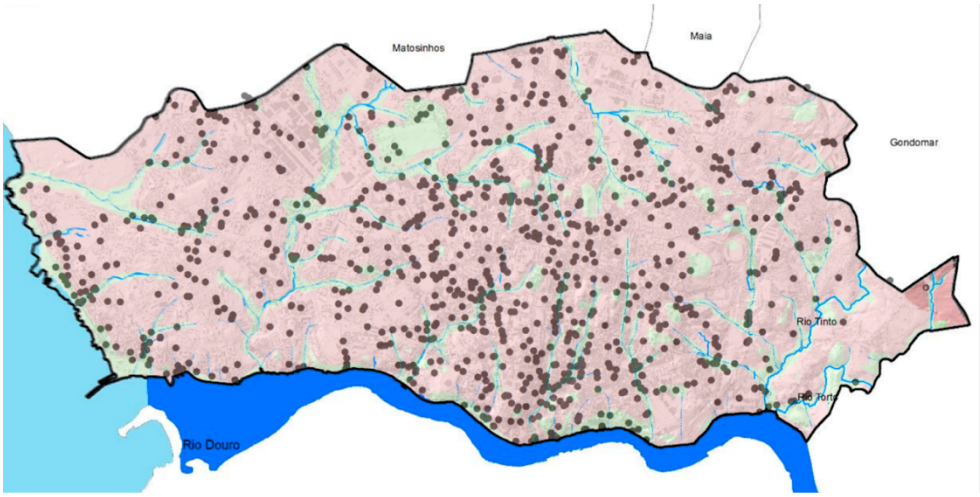


Figure 64: Frequency of urban floods and soil permeability map (Source: Personal elaboration)

Through this overlay, we can infer that many of the flooding events in recent years have occurred near the floodplain areas of rivers, where the soil is usually more permeable and capable of absorbing more water. One possible reason might be the impermeability of the ground in locations where, due to the natural morphology of the territory, water accumulation is more likely to occur.

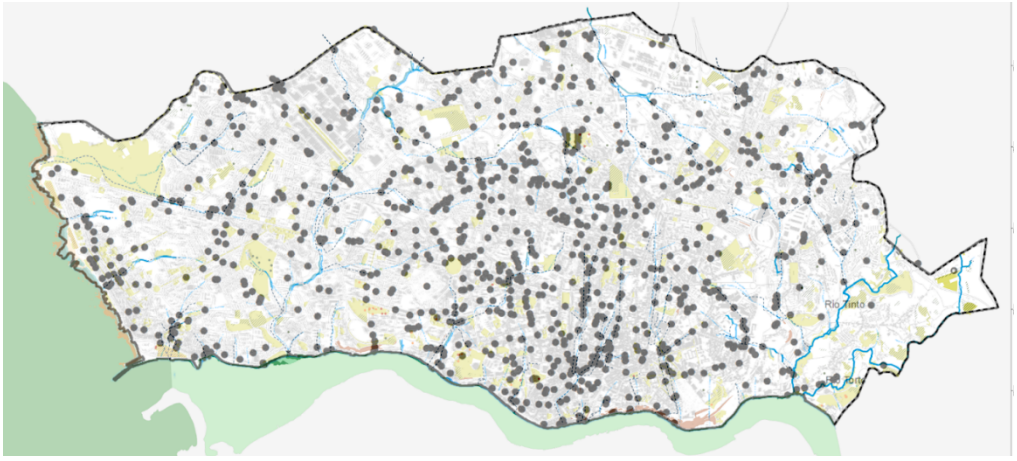


Figure 65: Frequency of urban floods and presence of waterways map (Source: Personal elaboration)

Through Figure 65, we have additional confirmation of what was established in the previous map. Additionally, it becomes apparent that these events are more frequent where waterways have been buried compared to where they are open.



Figure 66: Frequency of urban floods and land use map (Source: Personal elaboration)

Another interesting analysis is to correlate land uses to see if there's any connection. In this case, you can notice that most floods occur near the historic centre, particularly in the vicinity of those areas designated as *Unidade C* of *Type 1*, which are expansion zones characterised by a closed or semi-closed block structure with a clear separation between private and public spaces.

By making a quick comparison using Google Maps, you can observe that these housing units typically have a central private space with little or no green areas.

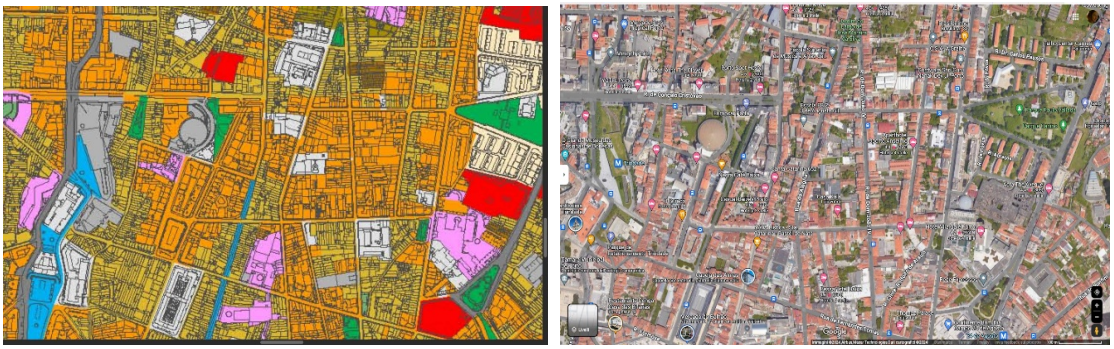


Figure 67: Example of comparison between land use map and Google Maps satellite image (Source: Personal elaboration)

You can also notice a high incidence of flooding along major thoroughfares where there are many impermeable surfaces.

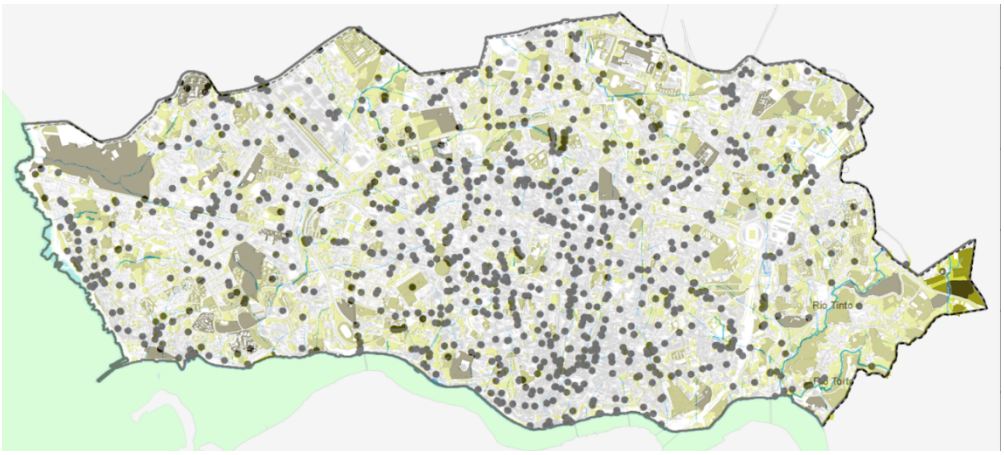


Figure 68: Frequency of urban floods and species diversity map (Source: Personal elaboration).

Finally, it's important to analyse the correlation between floods and the presence of urban greenery. Once again, we can see that the incidence of floods is higher in the city centre and historical areas, where there are fewer green spaces, both public and private. In terms of species diversity and ecological complexity, these factors might also play a role in flood risk. Indeed, where there are green spaces with a higher number of species, there's generally a lower occurrence of flooding. It's also true that a higher number of species are typically found in larger green spaces, which might lead to greater soil infiltration.

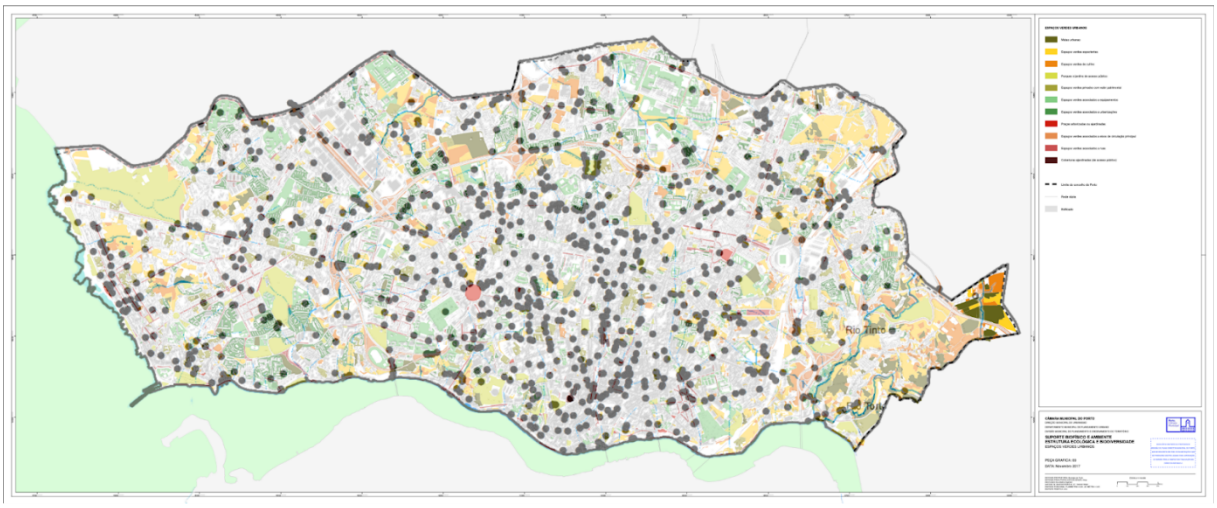


Figure 69: Frequency of urban floods and types of green areas (Source: Personal elaboration)

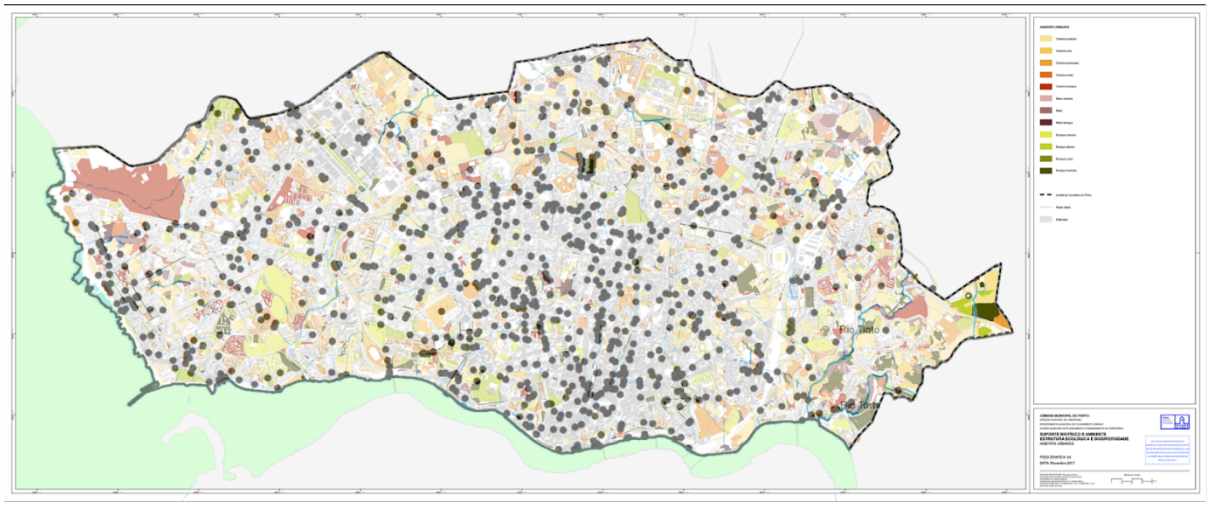


Figure 70: Frequency of urban floods and types of vegetation map (Source: Personal elaboration)

A comparison of the flood map with those indicating the types of vegetation or green areas reveals no straightforward correlation. However, it can be observed that in areas with a greater proportion of green space and a higher level of vegetation diversity, the incidence of flooding tends to be lower. Nevertheless, the central city and specific locations along the primary thoroughfares consistently demonstrate a higher frequency of flooding.

4.6 SYNTHESIS

Based on the data collected, several conclusions can be drawn. According to the rainfall data, it's clear that precipitation will decrease in frequency in the coming years, but extreme events with rainfalls exceeding

50 mm will increase. This increase in extreme precipitation will exacerbate issues related to surface runoff and cause more frequent flooding in parts of the city that already experience these problems. It is also important to think of solutions that not only prevent flooding but also allow for water collection and storage for use during dry periods, rather than letting it go to waste. Therefore, it's crucial to develop possible solutions to increase the soil's infiltration capacity. The most critical points are within the central part of Porto, a problem caused by the underground channelling of rivers, which results in the loss of floodplain areas, and the limited presence of greenery along streets or within housing units that are closed or semi-closed. These two factors exacerbate the challenges of absorbing rainwater. Another challenging element is the major roads, where impermeable surfaces are abundant, and there is a lack of trees or roadside greenery capable of absorbing large volumes of water. This leads to slower water absorption.

This text will present and propose various solutions observed in the city of Copenhagen to enhance soil permeability in different circumstances, taking into account the unique characteristics of the location. The use of permeable pavements and the implementation of green areas, with the potential for rain gardens or rainwater collection basins, could be feasible solutions for both public and private sectors, increasing the city's absorptive capacity. It is crucial to develop solutions that are practical and not overly costly but also improve the urban environment and the quality of life for residents.

5

ANALYSES OF RIBEIRA DA GRANJA

5.1 CASE STUDY

After becoming familiar with the main issues caused by climate change through the reading of the Climate Adaptation Plan, the search began for areas most affected by the aforementioned events, with particular attention to flooding due to heavy rains.

Several meetings were held on this topic with some representatives from the municipal company *Águas e Energia do Porto*, during which we analysed where these issues were most prevalent and where it would be best to investigate possible solutions. Two main and adjacent areas were identified for this purpose: one area that we will call *Carvalhido* and another associated with one of Porto's historic gardens, the *Jardim Arca D'Água*. Both areas are under the influence of the *Ribeira da Granja* stream, one of the main and largest waterways that cross the city.

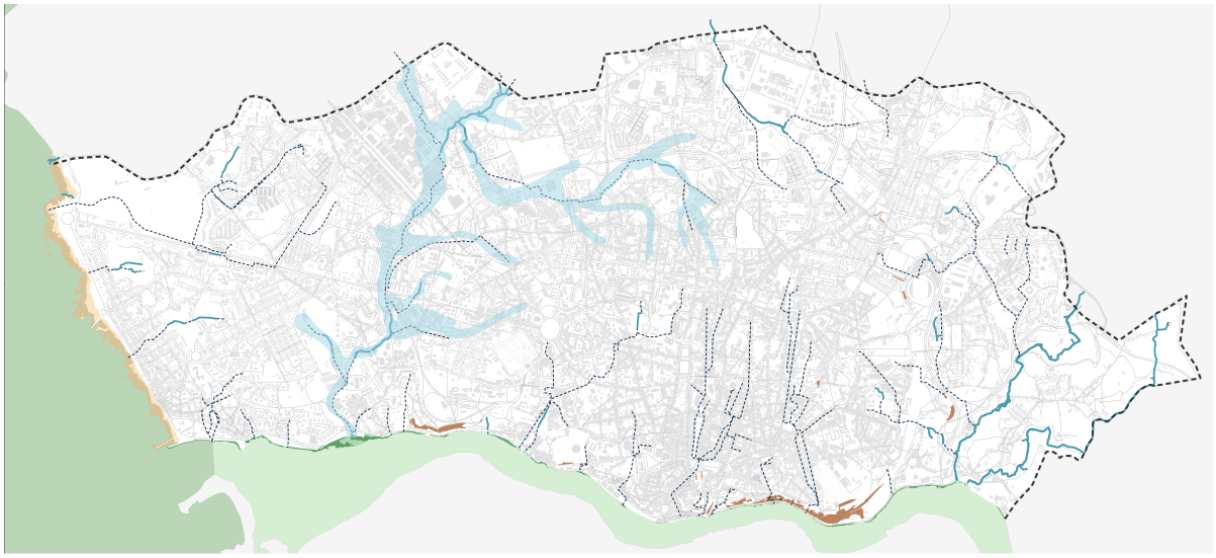


Figure 71: Ribeira da Granja map (Source: Personal elaboration)

Along the course of the river, we can find several challenging situations related to rainwater management due to various issues. The first is directly related to the size of the watercourse, which collects rainwater from the entire area and also transports some of the water collected in the nearby municipality of *Matosinhos* into the city. This causes a significant accumulation of water along the river during heavy rainfall events. This surface water accumulation is also due to the fact that the river flows underground for most of its journey, buried inside pipes that are no longer large enough compared to the period when they

were installed. The Ri*beira da Granja* stream represents an interesting and emblematic case for the city. Besides touching various parts of the urban fabric, it could play an important role in the city's adaptation to climate change. Some changes have been made to an uncovered portion of the stream in the *Ramalde* area, where, through the use of an open green space, an attempt was made to reconstruct the humid habitat, which is certainly more suitable for reacting to climate change. However, this intervention has not entirely achieved the desired effect because, although it helps in managing precipitation, too much rainwater still ends up in the river, which often does not have enough space within the pipes. Some of the areas most affected by this situation are the two zones investigated in this text: *Carvalhido* and *Jardim Arca D'Água.*

5.1.1 CARVALHIDO AND JARDIM ARCA DÁGUA. TWO STUDY AREA

The two areas are located in the northern part of the city, as can be seen in Figure 64, and are adjacent to each other.



Figure 72: Location of the Study Areas Map (Source: Personal Elaboration).

The two areas specifically consist of the streets *R. de Nove de Abril, R. de São Dinis, R. de Silva Porto*, and the two streets that cross the block *R. Nova do Regado* and *Tv. da Bica Velha* in the *Carvalhido* area. In *the Jardim Arca D'Água* area, the streets include *R. Delfim Maia, Praça de 9 de Abril* with the *Arca D'Água* gardens*, R. de Vale Formoso, R. do Campo Lindo, and R. de Costa e Almeida*. These two areas are better represented in the following map (Figure 73).



Figure 73: Identification of the Study Areas (Source: Personal Elaboration)

The depicted areas have been studied, and various issues have been taken into consideration to better understand which of these may be connected to the presence of flooding.



Figure 74: Overlay of the Two Areas with the Ribeira da Granja Stream (Source: Personal Elaboration).

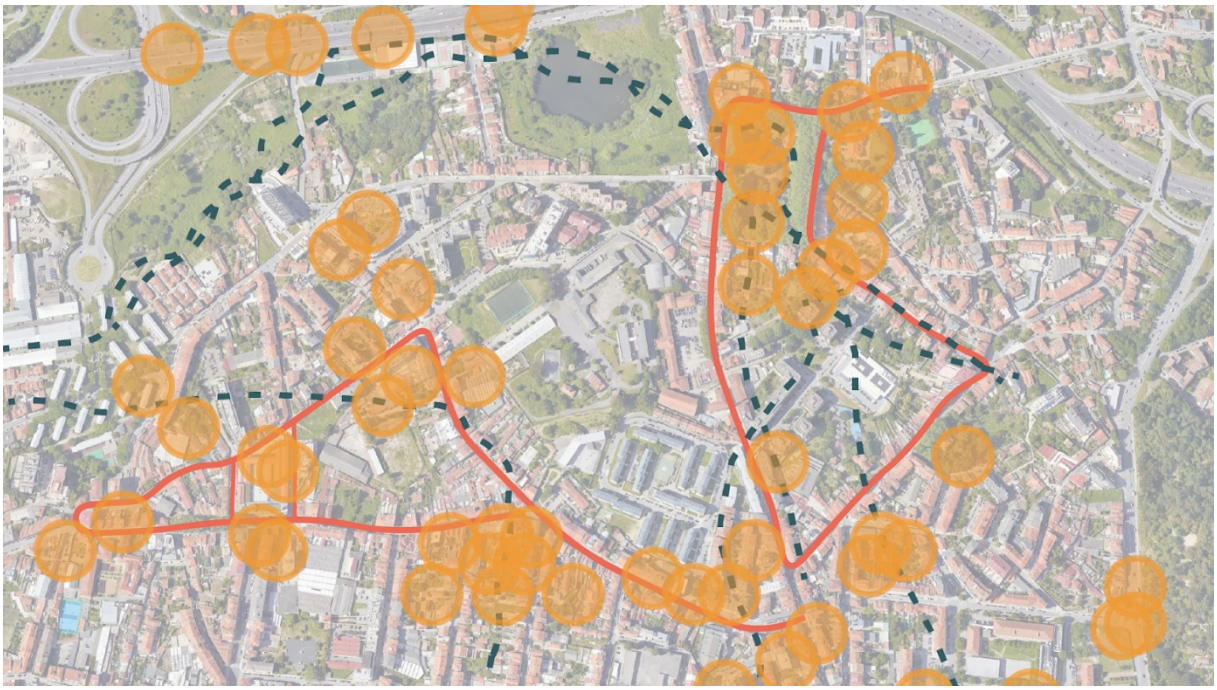


Figure 75: Overlay with Flooded Areas (Source: Personal Elaboration).

The represented areas have been studied, considering various issues to better understand which of these may be connected to the presence of flooding. Overlaying the map of the areas, first, with the position of the branches of the Ribeira da Granja stream and then, with the map containing the locations of floods recorded between 1974 and 2014 allows for an understanding of where water accumulation issues are most prevalent.

Regarding the *Carvalhido* area, they do not seem particularly linked to the river's position and could therefore be more attributed to urban planning factors, such as the terrain's conformation and how streets were designed. However, focusing more on the *Jardim Arca D'Água* area, it can be noted that some of the floods do indeed have a correlation with underground watercourses, focusing more around the garden itself. The garden is interesting because beneath it lies one of Porto's richest springs, a source that connected the city centre up to *Praça dos Leões* and provided drinking water along the way (agenda-porto.pt).

Following these considerations, the territory was subsequently studied using software such as Google Street View to aid in understanding the terrain itself and where it would be preferable to act.

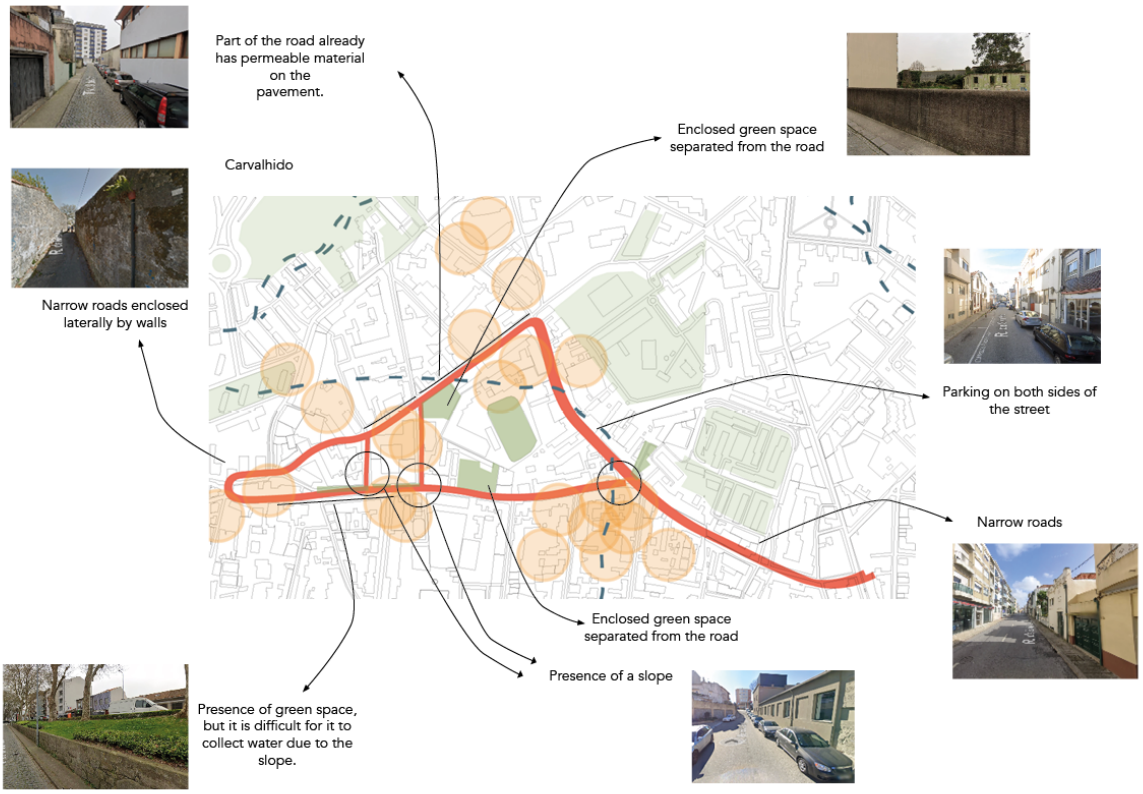


Figure 76: Carvalhido Map and Identified Main Issues (Source: Personal Elaboration).

For the *Carvalhido* area, several issues have been identified, especially concerning the terrain's conformation and the streets themselves. Regarding *Rua 9 de Abril*, it develops as a narrow street, especially in the section that measures just 1.5 metres wide. Partly positive is that the pavement of the roadway is already made of cobblestones, making it permeable. However, there are no other green spaces. Along the road, there is one, currently abandoned but privately owned and thus closed behind a wall. The rest of the street has sidewalks, sometimes on both sides, sometimes on only one, but they are usually small and therefore difficult to traverse. There is a significant presence of parked vehicles, both regular and irregular, and in general, a high presence of motor vehicles. Additionally, due to a slope resulting in various inclines, water accumulation in this initial stretch, where it intersects with *R. Nova do Regado* and *Tv. da Bica Velha*, could be a consideration.

Continuing along *Rua de São Dinis*, a similar situation is encountered, except that in this case, the road surface is only asphalt. Sidewalks are also present, often on both sides, but of small dimensions and almost always with a row of parked cars nearby. Green areas are also absent along this street, except for the first stretch that separates *Rua de São Dinis* from *Rua 9 de Abril*, where there are some green areas with a steep slope towards *Rua 9 de Abril*. However, this green area is disconnected from the road and cannot collect rainwater runoff.

As for *R. de Silva Porto* and the two cross streets *R. Nova do Regado* and *Tv. da Bica Velha*, the situation can be compared. The streets are narrow here as well, with little pedestrian space and no green space.

Only *Tv. da Bica Velha* is made using cobblestones, making it more permeable. From the analysis of this block, it can be understood that one of the main issues in this specific case is the lack of space. The roadways are narrow, and in some cases, the two-way traffic for cars utilises all available space, leaving little for pedestrians. The almost total absence of greenery prevents the creation of a more harmonious and pleasant environment to walk through, leading to the increased preference for using cars as a means of transportation, exacerbating the issues. With the almost total absence of greenery and few permeable surfaces, all water collected from the streets is channelled into the city's water network and consequently into the *Ribeira da Granja* stream.



Figure 77: Jardim Arca D'Água Map and Identified Main Issues (Source: Personal Elaboration).

For the *Jardim Arca D'Água* block, the urban fabric and various street characteristics have also been analysed to better understand how the issue of flooding may manifest in this case. As can be seen from Figure 59, most of the floods are indeed located around the garden structure itself.
Jardim Arca D'Água is a garden inaugurated in 1928 by Jerome Monteiro da Costa. The name refers to the fact that beneath it lies one of Porto's largest water reserves, which for a long time served much of the city by providing drinking water. Like other green areas, the garden is separated from the street by a level difference due to the sidewalk. Furthermore, it is partly covered by impermeable surfaces. The green areas, except those near the central part with the small pond, are flat and lack plant diversity. Partially, the streets around the garden are made of permeable material, but there is still a strong presence of cars and parking.

As for the rest of the streets recognized within this second block, their situation resembles those of the previous block. They are narrow, with little pedestrian space and an absence of greenery along the entire route. All surfaces are composed of asphalt. However, there is an interesting presence of some intersections that allow for a wider space, currently made only of impermeable materials.
In this case, the conditions of the block differ somewhat from those of the previous ones. While it is true that the streets face similar issues regarding space and the presence of many permeable surfaces, in this case, there is a large green space that nonetheless presents some challenges.

5.1.2 STUDYING THE ISSUES AND POTENTIAL SOLUTIONS

After studying the areas, it is possible to better understand the existing issues. One of the main ones that can be found in both blocks is the presence of narrow streets. The roadway for cars often allows only for two-way traffic, sometimes wider but with parked cars, sometimes in designated parking spots and sometimes illegally, on both sides of the street. Pedestrian space is limited, sidewalks are narrow to the point that only one person can walk on them at a time. Additionally, there are no green spaces or rest areas along the streets. The absence of green spaces or trees can be considered a problem not only related to the absorption of rainwater but also because they help create a more comfortable urban environment, especially during the summer months. Indeed, on hotter days, temperatures along these streets can rise even more due to the presence of a lot of asphalt and the almost total absence of shade, especially in the central hours of the day.
These two problems, namely the lack of pedestrian space and the presence of many cars, not only contribute to the creation of a hostile urban environment but also hinder possible changes in these areas to transform them into an environment more suited to climate change. For a more substantial modification of the spaces, it would be necessary to reconsider the road layout, transforming the narrower streets from two-way to one-way and trying to leave more space for pedestrians and greenery, as well as promoting public or sustainable transportation modes, in order to create an environment that is more suitable for the life of citizens. In this way, the number of cars would also decrease in the area, leading to less need for available parking spaces.
For this reason, regarding interventions aimed at the roads in both blocks, two options have been considered: an ideal one, but difficult to implement at this time because car dependency is still too strong in the area, and an intermediate one, where some changes are made to the streets but the basic structure remains mostly the same.

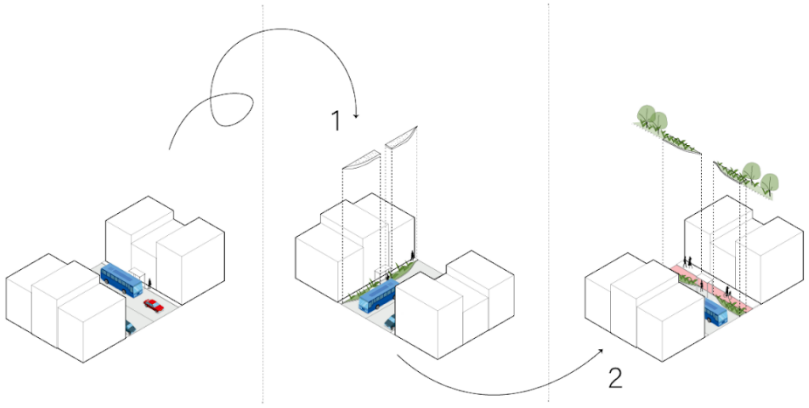


Figure 78: Urban Composition Modification Diagram (Source: Personal elaboration)

The easiest and most feasible solutions to increase permeable surface area in cases where space is limited involve modifying the materials used for road construction. This includes preferring permeable asphalt or, when possible, using even more permeable solutions such as pervious concrete or reinforced grass grids, especially in parking spaces. In some sections of the road, as explained in the previous chapter, there are already some areas built with permeable materials that could be further implemented. This is because, during heavy rainfall, permeable material alone often does not allow water to be absorbed quickly enough, making it important to channel excess water and direct it to appropriate areas.

The best solution found, also in consultation with *Águas e Energia do Porto*, is the implementation of rain gardens. These can be constructed in narrower spaces along the streets and therefore do not require a lot of space. Additionally, due to their design, they can accumulate enough water inside, allowing time to be absorbed by the soil or to evaporate without causing damage to infrastructure. The modification could be carried out in two different phases. As shown in the diagram in Figure 60, the increase in rain gardens along the road could be gradual, adapting to the needs of the resident citizens. Currently, on both sides, there is often a long line of parked cars. In the first phase of rain garden proposals, they are inserted only at some strategic points, such as before and after bus stops or before and after a long row of parking spaces. In *Rua de São Dinis*, some of these structures have already been planned, and work will begin soon. In this case, it would be possible to try to create a "permeable strip" initially composed of rain gardens and parking spaces for cars made with grass grids, where possible, and then gradually develop it into a long green strip that accompanies pedestrians along the road. Water collected from the roadway can be directed into them, thus avoiding it from entering the water network of *Ribeira da Granja*. Additionally, the green strip would have a positive aspect for citizens and pedestrians, protecting and separating them from the road, creating a more comfortable environment for walking. This is a fairly general solution that could be adopted in both blocks on almost all streets.

In the case of particularly narrow streets or streets with only one row of parking on each side, the solutions to be adopted may involve modifications. In the case of a single row of parking, the solution of implementing the green strip along that side could be the answer, perhaps stopping at phase 1, or alternating parking areas with rain garden areas, so that some parking spaces remain available. In the case

of even narrower streets, the solution could still be to implement permeable surfaces and, in the pedestrian area, to implement solutions such as the climate Tile, a tile capable of storing water inside and gradually releasing it into the soil once the meteorological event has ended. The climate Tile is a solution specifically designed for situations where there is not enough space to implement green areas and is also fully customizable, so a solution more in line with the aesthetic of the location can be sought.
Another issue, especially noticeable in the *Carvalhido* block, is the slopes and different heights of the streets.



Figure 79: Intersection of Rua de Nove de Abril and R. de São Dinis (Source: Personal elaboration).

Where *Rua de Nove de Abril* and *Rua de São Dinis* meet, there is a height difference of a few metres that divides the two roadways. In the middle, there is a green space with a significant slope.

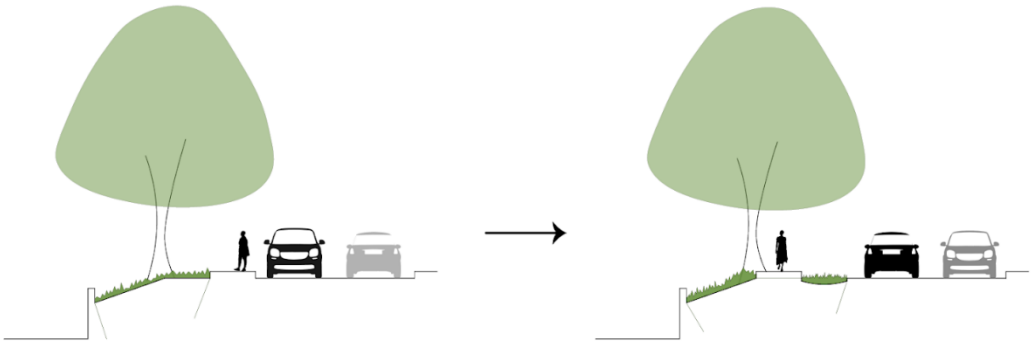


Figure 80: Addition of Green Space (Source: Personal elaboration).

Where *Rua de Nove de Abril* and *Rua de São Dinis* meet, there is a height difference of a few metres that divides the two roadways. In the middle, there is a green space with a significant slope. However, currently, the green space is separated from the roadway, so it cannot be used for collecting rainwater.

Instead, by making a slight modification to the road composition, namely by moving the sidewalk slightly to the left (as shown in Figure 80) and changing the sidewalk material to make it permeable, not only could the absorptive surface be enlarged, but water could also be collected directly from the roadway of *Rua de São Dinis*. Additionally, the pedestrian space would become more pleasant to traverse.
In this stretch of road, there are also two other problematic areas due to the different heights. Indeed, at the intersection with the two cross streets *R. Nova do Regado* and *Tv. da Bica Velha*, situations of rainwater accumulation could occur in the two cross streets themselves. Their position is indeed at a lower height compared to *Rua de São Dinis.* The presence of descents can lead to water accumulating more in some areas than others, which is why it is crucial for *Rua de São Dinis* to be as absorbent as possible, so that the collected rainwater already has a path to follow and places to be collected, and that even the initial part of the two cross streets seeks to increase absorbent capacity. The positive aspect is that these two cross streets are already made of permeable material, but currently, there is no place for the water to flow, which is why it would be important not only to increase the presence of rain gardens along these two streets but they could also be implemented at the intersections of the two streets, which are wider than normal streets and therefore have more space available (Figure 81).
With the presence of a slope, it would also be good for these structures to be implemented along the descent, always trying to create preferential channels to channel water, perhaps using another material or channels along the road edges.

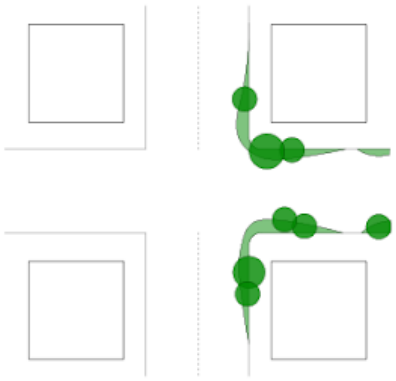


Figure 81:Intersection Transformed by Rain Gardens, Before and After (Source: Personal elaboration).

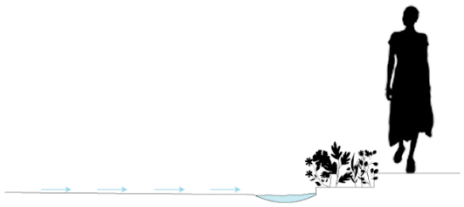


Figure 82: Idea of channels along the road (Source: Personal elaboration).

Regarding the first *Carvalhido* block, therefore, given the limited available space, the strategy to follow could be based on a network of rain gardens and high-absorbency zones along the streets. Unfortunately, space is not abundant, so it would be more important to increase these greener areas, even if small, and make them work together as a green network.

An additional aid that could be provided to this block is through the implementation of absorbent surfaces in private areas. Many residences, in fact, in the part hidden from the street, have additional green areas or areas that could be transformed into such. Creating courtyards or gardens that can collect all the rainwater from the buildings, instead of it ending up in the drainage system, is a solution already adopted in Copenhagen and has brought benefits. If the amount of rainfall were to increase further, it would be very difficult for the municipal drainage system alone to handle all the collected water, so mixed solutions must be considered. As it's easy to think, this specific manoeuvre is difficult to implement as it cannot be solely decided at the municipal level when it comes to private spaces. Part of the work should, therefore, be done by increasing citizens' awareness of the ongoing climate changes, what these changes entail, and which events will become more frequent. It's important to emphasise what the city can do alone and what will become, whether we like it or not, everyone's responsibility, by recommending some practices to adopt. Regarding private residences, incentives could be allocated, both for new constructions and for renovations of existing ones, to make them, if not entirely, at least partially capable of absorbing the water received on the building. The incentives could be given as part of money allocated at the start of the works or through discounts applicable later on bills. It would be important for the message conveyed through these practices to be that they are encouraged for the well-being not only of the individual but above all of the community.



Figure 83: Rainwater harvesting in private courtyards (Source: Personal elaboration).

As for the second block under examination, that of *Jardim Arca d'Água*, the approach considered might be partly different. As observed through the overlay of the flooding map, the problems in this area are concentrated mainly around the garden itself. Before moving on to this specific location, however, attention should also be paid to the rest of the streets that make up the block. The streets here are in some cases even narrower than in the previous block, often with no parking zones along the carriageways. This can lead to the awareness that, as in the previous block, in some cases it is only possible to try to increase the presence of permeable surfaces. In other cases, where possible, rain gardens could also be added to the street structure in this block, especially in the wider areas, such as intersections, which are currently completely paved even though with the presence of roundabouts or road curbs.

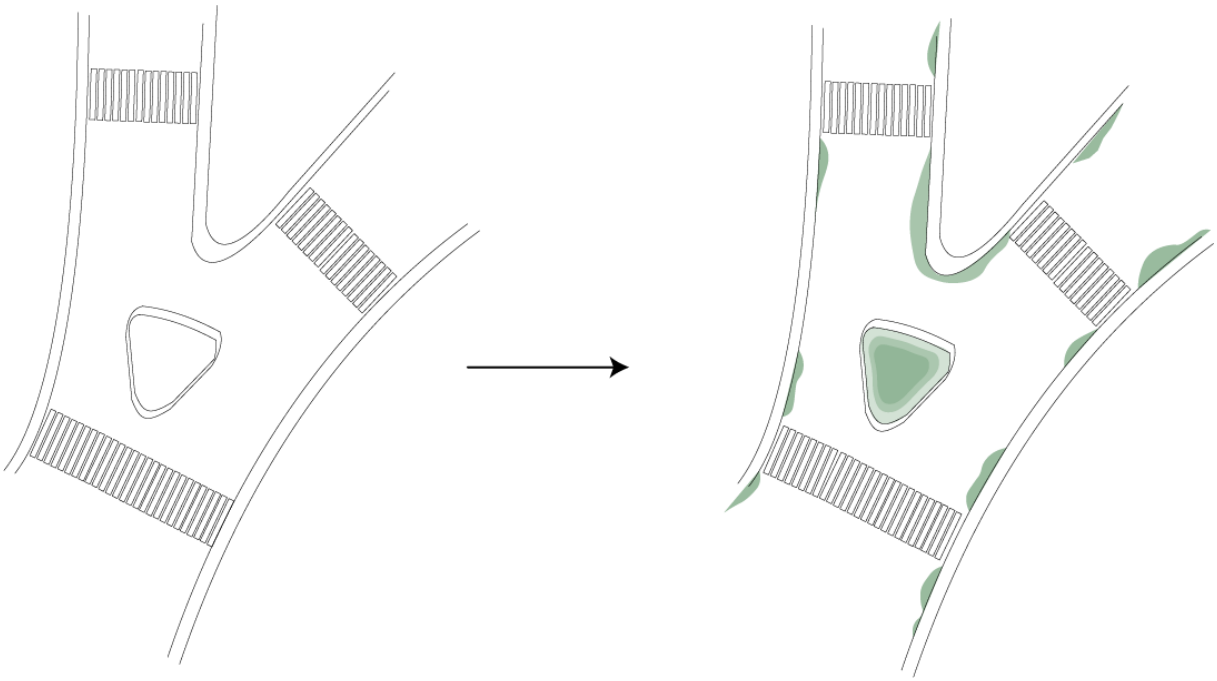


Figure 84: Raingardens in roundabouts (Source: Personal elaboration).

The big difference in this block compared to the other is found in the garden itself. A fairly large green area that could be transformed to serve as a rainwater collection point. Taking Enghaveparken in Copenhagen as an example, the modification could take into account events of different intensities and try to create different zones capable of collecting different amounts of water. The *Jardim Arca d'Agua*, like Enghaveparken, is a historic garden, so the changes must take these aspects into account. However, the area would be perfect for this purpose, so much so that the presence of water is also recalled in the name of the garden itself. One solution could be not to change the structure of the park itself but to use the existing divisions given by the streets within it, in the lower part of the park, creating areas that can fill with rainwater as needed. Furthermore, it would also be appropriate to use the pond, already present in the park, as another possible retention basin. In the northern part of the park, which resembles a more naturalistic garden also due to the presence of the water feature, another idea could be to add other small ponds along the streets or in the centre of green spaces, which could not only increase the absorbency but also make the park cooler during the warmer months. The southern part of the park could become the largest collection area, which can be flooded as needed and therefore does not maintain the presence of water all year round, as shown in figure 85.

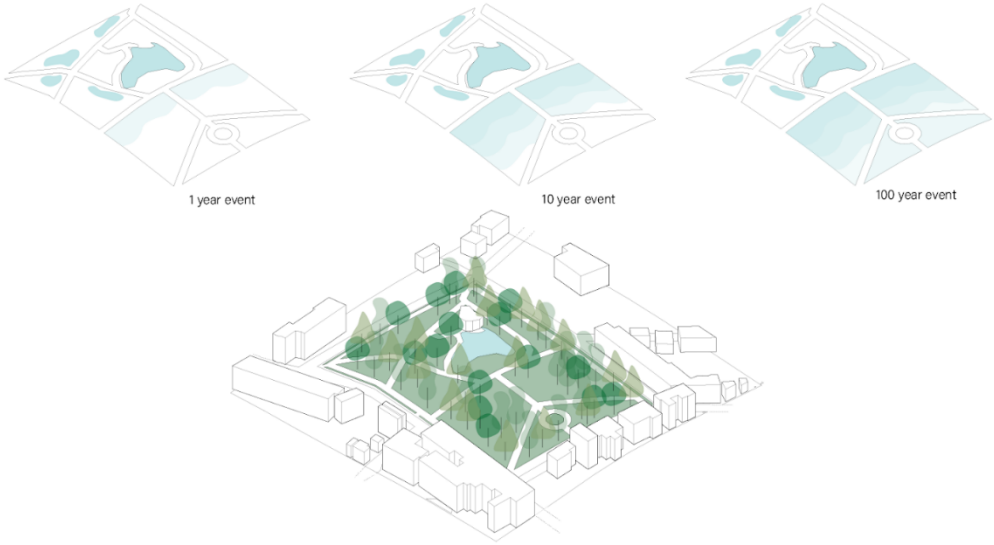


Figure 85: Transformation of Jardim Arca d'Água (Source: Personal elaboration).

The garden could therefore channel not only the water that falls directly on it but also from the surrounding streets, increasing the absorbent surface and making the area almost entirely independent from the public water network. Furthermore, just like in Enghaveparken, the collected water can be used for community purposes such as irrigation, especially during months with scarce rainfall. The area of Jardim Arca d'Água, in conclusion, could become the main centre for the urban redevelopment of the entire area, increasing absorbency capacity and serving as a mitigating factor. It could also be an important element in mitigation, especially in the case of extreme events like those occurring every 10 or 100 years, where the amount of water could cause damage not only to infrastructure but also to private residences.

5.1.3 DISCUSSION OF RESULTS

In the Carvalhido and Jardim Arca d'Água areas, a number of issues have been identified. These areas are part of one of the city's most significant watersheds, and they frequently experience flooding during periods of heavy rainfall. This issue is closely related to various land uses, which have resulted in a paucity of green areas, a high percentage of impermeable surfaces, and difficulties in creating alternative solutions due to the large number of cars parked legally and illegally.

In seeking potential solutions, Copenhagen was considered, given that recent climate adaptation interventions and research have significantly modified its urban fabric. In light of the contrasting characteristics between the two locations, a number of potential solutions were evaluated to ascertain their suitability for implementation in the Porto context.

A multitude of potential interventions exist, with multiple solutions often proposed to address the problem. One method for selecting these interventions is to meticulously assess the most appropriate locations for their implementation. In order to identify effective solutions, it is essential to conduct a thorough

examination of the location's unique characteristics, ensuring that the adaptation measures are tailored to the specific context. In order to modify the urban fabric for climate adaptation, it is necessary to consider not only the physical characteristics of the urban environment, but also the specific characteristics of the problem in question. For instance, it is important to evaluate how runoff water is collected and distributed, whether the water network can be implemented, and what such work would entail. At the same time, these evaluations must also be conducted concerning the approach to blue-green infrastructure. It is necessary to analyse where these could be implemented and their social and environmental impacts. It is crucial to anticipate how these changes might impact the surrounding environment, as well as the practical aspects of the work, including the associated costs and duration. To minimise disruption to residents, it is advisable to consider the most time-efficient solutions. Additionally, engaging and informing citizens about the city's activities in their territory is an important aspect to ensure a more positive attitude towards construction sites in their vicinity. In addition to the environmental impact, these interventions could also enhance the overall quality of the area in which they are implemented, thereby improving the liveability of the location and the value of the properties within it. Another crucial aspect to be considered is the necessity for monitoring and adaptation. The implementation of blue-green solutions must take into account environmental factors, such as the potential consequences of climate change occurring more rapidly or in an unforeseen manner. Additionally, social aspects must be considered, as the utilisation of urban spaces is influenced by societal shifts. For instance, solutions that are currently challenging to implement due to the high number of private vehicles in the area may be reconsidered in the future if the anticipated trend towards reduced car dependency continues. This would provide more space for urban greenery and shared social spaces than is currently possible.

Finally, as previously outlined in Copenhagen's climate adaptation plan, it is vital to emphasise that becoming more resilient to climate change should be a collective endeavour. It is evident that the municipality cannot solve all the problems from a public standpoint with its efforts alone. Firstly, climate change is not solely a public issue; it affects everyone indiscriminately. Secondly, the technique used today to increase the effectiveness of these interventions is inadequate. The answer lies in all the aspects studied so far, from the hypothetical model of the sponge city to the concrete examples from Copenhagen. An isolated intervention alone will hardly cause substantial differences in the territory. It is of greater consequence to establish connections between various blue-green spaces and to create a network. Consequently, private spaces should also be considered in the overall plan, with the objective of facilitating their implementation and sharing information and motivations for these changes with the citizens.

6

CONCLUSIONS

6.1 MAIN CONCLUSION

The findings of this document indicate that there is no single solution to climate adaptation in cities. The issue of rainwater accumulation, which is currently causing and is likely to cause further damage in urban areas, is now a central topic of discussion and study in many quarters. However, these issues extend beyond precipitation to encompass a range of other crucial topics, including social justice, urban biodiversity, public or sustainable transportation, and changes to urban environments. Additionally, citizen awareness and collaboration are key factors in addressing these challenges. **Consequently, the most effective approach to addressing climate change challenges is to implement solutions that are tailored to the specific context of each site. Furthermore, it is necessary to consider the implementation of holistic approaches that encompass a range of dimensions.** The data collected during the study indicated that extreme events are expected to increase in Porto in the coming years and decades. Furthermore, according to land use specifics, the city is currently unprepared to face them. This was, and still is in some areas, the situation in Copenhagen, which, after the extreme event that struck in June 2011, developed a climate adaptation plan and several annual updates that provide an idea of the progress of operations. The Copenhagen plan is not without flaws, and there are undoubtedly aspects that could be improved upon today. When comparing the two adaptation plans, it is evident that some differences are due to the differing geographies of the two cities, Porto and Copenhagen. However, there are also similarities to be observed. In both cases, the proposed interventions to enhance the resilience of cities to extreme weather events are blue-green solutions. Consequently, the two plans can be considered comparable. **However, it is important to note that adaptation plans of this nature cannot afford to be overly precise regarding the solutions to be adopted. Instead, they serve to outline a general direction. What is of interest is how, through the development of specific projects, one can gain insight into the direction being aimed at. Therefore, climate adaptation plans should not be considered static and closed documents. Instead, they should be updated and improved to respond to new climate challenges. The adaptation of best practices from other contexts can facilitate the improvement of climate adaptation strategies, provided that the solutions are adapted to the specificities of the local context.** An essential aspect is establishing a connection between the projects themselves. This is the foundation of the Klimakvarter concept, which entails developing a sustainable model that expands with the city, rather than being confined to specific areas. The interconnection between components could prove pivotal in the event of an extreme occurrence. In this scenario, the impact of the disaster would be mitigated by a larger surface area, making it more manageable**. Rather than assuming that climate adaptation solutions must involve radical urban transformations, it**

should be noted that often small interventions can have a significant impact. However, it is essential that these interventions are articulated and connected as part of a broader adaptation strategy.
In contrast, the subsequent revisions prepared by the Copenhagen municipality represent the practical application of the plan's expressed principles and have proven to be an invaluable tool in elucidating the city's trajectory. In the case of Porto, this could also be a solution to adopt. Rather than focusing on isolated interventions in specific areas, it would be more beneficial to consider the implementation of an action plan encompassing a wider geographical area. This would facilitate the identification of solutions that can be integrated into a unified framework, ensuring a more holistic and effective approach.
One potential solution is to divide the territory based on the area of the riverbeds, which are prevalent in the city and act as direct recipients of the city's rainwater. By implementing projects aimed at reducing the amount of water transported into these areas, it would be possible to simultaneously address the issue at hand. In the specific case of the *Ribeira da Granja* basin, for example, all the analysed interventions would serve to reduce the pressure this river receives during torrential rains. Thus, the first connection between the different projects has already been found. Moreover, the proposals have been designed to follow the current urban development of the city, taking into account not only aspects such as climate but also environmental and social aspects. The incorporation of green spaces, including rain gardens, can enhance biodiversity, promote healthier environments, and enrich the value of the area for the community.
The design of solutions should be conducted in a multi-scale process. On the one hand, to address flooding issues, it is essential to consider the entire river basin. It is evident that in order to address flooding problems, it is crucial to consider the entire river basin. However, zooming in allows for the identification of how to intervene effectively with small actions/projects for a greater impact. In this regard, green infrastructure and nature-based solutions have proven to be the most adequate.
It is acknowledged that public interventions to address flooding problems, although essential, may not be sufficient, especially if the RCP 4.5 emissions scenario cannot be maintained. Consequently, it is of paramount importance to foster closer collaboration with citizens in order to ensure that private buildings are adequately prepared for this purpose. It is becoming increasingly evident that rainwater absorption will soon become a more significant issue than it has been thus far, and that it cannot be managed by the municipality alone. It **is therefore clear that collaborative processes between public institutions and citizens are becoming increasingly necessary in order to implement concrete action plans that can truly make a difference. Furthermore, such initiatives can empower citizens, enabling them to become active agents of change. To enhance climate action by citizens, however, it is also essential to enhance climate literacy.**
In conclusion, the occurrence of intense rainfall will become increasingly common in the coming years, and the more studies there are on territories, the more solutions can be adopted in urban areas. This document outlines the various levels of collaboration that should result from this. At a broader level within the European Union and among the states themselves. It is also important to consider the role of collaboration between citizens and their municipalities or regions, as it is often the people on the ground who can make a real difference. Furthermore, it is also necessary to consider the collaboration between systems and green spaces adopted against climate change. As ecosystems often teach us, we need to find balance in everything to find a solution.

6.2 MAIN RECOMMENDATION

The increase in extreme weather events is having a significant impact on numerous regions across Europe. Despite the existence of a community plan, initiatives often originate primarily from small entities, and the plans created by member states tend to be too vague. It is of paramount importance to develop national, regional and municipal plans in the coming years, with a view to ensuring their seamless integration. It is frequently the case that initiatives implemented in different areas remain disconnected from one another.

6.3 FURTHER RESEARCH

How we will manage to adapt cities to climate change in the future is uncertain, although we are probably on the path to discovering it. Further research and analysis of interventions carried out in recent years will be fundamental to uncover this. Another certainty is that this change can modify not only our cities but also our society and the habits we have. One change cannot be implemented without considering the other. More engaged citizens in public life and personally involved in the climate adaptation of cities will prove to be an essential prerequisite for success, especially in very dense urban environments. Therefore, the methods of information and participation themselves need to be studied to make this transition smoother. Social changes are often the longest to implement, and they are probably influenced by the surrounding environment, but the reverse is also true. It would be interesting to better understand this phenomenon and how to make people more aware of their importance in the environment they live in, transforming them into active representatives of change.

7

REFERENCES

"*Adaptation Policy in the EU – Overview.*" Climate Policy Info Hub. Website (https://climatepolicyinfohub.eu/adaptation-policy-eu-–-overview.html). Accessed: [04/01/2024].

"*Aguas do Porto.*" IWA Network. Website (https://iwa-network.org/aguas-do-porto/). Accessed: [13/05/2024].

"*Aguas do Porto.*" https://pvrla.aguasdoporto.pt/pt/. Accessed: [13/05/2024].

Andresen, T., Gonçalves, A., Santiago, A., Séneca, A., Soares, C., Vieira, C., Almeida, D., Silva, E., Caldas, F. B., Hespanol, H., Bento, J., Honrado, J., Torres, J., Gonçalves, J. A., Brito, J. C., de Carvalho, L. G., Pereira, M. J. A., Curado, M. J., Afonso, M., de Almeida, N. F., Alexandrino, P., Alves, P., Marques, P. F., & Silva, V. *Estrutura Ecológica da Área Metropolitana do Porto*. ICETA - Instituto de Ciências e Tecnologias Agrárias e Agro-alimentares, Porto, 2004.

"An overview of the EU Solidarity Fund 2002-2022." 2022. Website (https://cohesiondata.ec.europa.eu/stories/s/An-overview-of-the-EU-Solidarity-Fund-2002-2022/qpif-qzyn/#:~:text=Between%202002%20and%20the%20end,,%20Montenegro,%20and%20Serbia). Accessed: [10/04/2024].

Câmara Municipal do Porto. *Cartas Históricas Interativas do Porto*. Website: https://www.cm-porto.pt/cartas-historicas-interativas-do-porto/cartas-historicas-interativas-do-porto.Accessed: [09/05/2024].

Câmara Municipal do Porto. *Portal GEO*. Website: https://portalgeo.cm-porto.pt/arcgis/apps/sites/#/mapas-do-porto/apps/507724d6cfeb4038b19e862b6ca8cb1f/explore. Accessed: [09/05/2024].

"Causes and Effects of Climate Change." United Nations. Website: (https://www.un.org/en/climatechange/science/causes-effects-climate-change). Accessed: [07/01/2024].

"Chaos in downtown Porto following 20 minutes of intense rain." Portugal Resident. Website: (https://www.portugalresident.com/chaos-in-downtown-porto-following-20-minutes-of-intense-rain/). Accessed: [09/05/2024].

Chui, Ting Fong May, Liu, Xin, & Zhan, Wenting. (2016). *"Assessing cost-effectiveness of specific LID practice designs in response to large storm events."* Journal of Hydrology, Volume 533, Pages 353-364.

City of Copenhagen. *Cloudburst Management Plan*. City of Copenhagen, Copenhagen, 2010

City of Copenhagen. *Copenhagen Climate Adaptation Plan*. City of Copenhagen, Copenhagen, 2011

City of Copenhagen. *Copenhagen 2025 Roadmap 2021-2025*. 2020

City of Copenhagen. *Climate Change Adaptation and Investment Statement*, 2015.

"Climate Change." European Commission. Website: (https://climate.ec.europa.eu/climate-change_en). Accessed: [03/02/2024].

Commission staff working document. *"Assessment of progress on climate adaptation in the individual Member States according to the European Climate Law."* European Commission. Website: (https://climate.ec.europa.eu/system/files/2023-12/SWD_2023_932_1_EN.pdf). Accessed: [03/02/2024].

"Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Green Infrastructure (GI) — Enhancing Europe's Natural Capital." European Commission. Website: (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52013DC0249). Accessed: [15/01/2024].

"Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change." European Commission. Website: (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A82%3AFIN). Accessed: [16/01/2024].

Conte, Giulio, Bolognesi, Andrea, Bragalli, Cristiana, Branchini, Sara, De Carli, Alessandro, Lenzi, Chiara, Masi, Fabio, Massarutto, Antonio, Pollastri, Marco, & Principi, Ilaria. 2012. *"Innovative Urban Water Management as a Climate Change Adaptation Strategy: Results from the Implementation of the Project 'Water Against Climate Change (WATACLIC)'."* Water, 4(4), 1025-1038. DOI: 10.3390/w4041025.

Copernicus. *Copernicus - European Union Earth Observation Programme*. Website: https://www.copernicus.eu/en. Accessed: [20/04/2024].

"Economic losses from climate-related events." European Environment Agency. Website: (https://www.eea.europa.eu/en/analysis/indicators/economic-losses-from-climate-related). Accessed: [12/03/2024].

"EU Regional Policy." European Environment Agency. Website: (https://climate-adapt.eea.europa.eu/en/other-eu-policies/eu-regional-policy). Accessed: [23/01/2024].

"European Commission. An overview of the EU Solidarity Fund - 2002-2022. Data. European Structural and Investment Funds." Website: https://cohesiondata.ec.europa.eu/stories/s/An-overview-of-the-EU-Solidarity-Fund-2002-2022/qpif-qzyn/#:~:text=Between%202002%20and%20the%20end,%2C%20Montenegro%2C%20and%20Serbia). Accessed: [29/04/2024]

European Commission. (2013). *Green infrastructure (GI) — Enhancing Europe's Natural Capital* (COM(2013) 236 final). EUR-Lex. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0236:FIN:EN:PDF Accessed: [20/01/2024]

European Commission. *Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change*. Website (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:82:FIN). Accessed: [09/01/2024].

European Environment Agency. (2021). *Europe's changing climate hazards — an index-based interactive EEA report* (Report No. 15/2021). DOI: 10.2800/458052. ISBN 978-92-9480-407-5. ISSN 1977-8449.

European Environment Agency. (n.d.). *Extreme weather, floods, droughts, and heatwaves*, from https://www.eea.europa.eu/en/topics/in-depth/extreme-weather-floods-droughts-and-heatwaves?activeAccordion= Accessed: [11/01/2024]

"Europe's changing climate: What will the future bring?" European Environment Agency. Website: (https://www.eea.europa.eu/publications/europes-changing-climate-hazards-1/what-will-the-future-bring). Accessed: [16/01/2024]

"Europe's changing climate hazards — an index-based interactive EEA report" on the European Environment Agency's website. This report, published as report no. 15/2021, is accessible in HTML format under the ISBN 978-92-9480-407-5 and ISSN 1977-8449, with the DOI 10.2800/458052. Accessed: [16/01/2024]

"Extreme weather: Floods, droughts and heatwaves." European Environment Agency. Website: (https://www.eea.europa.eu/en/topics/in-depth/extreme-weather-floods-droughts-and-heatwaves). Accessed: [16/01/2024]

"Executive Summary: Information Needs Assessment." Environmental Protection Agency (EPA). Website: https://www.epa.gov/epalibraries/executive-summary-information-needs-assessment. Accessed: [10/02/2024]

Ferguson, G., and A. D. Woodbury. "*Urban heat island in the subsurface."* Geophysical Research Letters, 2007, L23713, doi:10.1029/2007GL032324, AGU, Washington D.C.

Fini A, Frangi P, Mori J, Donzelli D, Ferrini F. (2017). *"Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements."* Environ Res, 156, 443-454. DOI: 10.1016/j.envres.2017.03.032.

Fünfgeld, Hartmut, Fila, Dennis, Dahlmann, Heindriken. *"Upscaling climate change adaptation in small- and medium-sized municipalities: current barriers and future potentials."* Current Opinion in Environmental Sustainability, Volume 61, 2023.

Giglou, A. N., Nazari, R., Karimi, M., Lawrence Museru, M., Ntow Opare, K., & Nikoo, M. R. *"Future eco-hydrological dynamics: Urbanization and climate change effects in a changing landscape: A case study of Birmingham's river basin."* Journal of Cleaner Production, 447, Article 141320. 2024.

Greenwalt, Julie, Nina Raasakka, and Keith Alverson. *"Building urban resilience to address urbanization and climate change."* In Resilience, edited by Zinta Zommers and Keith Alverson, Elsevier, Amsterdam, 2018.

Griffiths, J., Chan, F. K. S., Shao, M., Zhu, F., e Higgitt, D. L. "*Interpretation and application of Sponge City guidelines in China."* Philosophical Transactions of the Royal Society A, 17/02/2020. https://doi.org/10.1098/rsta.2019.0222

Guerra, F., & Syed, M.D. *"Identifying mindsets for urban sustainability transformation: insights from Urban Labs."* Sustain Sci, 19, 523–537 (2024). DOI: 10.1007/s11625-023-01437-7.

Hession, A. (2017, September 3). *The finger plan at 70. Danish Design Review.*, from https://danishdesignreview.com/townscape/2017/9/3/the-finger-plan-at-70 Accessed: [20/04/2024]

Hettiarachchi, Suresh, Wasko, Conrad, & Sharma, Ashish. (2022). *"Rethinking urban storm water management through resilience – The case for using green infrastructure in our warming world."* Cities, 128, 103789. DOI: 10.1016/j.cities.2022.103789.

Huang, Jian, He, Jianxun, Valeo, Caterina, & Chu, Angus. (2015). *"Temporal Evolution Modeling of Hydraulic and Water Quality Performance of Permeable Pavements."* Journal of Hydrology, 533. DOI: 10.1016/j.jhydrol.2015.11.042.

IPCC report, 2023, https://www.ipcc.ch/report/sixth-assessment-report-cycle/

Ji, Meicheng, & Bai, Xue. *"Construction of the sponge city regulatory detailed planning index system based on the SWMM model."* Environmental Technology & Innovation, Volume 23, 2021.

Jiang, Wei, Sha, Aimin, Xiao, Jingjing, Li, Yuliang, & Huang, Yue. (2015). *"Experimental study on filtration effect and mechanism of pavement runoff in permeable asphalt pavement."* Construction and Building Materials, 100, 102-110. DOI: 10.1016/j.conbuildmat.2015.09.055.

Kabano, Peter, Sarah Lindley, and Angela Harris. "*Evidence of urban heat island impacts on the vegetation growing season length in a tropical city."* Landscape and Urban Planning, Volume 206, 2021, Elsevier, Amsterdam.

Kirshen, Paul, Aytur, Semra, Hecht, Jory, Walker, Andrew, Burdick, David, Jones, Stephen, Fennessey, Neil, Bourdeau, Renee, & Mather, Lorilee. *"Integrated urban water management applied to adaptation to climate change."* Urban Climate, Volume 24, 2018.

Klimakvarter, Website: https://klimakvarter.dk/ Accessed: [10/03/2024]

Knittel, Nina. (2016). *"Climate Change Adaptation: Needs, Barriers and Limits."* Climate Policy Info Hub, 10 February 2016. Website: http://climatepolicyinfohub.eu/climate-change-adaptation-needs-barriers-and-limits. Accessed: [10/02/2024]

Koop, S.H.A., & van Leeuwen, C.J. (2017) *"The challenges of water, waste and climate change in cities."* Environ Dev Sustain, 19, 385–418. DOI: 10.1007/s10668-016-9760-4.

Kumar, S., Doshi, S., Mishra, G., & Iyer, M. (2024) "*Fostering Water-Sensitive Urban Planning in G20 Cities*." Doctoral dissertation, Faculty of Planning, CEPT University.

Lafortezza, Raffaele, and Giovanni Sanesi. (2019) *"Nature-based solutions: Settling the issue of sustainable urbanization."* Environmental Research, Volume 172, Elsevier, Amsterdam.

Lai, S.; Zoppi, C. Sustainable Spatial Planning Based on Ecosystem Services, Green Infrastructure and Nature-Based Solutions. *Sustainability* 2024,*16*,2591. https://doi.org/ 10.3390/su16062591

Lamond, Jessica, & Everett, Glyn. (2019) *"Sustainable Blue-Green Infrastructure: A social practice approach to understanding community preferences and stewardship."* Landscape and Urban Planning, Volume 191.

Liu, Li, & Jensen, Marina Bergen. (2018). *"Green infrastructure for sustainable urban water management: Practices of five forerunner cities."* Cities, Volume 74.

"LNEG Geoportal - Geological Maps - CGP50k - Sheet 09-C." Website: https://geoportal.lneg.pt/en/opendata/geological_maps/cgp50k/09-C. Accessed: [20/04/2024]

"LNEG. Geoportal." D Website: https://geoportal.lneg.pt/mapa/?lang=en. Accessed: [20/04/2024].

Malheiro, P., & Cunha, R. *"Basin Stories: Urban Water Cycle Integrated Management."* (2019). Website: (https://iwa-network.org/wp-content/uploads/2019/07/AguasdoPorto-Basin-Story_Final.pdf). Accessed: [19/01/2024].

MASU Planning Landscape architect Website: https://www.masuplanning.com/ Accessed: [02/03/2024]

Moretti, Laura, Di Mascio, Paola, & Fusco, Ciro. (2019). *"Porous Concrete for Pedestrian Pavements."* Water11, no. 10: 2105. DOI: 10.3390/w11102105.

Municipality of Porto. *Municipal Master Plan of Porto, Environmental Biophysical Support, Characterization and Diagnostic Study*. 2018.

Nguyen, Thu Thuy, Huu Hao Ngo, Wenshan Guo, Xiaochang C. Wang, Nanqi Ren, Guibai Li, Jie Ding, Heng Liang. (2019) *"Implementation of a specific urban water management - Sponge City."* Science of The Total Environment, Volume 652.

Nieuwenhuis, Eva, de Bruijn, Hans, Cuppen, Eefje, & Langeveld, Jeroen. (2023). *"Understanding cross-sectoral innovations for urban water management through the lens of organizational ambidexterity."* Urban Water Journal, 0(0), 1-13.

Özerol, Gül, Dolman, Nanco, Bormann, Helge, Bressers, Hans, Lulofs, Kris, & Böge, Mike. (2020) *"Urban water management and climate change adaptation: A self-assessment study by seven midsize cities in the North Sea Region."* Sustainable Cities and Society, Volume 55.

Perrelet, K., Moretti, M., Dietzel, A. *et al.* Engineering blue-green infrastructure for and with biodiversity in cities. *npj Urban Sustain* 4, 27 (2024). https://doi.org/10.1038/s42949-024-00163-y

Porto. (2016). *Climate Adaptation Plan*. Website: https://ambiente.cm-porto.pt/files/uploads/cms/1599064372-nVMQOn04Ez.pdf Accessed: [20/04/2024].

Raymond, Christopher M., Frantzeskaki, Niki, Kabisch, Nadja, Berry, Pam, Breil, Margaretha, Nita, Mihai Razvan, Geneletti, Davide, Calfapietra, Carlo (2017). *"A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas."* Environmental Science & Policy, Volume 77.

Richard, Ashley, Gersonius, Berry, & Horton, Bruce. (2020). *"Managing flooding: from a problem to an opportunity."* Phil. Trans. R. Soc. A, 378, 20190214. DOI: http://doi.org/10.1098/rsta.2019.0214.

"River meadows, also called alluvial areas". International Commission for the Protection of the Rhine (IKSR). Website: (https://www.iksr.org/en/topics/ecology/alluvial-

areas#:~:text=River%20meadows%2C%20also%20called%20%E2%80%9Ealluvial,of%20floods%20and%20low%20water). Accessed: [07/03/2024].

Santos, M., & Bateira, C. (2018). *Suporte Biofísico e Ambiente - Caracterização Biofísica - Relatório de Caracterização e Diagnóstico*.

RTL Today *"Heavy rain leads to flooding in the streets of Porto"* Website: https://today.rtl.lu/news/world/a/2013825.html Accessed: [02/03/2024].

SLA Website: https://www.sla.dk/ Accessed: [12/03/2024].

"Sound of Green - State of Green." Website: https://stateofgreen.com/en/sound-of-green/. Accessed: [10/05/2024].

Sørensen, E., & Torfing, J. (2019). *"The Copenhagen metropolitan 'fingerplan': A robust urban planning success based on collaborative governance."* In Compton, M., & 't Hart, P. (Eds.), Great Policy Successes (pp. 218-243). Oxford University Press. DOI: 10.1093/oso/9780198843719.003.0012.

"Sustainable cities and human settlements." United Nations Sustainable Development Goals. Website: (https://sdgs.un.org/topics/sustainable-cities-and-human-settlements). Accessed: [02/03/2024].

"The Finger Plan at 70." Danish Design Review. Website: (http://danishdesignreview.com/townscape/2017/9/3/the-finger-plan-at-70). Accessed: [23/04/2024].

Tredje nature, Website: https://www.tredjenatur.dk/portfolio/ Accessed: [15/03/2024].

United States Environmental Protection Agency (EPA). *EPA 2009 Progress Report*. Website (https://www.epa.gov/archive/epa/aboutepa/epa-2009-progress-report.html). Accessed: [02/03/2024].

"Urban sustainability." European Environment Agency. Website: (https://www.eea.europa.eu/en/topics/in-depth/urban-sustainability). Accessed: [02/03/2024].

Van der Meulen, Geert J.M., van Dorst, Machiel J., & Kuzniecow Bacchin, Taneha. (2023). *"Water sensitivity and context specificity – concept and context in Water-Sensitive Urban Design for secondary cities."* Urban Water Journal, 0(0), pages 1-13.

Vujovic, Svetlana, Haddad, Bechara, Karaky, Hamzé, Sebaibi, Nassim, & Boutouil, Mohamed. (2021). *"Urban Heat Island: Causes, Consequences, and Mitigation Measures with Emphasis on Reflective and Permeable Pavements."* CivilEng, 2(2), 459-484. DOI: 10.3390/civileng2020026.

Wamsler, Christine, & Brink, Ebba. (2014) *"Interfacing citizens' and institutions' practice and responsibilities for climate change adaptation."* Urban Climate, Volume 7.

Wamsler, C., & Brink, E. (2018) "*Mindsets for Sustainability: Exploring the Link Between Mindfulness and Sustainable Climate Adaptation*." Ecological Economics, 10/04/2018, 151, 10.1016/j.ecolecon.2018.04.029.

Wamsler, Christine, Mundaca, Luis, & Osberg, Gustav (2022). *"Rethinking political agency: The role of individuals' engagement, perceptions and trust in transitioning to a low-carbon transport system."* Journal of Cleaner Production, Volume 360.

Wamsler, Christine, & Raggers, Sanne (2018). *"Principles for supporting city–citizen commoning for climate adaptation: From adaptation governance to sustainable transformation."* Environmental Science & Policy, Volume 85.

Wan, Shuyan, Xu, Liyan, Qi, Qi, Yang, Hao, & Zhou, Yezhou. (2022). *"Building a multi-objective optimization model for Sponge City projects."* Urban Climate, Volume 43, 101171. ISSN 2212-0955.

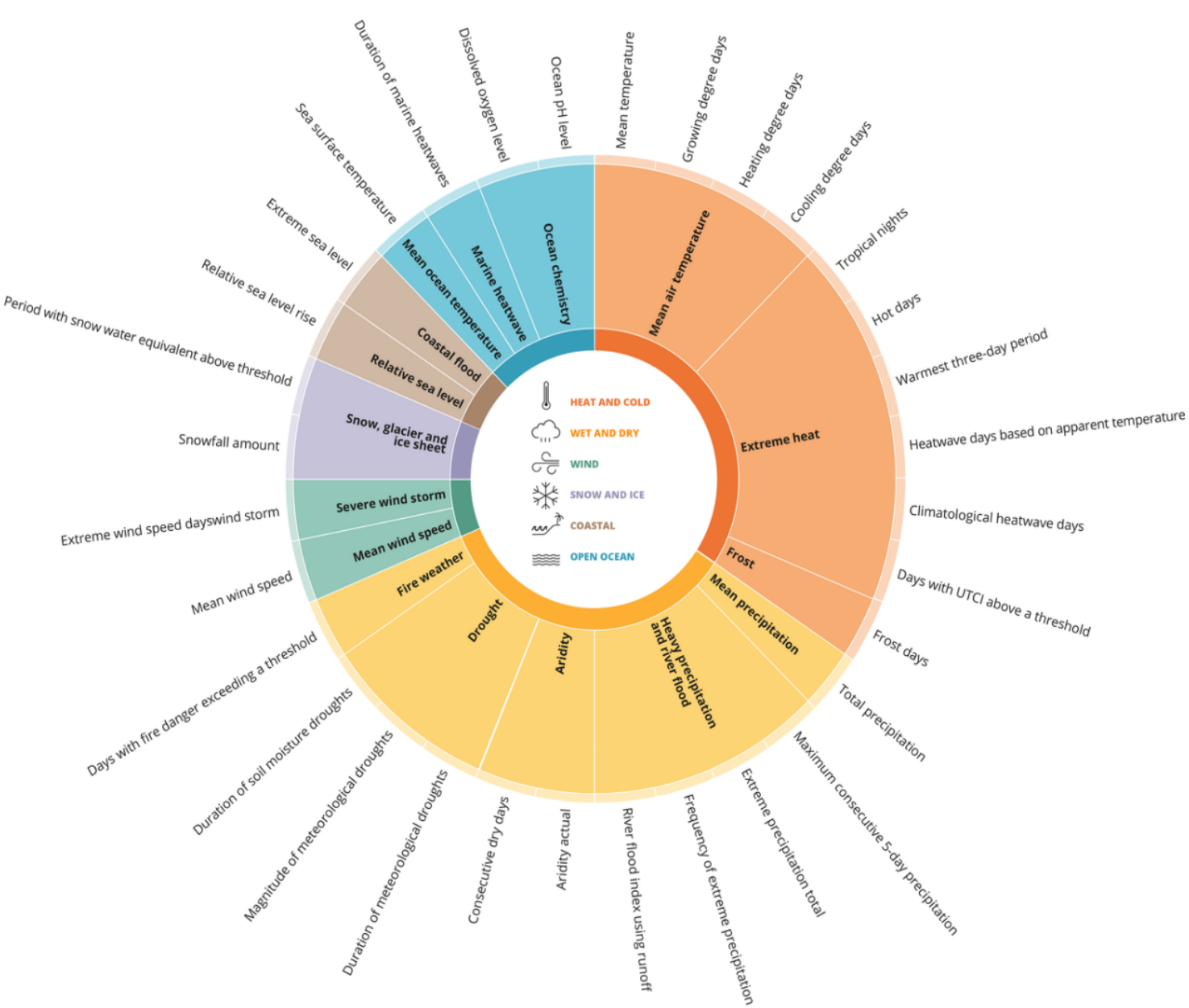
Wang J, Meng Q, Zou Y, Qi Q, Tan K, Santamouris M, He BJ. (2022). *"Performance synergism of pervious pavement on stormwater management and urban heat island mitigation: A review of its benefits, key parameters, and co-benefits approach."* Water Res, 221, 118755. DOI: 10.1016/j.watres.2022.118755.

Wong, T., & Eadie, M. L. (2000) *"Water sensitive urban design: a paradigm shift in urban design."* In Proceedings of the 10th World Water Congress, pp. 12-16.

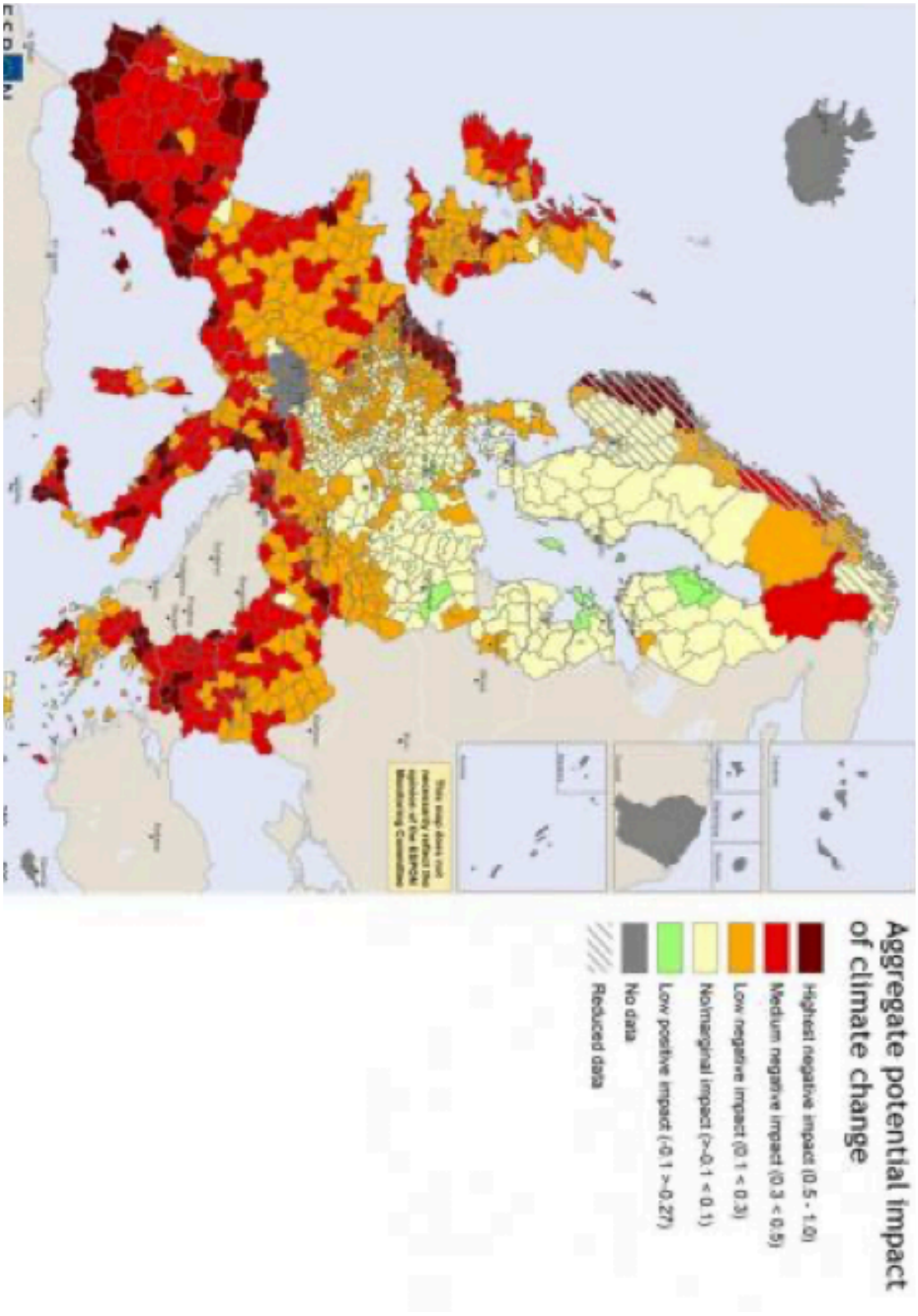
8

APPENDIX

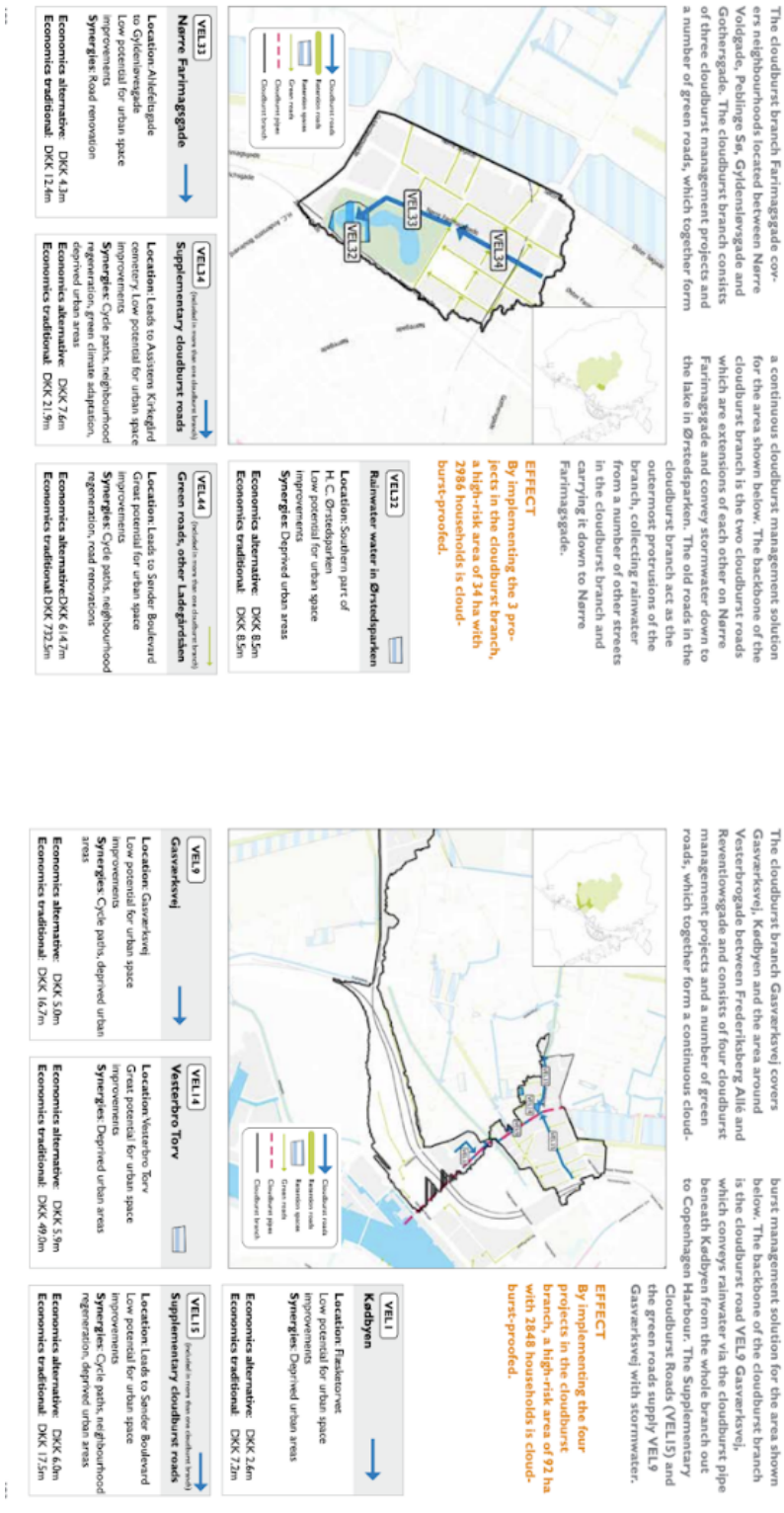
8.1 Climate indices for the 16 climate hazards



8.2 Aggregate potential impact of climate change on Europe's regions



8.3 Example of a specific branch of the Copenhagen climate adaptation plan



NEEDS, SOLUTION AND EFFECT

NØRRE FARIMAGSGADE

AREA 34 HA
HOUSEHOLDS 2986
RISK PROFILE HIGH
NUMBER OF PROJECTS 3

The cloudburst branch Farimagsgade covers neighbourhoods located between Nørre Voldgade, Peblinge Sø, Gyldenløvsgade and Gothersgade. The cloudburst branch consists of three cloudburst management projects and a number of green roads, which together form a continuous cloudburst management solution for the area shown below. The backbone of the cloudburst branch is the two cloudburst roads which are extensions of each other on Nørre Farimagsgade and convey stormwater down to the lake in Ørstedsparken. The old roads in the cloudburst branch act as the outermost protrusions of the branch, collecting rainwater from a number of other streets in the cloudburst branch and carrying it down to Nørre Farimagsgade.

EFFECT
By implementing the 3 projects in the cloudburst branch, a high-risk area of 34 ha with 2986 households is cloudburst-proofed.

VEL33
Nørre Farimagsgade
Location: Allétorvet to Gyldenløvsgade
Low potential for urban space improvements
Synergies: Road renovation
Economics alternative: DKK 4.3m
Economics traditional: DKK 12.4m

VEL34 (included in more than one cloudburst branch)
Supplementary cloudburst roads
Location: Leads to Assistens Kirkegård cemetery Low potential for urban space improvements
Synergies: Cycle paths, neighbourhood regeneration, green climate adaptation, deprived urban areas
Economics alternative: DKK 7.6m
Economics traditional: DKK 21.9m

VEL32
Rainwater water in Ørstedsparken
Location: Southern part of H. C. Ørstedsparken
Low potential for urban space improvements
Synergies: Deprived urban areas
Economics alternative: DKK 8.5m
Economics traditional: DKK 8.5m

VEL44 (included in more than one cloudburst branch)
Green roads, other Ladegårdsåen
Location: Leads to Sønder Boulevard
Great potential for urban space improvements
Synergies: Cycle paths, neighbourhood regeneration, road renovations
Economics alternative: DKK 6.147m
Economics traditional: DKK 722.5m

GASVÆRKSVEJ

AREA 92 HA
HOUSEHOLDS 2848
RISK PROFILE HIGH
NUMBER OF PROJECTS 4

The cloudburst branch Gasværksvej covers Gasværksvej, Kødbyen and the area around Vesterbrogade between Frederiksberg Allé and Reventlowsgade and consists of four cloudburst management projects and a number of green roads, which together form a continuous cloudburst management solution for the area shown below. The backbone of the cloudburst branch is the cloudburst road VEL9 Gasværksvej, which conveys rainwater via the cloudburst pipe beneath Kødbyen from the whole branch out to Copenhagen Harbour. The Supplementary Cloudburst Roads (VEL15) and the green roads supply VEL9 Gasværksvej with stormwater.

EFFECT
By implementing the four projects in the cloudburst branch, a high-risk area of 92 ha with 2848 households is cloudburst-proofed.

VEL9
Gasværksvej
Location: Gasværksvej
Low potential for urban space improvements
Synergies: Cycle paths, deprived urban areas
Economics alternative: DKK 5.0m
Economics traditional: DKK 16.7m

VEL14
Vesterbro Torv
Location Vesterbro Torv
Great potential for urban space improvements
Synergies: Deprived urban areas
Economics alternative: DKK 5.9m
Economics traditional: DKK 49.0m

VEL1
Kødbyen
Location Flasketorvet
Low potential for urban space improvements
Synergies: Deprived urban areas
Economics alternative: DKK 2.6m
Economics traditional: DKK 7.2m

VEL15 (included in more than one cloudburst branch)
Supplementary cloudburst roads
Location Leads to Sønder Boulevard
Low potential for urban space improvements
Synergies: Cycle paths, neighbourhood regeneration, deprived urban areas
Economics alternative: DKK 6.0m
Economics traditional: DKK 17.5m

8.4 Example of a specific branch of the Copenhagen climate adaptation plan

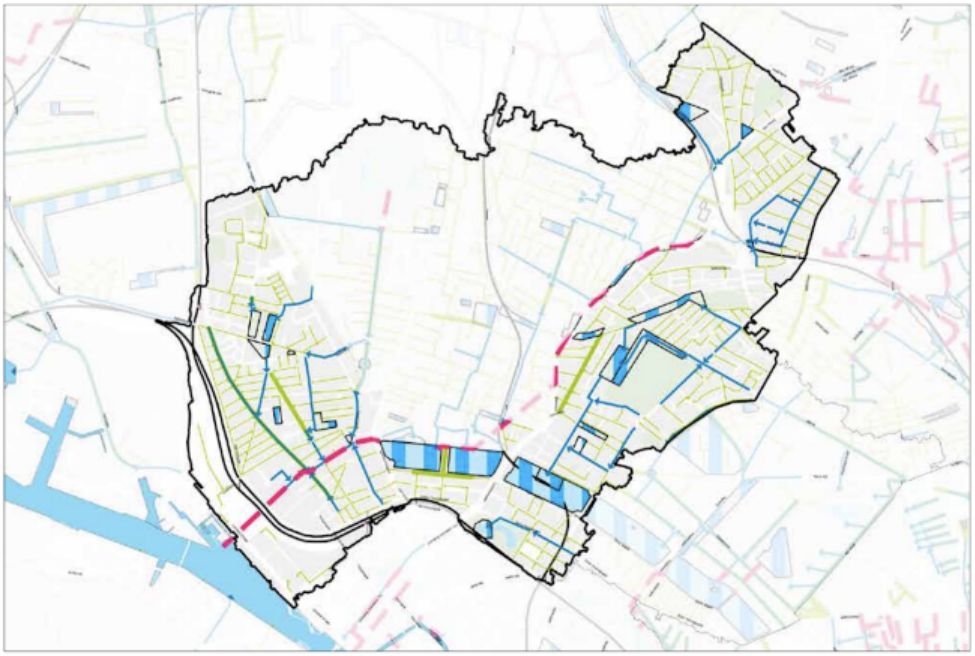
NEEDS, SOLUTION AND EFFECT

WATER CATCHMENT AREA OF LADEGÅRDÅEN, FREDERIKSBERG EAST AND VESTERBRO

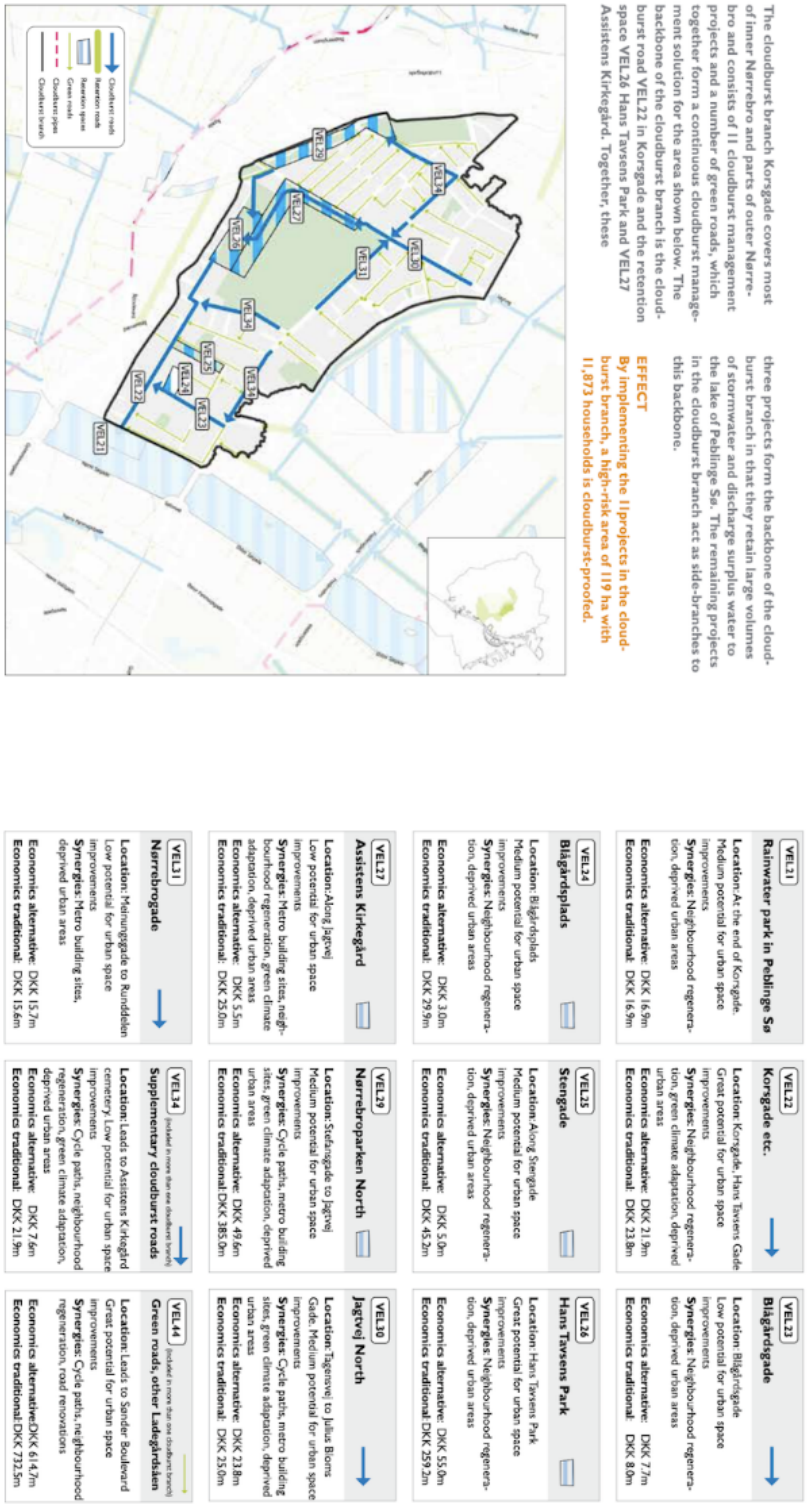
The water catchment area of Ladegårdsåen, Frederiksberg East and Vesterbro consists of seven cloudburst branches and 39 projects. The catchment area is named after the Ladegårds Å river, which runs in pipes beneath Åboulevarden and conveys water to the lake of Peblinge Sø. The catchment area, which extends from Bispebjerg and Nørrebro via Frederiksberg to Vesterbro and Sønder Boulevard, is characterised by very dense building development, and many obstacles to the stormwater. A large part of the solution is to convey the area's water via Skt. Jørgens Sø onward in a cloudburst pipe out into the harbour.

CHARACTERISTICS OF THE WATER CATCHMENT AREA

The water catchment area is among the most densely built-up and populated areas in Copenhagen, with a low proportion of green m2 per inhabitant in Vesterbro and Nørrebro. In addition to challenges with floods, a high heat island effect and poor air quality are experienced, and several areas in this catchment area are characterised as deprived areas of housing. Nørrebro is also for urban development as Sølund, areas along the lakes and neighbourhood regeneration projects, all of which it is logical to combine with climate adaptation measures. The green structure is principally formed by Frederiksberg Have, the Assistens Kirkegård cemetery, De Indre Søer (The Inner Lakes) and Nørrebroparken, as well as a number of smaller green urban spaces and pocket parks.



8.5 Example of a specific branch of the Copenhagen climate adaptation plan



8.6 Climate adaptation plan in the Klimakvarter Neighbourhood Area

CLOUDBURST ROADS
GREEN STREETS

We are establishing cloudburst roads in The Climate Resilient Neighbourhood. A cloudburst road is a public road that, in the situation of a heavy rain event, also acts as a channel, diverting rainwater safely away from the buildings.

In The Climate Resilient Neighbourhood, the first cloudburst roads will carry the water in Landskronagade and Tåsinggegade towards Østerbrogade, where it is collected and in the end discharged into the harbour through an underground cloudburst pipe. In the longer term, Nygårdsvej and Kildevældsgade will also become cloudburst roads.

When the rainwater is transported from the high-lying areas (upstream) of the neighbourhood, around Tåsinge Plads, Skt. Kjelds Plads and Bryggervangen through the neighbourhood and out into the harbour, the risk of flooding is reduced in the low-lying areas (downstream) of the neighbourhood around "Komponist kvarteret" and the Øresund Hospital.

◀ The water flow to the harbour, Fælledparken or other receiving bodies of water. The vision is to protect the entire neighbourhood against the consequences of cloudbursts by arranging green urban spaces for detention and infiltration of storm water and cloudburst roads, conveying the masses of water to areas where it doesn't cause damage.