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TESI DI LAUREA

WATER SENSITIVE CITY.
A NEW APPROACH IN PLANNING AND IN THE URBAN STORMWATER MANAGEMENT:
The case study of Copenhagen

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Contents

Abstract

The ongoing densification of cities combined with climate change impacts and the inadequacy of conventional urban drainage systems have led to a rise of flood phenomena, compromising the existing relationship between cities and water.

Since the technical and conventional engineering solutions of drainage systems cannot manage the climatic phenomena related to the water cycle, it is increasingly necessary to identify a new approach to managing water within the urban environment. This research sees the Water Sensitive City (WSC) concept as a new blueprint for a sustainable and resilient city capable of holistically integrating the natural water cycle elements with urban planning practices, promoting increasingly environmental and social objectives.

In the further exploration of the practical transposition of water sensitivity principles, the as yet under-expressed potential of rainwater management solutions emerged, not only as a new form of water resource but above all as a spatial modelling element. Indeed, the incorporation and restoration of water elements in cities favour adaptation to climate change and, at the same time, supports processes of social cohesion and integration.

For this reason, the focus of the thesis has been directed towards sustainable stormwater management (SSM) practices, specialising in technologies for the recycling, detention, infiltration, treatment and conveyance of rain. In order to facilitate the understanding of the theoretical concepts, a part of the analysis of the practice is introduced in which some case studies are reported that are considered exemplary both for SSM practices and for the concepts expressed in the WSC vision. More attention and detail is given to Copenhagen's case, selected as a best practice in rainwater management policies and solutions and a forerunner in sustainable urbanism and sensitivity to the natural and aquatic environment.

The Cloudburst Management Plan (CMP) is a prime example of the Danish capital's commitment to making the city cloudburst proof, working across the board to increase the city's quality of life and amenity. The conclusion of the work focuses on defining a possible criterion able to transpose and replicate the Copenhagen strategies in other contexts, such as the city of Padua. Through the proposal of the Padua Water Sensitive formula, the objective is to demonstrate how the assumption of a reference model can favour the process of socio-political transition, which favours the development of the water cities of the future.

Keywords:

Climate change, Water Sensitive City, flooding, stormwater management, urban planning, Copenhagen, Cloudburst Management Plan, Padua

Glossary

A
Action Plan = Piano degli Interventi (PI)

B
Basin Authority = Autorità di Bacino
Basin District Authority = Autorità di bacino distrettuale

C
Catchment area = Bacino idrografico d'utenza
Cloudburst = Nubifragio
Cloudburst branch = Ramo di nubifragio
Conference of Services = Conferenza dei Servizi

D
Downpours = Acquazzone

E
EU Flood Directive = Direttiva Alluvioni
EU Water Directive = Direttiva Acque

F
Flood Risk Management Plan = Piano di Gestione Rischio Alluvioni (PGRA)

G
General surveys framework= Quadro Conoscitivo

H
Hydrogeological Disposal Plan = Piano di Assetto Idrogeologico (PAI)

I
Inter-municipal Land Use Plan = Piano di Assetto del Territorio Intercomunale (PATI)

L
Land Reclamation and Protection General Plan = Piano Generale di Bonifica e Tutela del Territorio (PGBTT)
Land Reclamation Union = Consorzio di Bonifica
Land Use Plan = Piano di Assetto del Territorio (PAT)

M
Management tools = Strumenti di gestione

P
Provincial Spatial Plan = Piano Territoriale di Coordinamento Provinciale (PTCP)

R
Regional Plan = Piano urbanistico territoriale
Regional Spatial Plan = Piano Territoriale Regionale di Coordinamento (PTRC)

S
Sector plan = Piani di settore
Spatial planning system = Piani di governo del territorio
Stormwater = Pioggia intensa

W
Water Protection Plan = Piano di Tutela delle Acque (PTA)
Water Supply = Fornitura di acqua potabile
Water Utility = Azienda di gestione della risorsa idrica
Watershed = Area di displuvio

Introduction

Background

When talking about cities, it is difficult not to refer to water. In fact, the relationship between these two elements is rooted in human history as the link between human activity and water dates back to the origin of society and the close relationship between hydro resources and the natural or man-made landscape (Manigrasso, 2019). Water has always been a fundamental basic resource for the economic, social and cultural development of populations, characterising the development of human civilisation. Generally, an urban infrastructure system requires the use of energy which normally involves the use of water (Oral et al., 2020). In this way, in its physical and aesthetic forms, water has constituted for man an element of communication, division, protection, aesthetics but above all of livelihood. The continuous process of human domestication of nature has gradually begun to influence and compromise the relationship between man and water.

Since the industrial revolution and the consequent uncontrolled growth of urban settlements, water has started to become a disturbing element and an obstacle to human activities. As its presence in various forms, hinders the anthropological dynamics of urban life. The progressive lack of interest in the dynamics of water in the urban landscape has led it to become an element of risk for man, highlighting the extreme vulnerability of modern urban structures to natural hazard(Manigrasso, 2019). For this reason, sustainable water management is now the major challenge. This statement was acknowledged by the World Economy Forum in 2014, which listed the water crisis and related risks as a global problem in terms of probability of occurrence and negative impact. Further, which issues are you relating to water is high on the agenda of many international organisations such as the Organisation for Economic Cooperation and Development (OECD), UNESCO, the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) (Koop & van Leeuwen, 2017).

It is generally agreed that the rapid pace and scale of urban growth, combined with the impacts of climate change and economic development, result in the inability of existing urban infrastructure to cope with the new and complex objectives facing contemporary cities (Wong et al., 2020). The goals of the cities for fair resource management, access to clean water, health and hygiene services, environmental protection and citizen safety. All of these is closely interlinked with the quality and quantity of water resources available.

Urbanisation is mainly linked to the growth of the urban population and the depopulation of rural areas. According to United Nations, today about 55% of the world's population lives in urban areas and this percentage is expected to increase to 60% by 2030, resulting in among others in identifying 43 megacities with an average population of more than 10 million inhabitants (United Nation, 2018).

The most significant consequence of this phenomenon is the increase in land use required to 'adapt' cities to rapid population growth. An 'hasty' population growth will lead many countries to face the challenges of meeting the needs of a larger population with the availability of resources needed to ensure economic, social and environmental stability. In 2012, the European Commission addressed this issue in the working document "Guidelines on best practice to limit, mitigate or compensate soil sealing", which sets out guidelines on soil sealing, highlighting the substantial impact on the environment, biodiversity, food supply, alteration of social values, climate and natural cycles (Rodríguez & Cuevas, 2014).

All these aspects are linked to the use of water resources and the consequent processes on which the natural water cycle is structured. This means that the increase in soil sealing and urban population growth require the use of water in terms of both quantity and quality. As the number of people living in cities increases, so does the demand for and availability of water, which is under increasing pressure due to the alternation of all the phenomena linked to its natural regeneration. By 2050, drinking water consumption is expected to increase by 55% (UNESCO, 2020).

Soil denaturalization processes compromise groundwater infiltration and regeneration processes, as well as evaporation and water supply of receiving water bodies, processes that alter the availability of water for humans but also for the natural environment (Oral et al., 2020). A further consequence of urbanisation of the land is the deterioration of water quality, aggravated by the increase in pollution in cities. However the urbanization causes also the increase in surface runoff volumes, the main phenomenon responsible for the transport of heavy metals, threatening human health and the environment (Costa et al., 2015).

The variation of anthropogenic factors linked to urbanisation (which include not only natural land cover but also the regulation and management of water and its processes) introduces the second problem that indicates a profound vulnerability of the contemporary layout of cities, especially in relation to the management of water resources. Adaptation to climate change is one of the most problematic challenges facing urban areas in the future. Climate change is understood as the variation in intensity and frequency of climatic phenomena linked to the increase in temperature due to the accumulation of extensive amount of greenhouse gases in the atmosphere (Bates et al., 2008).

According to the 2018 Intergovernmental Panel on Climate Change

Figure 1:
Relation between the amount of fresh water used and available in the world.
Source: Author based on Manigrasso,2019

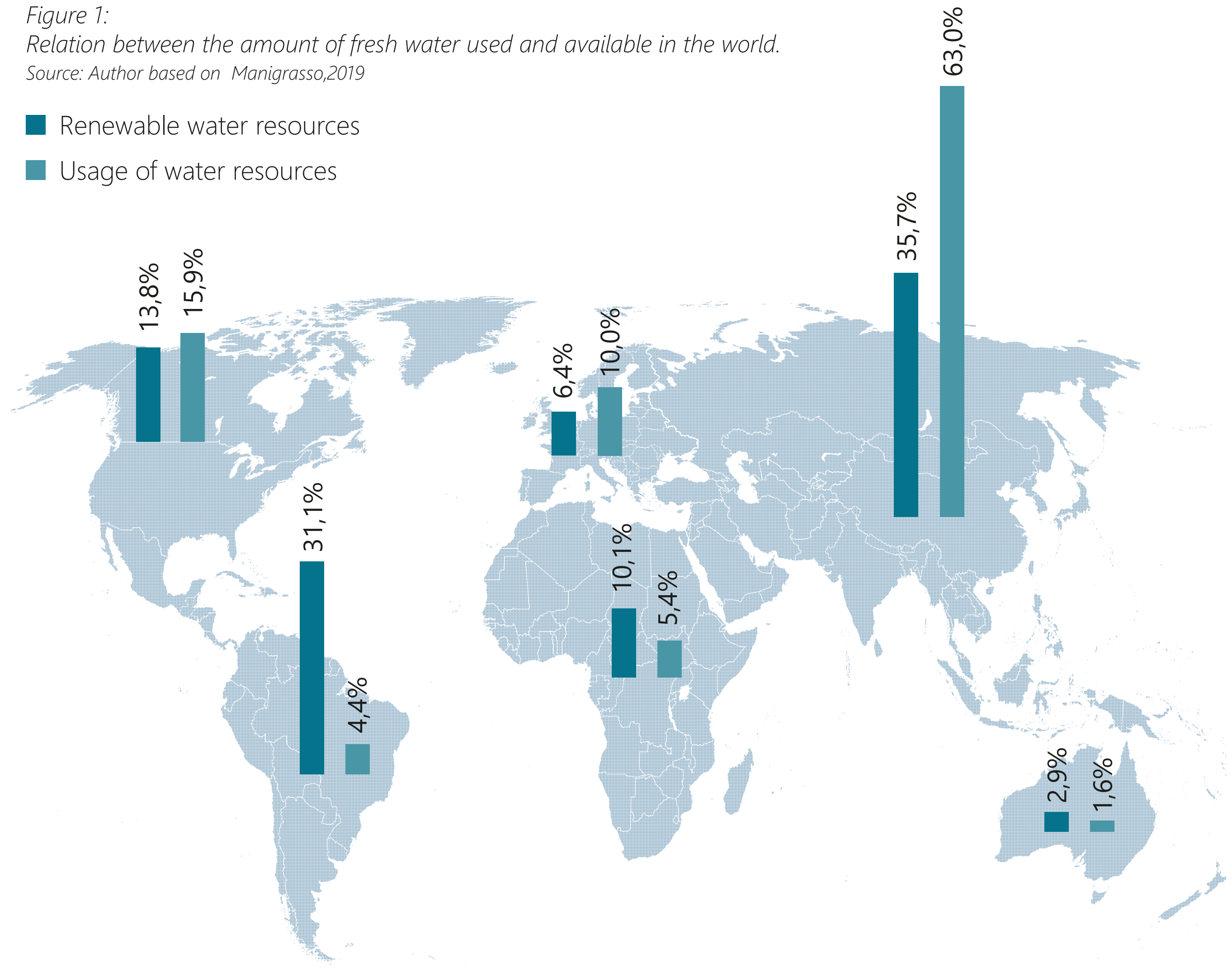
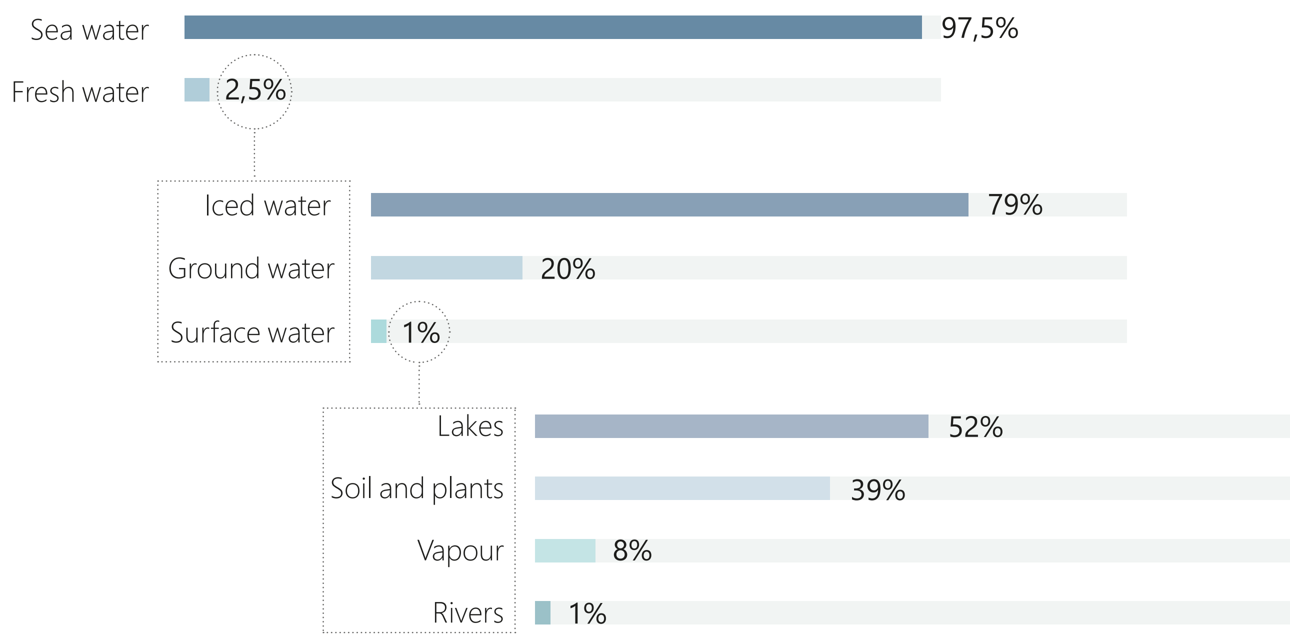


Figure 2:
Distribution of world's water by type and form
Source: Author based on World Bank Graphic



(IPCC), climate change will cause irreversible damage to humans, the built environment and terrestrial ecosystems. This is due to constantly increasing magnitude and frequency of climate events such as heat waves, cloudbursts, thunderstorms, storm surge, droughts, cyclones, typhoons or hurricanes, which make societies particularly vulnerable to water-related disasters (Oral et al., 2020).

Commonly, climate change refers to the global warming phenomenon, which, in addition to increasing the Earth temperature and altering the balance of the Earth's ecosystem, significantly influences other climatic events, the manifestations of which directly harm humans and the cities in which they live. The element most affected by climate change is certainly water. As a matter of fact, the hydrological cycle is an essential component of the climate system as it is responsible for the interaction between Earth and the atmosphere. So, a possible alteration facilitates the onset of natural events that compromise the natural balance, aggravating existing phenomena or introducing new ones. An example of this are sudden periods of drought during the winter seasons, with strong repercussions on the economy, liveability, energy consumption and with strong repercussions on natural habitats and the protection of biodiversity (UNESCO, 2020). According to 2019 data collected by the Emergency Events Database (EM-DAT), 74% of all natural disasters between 2001 and 2018 are related to water, especially flooding, droughts and sea level rise (Figure 1).

The former refer to events of overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged (Seneviratne et al., 2012). Periods of water stress are caused by the absence of precipitation or high temperatures that generate a water imbalance and can usually be influenced by local conditions related to geology, vegetation or water use. With regard to sea level rise, there is a widespread consensus that this phenomenon is attributed to melting ice and the consequent global threat to coastal areas, increased intensity of tides and storm surges, and an increase in the amount of water in the atmosphere (Seneviratne et al., 2012).

In general, climate projections indicate with high likelihood that the world will experience more frequent and intense extreme weather events in the future (Bates et al., 2012). However, it is still impossible to predict with any certainty when and how strong these events will occur, making it complicated but still necessary to implement protection and adaptation strategies. Examining in more detail the effects and variability of the water cycle subject to urbanisation and climate change, it can be seen that precipitation is the main driver in the management of the water balance and the most affected events (McCarthy et al., 2001).

Considering first the consequences of climate change on precipitation patterns, the increase in temperature and water evaporation leads to an increase in the percentage of water vapour retained in the

Figure 3:
Spatial distribution of water-related disasters (droughts, floods, landslides and storms), 1990–2020
Source: Author based on EM-DAT, CRED | www.emdat.be

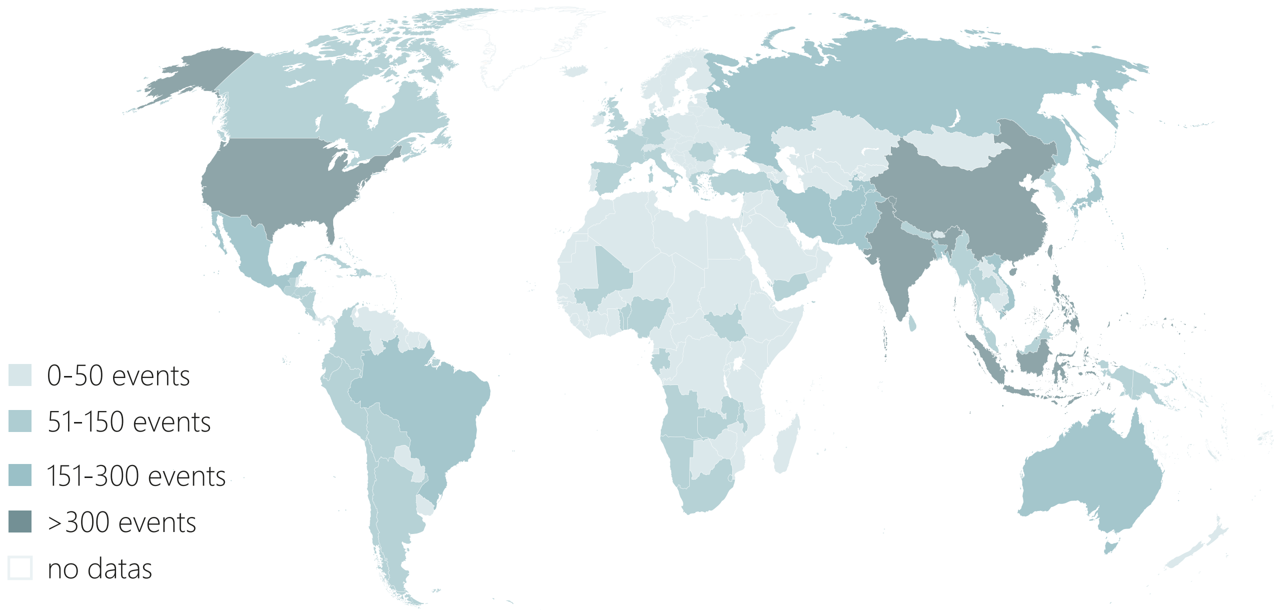
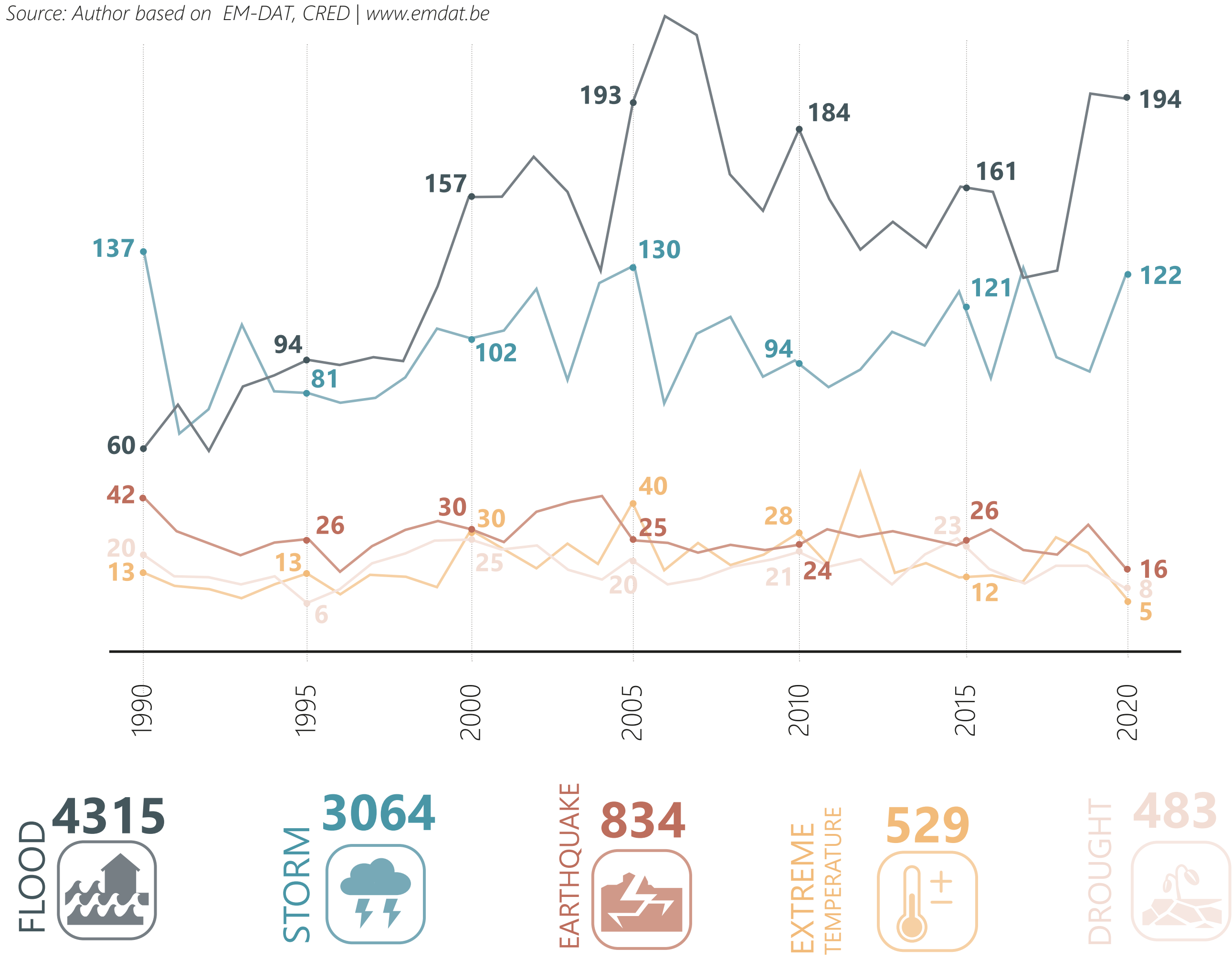


Figure 4:
Distribution of climate-related disasters, 1990–2020.
Source: Author based on EM-DAT, CRED | www.emdat.be



atmosphere and thus in the relative humidity of the air. According to the Clausius-Clapeyron's physics relationship, an increase in water vapour concentration corresponds to an increase in extreme precipitation events, resulting in flooding. Floods pose a number of risks to people and the urban environment, such as the destruction of property or public infrastructure, erosion and geological damage, the transport of pollutants and contamination of water bodies, the loss of economic opportunities and livelihoods, and the spread of water-related diseases and health risks (Ashley et al., 2005).

If we look at the statistics on climatic events, we can see that floods are the most frequent climatic phenomena and affect the largest number of people. The damage caused by flooding to urban environments is exacerbated by the continuing development of cities. Soil sealing results in a greater accumulation of surface water and an increase in the volume of runoff that is conveyed into the drainage system. Stormwater management infrastructures are loaded with more water than their capacity causing widespread overflow problems, contributing to the flooding of urban spaces. Among the most serious consequences is the spread of wastewater and surface pollutants with serious damage to the health and sanitation of the city and its inhabitants. Although climate studies show that it is extremely difficult to predict the occurrence and frequency of extreme precipitation events, future projection models reveal with high confidence an increase in the intensity of average rainfall with a substantial increase in extreme events in tropical and mid- and high-latitude areas, and an increase in droughts during the summer seasons in the mid-continental regions of the world (Figure 5). The uncertainty in the accuracy of climate events combined with the high risks associated with flooding has made stormwater management an increasingly topical issue in the administrative and planning dynamics of the world's major cities (UNESCO, 2020).

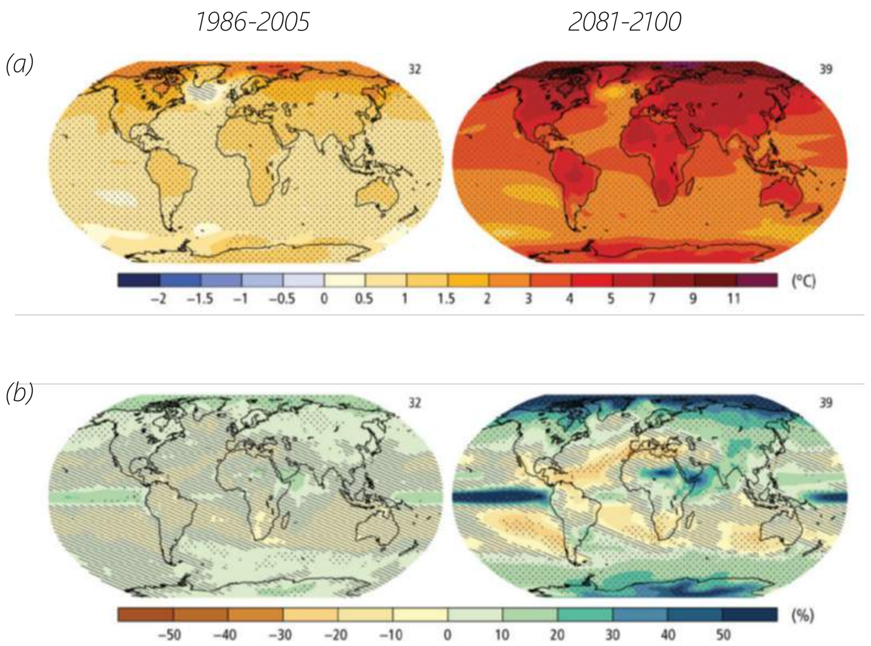


Figure 5:

The average of the model projections available the RCP2.6 (left) and RCP8.5 (right) scenarios for (a) change in annual mean surface temperature and (b) change in annual mean precipitation, in percentages. Stippling dots on indicates regions where the projected change is large compared to natural internal variability and where 90% of the models agree on the sign of change. Diagonal lines show regions where the projected change is less than one standard deviation of natural internal variability in 20-year means.

In conclusion, the linkages between climate change and water resources are subject to a number of anthropogenic factors that relate mainly to land use and land cover change, water regulation and withdrawal systems, and water contamination. These factors are embodied in the creation of engineering infrastructures for the control and management of water resources, infrastructures that are more commonly referred to as 'conventional' and that have ensured ever better access to safe water supply and sanitation services, as well as the protection of urban environments from climatic actions. Unfortunately, new climate scenarios, combined with the inadequacy of conventional infrastructures for the new size and demands of cities, threaten these strategies in several ways, requiring a new, climate-smart approach to water resource management.

As water management is an issue that affects many different sectors including energy, health, food security, mobility, labour and nature conservation, the new approach required must be multidisciplinary and include all water-dependent sectors. The city is recognised as having three key roles in the climate change debate (Manigrasso, 2019):

- active-negative, as its growth in terms of population affects consumption by altering and compromising the urban microclimate

- passive-negative, as the city is a direct subject of climate change effects

- active-positive, cities become laboratories for experimenting with new adaptation and mitigation strategies to combat the advance of climate change.

For this reason, the tool of urban planning is the most immediate, functional and lasting response to the problems described above, as it allows us to rethink the urban structure in order to limit its negative contributions by enhancing its active-passive role. This must be done according to the principles of resilience, going to re-establish the city-water relationship through sustainable solutions that look at water as a potential future resource rather than a present threat. The arguments and results reported within this thesis are functional to demonstrate how the adoption of urban planning focused on the safeguarding, integration and involvement of water in the various anthropic processes allows the cities of the future to be modelled in such a way as to resist the new climate scenarios and to exploit them for the development and innovation of the city itself.

BOX1: EUROPE AND CLIMATE CHANGE

Records of extreme climate events with disastrous consequences have raised general concern and highlighted the need to provide for measures to adapt to the climate changes already underway and to prevent future effects. For this reason, Europe has started a development policy years ago aimed at adopting concrete tools and solutions that equip the Union and its member countries to deal with future climate scenarios (Manigrasso, 2019). With regard to the initiatives taken by the EU, it is worth highlighting the establishment of specific bodies to facilitate the exchange of information and data to support decision-makers in the transition towards more sustainable and resilient Nations. Thus, in 1990 the European Environment Agency (EEA) was established for environmental policies, in 2005 the Euro-Mediterranean Center on Climate Change to promote knowledge on climate change and, in more recent years, The European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation (ETC/CCA) and The European Climate Adaption Platform (Clima-ADAPT) to support national policy makers. In particular, the Climate-ADAPT platform promotes the exchange of data on (Manigrasso, 2019):

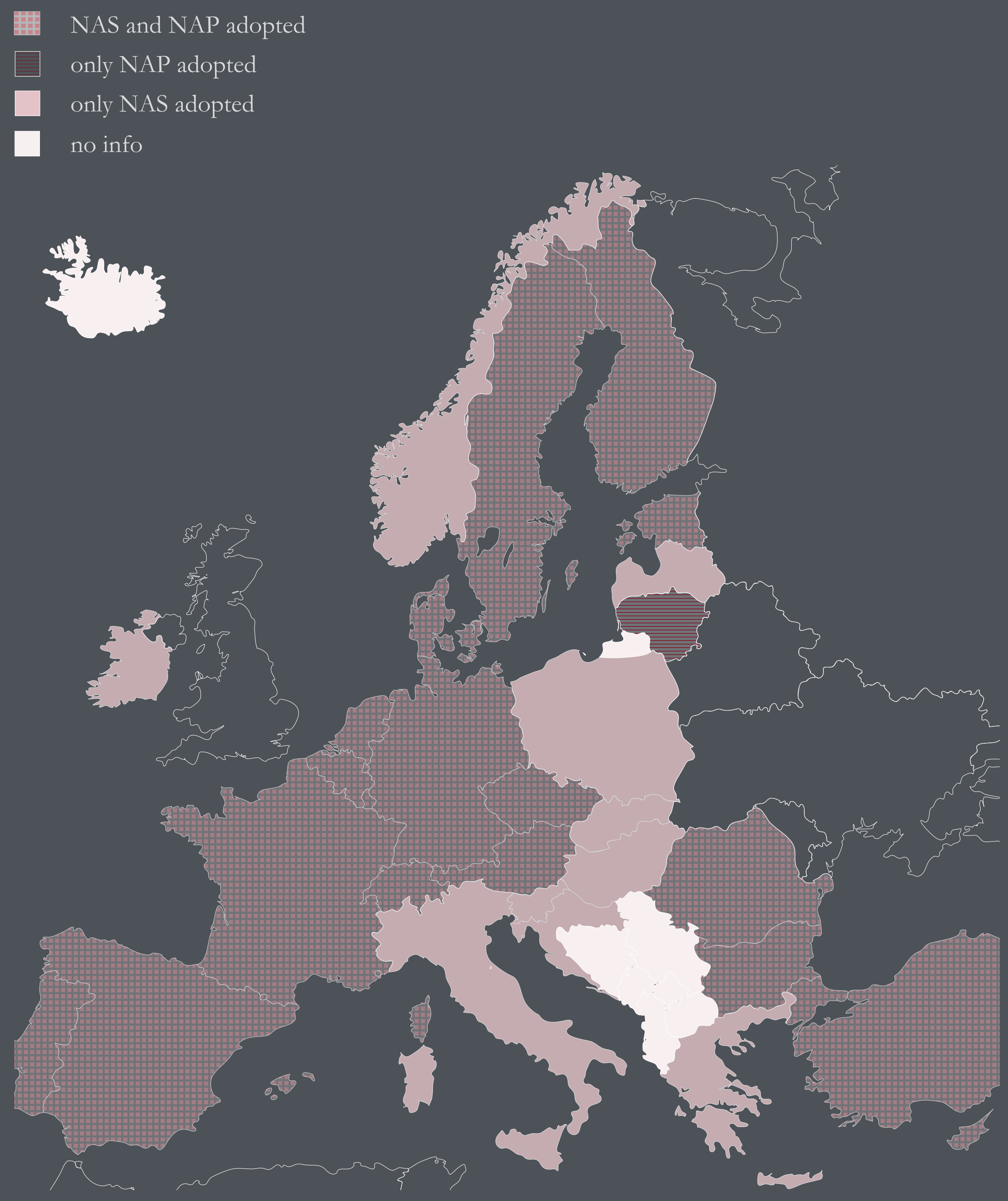
- climate change scenarios
- impacts and vulnerabilities on people and territory
- adaptation plans and strategies
- existing adaptation measures

In addition to setting up specialised organisations on climate and environmental issues, Europe has adopted several political strategies aimed at pushing Nations to adopt concrete adaptation and mitigation plans and policies. In 2013, the European Commission presented "A European Strategy for Adaptation to Climate Change", encouraging countries to adopt serious policies aimed at reducing sectoral and territorial vulnerability to the effects of climate (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2015).
According to a 2018 EEA report, European countries have moved in different ways and at different times in following EU guidance. In particular, 28 countries have adopted a National Strategy (NAS) on climate change issues but only 19 have translated it into a concrete Adaptation Plan (NAP)[1]. Countries such as Denmark had already adopted a strategy in 2008, which was translated in 2012 into an action plan focused on making the national territory rainproof. Other countries, such as Italy, have moved less quickly and are still in the process of developing a National Plan, but unlike some countries, they have at least a National Climate Change Adaptation Strategy (SNAC).

[1] *All information about the National Adaptation Strategy (NAS) and National Adaptation Plan (NAP) are available at: climate-adapt.eea.europa.eu-country profiles*

European Countries' Profile in Adopting Climate Change Adaptation Strategies and Plans

Source: Author based on climate-adapt.eea.europa.eu



Prologue

The present research took birth from the Internship at Southern University of Denmark (SDU) in collaboration with the Urban Resilience research group in the area of urban resilient transition and the causes and effects of climate change on cities. The research was developed in the frame of UNESCO's works, conducted by the Intergovernmental Hydrological Programme (IHP), an international cooperation programme on water-related issues and problems. Currently in its eighth phase, the IHP (2014-2021) covers six thematic areas focused on better manage and secure water in order to ensure the necessary human and institutional capacities.

The research contribution falls under the topic of " Water and human settlements of the future", responsible for investigating the relationship between water and cities. Specifically, the project has focused on the construction of a Literature Review regarding the concept of Water Sensitive City (WSC) and its applications in urban design. Through the study and analysis of the material available in the literature it was possible to define the state-of-the-art and highlight any gaps in the theory. The materials produced during the internship, in constant collaboration with the SDU Resilience team and UNESCO, made it possible to collect the materials necessary for the compilation and analysis reported in this paper.

Aim of the research

In current discussions about climate change and cities, the research focuses on the study of the new concept of Water Sensitive City, as a holistic and all-encompassing way to manage the urban water cycle, through the integration of technological development, social empowerment, policy and planning tools in order to make cities more sustainable and resilient.

From the theoretical concept of the research, it aims to demonstrate how a water-sensitive approach can promote alternative solutions for stormwater management that can adapt the urban environment to future extreme events, ensure greater safety for citizens and promote a range of alternative benefits towards greater sustainability, health and liveability of the city.

The practical application of these concepts is not yet commonly used, but there are some cities that are attempting to create such a water narrative to transit through a sensitive future. In this way, the final purpose of the research is to use the learning outcomes from a frontrunner example in urban water management to provide possible suggestions and promote debate on support Italian's planners and decision-makers in their future approaches.

Hypothesis and research questions

The aim of this thesis is to investigate the dependency between urban planning and the management of extreme climate events related to water. The starting hypothesis is that currently urban planning of cities does not sufficiently take into account the problems related to climate change and especially water management, leading cities to be helpless in the face of climate events that characterize contemporary scenarios. For this reason, the research aims to address:

How does water-sensitive urban planning affect the adaptation of cities to the problem of flooding?

In order to structure the discussion of this question more effectively, the thesis has been organised into sub-questions based on the analysis of specific case studies needed to exemplify the concept.

Is the city of Copenhagen an example of a city integrating water-sensitive policies and solutions to take advantage of stormwater events?

In particular, the final question concerns the evaluation of a possible replicability of the strategies and tools adopted by other realities to lead them to the achievement of a more water-sensitive urban form. The comparative case examined is the city of Padua.

Does the city of Padua have the necessary tools or the potential to become a more water-sensitive city regarding stormwater management?

Objectives

The objective of this thesis is to demonstrate how the lack of a sensitive and resilient approach to the management of water-related climate change problems can be resolved through the study of already implemented strategies and through a critical analysis of how they can be replicated in different contexts.

The analysis conducted involves the identification of a model by means of whose study and evaluation it is possible to determine the transposition of its peculiar characteristics to other geographical, political and economic contexts. This process is aimed at increasing global awareness on the theme of urban water cycle and stormwater management and at identifying solutions applicable to vulnerable realities in either general or context-specific terms.

Limitation of the study

The thesis focuses on the concepts of urban water management analysed from the theoretical and practical point of view of the tools used by decision-makers to develop an urban planning and development project. The subject matter covers a number of transversal urban planning issues such as affordability, political and regulatory frameworks and hydraulic characteristics, which would have required more in-depth and multidisciplinary research.

For this reason, the analysis of the expected economic costs, the necessary legal instruments and the technical calculations on the hydraulic dimensioning of the infrastructures have not been dealt with in depth in this work. Nevertheless, the importance of considering issues from other disciplines in order to define a comprehensive and truly applicable framework for action is stressed several times.

Structure of the thesis

The master thesis is framed as follows:

CHAPTER 1: The theoretical background of the thesis starts with an in-depth examination of the concept of Water Sensitive City, as an innovative approach that sees a change in the conventional way of managing water within cities. The chapter then focuses on the concept of Water Sensitive Urban Design, recognised in the literature as the translation of WSC theory into the practical context, and concludes with a greater focus on stormwater management strategies and solutions, one of the three areas in which the urban water cycle is presented.

CHAPTER 2: The following chapter focuses on the selection and analysis of some case studies related to the concept of Water Sensitive Cities and concerning in particular stormwater management. The selection and analysis of the case studies is done using particular indicators developed within the research conducted for the UNESCO IHP. The case studies presented are selected according to scale and are practical examples of recognised value for inspiration.

CHAPTER 3: This chapter is dedicated to the analysis of the policies and solutions adopted by the city of Copenhagen to adapt urban space to the new climate scenarios resulting from climate change. The case of Copenhagen is analysed as a best practice in order to understand how this can serve as a model for other cities in adopting urban strategies on cloudburst management.

CHAPTER 4: The fourth chapter focuses on the city of Padua. The analytical approach adopted aimed at highlighting the current state of the Veneto city in terms of policies and solutions for managing flooding phenomena in order to paint as precise a picture as possible of the vulnerability and potential of the territory and to understand the possible replicability of the principles reported in the Copenhagen study.

CHAPTER 5: The final chapter focuses on the processes that would need to be modified in order for Padua to initiate a transition process towards a more water-sensitive future, proposing an action strategy aimed at modifying the current institutional set-up to favour the introduction of more innovative practices in the water management sector.

1.

WATER SENSITIVE CITIES
A theoretical vision to urban stormwater management

1.1 Water Sensitive City: a vision for the city of future

The need for a new approach to urban water planning and management is clear as explained in the introductory chapter. Thus, the vision expressed by the Water Sensitive City (WSC) concept is a possible solution, which the practical development is realised through the idea of Water Sensitive Urban Design (WSUD). Pursuing the study of these two concepts, attention is focused on stormwater urban management as a planning intervention resulting from the application of the theoretical and then practical principles of WSC.

The concept of water sensitivity in urban environment has been firstly introduced, as stated goal, by Australian Commonwealth's National Water Initiative (Brown et al., 2009) under the label: "Innovation and Capacity Building to Create Water Sensitive Australian Cities":

Clause 92

The Parties agree to undertake the following actions in regard to innovation:

i) develop national health and environmental guidelines for priority elements of water sensitive urban designs (initially recycled water and stormwater) by 2005.

ii) develop national guidelines for evaluating options for water sensitive urban developments, both in new urban sub-divisions and high rise buildings by 2006.

iii) evaluate existing 'icon water sensitive urban developments' to identify gaps in knowledge and lessons for future strategically located developments by 2005.

iv) review the institutional and regulatory models for achieving integrated urban water cycle planning and management, followed by preparation of best practice guidelines by 2006; and

v) review of incentives to stimulate innovation by 2006.

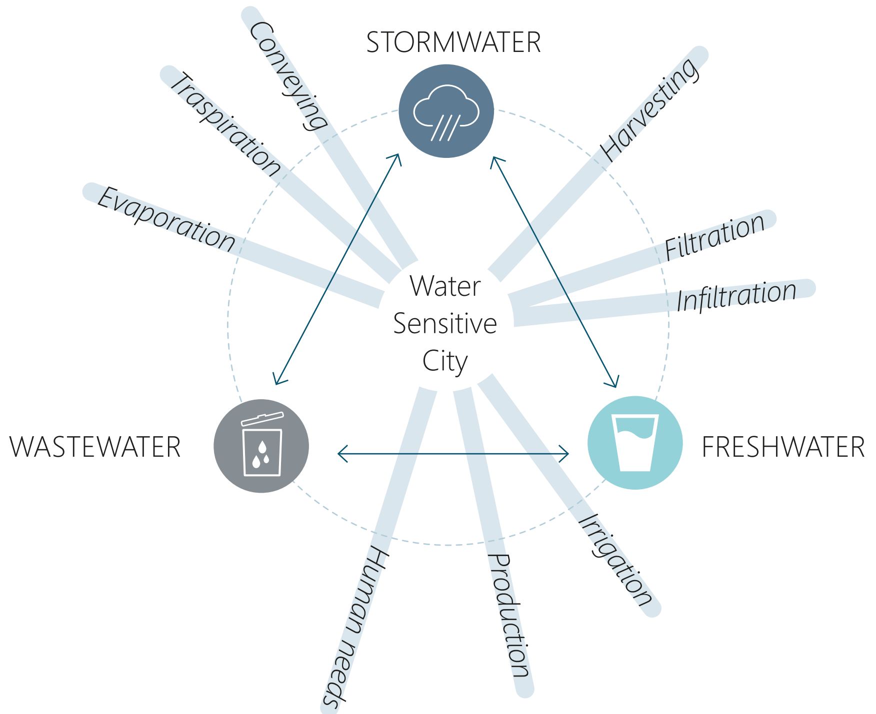
(Council of Australian Governments (COAG), 2004).

The Australian Government was trying to introduce a new water management approach which integrated social and institutional capital with different and sustainable technology to protect and enhance water in urban environment. The need of the Australian government to change policies on water comes from the rising awareness about climate change and water-wide disasters resulting from it (Wong & Brown, 2009).

This concern has led many experts to the formulating new theories and visions focusing on alternative ways of managing urban water. Among these is the concept of a "Water Sensitive City" which is grounded on *holistic management of the integrated water cycle to protect and enhance the health of receiving waterways, reduce flood risk, and create public spaces that harvest, clean, and recycle water* (Brown et al., 2016). Hence, one of the main topics and challenges in reaching the idea of WSC is seeking a socio-technical resilience, which can mitigate the uncertainty of climate change hazards. An urban resilient system is capable of harnessing external disturbances to create new opportunities for innovation and development. The ability to change under the pressure of external events needs a socio-technical perspective that combines human governance and complex infrastructure to develop a new issues management approach (Folke, 2006).

The Water Sensitive City vision is not an absolute principle but is presented in the literature as a set of factors specific to the context of analysis that lead a city to a more sustainable way in water management.

Figure 6:
Holistic action of the Water Sensitive City concept



According to Lundqvist et al., the achievement of more sustainability in this sector is based on the idea of the 'hydro-social contract' (Brown et al., 2009), as an implicit agreement between communities, governments, and business on the governance of water. The hydro-social contract aims to find a proper way to *transform cities through reconnecting best thinking and practice in urban water management, urban design, and social and institutional system* (Wong & Brown, 2009a).

1.1.1 Urban Water Management Transition Framework

Brown et al. (2009) have defined an urban water transition theory which analyses the historical, ecological, demographic, and climatic evolution of cities through the concept of the hydro-social contract. The theory, defined as Water Urban Transition Framework, has been developed as a benchmarking tool to help local governments in transforming cities to more water sensitivity and sustainable environment (Buurman & Padawangi, 2018). According to Brown, to reach the state of WSC it is necessary a transition through six different city-states characterized by a specific hydro-social contract modelled on a technological, ideological, and institutional background. The transition framework is a sequence of phases throughout rigid and conventional systems to more flexible and diversified urban states (Figure 7): Water supply city, Sewered city, Drained city, Waterways city, Water cycle city and Water sensitive city (Brown et al., 2009b).

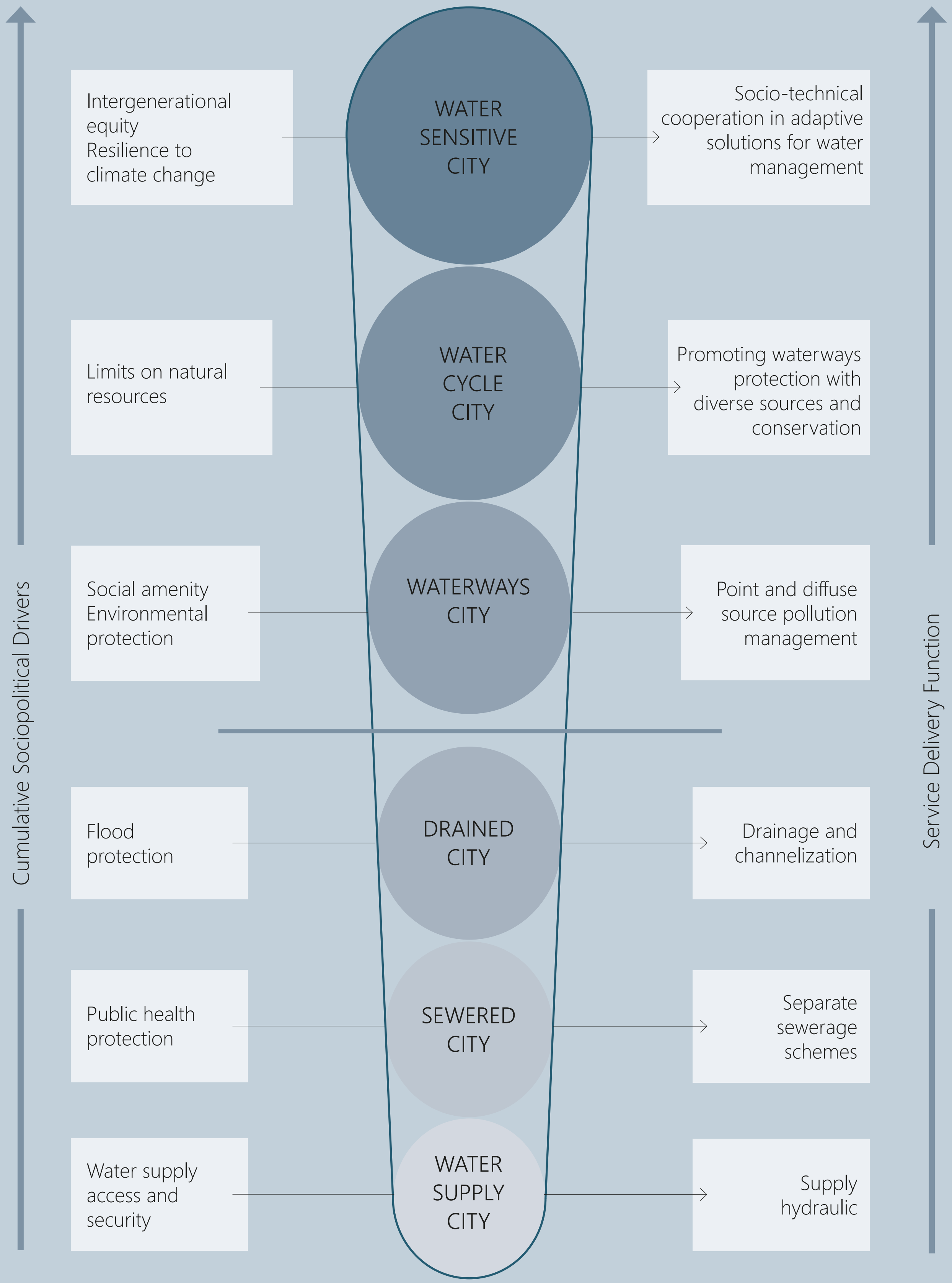
Each state is characterised by two specific indicators: the "Cumulative Socio-Political Drivers", which reflect the evolution in demands and expectation about water management; and the "Service Delivery Functions", which represent the translation of 'Drivers' in concrete services (Brown et al., 2009a). Through the analyses of the evolution of these indexes, it is possible to define the hydro-social contract of each state. The contract is structured as it provides diverse and flexible technologies, infrastructure, and urban forms, designed to reinforce sustainability and social cohesion within a strict collaboration between society and the technology sector (Wong & Brown, 2009). The states are combined in a nested continuum whereby the skeleton of the later city-state forms the basis of the following one (Brown et al., 2009b).

The transition model has been represented as a linear path, but this does not preclude the possibility of leapfrogging from not consecutive states (Barron et al., 2017). In point of fact, the purpose of the water management transition framework is to represent a set of water infrastructure related to specific institutional and community attitudes that reveal the city journey towards a water sensitivity (De Haan et al., 2015).

Examining in detail Brown's framework, the six city-states are defined as (Brown et al., 2016.; Brown et al., 2009b):

WATER SUPPLY CITY	The basic state of modern water management characterised by a centralised system that ensures the supply and distribution of water economically and fairly using infrastructures like pipes and dams (conventional development infrastructure). The community believes that water is an unlimited and harmless good for the environment.
SEWERED CITY	A sewered city aims to ensure public health protection devising a new system for collecting and removing wastewater to reduce the proliferation of diseases and infections. Hence, a sewerage system is built to deliver wastewater to a receiving waterway. As in the earlier state, discharging wastewater into natural receiving waterways is not considered as an environmental problem to the community.
DRAINED CITY	A drained city aims to protect urban environment from flooding, caused by the rapid process of urbanisation and natural soil sealing. Consequently, the institutions involve new urban water service providers and policy for stormwater management through the implementation of drainage and channelisation dumping ground systems to divert water to receiving waterways.
WATERWAYS CITY	The state of waterways city changes completely its perspective. The environmental impacts on water embracing the necessity of new approaches. The rise of pollution of waterways and the social and aesthetic needs of green open space in the urban environment, change the institution perspective towards water urban management. Community and institutions attention are addressed to new decentralized and green infrastructure which provide filtering of polluted waterways and new green recreative urban solution for social health and amenity.
WATER CYCLE CITY	The water cycle city-state derives from the recognition of the limits of natural water resources. Hence, stakeholders consider the possibility of an integrated urban water management focused on new practices of water conservation and unconventional water supply solutions. The water cycle city needs a co-management approach between business, communities, and the government to find new water conservative and protection policies.
WATER SENSITIVE CITY	The water Sensitive City state is framed on the idea of integrating water cycle in urban management to reach a wide of benefits for a better liveability and resilient to climate challenges related hazards. Fundamental is the strict collaboration between society and technology: community is actively engaged and sensitized to water in the city; innovation and technology in planning have to create adaptive and multifunctional infrastructure to protect the health of waterways, mitigate flood risk and create new opportunities through the design of green public spaces. As shown in the Transition Framework scheme, what a WSC aims to achieve is 'Intergeneration Equity', an international principle based on the preservation of natural resources and the environment for the benefit of future generations (Venn, 2018).

Figure 7:
Urban Water Management Transition Framework
Source: Author based on Brown et al.,2009



The six stages described by Brown can be organized in two different macro group: the supply, sewerage and drainage cities against waterways, water cycle and water sensitive cities. The first group cannot be considered as a real transition (change) because the political and administrative regimes are basically unchanged, but each state adds more utilities to the existing portfolio. Contrariwise, the other states deeply modify the establishment of existing infrastructure and policies in order to overcome new challenges related to the climate, cities and environment (De Haan et al., 2015).

A radical change in the social, institutional and technical processes underlying urban water management can fail and lead to unsuccessful conditions sometimes worse than the initial ones. In order to avoid possible failure, the transition process needs to follow ascending steps that facilitate the change of the water management regime step by step so that decision-makers have the time and tools to process the change and adopt effective strategies (Brown et al., 2016).

1.1.2 Water Sensitive City: fundamental principles

The concepts expressed by the Urban Water Management Transition Framework suggest a series of guidelines and strategies to guide decision-makers towards the planning and adoption of more sustainable solutions for urban water management. But how do these actions concretise into design practices?

Before outlining the technological solutions used to achieve the objectives of Water Sensitive City's theory, it is important to highlight the practical principles to achieve water sensitivity. Reflecting the water management transition theory, three pillars have been recognized as fundamental to translate the water sensitive city's hydro-social contract and system resiliency structure into principles for practice (Wong & Brown, 2009):

1- Cities as Water Supply Catchment

> *The first pillar represents the concept of cities not relying exclusively on their natural water sources- be that rainfall run-off accumulated in catchments or groundwater* (Brown et al., 2016).

The rising pressure on urban water supplies has increased the awareness about the alternative solution to collect and use water a part of conventional infrastructure. It becomes necessary to access to a diversity of water sources via centralized and decentralized infrastructure through adaptive and multi-functional solutions (Lloyd et al., 2012). The diversity of sources is associated with harvesting, treatment, storage, and deliver water in urban environment to minimizing the import and export of water from outside the city boundaries (Brown et al., 2016).

Cities have access to water inside the dynamics of the urban water cycle composed of potable water, stormwater, and wastewater systems. Conventional approaches in urban water managing use principally potable water and wastewater, while stormwater is not seen as a potential water source yet (Dobre, 2013).

To transform cities into water supply catchment, it is necessary to replace or implement conventional infrastructures with decentralised infrastructures capable of reducing the impact on fresh water, managing the water resource locally. Moreover, the economic aspects of implementation is a key element to stimulating change, so that preference should be given to solutions that are cheaper or have less impact on the environment (Brown et al., 2016). Using decentralized infrastructure provides diversify in local water utilities with the positive consequence of reducing fresh water demand and usage; upgrading aged and obsolete technologies; delivering more adaptive systems to adverse event (Leigh & Lee, 2019).

2- Cities Providing Ecosystem Services

> *The second pillar envisions an urban landscape that actively supports the environment, rather than degrading it and draining it of resources* (Brown et al., 2016).

The rise of environmental problems and pressure on urban water systems provides the new idea of ecosystem services for built and natural environments in cities. These aim to reach a harmonic balance between water planning and urban planning (Lloyd et al., 2012). Cities need to become more sustainable and resilient to climate change, global warming, and the impact of urbanization on the natural ecosystem. In general, ecosystem services related to urban planning comprise the design of public spaces as a source of amenity for the wide-city concept (urban space and citizen). The complexity of this point lies in the definition of practical solutions capable of conferring functional but environmentally friendly spaces, which combine sustainable water management practices, ecological services such as carbon sinks, innovative food production and elements that foster the development of different microclimates conditions (Brown et al., 2016).

To achieve the goal, it has stated the idea of implementing blue and green infrastructure related to the concept of Water Sensitive Urban Design (WSUD) especially in stormwater management, in terms of both quantity and quality. WSUD largely contributes to the idea of rehabilitating waterways through the union of treatment technologies and urban design, a mix of catchment wide and site-based works, such as wetlands and bioretention system (Brown et al., 2016).

3- Cities Comprising Water Sensitive Communities

The third pillar of practice points to the importance of institutional capacity and social support for achieving sustainable urban water management (Brown et al., 2016).

The concept of Water Sensitive City involves a whole series of principles related to the technical and the social sphere of urban water management. For new water management technologies to be effective, they must be socially related and accepted by local institutions to ensure their successful implementation. Furthermore, to reach a Water sensitive community, the socio-political contribution to sustainability and water sensitive behaviour needs a strict collaboration between science, policy, institutions, and community (Lloyd et al., 2012).The importance of creating a benchmarking network between public and private institutions at a different urban scale, encourage the inclusion of water-related issues in the political administration priorities. Equally important is community awareness and involvement in water services, a key element in promoting people's understanding of the challenges of water in urban environment and consequence need for different management approaches (Brown et al., 2016).

In conclusion, the implementation of decentralised infrastructures allows the adoption of water management solutions on a different scale. This multi-scale capability is essential to ensure that the community is brought closer to water, as it provides the opportunity to involve citizens in planning processes or awareness-raising campaigns about water and the environment in general (Leigh & Lee, 2019). Anyway, at the moment, the third pillar remains one of the most onerous and complex to achieve because it requires the collaborations and acting of different bodies.

As shown in the overview so far, the concept presented is very theoretical. Despite the fact that there are many works in the literature regarding the concept of a Water Sensitive City, it is still a utopian vision of the city of the future, as there are no tangible examples of a water sensitive city yet. Although goals to be achieved and guidelines to be followed have been discussed and presented, a common and shared practical methodology to ensure a concrete result is still missing. Reports can be found about some cities (especially in Australia) which are going through achieving the state of water sensitivity, but nowadays, there are still too many barriers and limits to the concretization of the concept (Brown et al., 2009; Ferguson et al., 2013; Rijke et al., 2012; Wong & Brown, 2009)

The literature on Water Sensitive City and sustainable urban water management agrees that gaps between theory and practice related to the achievement of the Water Sensitive City stage are related to the conventional establishment of water management. More in detail, the existing contrasts are largely caused by (Ferguson et al., 2013):

- Socio-institutional barriers
- Lack of proper community involvement and awareness
- Lack of benchmarking tools and sharing between states for the dissemination of knowledge and practices
- Lack of tools for the analysis of economic and ecosystem benefits derived from the implementation of innovative technologies.
- Without going into excessive detail on each issue, it is possible to define some common problems to all these limitations.

The first issue concerns the inadequate governmental machinery. Indeed, urban water management is still strongly linked to conventional methods, commonly called 'silo' approaches, which are too rigid and inadequate to face challenges characterised by uncertainty, complexity and variability, typical factors linked to climate change (Floyd et al., 2014). Within the water management sector there are several organisations, all with a specific function and interests. Through the introduction of cooperation, co-management and government partnership mechanisms, it is possible to create an environment of trust and collaboration between stakeholders. In such a manner it is possible to build practical experience of long-term, flexible and adaptive solutions (Dobbie et al., 2016).

The second key aspect not to be disregarded is social capital, presented as the third pillar of WSC theory. The implementation of sociological role of water in the city is fundamental for shifting from the conventional approach as this provides a fundamental change in the relationship that the population has with water (Ferguson et al., 2013). The need for a greater involvement of citizens within the planning dynamics, the so called 'bottom-up approach', is well-recognised by the scientific community However, it is also widely acknowledged that the relevance of planning interventions able to increase liveability and guarantee equity in the usage of public spaces to the whole community. The overcoming of the sociological barrier involves the practical recognition of water as element of social interactions between humankind and nature, a developing factor of respectful behaviour towards the environment and an instrument of community cohesion between people (Buurman & Padawangi, 2018).

Finally, a major limitation is recognised in the absence of appropriate cost-benefit assessment methods for decentralised water management solutions (Lloyd et al., 2012). Comparing the cost of conventional water management solutions with new decentralised management technologies, most of the time shows the latter as the more expensive. This is only since the economic-financial tools, for evaluating the cost-benefit of a solution do not consider the implicit returns linked to the benefits related to the environment and the increase in the liveability of urban spaces.

1.2 WSUD: excursus of core principles

After exploring the theoretical principles governing the new philosophy of urban water management, it is necessary to indicate the practical solutions to achieve a better water sensitivity and to provide knowledge for practitioners to implement new sustainable water practices.

A city is sensitive to water when its planning solutions are adaptive and resilient to broad-scale change and aim to minimise the hydrological impact that urban development has on the environment (Bevington et al., 2013). In particular, water must be managed in an integrated way in order to mitigate drought, flooding, to deliver different sources of water supply, to contribute to the preservation and health of the natural environment, and to foster social and institutional capacity (Gersonius et al., 2016). There are many examples in the literature where the concept of planning a water sensitive city is closely related to the concept of Water Sensitive Urban Design (WSUD) (Fletcher et al., 2015; Gersonius et al., 2016; Wong, 2007).

The concept of WSUD has developed in Australia and first appeared in a 1992 publication by Mouritz (Fletcher et al., 2015). The publication specified how the design of urban water management spaces had to aim at the balance between water supplies and water hazards; the maintenance of water quality and the protection and conservation of natural spaces by providing water-related recreational opportunities (Mouritz, 1992). In the 2000s the concept began to evolve, and scientific opinion started to recognise in the principles of WSUD those of integrated management of the entire urban water cycle (i.e. fresh water, stormwater, and wastewater) (Hoyer et al., 2011).

As theories on urban water management have progressively evolved, the concept of WSUD has begun to be confused with the neo-theory of WSC even though the latter considers the city from a socio-technical aspect where water must be managed through practices described as WSUD (Fletcher et al., 2015). Indeed, WSC constitutes the goal, the object to be achieved, while WSUD is the vehicle through which the water sensitive concept is achieved (Brown & Clarke, 2007).

However, the definition of Water Sensitive Urban Design is still not clear among practitioners, as different definitions can be found in various official papers. For example, the intergovernmental agreement on a National Water Initiative defines WSUD as *the integration of urban planning with the management, protection and conservation of the urban water cycle, that ensures that urban water management is sensitive to natural hydrological and ecological processes* (Wong, 2007).

On the other hand, at the IWA/IAHR Joint Committee on Urban Drainage, T. Wong and Ashley defined the concept of WSUD as the combination of two elements: 'Water Sensitive' and 'Urban Design'.

Quoting from Wong & Brown, 2011:

Urban Design is a well-recognised field associated with the planning and architectural design of urban environments, covering issues that have traditionally appeared outside of the water field but nevertheless interact or have implications to environmental effects on land and water. WSUD brings 'sensitivity to water' into urban design, i.e., it aims to ensure that water is given due prominence within the urban design processes.

The words 'Water Sensitive' define a new paradigm in integrated urban water cycle management that integrates the various disciplines of engineering and environmental sciences associated with the provision of water services including the protection of aquatic environments in urban areas. Community values and aspirations of urban places necessarily govern urban design decisions and therefore water management practices. Collectively WSUD integrates the social and physical sciences.

Thus, this concept fits within the idea of Ecologically Sustainable Development (ESD)[2] but focuses specifically on the water issues (Figure 8). More precisely, WSUD describes planning practices that integrate aspects of urban design and building form with water cycle management and socio-economic issues (Ashley et al., 2013). In particular, integrate water cycle in urban settings means to operate on potable water, stormwater and wastewater. The aim is to conserve water as a fundamental resource, control the level of pollution of wastewater and stormwater and mitigate the phenomena of city flooding due to increased surface runoff (Wong, 2007).

[2] *Australia's National Strategy for Ecologically Sustainable Development (1992) defines ecologically sustainable development as: 'using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased' (www.environment.gov.au/about-us/esd).*

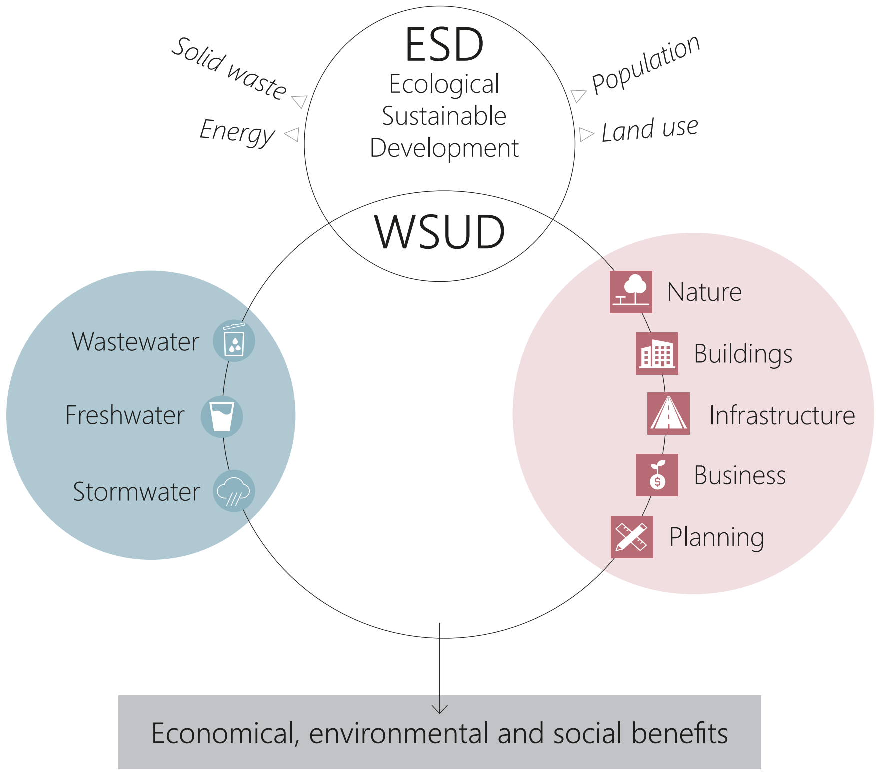


Figure 8:
Interactions between WSUD, the built environment,and the urban water cycle.
Source: Author based on Ashley et al., 2013

In this way water becomes an element of urban planning which must consider solutions related to the maintenance the natural hydrological behaviour of water resources and existing natural features. Moreover, WSUD solutions provide protection from damage related to climate events and provide a series of related environmental benefits on multiscale (Dolman et al., 2013). Furthermore, operating according to WSUD principles, water must be introduced as an element of the urban landscape in order to satisfy the desires of the local community and the stakeholders linked to the places but preserving the aesthetic, functional and intrinsic values of water (Wong & Brown, 2011).

In conclusion, the implementation of WSUD aims to minimise the impact of urbanisation on the urban environment and water, seeking to create a new idea of a city where man and nature live more symbiotically (Ashley et al., 2013).
Therefore, the pillars on which the application of WSUD solutions is based are: (Ashley et al., 2013; Bevington et al., 2013):

- Adopt planning strategies aimed at water conservation, i.e., manage water to deal with both water scarcity and water excess, managing both water quantity and quality, concurrently and in an integrated way.

- Manage and utilise the water cycle as locally as possible as all aspects and occurrences of water are potential opportunities (exploit local opportunities)

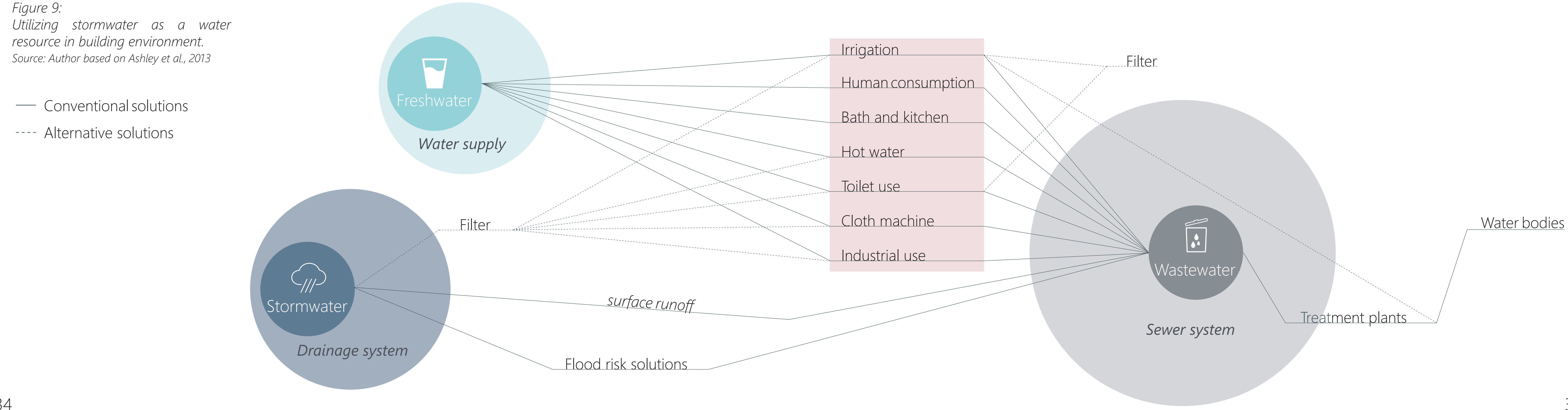
- Deal with water appropriately and synergistically in urban environments, including ecosystems, and across urban services, design and planning processes (Ashley et al., 2013).

On a practical level, the principles that describe the WSUD concept are realised through decentralised infrastructures. These operate as close as possible to the resource, treat urban water in its different forms in order to reduce its consumption, control the quality by reducing pollutants and recycle water to reintroduce it into other urban cycles (Figure 9) (Ashley et al., 2013). The implementation of a decentralised system consists of the synergy of physical and non-physical (social and institutional) solutions. The former concern the implementation of specific technologies in building and landscape forms, while the latter refers to political and governmental structures to manage and facilitate the integration of these practices into common urban and architectural planning (Wong & Brown, 2011).

The adoption of decentralised solutions, which are more precisely defined as green infrastructure (GI) in the WSUD framework, has to be done operating at different scales in order to cover water management on the whole territory (Dolman et al., 2013). Hence, technical solutions have to vary from the local to the district up to the regional scale, acting on buildings, parks and roadways.

This synergistic approach on different scales aims to create an integrated system of solutions that work together to create a unified system (Wong, 2007). In this way, the planning and management of the system not only allows urban water management to be more effective and sustainable but also increases the liveability and aesthetics of the area by introducing green and blue elements and combating soil sealing (Costa et al., 2015). The effects of the implementation of this type of solutions concern the reduction in the use of drinking water with the consequent decrease in the generation of wastewater.

Figure 9:
Utilizing stormwater as a water resource in building environment.
Source: Author based on Ashley et al., 2013



Furthermore, rainwater harvesting contributes to the mitigation of flood damage, provides a new alternative water resource and counteracts urban drought. The treatment of wastewater and stormwater saves drinking water, reduces pollutants and improves the health of waterways and the environment in general (Wong, 2007).

As regards non-physical solutions, it is widely recognised that the main problem related to the difficulty in adopting a WSUD approach concerns the socio-institutional barriers related to urban water management. In addition to the lack of collaboration between different stakeholders, but also between professionals from different fields, the main problem is the absence of guidelines that help designers and planners to introduce the strategies described above into the projects and development plans of a city (Rodríguez & Cuevas, 2014). It is also necessary to increase citizens' social sense of belonging to places in order to encourage them to collaborate in the maintenance and preservation of natural ecosystems within cities (Costa et al., 2015).

To overcome this limitation, it is necessary to introduce sustainable urban water management practices from the earliest planning stages by introducing planning criteria that allow the integration of water-sensitive solutions with common urban planning forms (Rodríguez & Cuevas, 2014).Articulating urban planning in 4 successive phases, the criteria can be exemplified as follows:

1- PRE PLANNING PHASE

The pre-planning phase consists of defining the objectives and strategies to be followed in planning. In order to introduce Water Sensitive Urban Design solutions into building and landscape forms it is necessary to have a dialogue with the authorities in order to define possible restrictions in the implementation of certain technologies, to involve all stakeholders and community representation to discuss the needs and to sensitise the different actors towards water sensitive practices. Finally, it is necessary to build a multidisciplinary team including town planners, urban designers, landscape architects, and highway and hydraulic engineers in order to meet the complexity needs of implementing these innovative solutions. *WSUD must be present at the early stages of the planning process, so that it can directly inform or influence local and city planning and plans. It must be part of the consultative process of planning process, where communities can engage with the concepts and accept advocate or reject them. Local communities are generally very responsive to concepts of water-sensitive urban design* (Costa et al., 2015).

2- EARLY PLANNING PHASE

Once the strategy has been defined, it is necessary to carry out all relevant analyses combining site surveys with hydraulic models, stormwater flow and flood risk maps. Concerning the water use and risk of the urban space, it is necessary to start thinking about which green and blue infrastructures could be more suitable for the case in question. The planned infrastructures must constitute an integrated system in order to generate ecological corridors and specific paths where water can flow and be managed in its different processes.

3- DEVELOP PLANNING PHASE

It is necessary to train planners on the different technologies already implemented to sensitively manage water in urban contexts. There are different solutions that collect, delay, treat and infiltrate water from the natural or built environment. Subsequently, it is necessary to carry out more in-depth analyses of the chosen solutions in order to size them according to the specific needs of the area. In general, these considerations are derived from climate scenarios and statistical forecasts based on the amount of water flowing on the surface and occupying the sewer systems. Before designing the plan, it is necessary to discuss the decisions made with the property owners and managers.

4- POST PLANNING PHASE

The maintenance process is fundamental to ensure the proper functioning of the built solutions. To ensure that proper and regular maintenance is done, it is necessary to involve stakeholders and inform them about how WSUD solutions work. It is essential to foresee measures to monitor the effectiveness of the solutions and eventually provide for a redesign or renovation of systems where it is needed.

1.3 Sustainable Stormwater Management

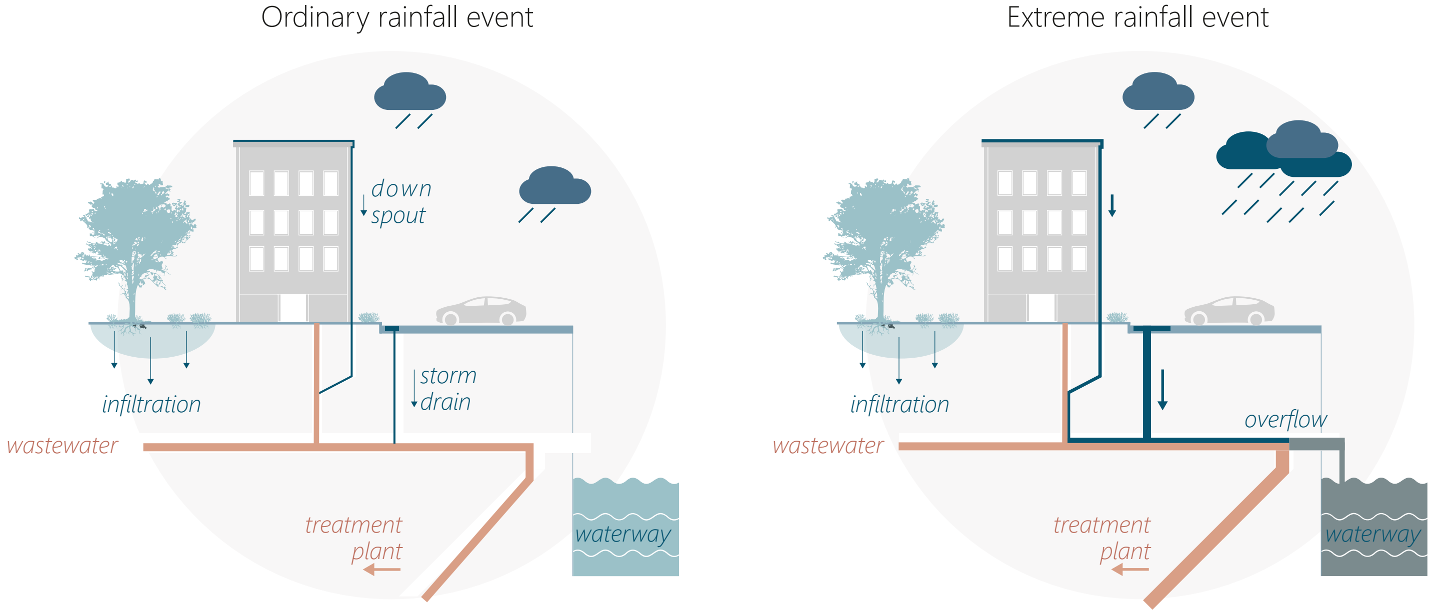
Managing the impacts of urban development on the water environment must include attention to all three streams of the urban water cycle and necessitates an integrated approach (Wong, 2007).

As previously explained, Water Sensitive Urban Design aims to combine planning with a sustainable approach to urban water management in its multiple forms. Originally, the concept of WSUD referred to the management of the entire urban water cycle. With the advancement of technology and the intensification of climate change issues on urbanisation, the same term started to be used to describe the practices of Sustainable Stormwater Management (SSM) (Hoyer et al., 2011). How previously stated, stormwater has always been seen as a source with no value (Costa et al., 2015; Dobre, 2013). For this reason, conventional stormwater management has traditionally been focused on drainage, where engineering works were built with the single aim of conveying rainwater runoff rapidly and economically from a local area to the treatment plants and finally to a receiving water-bodies. This practice is based on networks of pipes and drains and it is not able to exploit the enormous potential behind rainwater reuse (Wong, 2007).

Adopting a Sustainable Stormwater Management solution helps to save drinking water, recharges the water table even during the driest periods, reduces the risk of flooding by relieving pressure on the sewerage system, saves energy on water purification systems and contributes to a more liveable urban environment (Costa et al., 2015).

Stormwater management has become a central issue in urban water management as the infrastructure adopted so far has begun to show itself ineffective in managing future scenarios. Indeed, most of the countries have a combined sewer system, i.e., they use a single network for the disposal of wastewater and stormwater. During normal rainfall events, the water is directed to the treatment plants, whereas in the case of extreme events, the volume of water discharged is too large to be directed to the purification systems, so part is discharged (still in the form of wastewater) into natural waterways (Figure 10). This type of water infrastructure, called centralised urban water systems, is very vulnerable as it is not designed to adapt to changing anthropogenic and climatic conditions (increased urbanisation and climate change) (Leigh & Lee, 2019). Indeed, each element of the urban drainage network is designed exclusively to collect and remove a pre-determined amount of water. Adaptation and development of the network is sometimes very costly as it requires large amounts of energy and constant maintenance processes. A further drawback is the impact these infrastructures have on the environment and on humans. The implementation of large-scale engineering interventions leads to an alteration of the natural hydrological system and sometimes generates environmental problems, such as stream depletion, shoreline erosion, and other negative biological outcomes.

Figure 10:
Functioning of a combined sewer under different stormwater conditions
Source: Author based on www.shapeourwater.org



In addition, channelling and piping water underground detracts from the aesthetic value of the environment and leads to a lack of community participation in issues concerning water as a natural element (Ahiablame & Engel, 2012).

On the contrary, the use of decentralised solutions, such as Sustainable Stormwater Management techniques, are more flexible and therefore resilient in stormwater management. They can be integrated more into different urban dynamics as well as implemented jointly with other projects (Leigh & Lee, 2019). Indeed, adopting SSM policies can be used to create places that serve both the demands of urban drainage and urban planning. From the point of view of urban drainage, it is necessary to provide an efficient system that is simple and easy to maintain, also in terms of economic costs. Alongside, consider the aspect of urban planning, decentralised solutions allow to conceive pleasant, meaningful, and educational natural spaces (Hoyer et al., 2010). In more detail, SSM practices are based on green and blue infrastructures capable of retaining and slowing down rainwater to facilitate natural infiltration, avoid surface accumulation and treat heavy pollutants (Ahiablame & Engel, 2012).

The term treatment does not refer to conventional practices of water purification using special plants but concerns the use of natural processes such as infiltration, evapotranspiration, filtration and sedimentation. These processes decrease the concentration of pollutants in water and return it to a nature-oriented water cycle in the city (Hoyer et al., 2011). Implementing these solutions brings numerous economic, environmental and above all social benefits. Another key aspect that makes decentralised water infrastructures a better solution for rainwater management is their contribution to rain runoff management.

Indeed, by adopting green solutions that are spread throughout the territory but integrated as an action, they counteract the emergence of runoff mechanisms and reduce the peak flow that arrives on the downstream areas, so that the volume of rainwater to be managed is smaller.

When translating the principles underlying the concepts of SSM into practical solutions, many examples of different technologies, mainly concern systems, can be found in the literature. The proposed solutions refer to specific stormwater management needs and site situations, described according to their unique characteristics, advantages but also disadvantages in order to let practitioners choose the most appropriate and effective solution for the case (Hoyer et al., 2011).
Solutions are grouped according to their main function. In particular, it is possible to identify practices related to quality and quantity control such as rainwater use (storage), treatment, detention, infiltration, conveyance and evapotranspiration.

RAINWATER USE (storage and recycle)

- Rainwater use solutions are particularly effective when it is necessary to reduce the use of water, energy and general management costs. These techniques consist of using rainwater within the built environment, catching and detecting it before re-introducing it into building systems. Under this category can be found rainwater harvesting solutions as: Rainwater cisterns, water tanks or natural basins. Cisterns and tanks can be either surface or underground. Cisterns are usually large storage devices where water is collected and after treatment processes can be reused as a resource inside buildings for example in bathrooms, kitchens or for the fire-fighting system. Water tanks, on the other hand, are smaller devices normally used to collect water that is reused without purification processes for external use. Natural basins or ponds are normally only large infrastructures (fountains, pools or artificial lakes) that are used to retain and filter water in large open spaces, very often in urban settings such as parks or large communal courtyards. But these solutions are normally used to retain and infiltrate rain.

TREATMENT

Stormwater treatment is a key practice if rainwater is to be reused for domestic, public or industrial purposes. Indeed, it is essential to purify rainwater of pollutants before it seeps into the ground or it is discharged into reservoirs, helping to maintain its cleanliness. It is important to emphasise that the treatment infrastructures described do not guarantee a water quality that meets the standards expressed in the guidelines for the certification of drinking water quality. Within this category are:

- Bioretention areas are shallow landscaped depressions suitable for collecting rainwater runoff and releasing it gradually. Bioretention solutions typically drain from below and rely on engineered soils, enhanced vegetation or filtrating sands to remove pollution and reduce downstream runoff. Certainly, an advantage is that these systems come in various sizes and shapes and support different types of vegetation typical of the area, favouring the protection of floral biodiversity. The presence of various natural species facilitates the abatement of pollutants and the reduction of water volume through processes such as infiltration or evapotranspiration[3] . Because of this variety, bioretention systems can be landscaped and adapted for a variety of urban spaces, being perfect for residential or commercial settings but also versatile in other urban contexts. A further aspect is a possibility of hosting recreation activities during dry periods.

[3] *According to some studies, 20-50% of rainwater is consumed through evapotranspiration and 48-74% through infiltration (Ahiablame & Engel, 2012).*

- Biotopes or Raingardens are landscape configuration of plants (and animals) deliberately assembled for ecological stability. These solutions can be used to improve water quality using natural process such as oxygenation. These techniques involve the use of reed beds or other plants typical of wetland habitats. In addition to increasing water quality, biotopes can be used to add aesthetic value to the environment through the use of aquifer elements. Besides, the typical vegetation of these systems, tall and dense, can easily be used as protection from winds or to conceal unpleasant views. Wind, moving through the reeds creates a soothing atmosphere and educates visitors on natural processes while increasing biodiversity in the city.

- Gravel or sand filters are used as the main decentralised surface runoff filtration system. Their usage is versatile and can easily be integrated into the landscape, architectural, and urban design as edging along with green spaces, canals, or buildings. Different configurations in the concentration of the filter components make them more specific in the treatment of dissolved substances in rainwater such as fine dust, nitrogen oxides or carbon monoxides.

DETENTION

Detention practices are adopted in order to make urban space resilient to climate events. In particular, stormwater detention is designed to mitigate the risk of flooding, reduce surface runoff, alleviate stress on stormwater sewers, and restore natural hydrology. The principle behind these technologies is the ability to collect and temporarily store rain to let it gradually infiltrate or transport it to spaces where it can easily percolate into the ground. They belong to this category:

- Green roofs are water retention solutions applied to the roofs of buildings. They consist of a succession of different natural or artificial levels, designed according to their size, type and performance. The main function of these green surfaces is retaining rain within the natural pavement and releasing it slowly into the public drainage system, thus limiting the normal inflow of stormwater. Moreover, the use of green roof solutions compensates for the land consumption caused by constructions, making them an effective solution for introducing green elements in highly urbanised cities (Ahiablame & Engel, 2012).

Generally, the effectiveness of this solution depends on the thickness of the soil and the vegetation used, for this reason it is possible to identify two main types of green roofs: extensive and intensive.
The extensive green roofs are lighter and feature hardy succulent plants, for this reason it has typically a lower retention capacity. Whereas the intensive roofs are heavy and feature a thicker growing layer to support deep-rooted vegetation and withhold larger quantities of water. Intensive green roofs are usually installed on public buildings and designed as green living areas that can be used by people as recreational and meeting places. It should be noted that there is a third type of green roof, called brown roof which utilises locally sourced material, such as gravel, debris, and soil, and are typically intended to mitigate habitat loss in new development.

Green roofs can contribute to the performance and appearance of individual buildings as well as entire cities, especially encouraging the replacement of lost habitat, repairing urban ecology, and biodiversity. Additionally, there is a direct correlation to physical human health because green roofs increase evaporation and transpiration, curbing the heat island affect.

The negative element in the use of green roofs is the increase of pollutants contained in rainwater, which, as it filters through the soil, tends to retain the harmful substances contained in the fertilisers used to plant crops. In this case it is necessary to combine green roofs with other filtering systems such as rain gardens or to design them with alternative technologies (Ahiablame & Engel, 2012).

- The permeable pavement category includes paver, asphalt, or concrete that allows water to pass through specially-designed sub grade gravel bed or other porous substrates. Permeable pavement works as water retain system in the subgrade, facilitating the infiltration of water into the soil, evaporation, or urban drainage. This kind of technologies can be designed for vehicular or pedestrian traffic and are especially useful in urban situations where space is a commodity (Ahiablame & Engel, 2012). The dual usage allows for both water retention and hard surfaces to coexist in the same area. Recent technologies provide a variety of pavement designs, which when properly specified can add to the aesthetic amenity of a space.

- Infiltration zones and trenches are open channel systems inhabited by vegetation, capable of replacing and mimicking the functioning of conventional water collection channels. They are filled with detritus and marsh vegetation designed to convey, control and purify rainwater from impervious surfaces (Ahiablame & Engel, 2012). The design criteria are highly specific to rainwater intensities, local soil conditions and available space, but due to their dimensional characteristics they can be easily inserted in different contexts and scales. Indeed, these natural trenches can be incorporated into diverse settings including public and private gardens, roadside planters, parks, driveways, sidewalks, median strips.
  These installations can be used in conjunction with street quieting measures and other traffic control installations. When integrated into the sidewalk or street, community health and public perception of the environment can drastically improve, bringing the water back into vision.

- Swales (or green strips) also belong to this category, even though their main function is to channel and delay rainwater flows. In fact, swales can either have an impermeable base and therefore be designed only for water transport and downstream management, or permeable for infiltration during conveyance. In conclusion, when carefully designed, the delicate slope of swales creates an interesting landscape that can even be utilized for recreation when dry.

- Detention ponds are surface storage basins that mitigate and hold stormwater runoff. These systems can be compared to the biotopes described above, but they are usually larger, and their mechanism of operation involves the incorporation of other integrated drainage systems to facilitate the removal of water from the basin. Normally ponds are dry basins used for recreational activities, filled only when necessary. Unlike other retention systems, detention ponds become embedded in the landscape, changing their appearance and function according to climatic conditions, generating variable and dynamic environments even in the natural dynamics that govern them.

- Water squares are a new type of urban square that use water as a defining element that shapes the space according to the amount of water present. In other words, water squares are places designed to accommodate rainwater during different climatic events and take on a different configuration depending on the amount of water they hold. Normally the design of these spaces includes various recreational and social cohesion activities that are temporarily interrupted during extraordinary climatic periods.

CONVEYANCE

- Rainwater transport is traditionally done through pipe systems and underground channels, but these can be replaced by open stormwater canals. Canals are designed in order to collect water from impervious surfaces, such as rooftops, streets, and every impermeable surface and transport it to other collection, treatment or discharge systems. These types of techniques not only contribute in a sustainable way to water management within the city, but also put water in another perspective, making it an active part of the urban space. In this way, rainwater acquires a social and cultural value. Open canals provide different recreational opportunities, connect spaces, raise awareness of communities, bringing them closer to environmental sustainability issues. Finally, the inclusion of these infrastructures gives more opportunities to shape a more liveable and safe space for both people and environmental health. This includes swales and infiltration trenches, as natural open channels combining transport with infiltration and purification.

EVAPOTRANSPIRATION

The mechanism of evapotranspiration is a fundamental natural process to ensure the proper functioning of the water cycle. Evapotranspiration is the sum of two different mechanisms: evaporation and transpiration. The process is strongly related to the biological processes of vegetation which naturally absorbs and transpires water but retains a part of it at the surface level which evaporates under heat and sun exposure. There are two different kind of evapotranspiration:

- The passive evapotranspiration is defined as a natural process of green spaces that by consuming rainwater favours the creation and maintenance of a more comfortable climate in all periods of the year. Indeed, all vegetated systems contribute to passive evapotranspiration and for this reason the implementation of green infrastructure within the city is essential to maintain a more liveable climate.

- The active evapotranspiration concerns the use of water systems or elements within buildings to promote ventilation, temperature management and air quality. The design of blue elements, i.e., fountains, swimming pools, rainwater walls in collaboration with technical systems makes it possible to improve the internal ventilation of the buildings, encourage cooling in summer and maintain a milder climate in winter, lowering the building's energy consumption and cost. A less technical, but still important contribution is the aesthetic factor that these solutions can bring to the building and the space in which it fits, making it more attractive and pleasant.

In general, there are many examples of techniques and solutions to manage stormwater in a decentralised way, but these have been studied and implemented from an overly engineering perspective without integrating them effectively into planning instruments through appropriate standards and guidelines supported by policy instruments. The lack of an integrated approach and the silo structure of institutional bodies leads, as previously explained for the WSC concept, to a limited application and use of these solutions in common urban design (Costa et al., 2015). In addition to the limitations already described at the beginning of the chapter, when introducing physical solutions into the urban environment one has to consider the strong competition that exists around open spaces. Indeed, WSUD solutions (seen under the aspect of SSM) concern mainly open spaces or surfaces on which multiple interests fall, especially public ones, within which the implementation of infrastructures for sustainable water management is not a priority.

For this reason, it is necessary to introduce planning and governance tools that make the use of these practices part of the public interest, so as not to create conflicts of interest between different urban stakeholders (Costa et al., 2015). Another limiting factor is the lack of community participation in water-related issues. Decentralised infrastructures, by definition, can be multiscale solutions whose inclusion in private contexts can bring benefits on a larger scale, such as to entire areas of a city.

To encourage the active participation of private individuals in decentralised stormwater management, new measures are needed at government level, such as the introduction of wastewater taxes or tax breaks for disconnecting land from the public drainage network (Zhang et al., 2015).

In conclusion, from the above considerations it is possible to understand how the adoption of a different urban water management is necessary to overcome the incoming problems linked to the anthropisation of the world. Over the years, new theories have been developed in which water is seen as a structural and indispensable element for the development of the cities of the future, but the practice is still unable to impose itself and finds many obstacles linked to an institutional and governmental structure that is too rooted in conventional ways of acting and thinking. Uncertainty and complexity are the terms that will increasingly define future urban scenarios and therefore flexibility and dynamism are required. When we talk specifically about stormwater management, we see how the stormwater drainage system has become ineffective for the function for which it was designed and the fundamental need to introduce approaches based on the concept of decentralisation and sustainability. It is necessary to underline that the decentralised approach results as the most effective strategy even if it is not sufficient alone to make a city stormwater proof (especially in case of strong and extraordinary meteoric events). Therefore, it is necessary to adopt strategies which combine centralised and decentralised infrastructure, but which consider water as an essential element for a correct and sustainable urban development.

Figure 10:
Sustainable Stormwater Managmenet practices evaluation table

	Bioretention area	Filter area	Green roof	Infiltration zone	Open channel	Permeable pavement	Detention ponds	Raingarden	Swale/green strip	Water square	Water storage
WATER											
Decrease water consumption	●		●		●					●	●
Favour drought mitigation	●							●	●		●
Goundwater recharge	●	●		●		●		●	●		
Help in floods prevention	●		●	●	●	●	●	●	●	●	
Imporve water quality	●	●		●				●	●		
Water recycle	●	●	●					●		●	●
ECOLOGICAL											
Ensure biodiversity	●			●			●	●	●		
Environmental security	●				●		●	●	●		
Heat island effect mitigation	●		●				●	●	●		
Improve air quality	●		●					●	●		
Increase environmental health	●	●		●				●	●		
Reduction in $C0_2$ emission	●		●			●		●	●		
SOCIAL											
Improve aesthetics and amenity of the space	●		●		●	●	●	●	●	●	
Increase community awareness	●				●		●	●	●	●	●
Increase social cohesion	●		●			●	●			●	
Offer recreation activity		●		●	●		●			●	
Restore water visibility	●				●		●	●	●	●	

2.

APPLICATION OF URBAN STORMWATER MANAGEMENT: a cases studies analysis

Selected case studies are presented in this chapter as examples and models of Water Sensitive and SSM solutions. It has been decided to report a portfolio of projects divided and organised by scale of intervention. This choice is functional to demonstrate:

Firstly, the multiscalarity of innovative stormwater management solutions, which vary from the particular street design project to the complex and wide project of a park or an entire district.

Secondly, to present different solutions that adapt to the spaces and needs of a city, that contribute to a sustainable and resilient urban development, but above all that show different contexts of replicability.

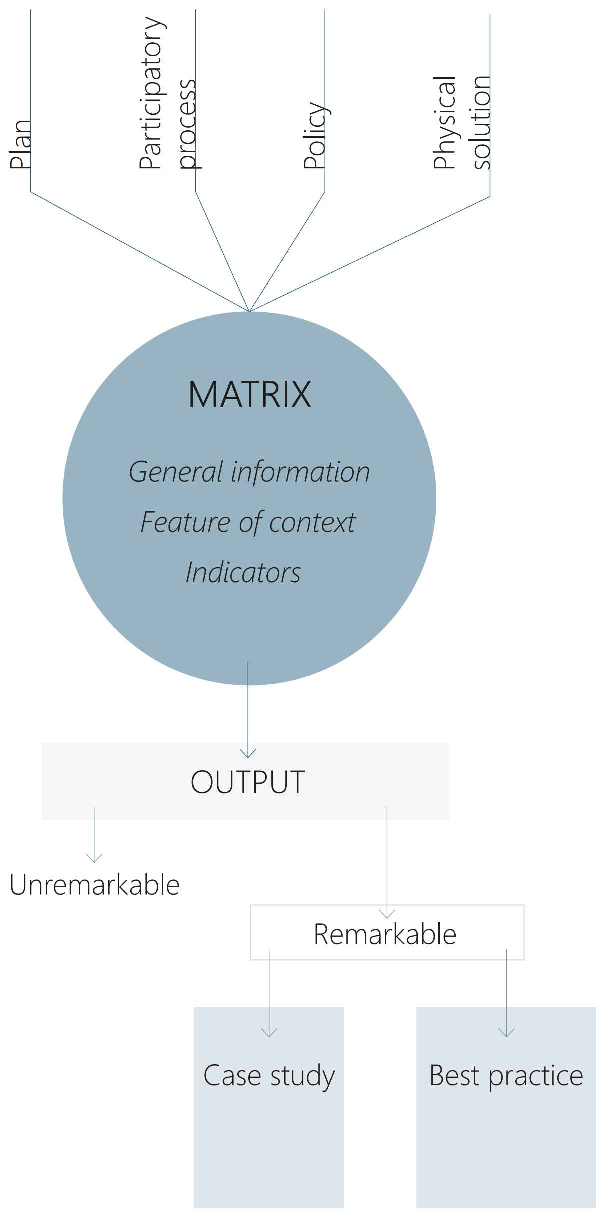
Lastly, demonstrate how specific technologies exist and have been implemented for adapting cities to climate phenomena and in particular for the management and use of stormwater as a resource.

2.1 Methodology of case studies selection

The methodology for selecting the case studies is based on the construction of a matrix of indicators (Figure 11). The different projects identified through grey literature or official water related organizations (IWA, UNESCO, C40) had been evaluated corresponding to a series of parameters to assess their relevance with respect to the theme and objectives dealt with. After evaluating the different cases, eight cases were selected, corresponding to eight different architectural scales, from the detailed to the planning scale. Finally, the selected case studies are collected and represented by 'fiches' that schematically summarise the characteristics and peculiarities of each project according to the evaluation criteria on which the matrix is based.

The assessment tools that make up the matrix cover both general and specific issues. Case studies are assessed according to general information about the location, type of solution and state of implementation. Other more specific information related to climatic, geopolitical and economic aspects of the country where the solution is implemented or planned. In addition to general information, the matrix presents a set of indicators to classify the case as belonging to stormwater management solutions but also to assess how it reflects the principles of the WSC concept. In this way, in order to obtain a tool able to discriminate remarkable case studies from less valid ones, two kinds of indicators have been developed on the basis of which projects can be preliminarily assessed as "stormwater sensitive" and those that do not.

Figure 11:
Scheme of the methodology used to select case studies.



The first type is specifically related to the concept of Sustainable Stormwater Management (see section 1.3) and consider the function performed by the solution:

STORAGE
Capacity of conserving rainwater in specific tanks. Usually, water is pre-cleaned through quality control solutions, such as filtration, sedimentation and bio-absorption.

DETENTION
Solutions which reduce stormwater's peak flow, temporarily harvesting water and slowly draining it after the event.
Conveyance: structures to control and transport the flow of rain from any point to a final receptor.

RECYCLE
Specific hydraulic solutions which reuse stormwater in non-potable usage such toilet flushing or plants irrigation.

EVAPOTRANSPIRATION
The changing form of water from liquid to vapour thanks to natural processes in the soil and plants.

TREATMENT
Separate procedure of sediments and pollutants from water by using a vegetated medium.

INFILTRATION
Mechanisms that favour the infiltration of water into the soil and the recharge of aquifers.

The second type of indicator is linked to the theoretical concept of WSC set out in the previous chapter. Indicators exist in the literature to define the extent to which a city reflects the concept of WSC, but they are very difficult and inquisitive to apply. In addition, the indicators assess the extent to which the general structure of a city is water sensitive but not that of individual projects or strategies. Therefore, the set of indicators used within this research is based on the definition of the official indicators and proposes a simpler and easier to apply version (see Annex 2).
Thus, the water sensitivity indicators are:

WATER SENSITIVE GOVERNANCE
Good water-sensitive governance is achieved through vertical cooperation of policies and plans regarding urban water management. In particular, there must be coherence with regard to the strategy to be adopted for water management at different levels of spatial planning. It is also necessary to stimulate collaboration between public and private as well as collaboration between the different actors involved in water management in an urban context.

COMMUNITY CAPITAL
It is necessary to undertake a series of policies aimed at educating the community towards the importance of water as a resource and urban element. Awareness-raising among citizens must aim to support them in managing climate risks related to water, the impact on urban water resources and the construction of a more attentive and participatory community towards new scenarios and possibilities concerning water management and planning in the urban environment.

EQUITY OF ESSENTIAL SERVICES
The provision of water services within the city must be equal for all, ensuring good water quality and quantity. Different water supply services must be provided to reduce the impact on potable use. Water quality must also be pursued for water basins, watercourses, and the sea in such a way as to ensure a healthy and pleasant space.

PRODUCTIVITY AND RESOURCE EFFICIENCY
Energy efficiency and waste reduction solutions must be provided within urban water management. It is important to provide alternative and sustainable solutions within the drinking water treatment and management processes to reduce consumption and CO2 emissions. Take advantage of new opportunities for resource management and consumption to stimulate investment and new job opportunities.

ECOLOGICAL HEALTH
Protect, restore, and create new water systems that can boost the development of new well-functioning ecosystems that contribute to the resilience of the city. Green and blue infrastructure is needed to connect disconnected part of cities and create ecological corridors within the city that promote biodiversity.

ADAPTIVE INFRASTRUCTURE
The design of new blue infrastructure must be aimed at adapting the city to climate change. To operate according to an integrated approach that favours the inclusion of water on different scales within the city providing multifunctional solutions and removing sensitivities and vulnerabilities regarding extreme climate events.

QUALITY URBAN SPACE
Planning and designing urban forms in order to provide pleasant and liveable spaces. It is fundamental to conceive multifunctional and adaptable solutions to optimize the use and supply of water, to guarantee liveable public spaces where to consume social dynamics and to favour the inclusion of green areas at all levels of design in order to guarantee ecosystem services.

2.2 Solutions for Sustainable Stormwater Management

The selected case studies belong to different world realities and cover different urban scales, even reaching the detailed scale of the street element. The chosen scales are street design element, roads, building, urban square, urban park, district, landscape, plan. Through the proposed case studies, it has been tried to tell the different typologies of stormwater management solutions that can be implemented in an urban or natural environment.

Through the presentation of selected case studies, it is intended to demonstrate how the revolution in water management, through WSUD and SSM solutions, is already underway in many parts of the world. For those governments and cities that are more sensitive to environmental issues, the implementation of water-sensitive solutions or, more specifically, of sustainable stormwater management, becomes an opportunity to revitalise and develop the city, not only in terms of liveability but above all for the economy.

Figure 12:
Case studies' map

In Australia, for example, the creation of numerous parks and gardens that collect and retain water has made it possible to cope with severe droughts events, alleviating the economic burden of seawater desalination and improving the living conditions of entire communities. In addition, projects in the city of Melbourne have prompted many smaller communities to act similarly and adopt policies and measures to preserve water and its natural environment.

Similar examples can also be found in various parts of Asia where rainfall has always characterised and shaped the land. Because of the high economic and demographic development of the country, cities have experienced an uncontrolled expansion, intensifying the problems of surface water drainage. Highly urbanised realities, such as Singapore or Jinhua, are an emblematic example of how SSM solutions can be integrated into any type of scale and project.

Western cities have also embarked on similar paths, especially in those areas where water has always been a key element in the economic and urban development of communities. The Dutch city of Rotterdam, one of the European cities most committed to climate change adaptation policies, is an emblematic example, as are Portland and Chicago in USA. These two American cities, although very different, have in common their desire to introduce sustainable rainfall management policies into future urban development plans.

01
CS

Kings Square raingardens

Perth City Link

The intervention is part of the urban redevelopment project Perth City Link which provides a connection between Northbridge and Perth's Central Business District through the implementation of existing infrastructure and the construction of new residential buildings, offices, retail space, and shops. In particular, the project for Kings Square envisages the use of raingardens spread along the road infrastructure and public spaces with the aim of encouraging rainwater management and on the other hand restoring a more liveable and healthy urban space.

The objective behind the implementation of these punctual solutions is to design roads where vegetation is not only an aesthetic and contour element but also contributes to the management of air and water contaminants and contributes to the collection and removal of first flush during rain events.

The raingardens are designed as part of a unique street furniture project that interconnects the streets with the Kings Square Wellington Gardens. The raingardens combine retention and filtration technologies to protect the quality of the groundwater and the Swan River reservoir. 10 raingardens (4m x 9m x 2.5m) have been designed with a 1:2 ratio of infiltration area to parking area. Each raingarden is built over a pit and pipe system that transports filtered water from the ground to the receiving waterways. Inside the raingarden 8 plants per m2 are planted whose main purpose is to eliminate the pollutants contained in rain and drainage water from the road surfaces. Small leaf tree species are chosen to avoid clogging of the hydraulic system and to take advantage of rain interception and evapotranspiration through the tree crowns. The raingardens are designed in an integral way combining elements of street furniture and street lighting so that in addition to the ecosystemic benefits deriving from the vegetation used, they can be integrated with urban services and spaces.

- Provides a passive irrigation service and through infiltration promotes the recharging of the aquifer.
- Combines bioretention with the use of native vegetation to create a self-sustainable habitat and promotes biodiversity.
- Contributes to raising public awareness of the effectiveness of water-sensitive solutions in urban spatial planning.

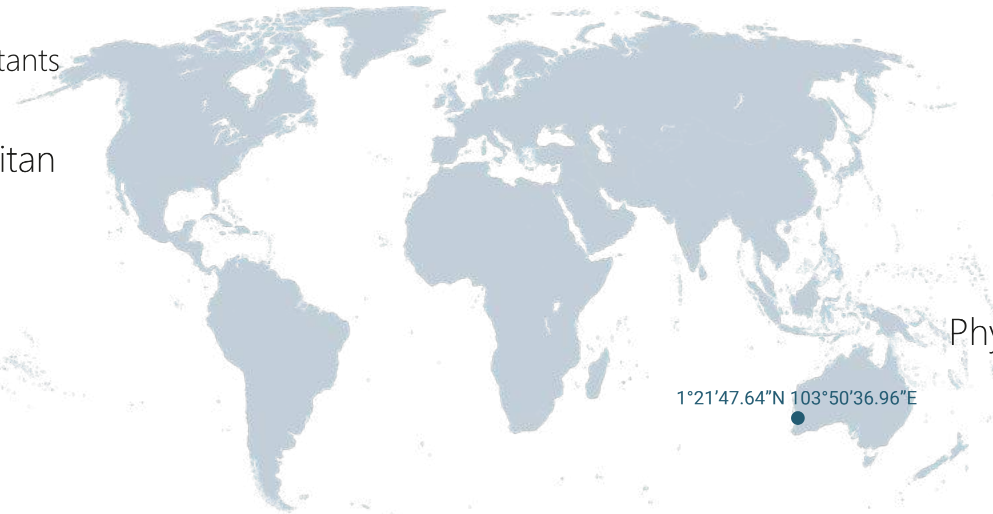
Population size
2.041.959 inhabitants
source. Worldbank

Area size
Large Metropolitan
source. OECD

Economic type
High-income
source. Worldbank

Climate region
Dry summer
source. Kopper-Geiger

Rainfall
807 mm annual
source. en.climate-data



City
Perth
Australia

Status
Projected

Type
Physical solution

Renewal urban project of Perth's Central Business District which includes different actions that connect the neighbourhood to Northbridge. Particularly, the King Square Raingardens consist of a streetscape project which uses water sensitive stormwater management solutions to treat stormwater, protect groundwater systems and prevent extra pollutions flowing into the Swan River. The raingardens are designed to catch the first rain from streets and collect it into a below pipes drainage system. Each raingarden is composed of local dense plants which delay and filter the water before to reach the receiving waterways. In addition, the vegetation contributes to the microclimate of streets surroundings.

Indicators

Indicator	
Water sensitive governance	●
Community capital	○
Equity of essential services	●
Productivity and resource efficiency	●
Ecological health	●
Adaptive infrastructure	●
Quality urban space	○

02
CS

The Pilsen Sustainable streets
Cermak/Blue Island roads

The Cermak/Blue Island street is part of a sustainable street renewal programme in Chicago undertaken by the Chicago Department of Transport. The project street runs through a heavily industrial area next to an active freight railway and still serves a significant volume of heavy truck traffic.

The aim of the project is to repave the road section of two roads, increasing the green area and introducing a series of systems that favour the localised management of the rain that drains off the road. In addition, the vegetation cover will counteract the 'heat island effect' generated by the asphalt road, contributing to temperature mitigation. The biggest challenge is to find the right balance to ensure maximum efficiency in collecting and infiltrating stormwater while at the same time serving the mobility and economic needs of the pathway.

The solution principle involves the redesign of approximately 1.4 miles of road through the introduction of stormwater management solutions to collect, reuse and infiltrate large amounts of rain drained from the road. These solutions include the installation of bioswales, raingardens and permeable pavements through which water can be reused for irrigation or percolate into the ground. To promote infiltration and above all the elimination of heavy pollutants carried along the roads, infiltration plants have been planted which treat the rainwater before it infiltrates or is reused. In addition to the natural elements, permeable pavements have been used for the cycle path and pavement to help rainwater infiltrate and counteract surface accumulation. The strategic positioning of the raingardens allows to disconnect some buildings facing the streets from the sewage system, draining the water directly into the green elements of the street. The project includes the introduction of elements that improve conditions for pedestrians and cyclists, providing a safer space for movement separate from the busy street, new pedestrian plazas with raingardens and seating that encourage people to walk and stop. In order to make this project a boost for the renewal of other streets within the city of Chicago, a system of education and sponsorship of the interventions has been introduced through community identifiers and self-guided tour brochures that highlight the positive factors of the different solutions on the urban environment and the liveability of the street.

- 80% of stormwater runoff is managed along the green corridor.
- 23% of the materials used in the construction of the road are recycled.
- The renovation of the two roads was 21% less expensive than the average renovation in Chicago.

Population size
8.865.000 inhabitants
source. Worldbank

Area size
Large Metropolitan
source. OECD

Economic type
High-income
source. Worldbank

Climate region
Humid continental
source. Kopper-Geiger

Rainfall
918 mm annual
source. en.climate-data

City
Chicago, Illinois
USA

Status
Projected

Type
Physical solution

The renovation of The Cermak and Blue Island streets is part of a climate adaptation programme adopted by the city of Chicago on making streets greener and more sustainable. The two examples described exemplify this goal by showing how the introduction of green elements, raingardens and permeable pavements can help manage surface runoff accumulating on streets while improving air quality and safety for pedestrians and cyclists. The projects involve the Chicago Transportation Company and other interested stakeholders in studying and monitoring these new urban design ideas.

Indicators

- Water sensitive governance ●
- Community capital ●
- Equity of essential services ○
- Productivity and resource efficiency ○
- Ecological health ●
- Adaptive infrastructure ●
- Quality urban space ●

Infiltration

Detention

Conveyance

Treatment

Transpiration

03
CS

Kampung Admiralty

Kampung Admiralty is designed to accommodate a community hub for the elderly, providing several spaces that accommodate studio apartments for elderly people, medical and care centre, retail shop and other public services.

The concept behind the project is proposed as a prototype for integrating green and blue infrastructure into the building form. The building form is presented as a succession of layers of green and blue elements that simulate the behaviour of a tropical forest and locally manage rainwater. The design of the water system at the basis of the building's operation makes it possible to conserve, filter and reuse the water collected by the green elements so as to reduce the waste of drinking water and contribute to reducing surface runoff. The integration of greenery and buildings alleviates the impact of intensive urbanisation on social alienation and climate change.

The building is organised as a vertical village on whose flat roofs intensive green roofs are planted covering more than half of the building's surface. These green spaces are designed as liveable spaces and accommodate different recreational and social functions and also a community farm on the highest level. The greenery is the central element of the whole composition and associated with the blue elements, it forms a dense network that mimics the processes and behaviours of a natural forest. The rainwater flowing between the different levels of the building is conveyed into vegetated filters, rain chains or raingardens through which it undergoes purification processes before being collected in harvesting tanks. The tanks store the water for reuse in external irrigation. Biotopes and eco-ponds have been provided at the ground floor which collect and filter the water drained from the road, filtering it from the heaviest pollutants before conveying it to the sewage system. Through these solutions it is possible to manage rain locally, avoiding surface flooding problems. The use of green solutions confers other benefits such as promoting the physical and mental health of the building's residents, but above all regulating the temperature and humidity of the air and helping to safeguard biodiversity by encouraging the growth of new plant species and the proliferation of animals, thanks to diverse planting solutions.

- Over 100% landscape replacement was achieved through ground level planting, green roofs and vertical green walls.
- The design of the Hydrological system allows for over a million gallons of tap water can be conserved from reusing stormwater runoff.
- Nearly 4 million litres of water a year to be harvested, stored, and reused for irrigation.

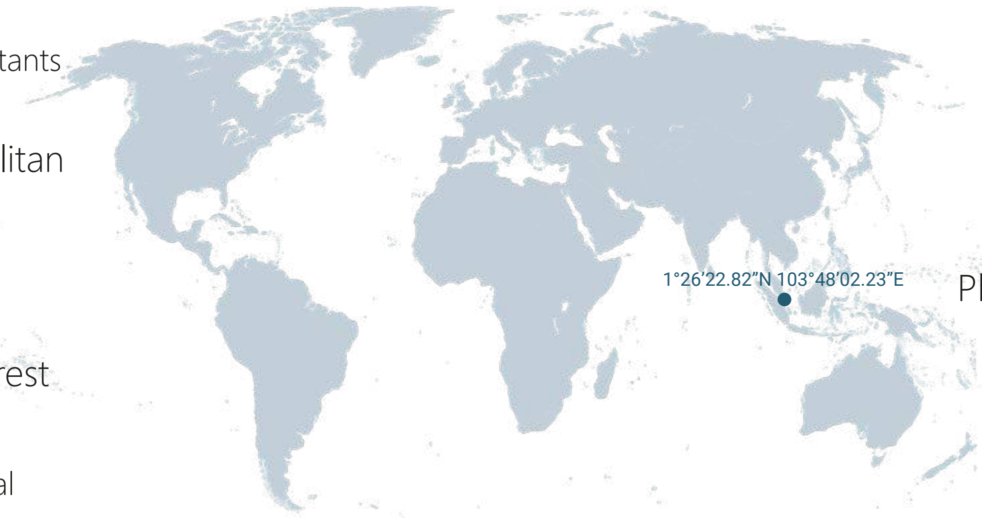
Population size
5.867.116 inhabitants
source. Worldbank

Area size
Large Metropolitan
source. OECD

Economic type
High-income
source. Worldbank

Climate region
Tropical Rainforest
source. Kopper-Geiger

Rainfall
2378 mm annual
source. en.climate-data



City
Singapore

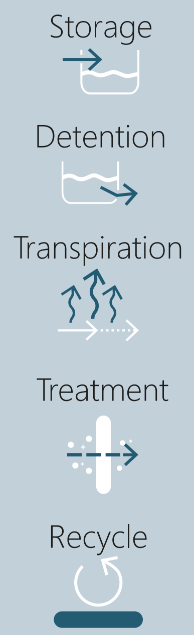
Status
Projected

Type
Physical solution

The design for the Kampung Admiralty multifunctional building aims to integrate the use of green and blue infrastructure at the architectural scale of the building. This process saves the building's resource consumption but at the same time contributes to the improvement of the urban environment by promoting localised stormwater management and contributing to the creation of multiple ecosystem services. The building's flat surfaces are designed as lush green gardens that accommodate a variety of recreational activities but also manage and channel rain into the building's plumbing system for future reuse.

Indicators

Indicator	
Water sensitive governance	○
Community capital	○
Equity of essential services	●
Productivity and resource efficiency	●
Ecological health	●
Adaptive infrastructure	●
Quality urban space	●



04 CS

Potsdamer Pladz
Daimler district

The Potsdamer pladz urban plan can be defined as an operation to reconnect parts of the city that were degraded during the Cold War and divided by the construction of the Berlin Wall. The project includes 65000 m2 of land that has been organised in 19 buildings, several public spaces and 10 streets. The site involved numerous international professionals coordinated by architect Renzo Piano and is divided into three main sectors, identified by 3 building complexes: Daimler-Chrysler-Areal, Beisheim Center and Sony Center. The concept behind the project is to provide a new, vibrant space reflecting the regeneration of Berlin after the war, which is not just an office district but provides numerous recreational and leisure opportunities for citizens. Within Daimler's site is an urban design solution involving water as a key element of the architectural composition.

Even though the regeneration project at Potsdamer pladz is not based on the idea of a water-sensitive solution, the Daimler centre's design includes a number of solutions that can be traced back to the concept of sensitivity to water management. In particular, the objective set by Atelier Dreiseitl was to conceive a system that could exploit rainwater through green roofs to integrate water in a sustainable way within urban environment.

The buildings that characterise the Daimler site at Potsdamer pladz are covered by green roofs which, in addition to providing an energy contribution to the building, constitute a system of harvesting, delaying and retention of stormwater. In fact, the rain that penetrates the ground on the roof is channelled into three tanks built under the public square around which the various buildings are arranged. From the cisterns, the water is used by the buildings themselves to irrigate the vegetation, fire suppression system, and sanitation systems. In case of heavy rainfall, the excess water is let out into the canals and artificial lake designed as elements of a natural oasis within the urban environment. The water that flows into the ponds is filtered through biotopes and once purified is released into the public water system. The project is completed with the integration of numerous green areas that provide multiple ecosystem benefits including the reduction of the heat island effect, the creation of a pleasant and more liveable space and a contribution to the biodiversity of flora and fauna.

- 70% carbon emission reduction and 2°C temperature reduction
- 50% energy saved in building conditioned systems.
- 20000 m3 Potable water saved and combined stormwater storage.

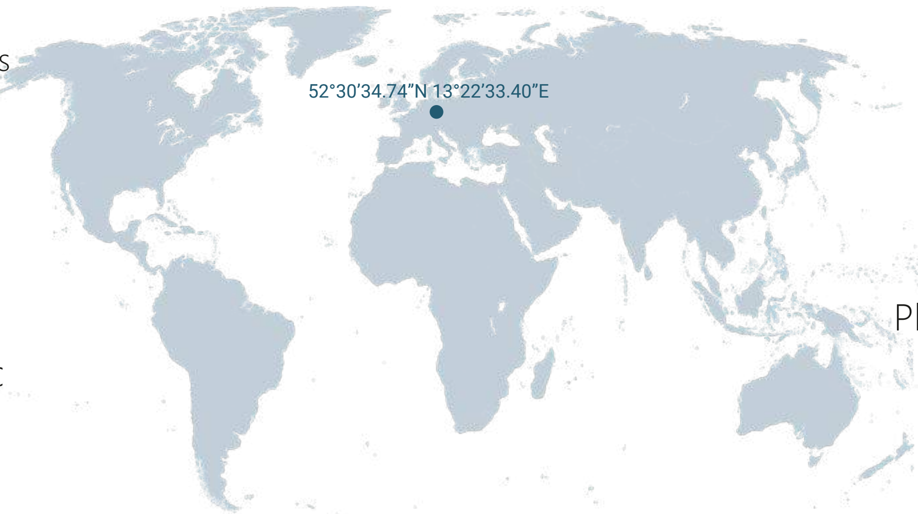
Population size
3.769.000 inhabitants
source. Worldbank

Area size
Large Metropolitan
source. OECD

Economic type
High-income
source. Worldbank

Climate region
Temperate Oceanic
source. Kopper-Geiger

Rainfall
570 mm annual
source. en.climate-data



City
Berlin
Germany

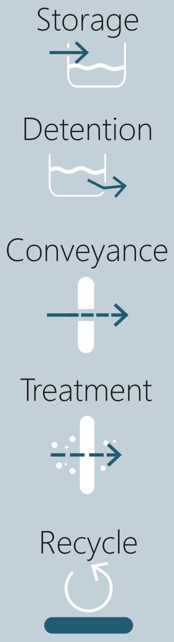
Status
Projected

Type
Physical solution

Inside the regeneration project of Potsdamer Pladz, many solutions had been carried on with the aim of integrate water in urban and building space. Particularly, the Daimler's district has been conceived as a system of green roofs connected to underground tanks where stormwater is collected and recycle. The public space is design with different channels and a pool that define the urban environment. Beside microclimate benefits of water in reducing heat waves, channels and pool, in particularly, are structured in order to collect excess water during extreme rain events, filter it through ponds and pour it into the nearest waterways.

Indicators

Indicator	
Water sensitive governance	○
Community capital	●
Equity of essential services	●
Productivity and resource efficiency	○
Ecological health	●
Adaptive infrastructure	●
Quality urban space	●



05
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The Trin Warren Tam-boore wetland
Royal Park area

The Trin Warren Tam-boore wetland is one of a series of wetland parks in the Royal Park Masterplan adopted by the City of Melbourne in 1998. The Royal Park is recognised as one of the most remarkable landscapes of Melbourne due to the variety of sports fields, recreation spaces but also different kinds of plants and trees.

The design of the park was conceived mainly for two functions. The first is to create a wet but usable space for the population to collect and manage stormwater from surrounding suburbs. The managed water is recycled and used for external purposes in order to limit the use of potable water in the irrigation of the Royal Park and to counteract drought phenomena. The second motivation is to increase and protect the local flora and fauna, encouraging biodiversity and creating a natural ecosystem protected from the city's anthropic dynamics. Common to both objectives is providing the city of Melbourne with an attractive landscape that encourages education about water and environmental conservation and provides recreational activities.

The design of the project includes two wetlands connected by an underground pipe that collect, treat and store water from the park and the urban area. One basin is designed with an S-shape and its main function is to purify the rain. The other has a spiral shape and serves as a reservoir. Both ponds have raised embankments over which pedestrian paths have been designed which, being raised, allow constant walking. The rain runoff is conveyed into a channel which, through a system of grates, retains pollutants and larger debris before discharging water into the S-shaped pool. Here the water flows along a winding path and is purified through the action of 70000 plants, specially designed to retain the nitrates and particulates dissolved in the water. The purified water flows into the second storage basin with a capacity of 13.4 million litres. From here, a complex system of pipes leads the clean water to the different areas of the Royal Park, ensuring irrigation and healthiness for the proliferation and life of various animal and plant species. A few years after the park was completed, a storage tank was introduced underneath the playground next to the S-shaped wetland. The complexity and grandeur of the park led to close collaboration between various institutions and professionals including engineers, landscape designers, architects, the municipality and the Water utility of Melbourne. In addition, the development of the masterplan involved a large number of consultations with various environmental protection organisations, community members and other environmental organisations.

- It irrigates 89% of the Royal Park, reducing drinking water consumption.

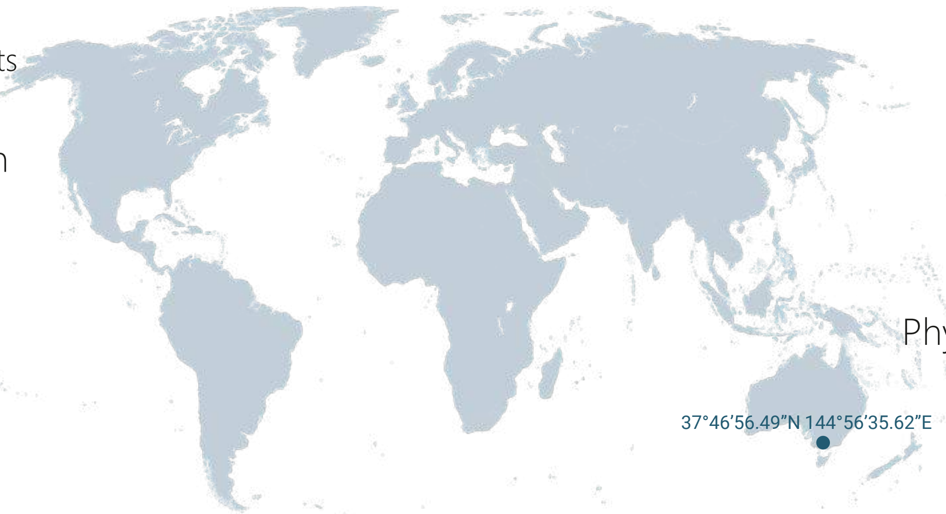
Population size
5.078.000 inhabitants
source. Worldbank

Area size
Large Metropolitan
source. OECD

Economic type
High-income
source. Worldbank

Climate region
Oceanic
source. Kopper-Geiger

Rainfall
666 mm annual
source. en.climate-data



City
Melbourne
Australia

Status
Projected

Type
Physical solution

The Trin Warren Tam-boore park is part of the large green complex of the Royal Park and its construction was intended to encourage the adoption of alternative, sustainable stormwater management solutions. The modelling of the park around two wetlands make it possible to collect, purify and conserve rainwater from the neighbourhood and recycle it to irrigate the entire green roof of the Royal Park. The Trin Warren Tam-boore was designed with the aim of creating a park in the form of a nature reserve for the protection and proliferation of local fauna and flora, creating a variety of different habitats, which has resulted in greater biodiversity.

Indicators
- Water sensitive governance
- Community capital
- Equity of essential services
- Productivity and resource efficiency
- Ecological health
- Adaptive infrastructure
- Quality urban space

Storage
Detention
Conveyance
Treatment
Recycle
Infiltration

06
CS

Climate Adaptive ZOHO
Rotterdam Climate Quarter

The urban renewal project for the Zomerhofkwartier (ZoHo) district is a consequence of the city of Rotterdam's goal to become climate proof according to the Rotterdam Adaptation Strategy, adopted in 2008. Rotterdam's strategy to combat climate change includes a series of measures to make urban space more resistant to increasing excessive rain events, longer periods of drought and more intense periods of heat stress. The ZoHo district is a laboratory district in which innovative solutions to mitigate the effects of climate change are being experimented. A perfect pilot location as it is one of the areas of the city most affected by climate change events and already presents some solutions built to adapt the space to new climate scenarios.

The renewal of the district includes a whole series of solutions aimed at solving three critical issues: flooding risk, drought, and the heat island effect. Despite the general objective of making the district climate proof, the strategies adopted mainly concern innovative water management, in particular using rain as an extra resource whose collection, recycling and infiltration through green spaces brings multiple benefits, not always strictly related to stormwater management.

The different projects adopted within the district aim to increase the green coverage of the city by using green and blue infrastructure, to solve the problems of undersized sewerage system which is inadequate to drain the volumes of water running on the surface and to help recharge the groundwater threatened by the frequent droughts that hit Rotterdam during the summer. Another fundamental aspect of this project is the involvement of different stakeholders in the transformation process of the neighbourhood. In fact, the transversal target of all interventions is to create new public spaces that are safe but at the same time attractive and liveable for all. To do this, numerous workshops and discussion groups have been organised to gather ideas and learn about the needs of the population living in the neighbourhood.

In general, the Climateproofing ZoHo project covers 6 main measures, but neighbourhood planning is seen as a continuous work in progress that might involve other areas in the future.

1- Benthemplein watersquare is a pilot project that has already been carried out in the neighbourhood and which sets an example for other projects to follow. The square is designed as a multi-purpose recreational space composed of three basins into which rainwater from the surrounding roofs and impermeable surfaces is conveyed. The square is designed to collect and retain large amounts of rainwater, preventing it from overloading the sewer system and flooding the area. Every element of the square has been designed to highlight water as the dominant element of the project. The surfaces have been coloured with different shades of blue and the use of steel for the gutters allows for interesting play of reflections.

2- Polder roof project proposes the transformation of the roof of the 'Katshoek' parking garage into an attractive green roof that stores and reuses rainwater from the nearby buildings in a controlled way for urban agriculture. The green roof keeps rain out of the sewage system, holding it back and releasing it slowly into raingardens to help it infiltrate the soil. It will also become a place for everyday recreation and outdoor events, adding new social, economic, environmental and ecological values to the ZOHO district.

3- Katshoek Rain(a)way Garden intervention involving the repaving of the Heer Bokelweg street adjacent to the Katshoek building. The project involves reducing the hard surface covering and replacing it with green swales designed as colourful linear gardens. The new green corridors are designed to encourage underground water drainage but are also designed from a naturalistic point of view, accommodating different species of flowers and plants which grow and bloom in different seasons.

4- ZoHo Rainbarel is a special water storage system designed to provide a small and smart solution to reuse rainwater for non-potable purpuse. The system, built on the roof of a multifunctional building, includes the integration of green roofs and water collection tanks whose purpose is to reuse the collected water for irrigating vegetation and flushing toilets. The system aims to involve the community in the management and maintenance of the system and is part of educational programmes on climate adaptations at schools.

5- Greening Hofbogen is about the transformation of the monumental structure of the Hofpleinlijn, over which the Rotterdam railway lines run. The project concerns the greening of the facade and street overlooked by the building through which rainwater can be collected and reused for local irrigation or infiltration. The project aims to completely transform the green infrastructure of stormwater management to restore the urban ecosystem, edible growth but also involving public urban furniture projects to liven up the environment.

06
CS

6- ZoHo Raingarden The latest project involves the construction of several raingardens in the asphalt area that serves as the entrance to the neighbourhood. The area is being completely redesigned in terms of traffic so as to keep cars outside and allow only pedestrians and bicycles to pass through. The solutions adopted are very simple and involve repaving the area by introducing a series of small gardens and flowerbeds built with a slight slope to receive and hold back the rain that runs off the surface. The water flows and flows into the larger depression where it is slowly infiltrated. The whole area thus becomes an attractive garden to lunch, linger and enjoy.

- Replacement of impervious and asphalted areas with green cover and trees favouring the establishment of a new urban ecosystem.
- Localised and decentralised rainwater management through collection, recycling and infiltration infrastructures.
- Involvement of the population and various associations in the process of planning and maintenance of solutions.
- Bring visibility to water as a fundamental element in the urban composition of spaces.

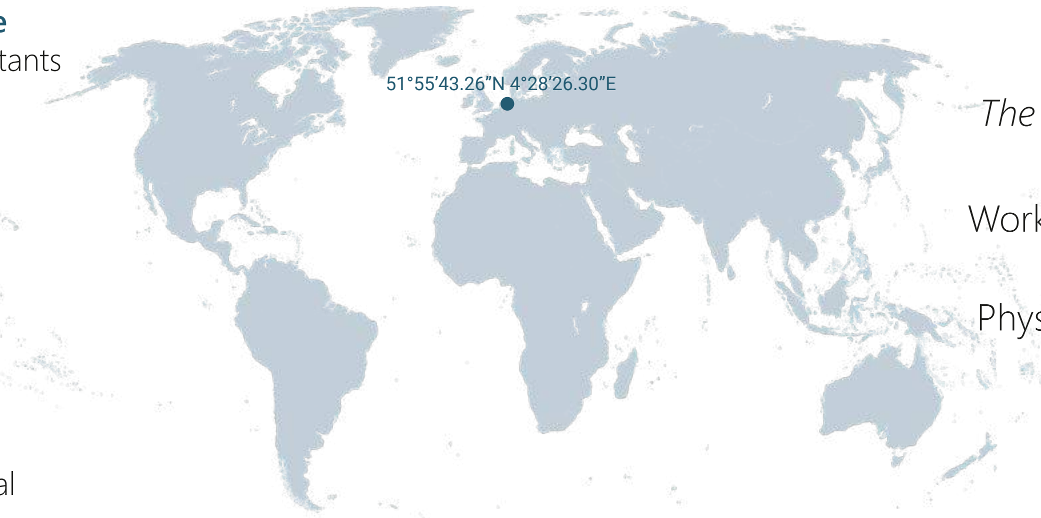
Population size
651.446 inhabitants
source. Worldbank

Area size
Metropolitan
source. OECD

Economic type
High-income
source. Worldbank

Climate region
Oceanic
source. Kopper-Geiger

Rainfall
782 mm annual
source. en.climate-data



City
Rotterdam
The Netherlands

Status
Work in progress

Type
Physical solution

The Zomerhofkwartier and Agniesebuurt are among the areas in Rotterdam that are vulnerable for the effects of climate change. Regarding the ZOHO district, a first step towards its transformation has been taken with the Benthemplein Watersquare, but many other projects are planned to increase the adaptability of the area. Climate Proof Zomerhofkwartier initiative combines the urban transformation with innovative resiliency measures based on the Rotterdam Adaptation Strategy, mainly focused on stormwater management. The process included a deep analysis of the district climate conditions, workshops to collaborate to define specific strategies and a shared perspective to follow.

Indicators
- Water sensitive governance ●
- Community capital ●
- Equity of essential services ●
- Productivity and resource efficiency ○
- Ecological health ●
- Adaptive infrastructure ●
- Quality urban space ●

Storage
Infiltration
Detention
Conveyance
Treatment
Recycle
Transpiration

07
CS

Yanweizhou Park
Jindong District

The park is located within the riparian wetland area where the Wuyi and Yiwu rivers join to form the wide Jinhua River. The site covers a total area of 26 hectares, and was previously home to a sand quarry, the cessation of whose activities led to severe degradation. Adjacent to the area stands the city's Opera House, which together with the associated cultural and public spaces, form the cultural heart of Jinhua. The area has always been subject to heavy flooding, which has been buffered over the years by the construction of huge concrete walls.

The first objective of the project is the modelling of a water resilient landscape capable of accommodating and adapting to the monsoon floods and completely replacing the use of expensive and inefficient concrete barriers. In addition, the design of the park aims to preserve and protect the last strip of reparian habitat in the city, encouraging an increase in urban greenery, bringing respite from the heavy urbanisation of the city. The last objective is to favour the access and use of the whole area by the population, improving the connections between the city and the Opera House and integrating the building into the nature, offering social and cohesion opportunities

The concept behind the project is the complete demolition of the concrete walls and their replacement with sinuous terraces covered and native wetland vegetation, forming a water resilient river embankment. The terraced slopes are sprinkled with pedestrian paths, rest areas and pavilions that are partially or totally flooded in case of need, protecting the raised area where the Opera stands. The spaces are designed to accommodate large numbers of temporary visitors who use the Opera House but also to accommodate people who want to take a walk in nature on a daily walk. The cultural building remains continuously served and used thanks to the construction of an elevated bridge that connects the different riverbanks. The 764-metre-long bridge was designed at a height to remain above the estimated flood level with a return time of 200 years, providing an effective long-term solution. In addition to the terraced river embankment, the inland area is entirely permeable in order to create a water resilient landscape through the extensive use of gravel that is re-used material from the site. The combination of the gravel material and the green covers provides the whole area with important phytodepurative properties. In this way the water infiltrates through the vegetation and the different gravel layers, lowering the pollution load. As far as the environmental aspect is concerned, various species of marsh plants have been used which, in association with the typical Chinese 'water trees', provide multiple ecosystem services and allow the proliferation of various animal species, favouring the biodiversity of the site.

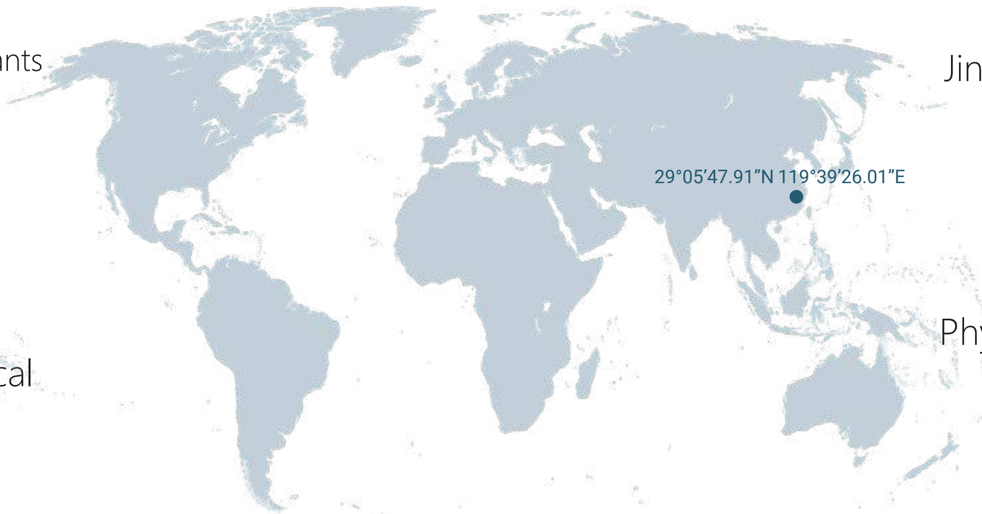
Population size
1.170.000 inhabitants
source. Worldbank

Area size
Metropolitan
source. OECD

Economic type
High-income
source. Worldbank

Climate region
Humid subtropical
source. Kopper-Geiger

Rainfall
1419 mm annual
source. en.climate-data



City
Jinhua, Zhejiang
China

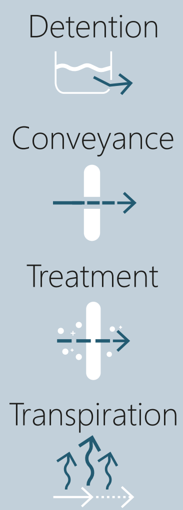
Status
Projected

Type
Physical solution

The Yanweizhou Park project concerns the redevelopment of an abandoned area with a strong environmental identity as the last undeveloped riparian wetland in Jinhuan. The aim of the project is to build a park capable of accommodating the waters of the river during periods of flooding and preventing them from damaging the city. At the same time, the park should make the area more attractive and help protect the biodiversity of the area.

Indicators

Indicator	
Water sensitive governance	○
Community capital	○
Equity of essential services	●
Productivity and resource efficiency	○
Ecological health	●
Adaptive infrastructure	●
Quality urban space	●



08
CS

Portland Stormwater Management Manual
Urban planning strategy

The city of Portland is known as one of the rainiest cities in the United States, receiving more than 900 mm of rain annually. In addition, the city is located at the confluence of two rivers, making the area particularly sensitive and vulnerable to water management during severe weather events. Being a very built-up city with about half of the territory still served by a combined sewage system, it presents many problems of flooding caused by the overflow of the sewage system and of pollution of the water bodies due to the pollutants carried by the stormwater runoff. For this reason, the city has always tried to adopt urban water management policies in order to implement and adopt alternative solutions that protect the space from severe weather events. The Bureau of Environment Service of the City of Portland decided to adopt urban development policies aimed at protecting publich health, improving water quality and manage stormwater as a valuable resource. In 2016, the first Stormwater Management Manual (SWMM) was created, with the latest update in December 2020. The manual presents stormwater management solutions applicable to all new urban development projects, redevelopment projects, in public but also private contexts so that there is collaboration at all levels of the city.

The City of Portland's goal is to create a new stormwater infrastructure plan that will bring better rainwater management to the city in order to make it a valuable resource and prevent it from damaging the landscape and people. For this reason, the development of the SWMM aims to decrease the amount of impervious surface in order to limit the amounts of rainwater runoff which affects the erosion of stream channels and prevents groundwater recharge. Introduce a dense green infrastructure system that can manage water locally and decrease the load of transported pollutants. The implementation of green spaces decreases opportunities for sewer overflows, contributes to the improvement of sanitary conditions in the city and counteracts flooding and damage to buildings. The indications respected within this strategic plan are fundamental to ensuring greater liveability of the population and the health of the watershed by maintaining the correct balance between natural and urban elements.

Referring to the most updated version of 2020, the handbook presents a series of chapters detailing all the legislative and planning guidance for adopting and scaling up decentralised stormwater management infrastructures in different urban contexts. Chapter 1 contains information about the requirements and policies for stormwater management. This section contains information about the applicability of decentralised infrastructures, the performance requirements of these infrastructures, indications about the drafting of dedicated masterplans and other requirements related to the maintenance of the systems.

In chapter 2 guidelines for the implementation of green infrastructure for stormwater management are presented. The indications are divided by type of intervention and refer to the geomorphologic characteristics of the city in order to evaluate which system is best implemented according to the characteristics and vulnerability of the project area.
Chapter 6 focuses on drainageways and their ecological importance in maintaining and controlling water quality, especially in receiving watersheds. Stormwater management has become a priority in Portland's development policies over the years, as evidenced by the numerous interventions and projects that have already been implemented. In addition, the Portland Bureau of Environmental Services has decided to undertake a public awareness campaign on these issues by organising free public seminars on stormwater infrastructure and educational programmes for public schools. Moreover, citizens have the possibility to request the municipality to implement rainwater facilities in their neighbourhood, to make it safer but also more attractive and economically viable.

- Adoption of urban development programmes focused on the use of decentralised infrastructure as an alternative solution to conventional grey infrastructure

- Increasing green cover not only helps water management but also helps the city increase the quality of space by increasing the liveability of the city.

- A great deal of importance is attached to rainwater filtering and treatment solutions in order to drastically reduce pollutants in river basins.

- Specific laws and incentives that stimulate the adoption of green rather than grey solutions by both private and public entities.

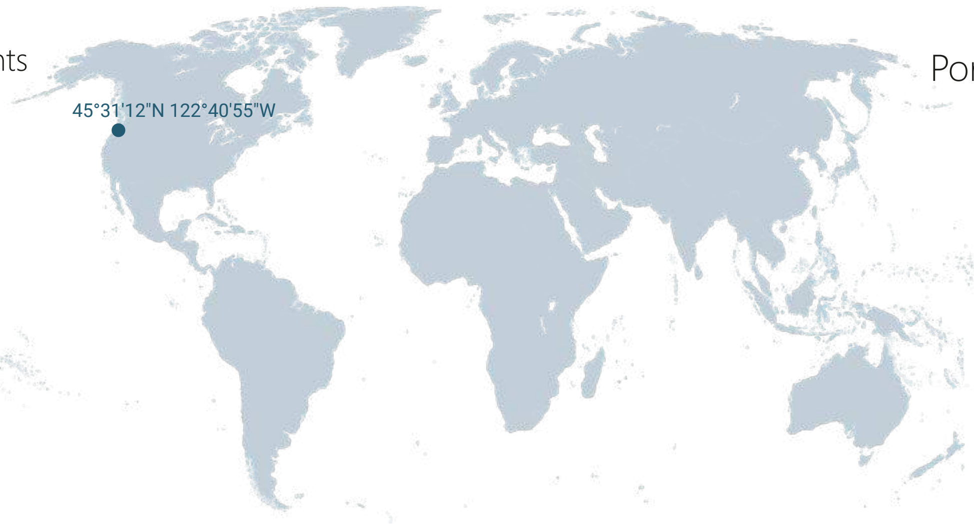
Population size
654.741 inhabitants
source. Worldbank

Area size
Metropolitan
source. OECD

Economic type
High-income
source. Worldbank

Climate region
Dry summer
source. Kopper-Geiger

Rainfall
1001 mm annual
source. en.climate-data



City
Portland, Oregon
USA

Status
Adopted

Type
Policies

The city of Portland is subject to several climatic events that subject it to frequent flooding, amplified by the city's geographical location at two major rivers. For this reason, the city government has decided to undertake several climate adaptation policies for the city in order to protect the environment and citizens. Among the policies, the Portland Stormwater Management Plan proposes a series of water management solutions that involve the commitment of the public sector but also of the privates. The proposed solutions concern the implementation of green infrastructures that contribute to making the city more liveable and attractive.

Indicators
- Water sensitive governance
- Community capital
- Equity of essential services
- Productivity and resource efficiency
- Ecological health
- Adaptive infrastructure
- Quality urban space

Storage
Infiltration
Detention
Conveyance
Treatment
Recycle
Transpiration

3.

THE CASE OF COPENHAGEN: a model for other cities

This chapter has analysed the case of Copenhagen as an international frontrunner for urban policies and solutions regarding urban stormwater management. The choice fell on this city because it is the capital of a country that has always seen sustainability and climate change issues as a priority in its development policies, including urban planning. In particular, the municipality of Copenhagen has recently embarked on a process of urban adaptation to climate change that closely mirrors Brown's theory on the concept of Water Sensitive Cities, discussed in the opening section. Therefore, the following chapter will analyse the structure of Danish planning tools and then focus on the policies and solutions for stormwater management within the city. The excursus is functional to analyse in detail the work that Copenhagen is carrying out regarding urban adaptation to flooding risk in order to assess the potential for replication in other contexts, so as to other cities undertake similar paths, developing with more sustainable and resilient perspective.

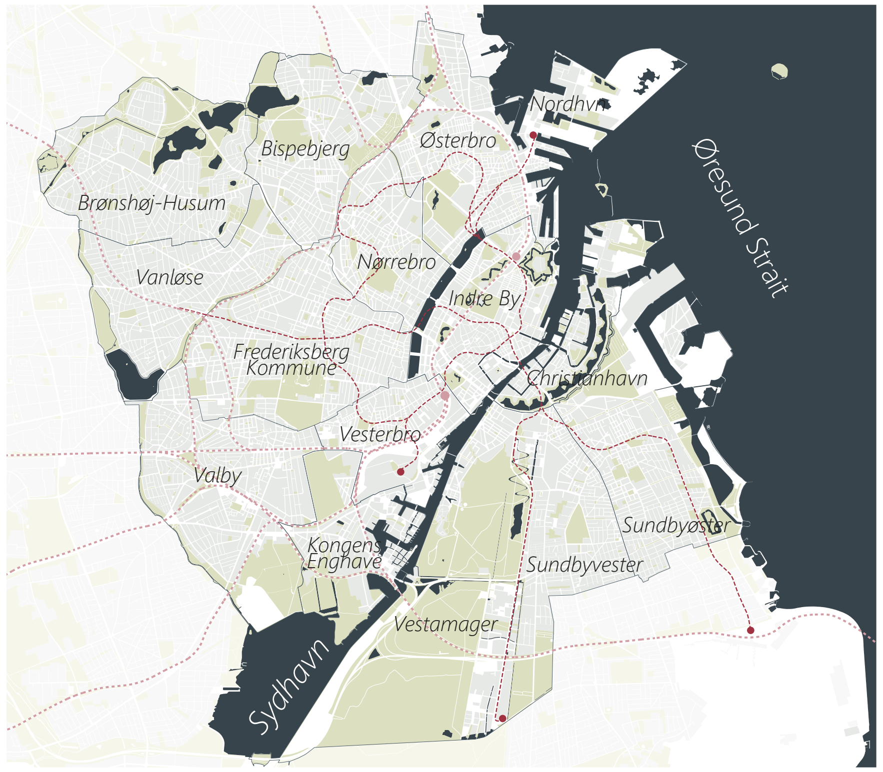
3.1 Copenhagen context

The city of Copenhagen is located in the west of Denmark, on the Sjælland island. Copenhagen, besides being the capital and largest city of Denmark, is the biggest city in the Nordic countries and one of the most important port poles in northern Europe. Geographically the city is situated within the Øresund Strait, the natural border between Denmark and Sweden (Hallegatte et al., 2011).

According to Köppen-Geiger's climate identification, Copenhagen has a special climate, on the one hand, a marine west coast climate, typical of Great Britain, the Netherlands and northern France; on the other, it is very much influenced by the humid continental climate, characteristic of eastern Europe (Kottek et al., 2006). To sum up, the predominant climate is humid with the lack of a dry season but a more or less uniform distribution of rainfall throughout the year. Winters are cold and summers tend to be cool (Lu, 2020).

At the administrative level, the city of Copenhagen is located in the Hovedstaden region, which stretches from the capital to Helsingør, the danish closest point to Sweden. The municipality of Copenhagen comprises several neighbourhoods that extend in a crown around Indre By, the city centre. To the north Østerbro with the port area of Nordhavn, Nørrebro to the northwest is the most multi-ethnic district of the city, the municipality of Frederiksberg which administratively is not part of the city of Copenhagen but is an independent city quarter within the capital, Vesterbro to the south-east with the port area of Sydhavnen and the

Figure 13:
Copenhagen urban context
scale 1:125000



island of Amager, separated from the hinterland but connected to the city by different infrastructures. The districts of Bispebjerg, Brønshøj-Husum, Vanløse and Valby are also part of the Municipality of Copenhagen (Lu, 2020), but they form the external belt.

According to data from the Statistical Centre of Denmark (Denmarks Statistik, 2020), the city of Copenhagen has an extension of 90.1 km2, a population of 632340 inhabitants and a density of 8232 people/km2, which certifies it as a metropolitan city. Due to the geographical and climatic characteristics described above, Copenhagen has always had to contend with climatic events mainly related to the sea and rain. It is possible to define the metropolitan area as a low-lying city, where the highest elevation reaches 45 metres above sea level (Hallegatte et al., 2011).

This strong link with water has always defined the urban life of the city of Copenhagen, characterising it with frequent climatic events such as rain and wind that sometimes cause storms and floods. According to DMI (DMI, 2020), about 600 mm of water falls in the form of rain, distributed over the course of a year but with greater intensity in the summer months of July and August. Although Copenhagen's coastal area is not one of the most dangerous in the Baltic area[4], as it is not located inside a deep bay where tidal variations are more sensitive, the city has had to face several extreme events over the years (Kettle, 2016), effect of climate change. These include the floods of August 2010 and the subsequent one of June 2011, whose intensity was equal to a climatic event with a return time of 100 years. The cloudburst of 2011 caused an amount of economic damage equal to 1 billion US dollars.
Therefore, it can be said that although its geographical location is not the worst among the Scandinavian countries, Copenhagen is particularly vulnerable to the effects of climate change due to the overwhelming impact of climate change at the same time as the city's population and urban growth in recent years, which predicts a population increase of up to 100,000 inhabitants by 2025 (IWA, 2015). Furthermore, it is important to underline that from a technological point of view, the city of Copenhagen is structured on top of a combined sewer system dimensioned for 10-years events (Liu & Jensen, 2017). This means that today, the sewer system in Copenhagen is not able to contain rainfall amounts equivalent to a return time event of more than 10 years, causing an overflow of the system and a surface accumulation of wastewater (Ziersen et al., 2017).

Considering the future scenarios predicted by the UN's Intergovernmental Panel on Climate Change (IPCC), there will be a general change in weather events with an increase in the volume of rain and a change in its intensity. In particular, less rain is expected but of greater intensity, especially during the summer seasons. As previously mentioned, Denmark and especially Copenhagen has already experienced this change in climate behaviour and will experience more frequent and disastrous events in the future. According to the reports of the Danish Meteorology Institution (DMI), the scenario for 2100 for Denmark foresees, in the worst case scenario, a temperature increases of 3.4 °C, an increase in winter precipitation by 25% in the form of rain, not a significant increase in summer precipitation but will be high intensity. The sea level is expected to rise by 2.4 °C, with a consequent increase in storm surges and their intensity (DMI, 2020).

Within this global scenario, the goal and vision that the city of Copenhagen is setting itself is to ensure high quality drinking water for future generations and the protection of citizens and the economy from the consequences and events related to climate change (IWA, 2015). To achieve these results, the City of Copenhagen in close cooperation with the Water Utility (HOFOR) and several private institutions has tried to develop different political strategies, urban plans and flood proofing infrastructure to adapt the city to the scenarios described above.

Before describing the plans adopted by the city to guarantee a certain level of security for the population against climatic events, it is worth taking a quick look at the legislation and planning instruments in force in Denmark with regard to spatial and development planning.

[4] The coastal area of Copenaghen is not located inside a deep bay so that it suffers less from tidal variations (Kettle, 2016).

3.2 Plans and Legislations in Denmark

Analysing what is commonly defined as planning systems, it is possible to identify, the terminology Special Governance and Planning Systems (SGPSs). In the European context, it includes both spatial governance and spatial planning (Berisha et al., 2021). SGPSs are defined as 'Institutional Technology', which means tools that by *social convention and according to different evolving social models, allow the public authority to guide and control the transformation of physical space through the allocation of land use and spatial development rights* (Berisha et al., 2021).

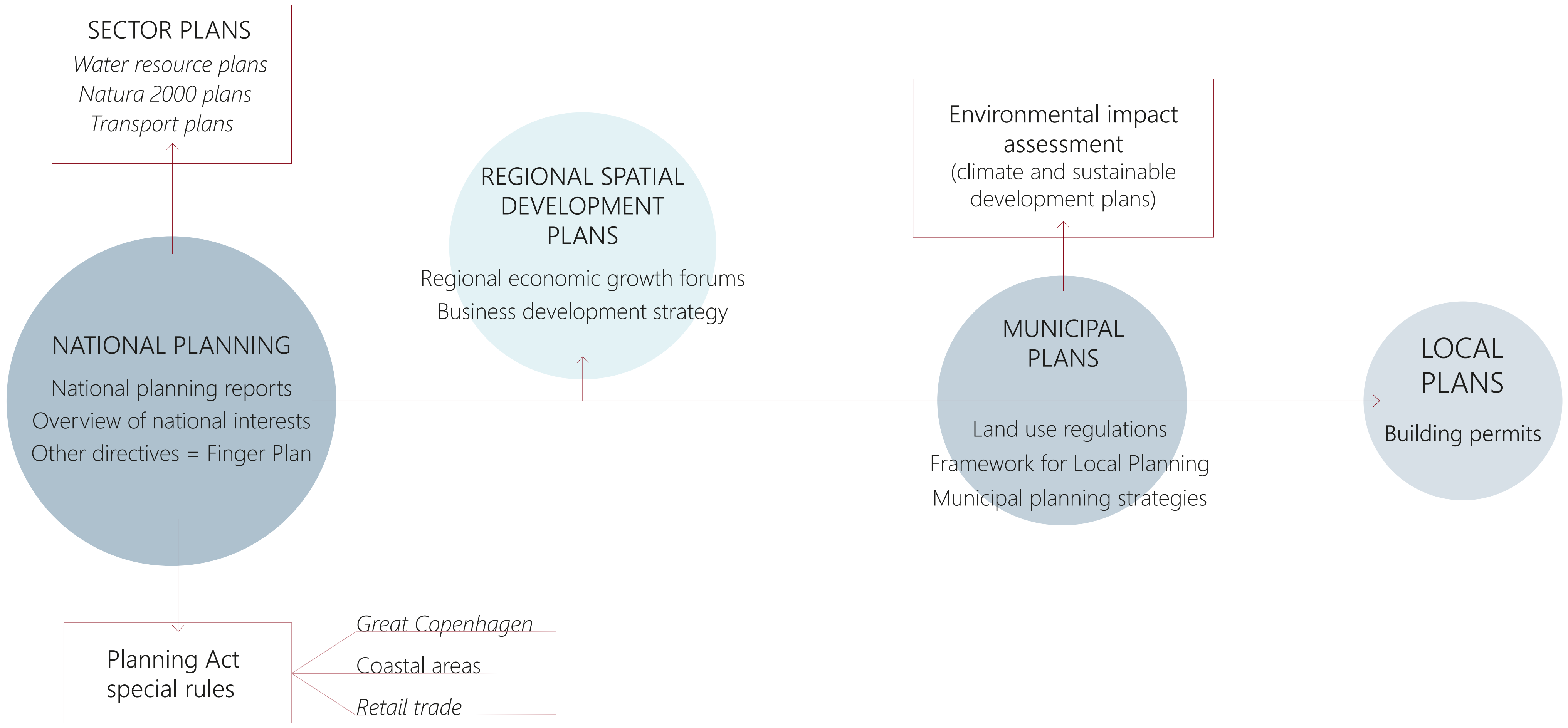
Using this classification, the Danish system is part of the neo-performative model. More specifically, this model foresees that land use rights are established by general urban plans while spatial development rights are provided by specific binding plans concerning small areas (Local Plans). Thus, the Danish planning system partly adopts the instrument of binding zoning, but the development rights of areas must be subject to specific planning negotiated and discussed with developers and landowners. Further, Danish's SGPS can be defined as a state-led system because the allocation of urban development rights is decided on the basis of state interests with respect to market's impact (Berisha et al., 2021).

Denmark's planning structure is administered by the Planning Act, which has been last revised in 2007 with the aim of simplifying, clarifying and decentralising spatial planning work (Danish Ministry of the Environment, 2007). The new Planning Act provides for the subdivision of planning instruments into a vertical hierarchical system organised into four main levels (Figure 14): The National Plan, the Regional Plan, the Municipal Plan and the Local Plan.

In addition, three specific national planning rules are included. These concern the Great Copenhagen area, the Coastal areas and the planning of Retail Trade (Berisha et al., 2021).

Every level has different interests, but each of them has to fall under the provisions of the general level above. Another element foreseen in the Planning Act is the engagement of the private sector in the planning processes, providing minimum rules on the organisation of discussions, meetings, workshops and other instruments of citizens' involvement in the decisions of urban space development (Berisha et al., 2021). Going into more detail about the different planning layers, the most general and comprehensive level is the National Plan.

Figure 14:
Denmark layers of planning
Source: Author based on Danish Ministry of the Environment, 2007



The National Plan provides a vision of national development to be pursued at the level of regional and municipal planning. In addition, it may include specific development directives crucial to social dynamics such as, for example, the definition of new urban areas, new pipelines for natural gas or locate national stations for wind turbines or electrical transmission lines (Danish Ministry of the Environment, 2007). The National Plan is expressed through reports, general guidelines, national planning directives and state planning announcements. State directions are issued at four-year intervals, prior to the issuance of municipal plans so that they can provide for development reforms inherent in the country's shared vision (Københavns Kommune, n.d.).

The Regional Plan, on the other hand, concerns the development lines envisaged by the region regarding cities, rural areas and peripheral areas. The regional plan is the set of collective projects discussed by city councils, businesses, the regional council and other institutions operating at regional level (Københavns Kommune, n.d.). The issues addressed within the plan cover various topics such as the environment, economy and work, education and culture, which in turn must be provided for in the development strategy of the individual municipalities (Berisha et al., 2021).

In the same way the Municipal Plan defines the general objectives and guidelines for the development of the individual municipality, including guidelines for local planning (Københavns Kommune, n.d.). The Municipal Plan is the connecting element between the National Plan and the Local Plan, as the state establishes general guidelines for planning which are subsequently translated by the municipality into directives for physical planning through local plans. Within the municipal plan, the framework for local plans is prepared, indicating what should be foreseen in the different areas subjected to a local plan (Berisha et al., 2021). Each municipality is obliged to adopt a Municipal Plan, which lasts 12 years and must be revised every four years in line with any new supra-municipal development strategies. All the indications contained in the Municipal Plans cannot oppose the guidelines of the National and Regional Plans with the consequent possibility of a veto by The Minister for the Environment.

Finally, Local Plans are the planning instruments with the power to concretise the political strategies expressed in the previous levels. Through the Local Plan it is possible to determine the rules defining: use, building density, open spaces, building heights and retail sales inherent in an area or individual property. *A local plan gives property owners the right to develop and use property in accordance with the local plan* (Niels & Helle, 2007).

Crucially, local plans are legally binding, which means that the landowner must comply with the provisions of the local plan. It is through this instrument that the definition of the neo-performative bread-making model takes place.

The adoption of a Local Plan does not force the landowner to act but provides specific rules on how to eventually act (Berisha et al., 2021). Some local plans are included at the level of the municipal plan, while others may also be requested later by the citizens (Københavns Kommune, n.d.). The Municipal Plan covers all strategic development or climate adaptation plans of the city or municipality. Anticipating what will be specified later, the Municipal Plan includes all plans that the city of Copenhagen has established to adapt the city to climate change and to achieve greater sustainability in the use of resources.

3.3 Water Sensitive Copenhagen

At the beginning of the 21st century, the term Water Sensitive City emerged as a useful tool to bring together the vague concepts that link water with people, government, the built environment, infrastructure, the living ecosystem and resource use. The concept serves the practical purpose of educating people and adapting the forms of nature to accommodate water in its various expressions to make it a potential element of future city development (Januszkiewicz & Golebieski, 2019). If we consider the principles and characteristics that outline the concept of Water Sensitive City, it is possible to recognize in Copenhagen a transition path towards a model of a city more sensitive to water issues and more generally to climate change.

> *In Copenhagen we always try to find solutions that do not just solve the problem, but also create a better quality of life for the citizens in Copenhagen. We incorporate climate change adaptation at all levels of city planning and prepare comprehensive solutions for the entire city.*

Morten Kabell
Mayor for Technical and Environmental Affairs
Københavns Kommune, 2012.

In the words of Mayor M. Kabell it is possible to understand how the commitment of the Municipality of Copenhagen in solving climate change problems requires integrated and systemic planning (Confederation of Danish Industry, 2014). Over the last decade (Figure 15), the City of Copenhagen has developed and implemented a series of urban plans and strategies aimed at a greener, sustainable, and resilient city towards climate change.
Among these solutions, is the following:

- Urban Plans (national, regional, municipal, local and district)
- Urban Life Account 2010-2015: strategy that measures and monitors the quality and satisfaction of urban life
- Climate Adaptation Plan 2011: urban plan on climate change adaptation strategies
- CPH2025 Climate Plan 2012: strategic plan to make the city carbon neutral by 2025

- Cloudburst Management Plan 2012: specific plan to combat extreme climatic events
- A Harbour of Opportunities 2013: planning vision of Copenhagen's port areas
- Co-create Copenhagen 2015: replaces the previous Urban Life Account plan by pushing for greater use of a participatory process within urban planning. Urban Nature Copenhagen 2015: planning strategy to increase green coverage within the city
- Stormflods Plan 2017: plan introducing new strategies to counter future sea storms
- Hofor Utility strategies (Wastewater plans)

Comparing the principles that in the literature identify the concept of Water Sensitive City (WSC) with the guidelines, visions and strategies expressed in the various plans listed above, it is easy to see how the vision of the city of Copenhagen is projected towards greater liveability, sustainability and resilience by recognising water as a strong dominant element of policies and the urban environment. Although only the Climate Adaptation Plan, the Cloudburst Management Plan and the more recent Stormfloods Plan deal specifically with the management of urban water as a resource and an element of the landscape, the other plans reread some principles linked to the WSC concept.

Indeed, thanks to the flexibility of the Danish system (Danish Ministry of the Environment, 2007) it is possible to retrieve principles of adaptability, sustainability and protection of natural resources at all planning levels. As a result, the result is an intertwined system that aims at a dynamic development aimed at the continuous improvement of citizens' lives. In this way also the strategies concerning issues unrelated to water management or climate change adaptation solutions must adjust to the sustainable policies outlined in the plans. By looking specifically at Copenhagen as a water-sensitive city it is possible to find within its plans several examples (Figure 15) that can be classified according to the WSC Indicators (see section 2.1).

From the proposed scheme it is possible to see how all the indicators identified to outline a water-sensitive attitude dealt with the different planning strategies adopted by Copenhagen but also in general by regional and national levels. In conclusion, admitting the fact that a model of Water Sensitive City in the world has not yet been recognised, the study and analysis of the urban planning policies adopted and implemented over the years by the city of Copenhagen can be seen as a process of transition towards an increasingly sustainable and water-sensitive future. For this reason, the path undertaken by the Danish capital can somehow be seen as an example for other urban contexts.

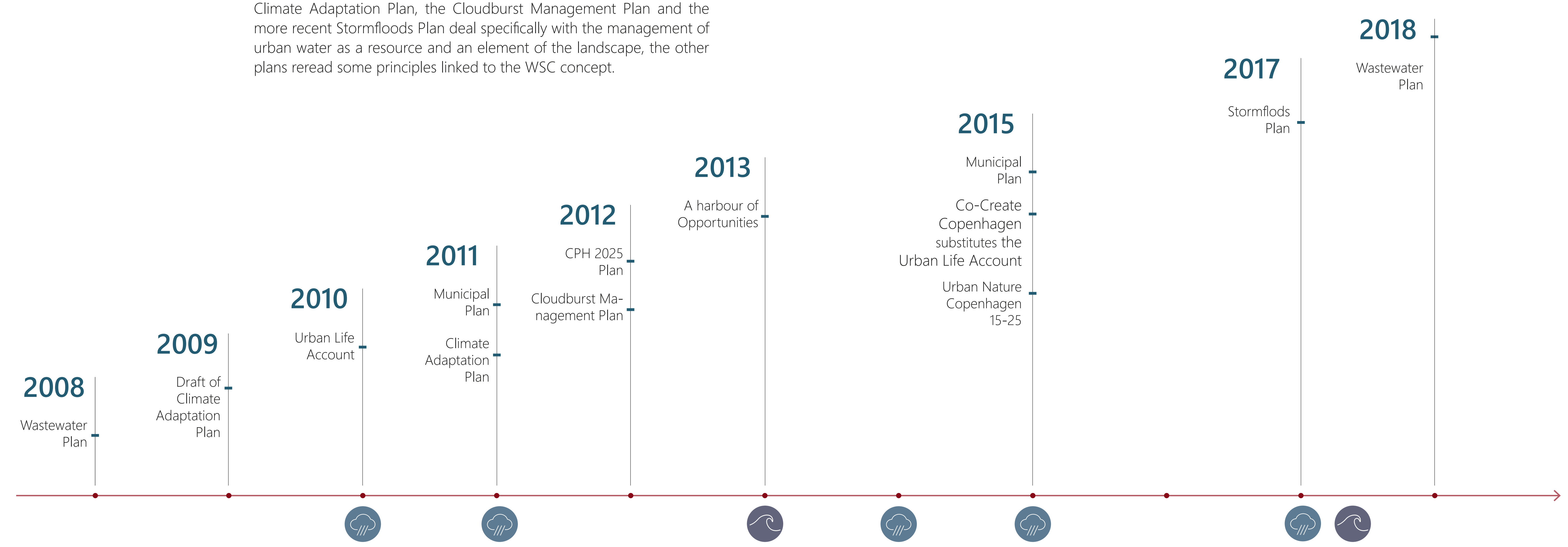


Figure 15:
Correlation between urban plans and indicators of water sensitive strategies.

● *counted*

• *partly counted*

○ *no counted*

	National Plan	Regional Plan	CA Plan	CM Plan	CPH 2025	Wastewater plans	Stategic plans
Water sensitive governance	●	•	●	●	•	●	●
Community capital	○	○	●	●	○	○	●
Equity of essential services	○	○	•	•	●	●	○
Productivity and resource efficiency	•	○	●	○	●	●	○
Ecological health	●	•	●	●	○	•	●
Adaptive infrastructure	○	○	●	●	○	●	•
Quality of urban space	•	●	●	●	•	•	●

3.4 Stormwater Management solutions for a Copenhagen cloudburst proof

In this section two main plans are presented which the city of Copenhagen has adopted to counter flooding and improve stormwater management. Firstly, the structure and directions of CAP 2011 and CMP 2012 are presented. Secondly a specific focus is made on area of the city where stormwater projects are presented in their fundamental points, showing how the projects actually reflect the indications of the plans.

3.4.1 Climate Adaptation Plan 2011

In 2008, the Municipality of Copenhagen began a campaign of technical and economic analysis of solutions to tackle the current climate change phenomena. The objective of the analysis was to find ways which could ensure a safe and liveable urban environment for the population. In 2009 the City of Copenhagen Climate Plan was published and its final adoption as Climate Adaptation Plan took place on 25 August 2011, coinciding with the publication of the new Municipal Plan. In August 2010, the city experienced a heavy downpour that underlined how climate and rainwater management are serious problems that require an immediate hard intervention. The objective of the Copenhagen CAP is to identify short and medium-term solutions to prepare the city to face and cope with future climate scenarios. Due to the fact that climate events are difficult to predict with certainty, it is necessary to provide flexible solutions which can adapt spaces to different and severe scenarios. The evidence in the plan is based on the reports of the UN's Intergovernmental Panel on Climate Change (IPCC), data from the Danish Meteorological Institute (DMI) and other guidelines from the climate strategies of the Capital Region. Further information comes from publications of Water Pollution Committee of the Society of Danish Engineers and statistics provided by the Danish Coastal Authority and others related to the policies of HOFOR, the Great Copenhagen Utility.

STRATEGY

The strategy proposed in the plan is based on the concept of uncertainty, a key factor in climate change events. For this reason, the solutions proposed must provide for continuous revision and updating according to the advancement of knowledge on the field and technical innovation. Moreover, the plan points the need to map the city according to a different degree of risk commensurate with the economic cost and social loss that the occurrence of a catastrophic event entails. The identification of three levels of risk (Low, Medium and High) allows to identify the entity of the countermeasure to be adopted to contrast the event. In particular, the plan suggests the application of measures that: (a) reduce the probability of an event occurring, (b) measures that reduce the scale of the event and (c) less drastic measures aimed at reducing vulnerability and helping recovery after the event.
All solutions that are implemented must also have the second objective of helping to improve citizens' quality of life, providing more recreational

opportunities, new jobs and businesses but also improving local environment with more green elements.
In reference to the strategy just exemplified, the Climate Adaptation Plan aims to solve many climate challenges such as the following:

- Heavier downpours
- Higher sea level
  - Higher temperature and urban heat islands
  - Groundwater
  - Indirect consequences:
    - Public health
    - UV Radiation and Heat Stroke
    - Diseases
    - Damp nuisance
    - Pollen allergies
    - Air quality

The listed challenges are divided into two categories: Primary challenges and Other challenges. It is very important to underline that the primary challenges are strictly related to water management in terms of stormwater and seawater. This distinction underlines how water is the most important climate factor for Copenhagen as it permeates the city's activities completely. For this reason and in line with what has been discussed up to this point, the following considerations are given to the stormwater challenge, not going into the details of the others.

HEAVIER DOWNPOURS

Considering the IPCC scenario, it is expected a continuous increase in the annual rainfall volume and an increment in the intensity of events. Indeed, it can be said that events with a return time of 10 years will increase by about 30% in 2100. Copenhagen presents a combined sewer system, i.e., a single drainage system for wastewater and stormwater. So that, the major consequences of the new precipitation patterns are more frequently overflowing phenomena. The prevention from sewer overflowing is necessary for many reasons: on the one hand to prevent the accumulation of too much surface water and damage to buildings, infrastructures and people; on the other, overflowing causes the flow of wastewater and stormwater inside the city, contributing to the increase in pollution of waterways receivers and generating sanitation problems. Therefore, the city will have to deal with more flooding phenomena similar to those already occurred in 2010 and 2011.

To avoid these scenarios, it is necessary to implement a correct planning strategy that defines WHERE the water will flow superficially and HOW HIGH it will reach and WHAT interventions it is better to adopt. The plan proposes two main solutions, based on the analysis of different likely scenarios and the drafting of flash flooding maps identifying the most vulnerable areas of the city.

The first solution involves disconnecting 30% of the stormwater volume from the sewer through the implementation of a new centralized infrastructure or better implementing decentralized infrastructures, such as sustainable urban design solutions (o LAR[5] in danish). The adoption of LAR solutions allows to manage the stormwater locally through delay, store and treat of rainwater it will be discharged into water basins or infiltrated into the ground. The adoption of this type of intervention makes it possible on the one hand to reduce the load on the sewer, and on the other to integrate natural elements that contribute to making the city greener.

The second, called "Plan B", involves the conveying of water that accumulates superficially in low-lying areas where it causes the minimum damage possible. This type of space includes parks, squares, ponds, and playgrounds. These spaces must be designed so that they can accommodate a volume of rain equivalent to an event with a return time of 100 years. In other words, the flooding of these public spaces is only foreseen in case of exceptional events, for ordinary events it is better to implement LAR infrastructure.

The plan emphasises who is responsible for providing these solutions, how much money and how far their competencies extend. Most of the responsibilities for water management and sustainable climate solutions lie with HOFOR. Prevention and securing of private buildings, in particular basement flooding problems, is not the responsibility of HOFOR or the municipality. For this reason, the plan emphasises the need for community awareness campaigns on climate and environmental topics. An appropriate education programme raises citizens' awareness of the risks of extreme weather events, increases their sensitivity to the issues and promotes the application of innovative protective measures in the private sector.

The Climate Adaptation Plan proposes guidelines for action but not practical information on what to implement and where to implement since these is the task of Municipal and Local Plan in cooperation with HOFOR. However, within the plan there is a demand for collaboration between different public and private professional bodies, neighbouring municipalities, and continuous coordination with other planning levels, from national to specific regulations (as an example the wastewater plan).

[5] LAR stands for Local Removal of Rainwater (Lokal Afledning af Regnvand) and involves managing rainwater locally, so that less water is carried to the sewers. When LAR is used, the rainwater percolates and evaporates. If this cannot be done at the particular location, the water is retained before it is transported to a receiving body of water, an artificial water element or a road.
(Københavns Kommune, 2012)

In the vision of a Copenhagen Climate-Proof, nature plays a fundamental role at different levels. That is the reason why, an entire section of the plan is dedicated to "A Greener Copenhagen". The section underlines the need to increase green coverage within the city to address all aspects of climate change, improve quality of life, health and provide what are known as " Ecosystem Services" (i.e., regulation of air temperature, encourage biodiversity, contribute in reduce city energy consumptions and provide social and liveable urban space). The creation of a green network that permeates the city is fundamental in stormwater management but also provides many life and recreational opportunities. Copenhagen is recognised as a 'Green City' because it has always considered nature as an integrated element in the urban environment. Thus, the actions proposed envisage the protection and extension of green cover by creating ecological corridors, acting on renewal or development areas where it is easier to implement greener solutions. A fundamental aspect is the integration of greenery with blue infrastructures to provide a backdrop for climate events, but above all to confer richness and amenity to the space.

PROJECT OVERVIEW

The final part of the 2011 CAP is dedicated to future actions, underlining which has to be implemented in conformity with the policies expressed above.
As far as the stormwater issue is concerned, the plan foresees:

- Reduction of the hydraulic loading of watercourses
- Passing on knowledge to the public/businesses on options for climate-proofing
- Planning and implementation of "plan B" solutions in the city of Copenhagen
- Opening of piped watercourses
- Disconnection of stormwater from the sewer
- Quantification of the effect of different LAR solutions
- Coordinated wastewater planning

3.4.2 Cloudburst Management Plan 2012

The Cloudburst Management Plan (CMP) is part of the Copenhagen Climate Adaptation strategies. The Plan has been adopted by the Municipal Council on 13 December 2012 as an extreme measure after the heavy downpour in June 2011. The vision proposed aims at mitigating "extreme rainfall events" defined by the Danish Meteorological Institute as meteorological events with "more than 15 mm of precipitation in the course of 30 minutes" and which are usually characterised by a return time of 100 years. Due to the variation in rainfall regimes in the coming years due to climate change, extreme events like the one in 2011 will become more frequent and occur with greater strength. For this reason, the plan aims at defining concrete and targeted actions to reduce the intensity of climate hazards. The Cloudburst Plan can be considered as an extension of the CCAP 2011, owing to propose additional methods, priorities, and measures to minimize the risks and damage arising from heavy downpours. The stormwater management strategy presented in the CCAP seems to be not largely efficient in case of extreme events so that Cloudburst Management Plan needs to add further and specific measures.

The CMP's formula is based on different steps that start from the analysis of the characteristics of the contest and lead to the definition of practical and specific actions on the basis of which an economic implementation plan is structured. The preliminary study concerns the basic elements of the city (hydrology, land-use, society, buildings and infrastructure) on which hydraulic models are built to identify the most vulnerable areas and the related risk of economic damage due to flood phenomena. The risk analysis is fundamental in order to prioritize solutions according to economical budgets and social losses. Understanding the economic cost of flooding is necessary to justify the importance of adaptive solutions as an alternative to 'doing nothing' strategies.

Considering the impossibility of having zero risk condition, its quantification takes into account HOW frequently flooding is acceptable and WHAT surface water level is acceptable in case of floods. Through the study of the city's characteristics and contexts such that its infrastructures remain functional, the plan foresees practices aimed to have a maximum of 10 cm of surface water during an extreme event. Furthermore, considering the risks connected to the sewer system, it must be ensured that the overflow occurs once every 10 years. Further recommendations pinpoint the implementation of stormwater control measures during ordinary rainfall events and consistent adaptive infrastructure, implemented in coordination with other urban development regulations.

Once the action strategy has been defined, it is necessary to design robust solutions that combine the principles of engineering with the tools of urban planning and architecture in order to create effective solutions that integrate harmoniously with the city and contribute to increased aesthetic and social values. Fundamental to the planning process is the involvement and collaboration of different stakeholders. Design concepts are discussed with different actors and consultants in order to refine the design and evaluate possible alternatives. The final step of the Cloudburst Management Plan is the analysis of the economic profile related to the realisation of the indicated projects. The economic balance is crucial to understand the financing of the plan and thus its realisation (Hansen et al., 2016).

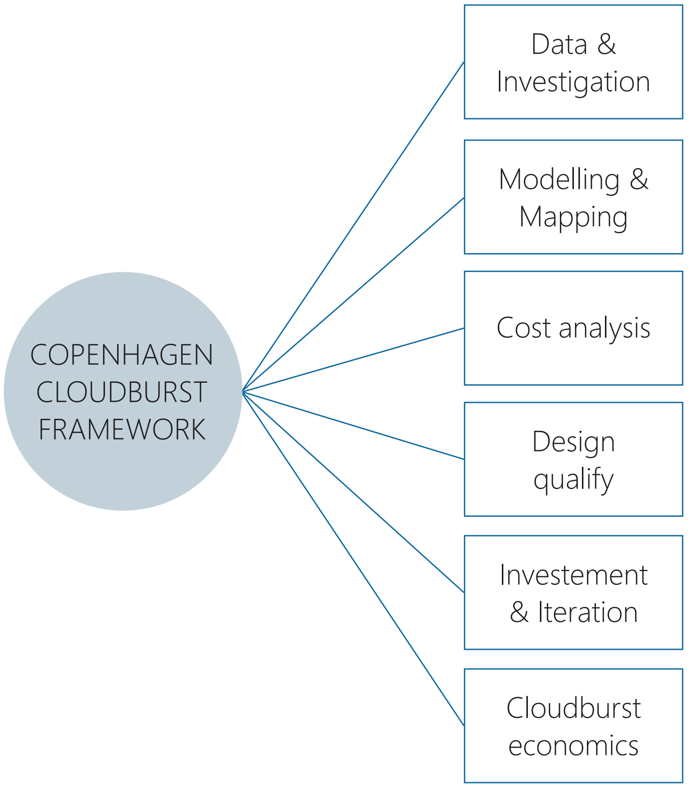


Figure 16:
Copenhagen Cloudburst Management framework
Source: Author based on Hansen et al., 2016

STRATEGY

The strategy proposed in the CMP foresees the reduction of pluvial flood risk through long-term projects. These have to counteract sewer overflows and avoid surface water accumulations hazardous to normal city activities. The plan's strategy mainly involves two types of action:

The first action considers the implementation of surface projects to delay, store or drain excess water at ground level and avoid accumulation or massive discharging into the sewer system. Solutions of this kind can include reopening streams, building new canals or lakes, increasing green spaces and using roads with high curbs to lead the pluvial flood water into these.

The second involves underground infrastructure (cloudburst pipelines) in the most densely build-up area of central Copenhagen, which ensure rapid drainage of excess rainwater directly to harbours or lakes. Cloudburst pipes build the infrastructural skeleton of the whole Plan and interact with the existing or renewed urban drainage system.

Between 2013 and 2014, the Detailing of Cloudburst Management Plan was approved, specifying in detail the type of actions envisaged in the plan. As a consequence, the city of Copenhagen has been divided into 7 catchments areas[6] according to the hydraulic and topographical characteristics of the territory. Within these areas about 350 projects (Figure 16) are planned (which 300 are on surface), financed partly by private funds but mostly by taxes on water use (managed by HOFOR). Moreover, the lines where the cloudburst pipes are to pass have been marked out. To better planning and design all these solutions, each catchment area has been divided into sub-categories called *cloudburst branches*[7] in which a series of interconnected projects are foreseen depending on the watershed hydraulic characteristics. The Cloudburst Management Plan has drawn 60 branches within which between 1 and 17 different projects are reported depending on the complexity and size of the branch (Figure 17).

Stormwater solutions in these areas are conceived as a complex matrix that combine together different elements in cooperation with the solutions adopted in the surrounding sub-areas. In this way most of the stormwater is transported, delayed, retained and drained from the upper-stream areas to the downer-stream, out to sea. Therefore, the 350 cloudburst projects reported in the plan are divided into 5 main categories. Two measures based on conveyance and three based on a combination of retention and detention solutions:

[6] A demarcated area of the city where collective management of rainwater can be done. The individual catchment areas are said to make up a hydraulic unit, that is to say the projects in the catchment area are mutually dependent. A project therefore cannot be removed without replacing it with something else that serves the same function. Catchment areas do not follow the normal boundaries between urban districts but are based on the local topography. In several cases, the catchment areas also transcend municipal boundaries (Københavns Kommune, 2015).

[7] A cloudburst branch is a collection of projects that ensure that the water is removed from a given catchment area based on hydraulic calculations of how the water flows through the city. The cloudburst branches are thus to be regarded as continuous hydraulic solutions (Københavns Kommune, 2015).

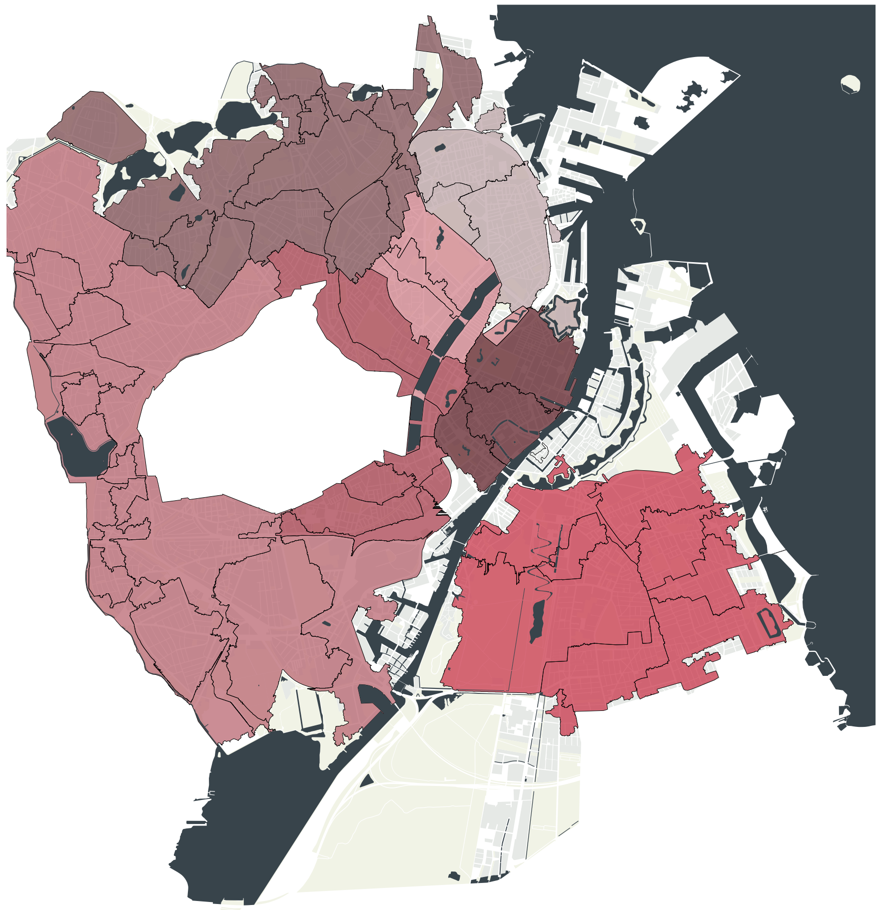


Figure 17:
Copenhagen catchments areas and cloudburst branches

- *Amager og Christianshavn*
- *Bispebjerg, Ryparken og Dyssegård*
- *København Vest og Frederiksberg Vest*
- *Ladegårds åen, Frederiksberg Øst and Vesterbro*
- *Indre By*
- *Nørrebro*
- *Østerbro*

CLOUDBURST
MANAGEMENT PLAN
COPENHAGEN

scale 1:50000

CLOUDBURST ROAD

A cloudburst road is a road which in normal weather functions as a road in the city and when torrential downpours and large volumes of water occur transport the water to places from which they can either be collected or discharged. Cloudburst roads are established by re-profiling the road, making changes to terrain, or raising the kerb to ensure water will flow in the middle of the road away from the buildings. Cloudburst roads may also be combined with Cloudburst piping below the surface to create tool synergies. Generally, no green elements are incorporated in a cloudburst road.

RETENTION ROAD

A retention road retains and stores water. This retention can be done with green elements. This is done by integrating various retention elements into the road – roadside beds, rain beds and similar features. There will often be good opportunities to incorporate urban space improvements, for example in the form of green and blue elements. Retention roads are typically located slightly upstream of vulnerable low points to handle stormwater before reaching the more vulnerable points downstream.

RETENTION SPACE

A retention space is a square or a park arranged to store water when cloudbursts occur, to avoid having too much water on the surface and delay its infiltration into the sewer. When the downpour is over, the facility is drained either to the sewers or to the cloudburst management system. The retention spaces can be advantageously designed as multifunctional urban space elements, which in everyday conditions function for example as sunk parking areas, squares, sports fields, or similar. Alternatively, they can be established as underground storage such as soak-away crates or rain gardens. Central retention elements will typically be placed in connection with adjacent Cloudburst roads.

GREEN ROAD

The hydraulic function of green roads is to remove and retain the water locally and at a small scale. They are established typically on smaller roads, as private shared roads. Green roads are proposed as upstream connections to all Cloudburst roads. They should be established with a combination of small-scale channels and stormwater planters or permeable paving. In this way stormwater should be collected, delayed and then channelled towards the Cloudburst roads.

CLOUDBURST PIPELINE

Underground solution for conveying and discharging stormwater mainly during cloudbursts, usually of larger dimension than a typical drainage pipe and installed only where existing city topography and infrastructure is not able to manage the surface rain flow. A cloudburst pipe is designed to drain large quantities of water to the harbour or other sufficiently large water reservoirs.

In conclusion, it has to be underlined that the contents of the Cloudburst Management Plan are not legally binding neither for the private landowner, nor for the water utility or the Municipal Administration. Consequently, the contents of the Cloudburst Management Plan need incorporating into the Administration's general planning process like Municipal Plan, Local Plan and Wastewater Plan.

GOVERNANCE PROCESS

The governance process leading to the implementation of the projects described in the Cloudburst Management Plan is based on close cooperation between two institutions: The Municipality of Copenhagen and HOFOR, the water utility. Indeed, HOFOR and the Municipality are recognised as being primarily responsible for the planning, implementation and maintenance mechanisms of the climate adaptation and cloudburst proofing projects. In 2013, the Danish government enacted a new law that gives the possibility to water utilities to finance surface water management solutions with part of the water service taxes (Københavns Kommune, 2015). Thanks to the new legislation, the projects described by CMP are economically feasible through a co-financing programme between HOFOR and the Municipality, or landowners. The partnership stipulates that HOFOR is directly responsible for the design and management of all the hydraulic infrastructure, as well as for ensuring the correct level of service of the drainage system (Ziersen et al., 2017). On the other hand, the Municipality's Technical Office (TMF) is responsible for planning and implementing surface projects in conformity and integration with existing plans. Through the co-financing agreement, the Municipality implements the cloudburst projects, and it is subsequently reimbursed by HOFOR for the full cost. In case the surface projects contribute to social cohesion and enhance the liveability of the area, the municipality can apply to the state for extra funds for the implementation of these projects.

Concerning the responsibilities of private individuals, they are legally responsible for securing their property against the risks caused by flooding. Normally cloudburst projects do not involve private property as their implementation requires a voluntary agreement or expropriation of the property. In case this is not possible HOFOR intercedes for the Municipality by implementing the project as if it were a regular utility infrastructure, or it makes a co-finance agreement with the private property owner (similarly to the agreement between HOFOR and the Municipality) to handle rainwater from the private land. In that case, the private owner is the titleholder of the projects and oversees everything from the planning process to execution (Københavns Kommune, 2015). Moreover, it is possible that during the drafting of a Local Plan, private areas with a request of use change, are granted in exchange for the implementation of flood management solutions.

More specifically on the dynamics that led to the realisation of the CMP, it is worth highlighting the continuous involvement of different stakeholders in the planning processes.

These include industry, universities, consulting companies, but also other city authorities and water utilities outside the City of Copenhagen, whose involvement is instrumental in achieving effective and shared results. Equally important is citizens inclusion in the discussion processes taking place before the drafting of plans or the implementation of specific projects. Citizen participation processes are stimulated through platforms for the sharing of ideas and dialogue between municipality staff and neighbourhood committees as well as via the organisation of educational and information events. Through this dialogue, the City Council is able to take a closer look at the dynamics and problems of different urban realities, making planning actions more targeted and effective. It can also raise people's awareness of climate issues by getting them active in urban development activities (Københavns Kommune, 2011).

Looking at the process that leads from the indications of the plan to the realisation of the individual project, it is possible to identify three fundamental phases:

1. Drafting and adoption of the CMP within which general indications are reported on how to make the city resilient to flooding phenomena, it sets out the existing financial and legislative instruments and the bodies responsible for the different processes.

2. The compilation of Masterplans, more detailed plans concerning particular areas of the city (branches) with a certain social and hydrological homogeneity.

3. Drafting of the Construction Plan, the plan that describes in detail the execution of an approved project and precedes its actual implementation.

The Masterplan phase works to bridge the gaps between the two extreme project phases. Indeed, the complexity of the issues dealt with, the strong dependence on hydraulic calculations and analyses of the projects, the capacity of each element and the extension of the different catchment areas requires an intermediate level where the individual cloudburst projects are planned holistically with a focus on the whole picture as well as a level of detail that makes them technically feasible.

The compilation of masterplans has to ensure coherence between solutions and problems by acting through integration with existing infrastructures and increase the enforceability of future projects. Inside a masterplan there are indications about the project area with its development vision, potential and risks related to the urban space. Information on the maintenance and renovation of the conventional drainage system to ensure its proper functioning during ordinary climatic events and guidance for new decentralised infrastructures that disconnect urban areas from the public drainage system.

At the end, the implementation plan is presented with indications on the realization of the projects contained in the CMP. Frequently, projects indicated do not exactly reflect those foreseen in the Cloudburst Management Plan as they are revised according to subsequent and more accurate technical analyses, but also according to the presence of other plans or strategies for the development and urban regeneration of the area.

After being compiled, the masterplan functions as dimension giving framework for the implementation of each of the projects entailed therein. The level of detail of the projects indicated in the masterplan depends on the proximity with which they are implemented. That is why projects with very long lead times may be subject to future revisions. In general, the minimum level of detail contained should include the general hydraulic dimensioning and elevation of each project.

The procedure for compiling a masterplan contains seven stages, briefly listed below (Figure 18) (Office of Masterplans, 2019):

Stage 1: Project start up
This is the preliminary phase of the work where the official collaboration between the HOFOR and the municipality working groups on the project area begins. In this phase the corresponding leaders of the two institutions agree on the objectives to be achieved and discuss the guidelines contained in the Cloudburst Management Plan. The phase concludes with a preliminary analysis of the area and its problems and the drafting of the project agreement.

Stage 2: Status mapping and sewage plan proposal
In the second stage the challenges that the plan wants to solve through the combination of climate adaptation solutions and direct interventions in the city's drainage network are highlighted. At this stage, hydraulic scenarios are analysed in the form of flood maps for events of different intensity (return times of 10 and 100 years). The final output is a draft master plan, which constitutes the basis for future considerations. This phase is mainly carried out by the Water Utility.

Stage 3: Screening the urban space and assessing risks
An assessment of existing urban plans and projects in the study area is essential in order to identify synergistic elements, whose planning can contribute to mitigate the flooding problem but at the same time bring added values to urban space and city life. At this stage, risk maps related to the potential flooding of specific areas are also drawn up in order to prioritize interventions. The municipality's technical office has the main responsibility for producing this type of documentation.

Stage 4: Assessment of service level for cloudbursts
At this level of planning, it is necessary to assess the impact that the different solutions envisaged have on mitigating and counteracting the effects of cloudbursts but also on stormwater management in general.

The different projects within the master plan are identified and the level of service they should guarantee. This phase is necessary for the subsequent dimensioning.

Stage 5: Qualifying solutions
In the fifth stage, it is necessary to quantify the solutions, i.e., to size the different projects at urban level, but especially at hydraulic level, in such a way that they comply with the performances established in the previous stage. In addition, it is necessary to assess whether the different solutions conflict with existing legislation on municipal planning.

Stage 6: Construction expenditure estimate, project description and masterplan
A fundamental part of drawing up a master plan is the financial analysis linked to each project. The different solutions in the plan are uniquely identified with a code referring to a particular financial project, to which the analysis of the implementation cost and the parties responsible for financing is associated. At the end of this phase the two different templates of the master plan have to be filled in: part 1 with the general description and part 2 with the details of the different projects.

Stage 7: Embedment and initialization
The final part of the whole process is the adoption of the plan by HOFOR and the municipality in order to proceed with its implementation. The approval of the plan is essential to proceed with the next phase of physical construction of the different solutions. Notice that the master plan must be approved by the Secretariat for Water Supplies, a state organ, which is responsible for verifying the legitimacy of climate-related plans and ensuring that the municipality does not use the co-financing scheme to finance municipal tasks.

Concurrently with the realisation of masterplans, the Municipality annually discusses the approval of a project package (about 5-15) from among those contained in the already approved plans. These projects are selected according to their consistency in reducing the vulnerability of the area concerned and the socio-economic impetus they can bring. The package, selected in cooperation with local committees, must be reviewed by HOFOR and subsequently approved by local politicians. In addition to the approval of the Technical and Environmental Administration, the project package must be sent for final endorsement to the Secretariat for Water Supplies. Among the Secretariat's responsibilities is to check that the cloudburst management projects comply with the requirements of the planning instruments and do not reflect the personal interests of the municipality (Office of Masterplans, 2019). Only after this phase, the executive design and implementation of the works can begin.

Figure 18:
Process diagram for the compilation of masterplans.
Source: Author based on Office of Masterplans, 2019

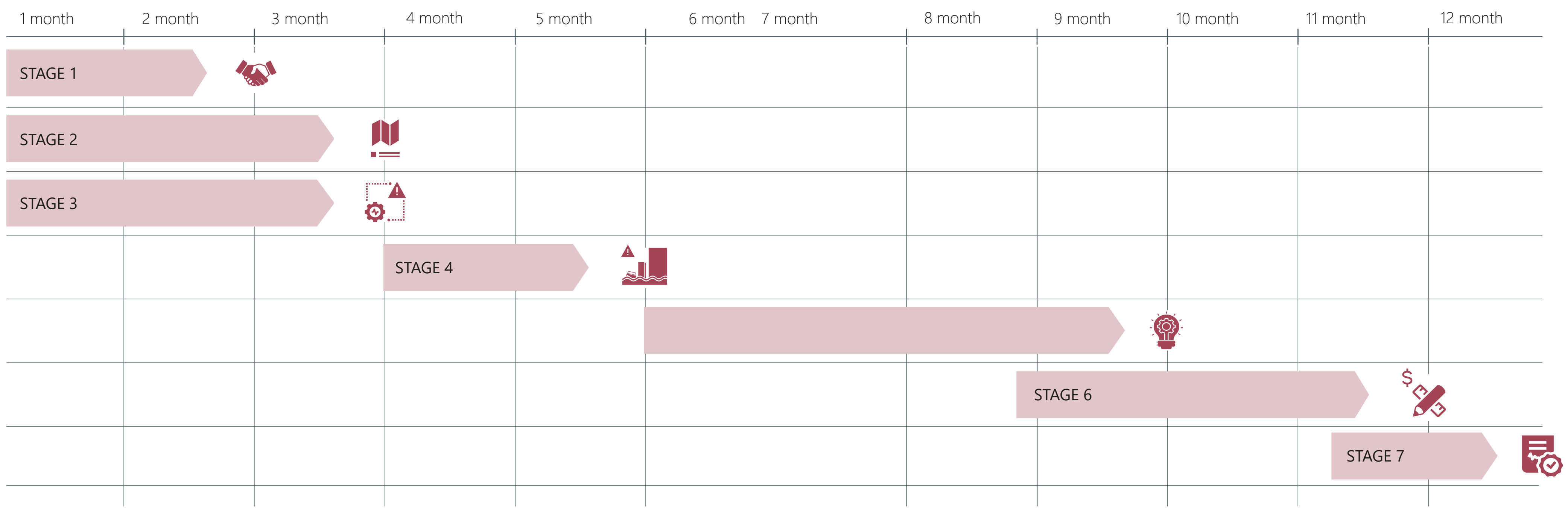
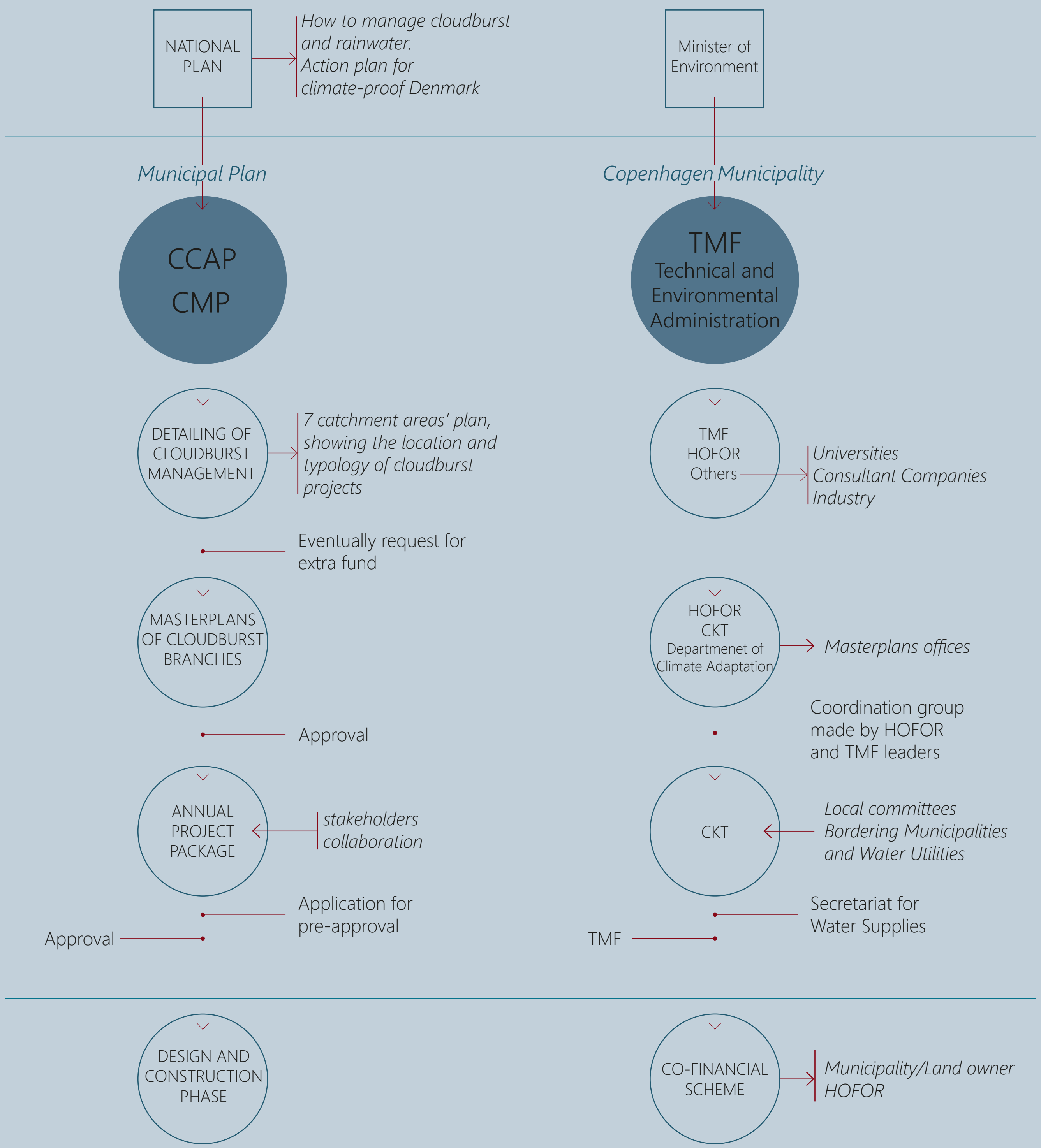


Figure 19:
Scheme of tools and institutions involved in planning cloudburst management solutions.



3.5 How projects reflect the plan

3.5.1 Status of implementation

The implementation of the projects is established annually and according to the level of priority associated with the catchment area. The level of priority is given according to:

1. Hydrological risk of the area
2. Ease of implementation of the intervention
3. Presence of projects in the realisation
4. Possibility of creating synergistic solutions and boost opportunities for the city development.

Furthermore, the execution of different flooding projects follows a priority dictated by the "path of the water" along the area. So that works in the upper stream part of the branch are not normally completed until the receiving areas is commissioned. This tends to slow down or complicate the execution of works throughout the city and consequently it is necessary to always establish timeframes and priorities in order not to create conflicts.

According to the report submitted by the Municipality (Københavns Kommune, 2019) on the status of implementation of the Cloudburst Management Plan's projects, the condition as of 2019 shows that 65/300 surface projects have been initiated by the Municipality of Copenhagen in cooperation with HOFOR and 9 major projects have been completed (Tåsinge Plads, Skt. Annæ Plads, Ryparken, Folehaven, De Gamles By, Bryggervangen and Skt. Kjelds Plads, Scandiagade, Amagerbanen and Enghaveparken). Of those 65 projects, 5 have been suspended and the remaining 60 are at different stages: planning, design, construction, commissioned (Figure 21). According to municipal analyses, the flood projects that the City of Copenhagen and HOFOR have implemented so far have reduced the risk of flooding in the city by approximately 4-7%, corresponding to 2,000-4,000 citizens protected from flooding. The final forecast for completion of the projects is for 2035, which is later than in the first version of the plan.

To better comprehend the mechanisms and tools proposed in the Cloudburst Management Plan it is indispensable to analyse in detail the contents and structure of one of its masterplans. In this way it is easier to understand how the projects actually reflect the Plan and what impact they have on stormwater management and city development. This kind of considerations are functional to grasp the structural principles of these solutions and to insight their possible replicability in different contexts.
From the 60 branches presented in the CMP, only 6 have a defined masterplan, others are on a revision or start-up phase. Among the approved there is Lersøparken's, an urban district located on the northern edge of the municipality of Copenhagen (Figure 22).

Figure 20:
Projects status according to the CMP report of 2019.
Source: Author based on Københavns Kommune, 2019

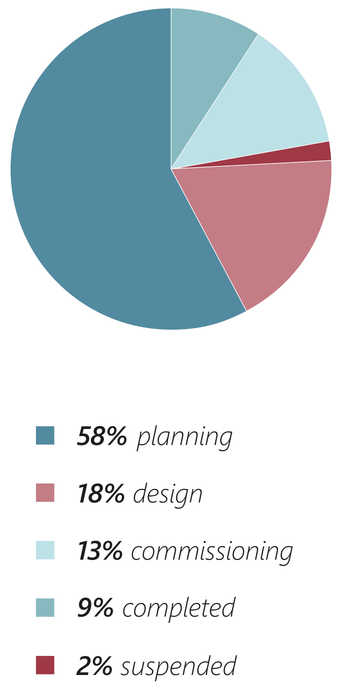
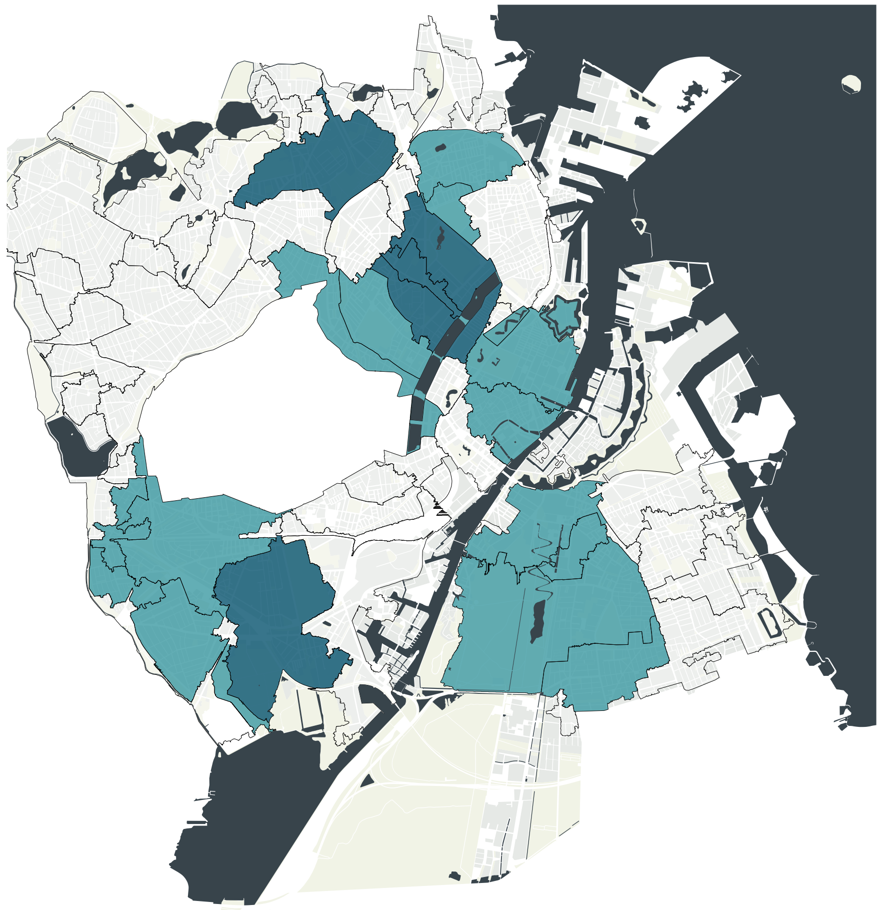


Figure 21:
Status of projects initiated by the City of Copenhagen and HOFOR.
Source: Author based on Københavns Kommune, 2019

Figure 22:
Masterplans status at 2019.
Source: Author based on Københavns Kommune, 2019



3.5.2 Lersøparken Branch

The Lersøparken cloudburst branch is located in the north-western part of Copenhagen, more precisely in the Bispebjerg district. The branch is part of the water catchment area of Bispebjerg, Ryparken and Dyssegård, of approximately 218 hectares. It is stretched from Lyngbyvejen in the east to Utterslev Torv in the west, including a population of approximately 20000 inhabitants. The area is recognised as one of the most vulnerable and dangerous in Copenhagen due to the highest crime and unemployment rates. Architecturally, the neighbourhood is mainly characterised by public housing connected to the former industrial area of Bispebjerg in the south, bordering the district of Nørrebro. In terms of urban structure, the area is based on proper spatial planning, with multi-storey buildings arranged around large green courtyards and facing wide streets that allow ventilation. The buildings date back to the 1930s and 1940s and are recognised for their aesthetic and architectural value. However, the neighbourhood has undergone a process of degradation over the years, as a result of the transformation of the main access roads into large, busy thoroughfares which have progressively fragmented the area.

The Bispebjerg's landscape and morphology stand out from the capital's other districts. Rising on a hilly area, it is characterised by large green areas and small gardens between the houses that flow into wide streets marked by trees and green yards. The district's green areas are fundamental to Copenhagen as they form part of the city's green arches, concentric green belts panned in the Finger Plan of 1949. As far as the Climate Adaptation and Cloudburst Plan are concerned, morphological characteristics are central to the aim of the action. Indeed, most of the area, facing north, rises above a hill at 30 masl while the southern-most part is at 5 masl. The natural slope of the land implicates that large quantities of rainwater are channelled from the district to the rest of the city during cloudbursts and heavy rain.

That is the reason why projects, included in the Cloudburst Management Plan, must ensure that rainwater does not flow and accumulate in the most depressed areas and cause considerable damage. For this reason and due to the hydric characteristics of the area, the Bispebjerg district and in particular the Lersøparken branch is classified as a high-risk area on which there is a priority for intervention.

In line with the considerations made earlier about the integration between climate change strategies with other urban development plans in Copenhagen, Lersøparken Masterplan has a section referred to the development plans already submitted or being adopted for the areas included in the branch.

This includes:

- District plan for Bispebjerg - *Bydelsplan for Bispebjerg 2017-2020*
- Renewal Northwest Area - *Områdefornyelse Nordvest, Kvarterplan 2016-2021*
- Lersøparken Development Plan - *Lersøparkens Udviklingsplan 2018*
- Bispebjerg Cemetery Development Plan - *Bispebjerg Kirkegård Udviklingsplan, 2015*
- Plans for development and water management of the New Bispebjerg Hospital - *Planer for udvikling og vandhåndtering af Nyt Hospital Bispebjerg*

The development plans include a series of actions to regenerate the area linked to buildings energy efficiency, increment of green areas (max 500 metres between public green areas) and improvement of connections. These objectives want to favour social aggregation and neighbourhood's security particularly looking at 3 core areas: Bispebjerg cemetery, Bispebjerg hospital and Lersøparken.

Therefore, the goals presented within the Masterplan combine the needs dictated by the water vulnerability and CMP guidelines with urban regeneration strategies reported in other Local Plans.

Thus, it is possible to divide the goals of the plan into:

- Provide a maximum of 10 cm of surface water during events calculated with a return time of 100 years. The surface water level cannot exceed the predetermined plan level as it must allow for the normal flow of traffic or activities in general.
- Climatic adaptation of the sewage system with the disconnection of 23% of the project areas.
- Improvement of wastewater quality in order not to discharge excessive pollutants into bathing areas.
- Efficient use of rainwater management solutions with a preference for decentralised local management systems.

The masterplan identifies 15 cloudburst projects that are arranged in the area to form a continuous solution for managing rainwater from the highest point, corresponding to the Bispebjerg cemetery, to the lowest collection point located inside the Lersøparken (Figure 23). Lersøparken is the key element of the entire masterplan as it is the main catchment area for all the cloudburst projects.

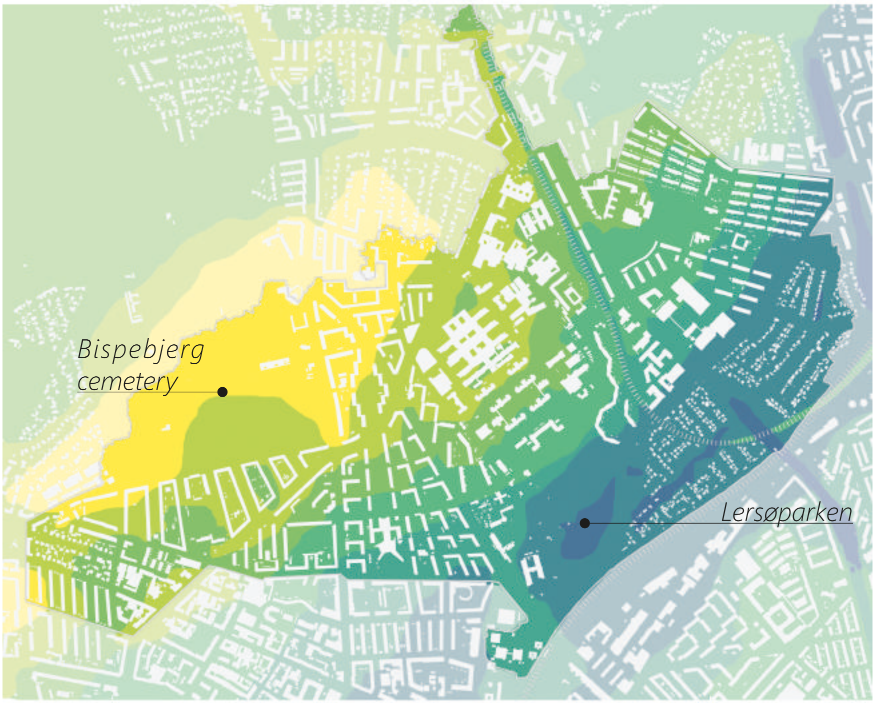


Figure 23:
Map of natural terrain slope.
Source: Vandopland et al., 2020

The envisaged interventions are green and blue infrastructures that manage water locally and delay its natural flow to lower areas. Or mixed infrastructure which retains and drains rainwater through conventional pipes when the system is not overloaded.

This infrastructure matrix is designed to direct water to a single point downstream of the cloudburst branch (Lersøparken), which is dimensioned to collect and retain water from all parts off the cloudburst branch. When it reaches its limit capacity, it discharges the water into the cloudburst pipeline (named "Svanemøllen Skybrudstunnel") directly to the harbour in Svanemøllen Bay. In this way the amount of rainwater runoff generated in this branch does not flow towards the city reducing the drained overall volume of water.

Before defining in detail WHERE and HOW to act in the cloudburst branch area, the plan makes use of few technical analyses concerning different cloudburst scenario. So that it is possible to identify the most critical areas, their hydraulic dependence and the problems which have to be directly managed or limited. Hence, it is made a preliminary general screening of the project area as well, flood maps are generated showing potential flooding areas and sewer overflow points through the use of different software (MIKE FLOOD, SCALGO,...). These maps are framed on the morphological (depressions, flow accumulation and watersheds) and urban characteristics of the area. The analyses result necessary to map the area and identify the critical points where action has to be taken to mitigate and counteract the flooding problem.

Simulations show flooding scenarios corresponding to events with a return time of 10 years (ordinary or daily rainfall) and events with a return time of 100 years (cloudburst events), the magnitude of which depends on the calculation model used by the analysis software. In this way it is possible to assess the current state of the stormwater management system under different events and highlight weaknesses.
Regarding the Lersøparken branch:

- For events with a return time (T) of 10 years, the analyses focus mainly on the capacity of the sewer system to accommodate the expected amount of rainfall. The hydraulic analyses carried out and reported in the technical documents (Vandopland et al., 2020) show that, today, many points in the sewer system are not able to accommodate the amount of water equivalent to an ordinary event. This underlines the urgency of adopting strategies to disconnect parts of the area from the sewage system. From the data shown in figure 24, the most vulnerable areas are focused on east and south of the cemetery (1), on Tagensvej (2), Tuborgvej (3) and north of Lersøparken (4).

- On the other hand, analysing cloudburst scenario (T=100), it should be noted that flooding phenomena related to this category of climatic events occur mainly for three reasons:

  (a) The water does not run down the drainage system fast enough.
  (b) The drainage system does not support large amounts of water at any one time.
  (c) Flooding that cannot be attributed to the drainage system.

  Referring to the map shown in figure 25, it can be seen that in a rainfall scenario with a return time of 100 years and an unaltered drainage system, flooding areas can be distinguished into two types: those in blue/light blue refer to runoff flow accumulation in depressed areas (reason (c)); the areas in yellow refer to flooding due to overflow of the sewer system (reason (a) and (b)).
  To notice, the presence of the hospital area makes it a sensitive element as it must maintain its functionality under any type of event.

Based on the above-mentioned hydraulic analyses, the masterplan sets out a series of objectives to be achieved through the implementation of decentralised and centralised solutions. These act synergistically, ensuring a safe management of surface water in order to not cause damage to buildings and infrastructure, minimises traffic disturbance and general activities. Last but not least solutions have to counteract the generation of additional pollutant substances in water drained to the sea or filter systems.

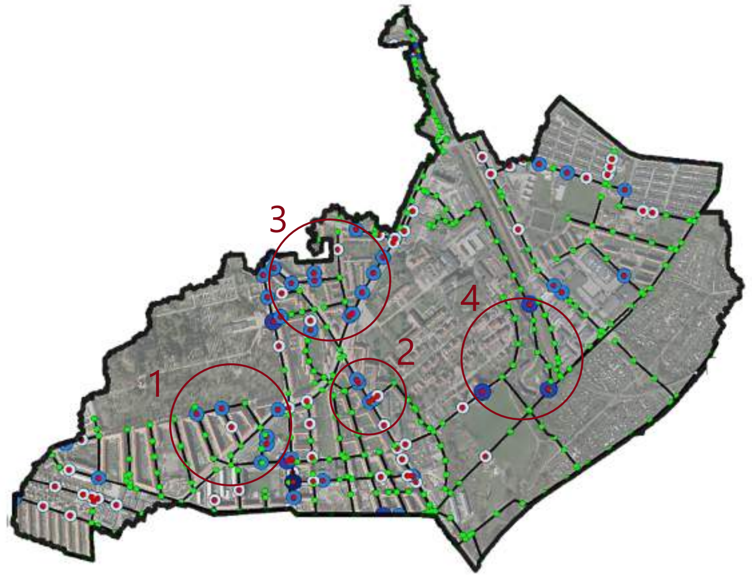


Figure 24:
Efficiency of the existing urban drainage system during events with a return time of 10 years.
Source: Vandopland et al., 2020

- *Overflow*
- *No overflow*
- *10-100 m³ surface water*
- *100-500 m³ surface water*
- *Sewer pipeline*

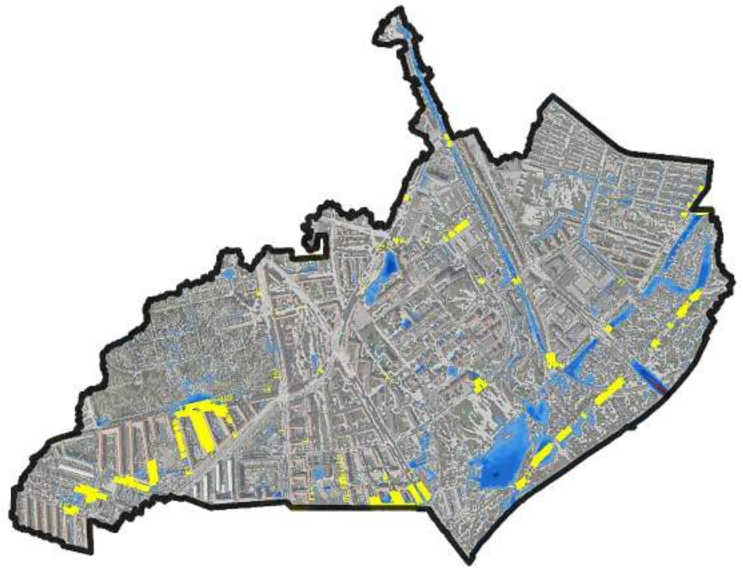


Figure 25:
Surface water accumulation during a 100-year return time event.
Source: Vandopland et al., 2020

- *Sewer overflow*

Stormwater accumulation

- *10-30 cm*
- *31-50 cm*
- *51-100 cm*
- *101- 150 cm*

In short, the strategies proposed in the Masterplan suggest to:

- Use high local green areas for downpour delay to cope with cloudbursts. The purpose of the delay is to reduce flooding in the lower parts of the catchment area and reduce the need to drain the water through pipe systems. Floods that cannot be delayed in the higher catchment areas must be diverted to Lersøparken or run to the viaduct on Lersø Parkallé, using underground pipes or surface roads used to transport the rain. Here the water has to be partly retained until there is space to drain it to the downstream system or directly into the cloudburst tunnel and discharge it into the sea.

- Reduce the accumulated rain load in the sewer system by 30% by decoupling rainwater in a separate rainwater system or in a stormwater system (as noted in CCAP). Manage local rainfall through specific systems that promote infiltration into the ground; and delaying the runoff of water on the road surface to the sewer system. The implementation of this objective corresponds to the disconnection of 23% of the area contained within the Lersøparken branch.

- In relation to the objective of improving the quality of wastewater in order to maintain the standard of bathing in the harbour areas, it is necessary to adopt local water filtration and purification solutions to reduce the hydraulic load on the Lynetten treatment plant and to allow the safe discharge of drained water through the Svanemøllen Skybrudstunnel.

- Studied and designed the surface projects proposed in the masterplan in such a way that they manage the greatest amount of rain locally in order to use centralised drainage systems only when necessary.

In conclusion, figure 26 shows the conformity of the service level in the area after the implementation of the projects foreseen by the masterplan (previously listed). As can be seen from the scenario proposed, there are still some areas where surface water accumulates (not considering retention basins) or where the drainage system fails, overflowing to the surface. This demonstrates that urban planning focused on land adaptation to climate change events does not aim at finding an all-encompassing and perfect solution, but rather focuses on framing a few projects with a real potential to mitigate climate hazards. Consequently, areas that are still yellow represent points where the assessed risk is minimal, so the sewer overflow does not generate relevant damage to the area.

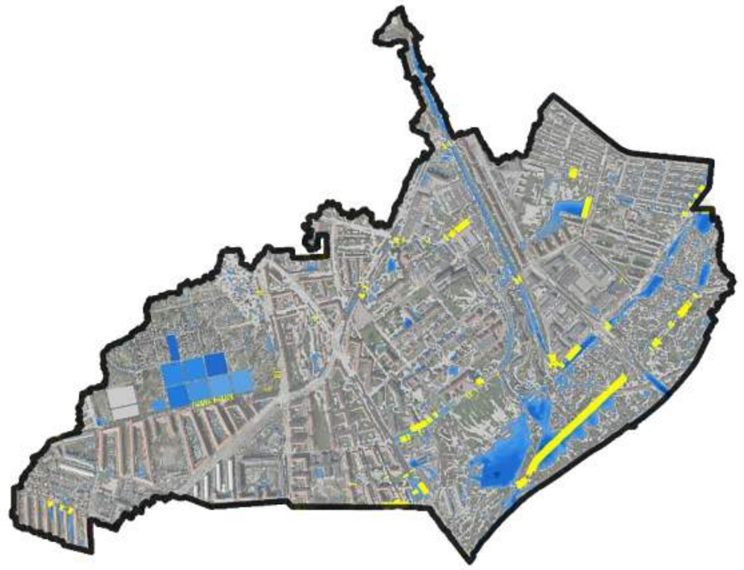


Figure 26:
Surface water accumulation during a 100-year return time event. after projects implementation.
Source: Vandopland et al., 2020

Sewer overflow

Stormwater accumulation

10-30 cm

31-50 cm

51-100 cm

101- 150 cm

A more detailed description of the different projects expected within the Masterplan is given below, showing the mechanisms of cooperation between the different solutions and the function they play within the overall stormwater management. In order to simplify the discussion, the projects are grouped in 4 macro-areas but all of them are conceived to function as a single solution.

It should be noted that each cloudburst branch project seeks to achieve the objective for which it is designed by considering both the main characteristics and contexts of the city and local differences. So that the values of the city, including its urban nature, are reinforced by the unique characters and contexts of local neighbourhoods. In addition, individual projects are assessed for technical effectiveness but above all for economic feasibility (always reported at the end of each official report), a factor that determines which solution is better to adopt than others.

In conclusion, the aim is that individual projects add value to urban space so that storm management is an integral part of urban and local coherence, design and use of urban space regardless of season and weather conditions. But also, that they are an effective investment to ensure lower future costs and an improvement in the overall value of areas (Dyssegård, 2020).

MASTERPLAN OF LERSØPARKEN

scale 1:7500

- *Cloudburst road*
- *Retention space*
- *Green road*
- *Green area*
- *Drainage pipeline*
- *Cloudburst pipeline*
- *Terrain adjustment*

BISPEBJERG KIRKEGARDE

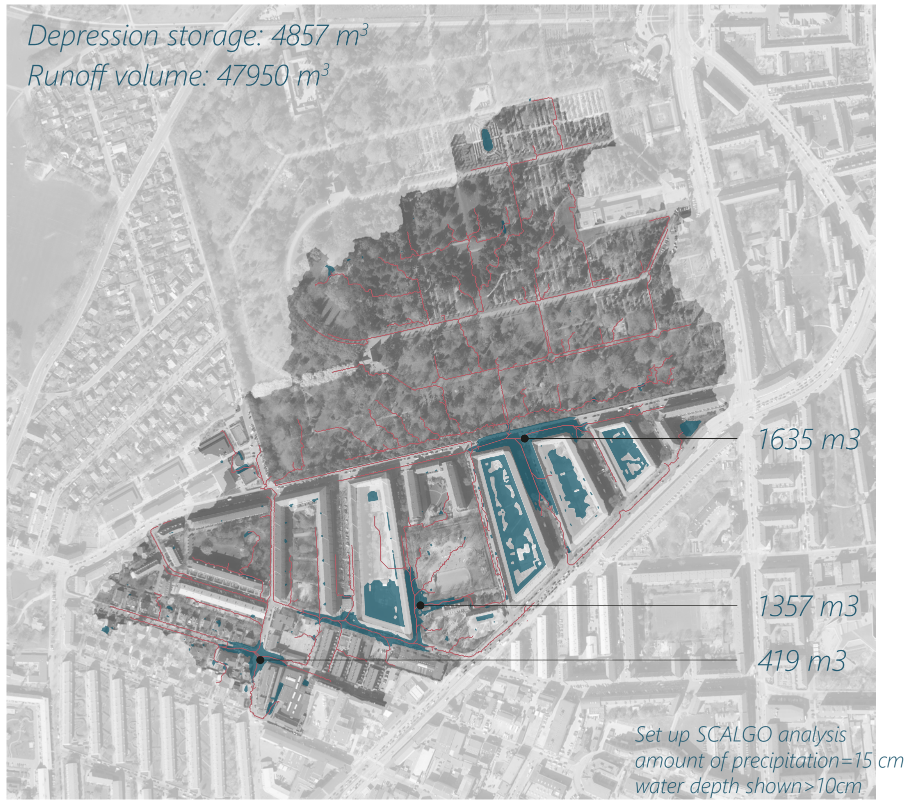
The first sub-area analysed is the area that refers to Bispebjerg Cemetery. The area corresponds to the western part of the Lersøparken branch and includes the cemetery and Birkedommervej street that separates the cemetery from the residential area. The housing estate, designed in the 1920s, is characterised by tall buildings with a central courtyard. In addition to the cemetery, the focal points of the area are the two main streets (Birkedommervej and Tomgårdsvej) and the Degnestavnen playground. The measures included in the master plan include the establishment of green lag roads, new rain retention basins and a series of measures to redirect rain runoff and drain it via underground pipes to the main catchment and lag basin in Lersøparken.

According to the flash flood map (Figure 27) the watershed of which Bispebjerg Cemetery is part, shows the most critical point in the area at the entrance to the cemetery on Skoleholdervej. Due to the steepness of the road and the natural slope of the land on which the cemetery stands, rainwater naturally flows into the depression in front of the cemetery, flooding and damaging the buildings and the road they face. The management of water at this point is essential to prevent it from flowing southwards, contributing to the flooding of other areas. Therefore, based on the 2015 cemetery development plan and the objectives of the Cloudburst Management Plan, several rain delay and collection basins were designed in the southern area of the graveyard in order to retain runoff within the perimeter of the green area without it discharging into the street.

Figure 27:
Bispebjerrg Kirkegarde flooded areas and flow accumulation.
Source: SCALGO Live

0,35 km² *Area*

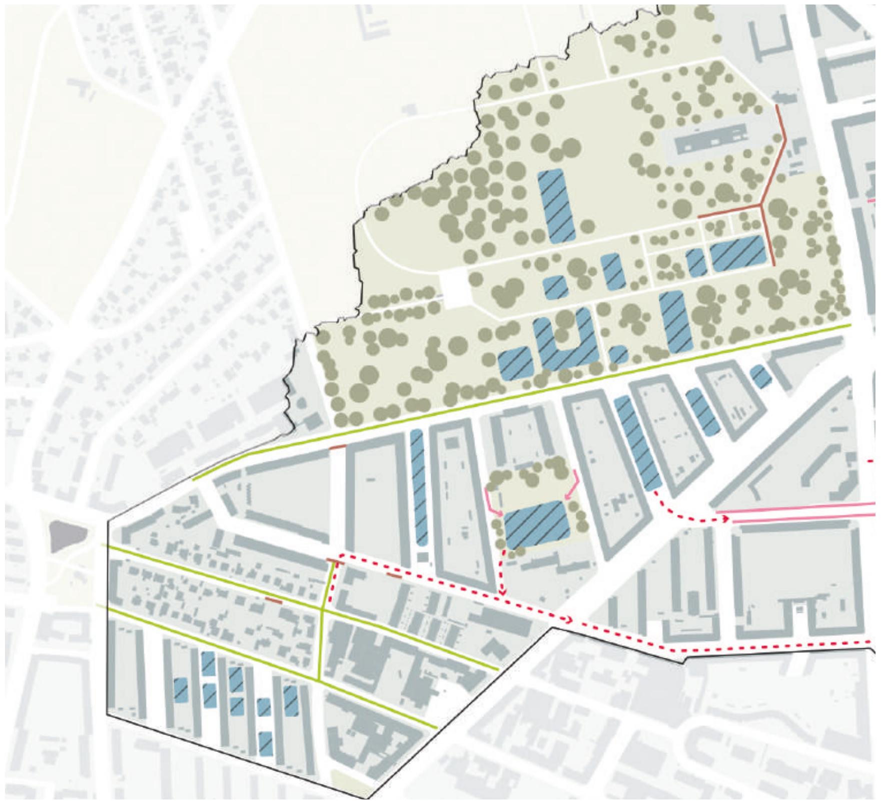
62% *Pervious surface*
38% *Impervious surface*



The construction of the ponds should contribute to making the area more attractive by designing recreational and meeting areas, respecting the function of the site. The interventions on the cemetery must favour its disconnection from the public drainage network in order to limit its future water load. However, an urban plan for the cemetery describing its transformation in respect of the existing burial sites has not yet been prepared.

The second critical point in the analysed area is located on Birkedommervej, in the street area below the playground in Degnestavnen. This area refers to the triangle of buildings between Skoleholdervej, Tomsgårdsvej and Birkedommervej where rain from the cemetery and the buildings flows naturally into a large depression located between Birkedommervej and Degnestavnen. The accumulation of surface water not only causes damage to roads and buildings but also generates a new surface flow that rushes further south contributing to the flooding of other areas. The solution principle is delay by using green elements along the road and constructing two retention basins. Everyday rain must filter through the ground as much as possible, turning Skoleholdervej into a green street, while during cloudbursts: water from the cemetery is directed into the green pond on Gravervænget and then drained towards Lersoparken; water flowing towards Birkedommervej, on the other hand, must be retained in a pool built inside the playground that also functions as a catch basin for rain from neighbouring buildings.

Figure 28:
Zoom in Bispebjerg quarter cloudburst projects.



Cloudburst road
Retention space
Green road
Drainage pipeline
Terrain adjustment

In this way, the measures manage water accumulation locally, limiting downstream outflows and helping to disconnect parts of the neighbourhood from the public sewage system. When the storm is over, the water collected in the playground is removed using a pipe connected to Lersøparken.

The last critical point in the area coincides with the intersection of Birkedommervej and Smedetoften, as it is located in a slight depression that favours the accumulation of runoff generated by neighbouring lots and coming from upstream areas. To manage water, the master plan envisages converting the roads in the area into greenways to encourage infiltration of first rain and manage up to 30 mm of surface rain. Road elevations (in orange) are also provided to prevent water runoff into sensitive residential areas or to direct the flow towards the cloudburst tunnel. Finally, a number of cloudburst basins are provided at the inner courtyards of residential buildings, in order to help retain and/or delay rainwater runoff by decoupling large built-up areas. The aim of the measures is to direct as much rain as possible to the drainage channel under Birkedommervej, which carries the water to Lersøparken.

Illustration of a flood event in the Bispebjerg Kirkegarde area.

BISPEPARKEN

The Bispeparken area, due to its natural slope, is not a place for accumulation of surface rain but generates large amounts of water runoff that flow quickly southwards and accumulate in a large depression in the Lygten area and in a depression on Tagensvej Nyd. The Lygten area has been particularly badly damaged during recent storms, so it is necessary to provide solutions to manage the flow of rain in upstream areas, preventing large amounts of runoff into this vulnerable area. The masterplan includes the insertion of delay ponds and the transformation of some roads to accommodate the rain runoff and direct it towards the Lersøparken area.

Considering as a starting point the flash flood map (Figure 29) of the Lygten watershed, where the largest accumulation of surface water is expected, it can be seen that the watershed boundaries include the Bispeparken area but also the whole Bispebjerg Hospitalsgrund area. As will be described in detail later on, although the hospital area is part of this watershed, the solutions will directly connect its surface with the Lersoparken area. In this way the amount of rain that would naturally flow towards Lygten is completely diverted.

In order to prevent water from Bispeparken from accumulating downstream, the plan provides for a series of retention pools that promote local runoff management and create additional landscape value for the whole area. The Bispeparken area consists of a northern and a southern part, divided by a wide traffic road, Tuborgvej. For this reason, the projects represent a boost for the neighbourhood by redeveloping the park, reconnecting it to neighbourhood life and encouraging its daily use as a place for meeting, cohesion and socialisation. In Bispeparken Nyd a large collection pond is designed to receive the water coming from the northern part of Tagensvej and drain it along the green park. The pool must also be designed to be able to manage the water from neighbouring buildings in a decentralised way so that it can be disconnected from the public network. Excess water flowing to Bispeparken Syd is transported through an under-road canal and then managed in the green area through six pools that shape the park into the hub of the neighbourhood. Again, the pools must be sized to accommodate the rain draining off the perimeter buildings. The park must be thought of as a unique element, taking into account the appearance of the planting materials and vegetation.

Figure 29:
Bispeparken quarter flooded areas and flow accumulation.
Source: SCALGO Live

0,65 km² *Area*

39% *Pervious surface*
61% *Impervious surface*

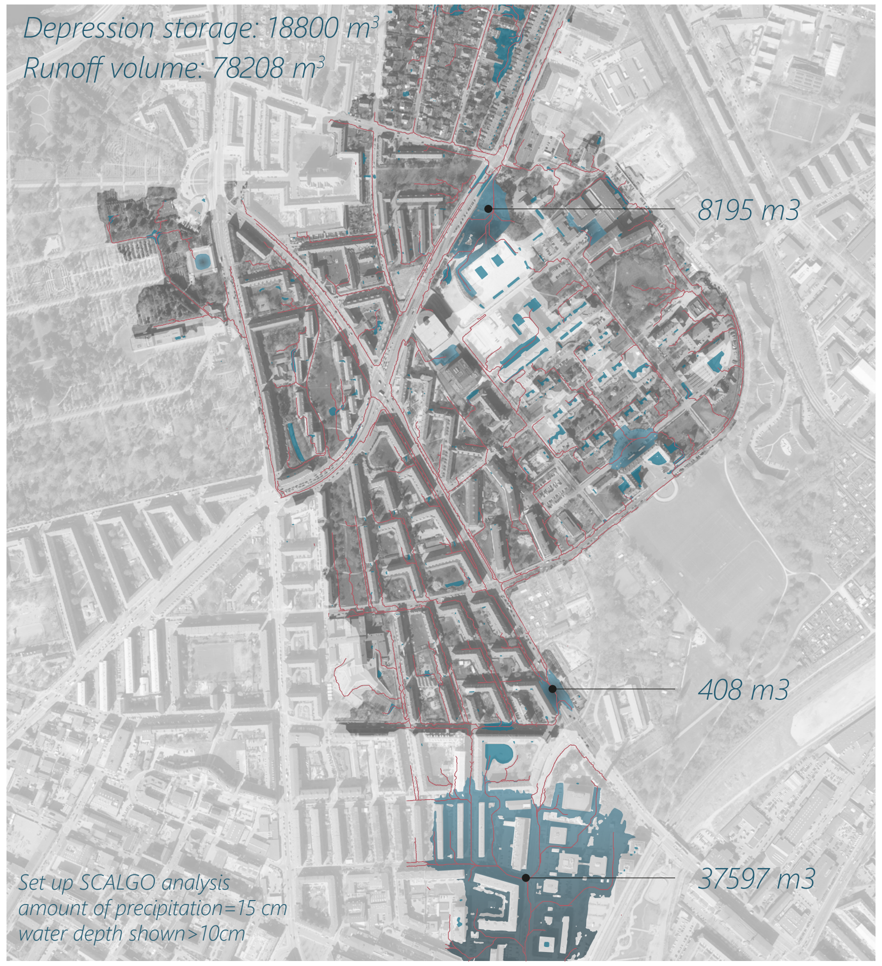
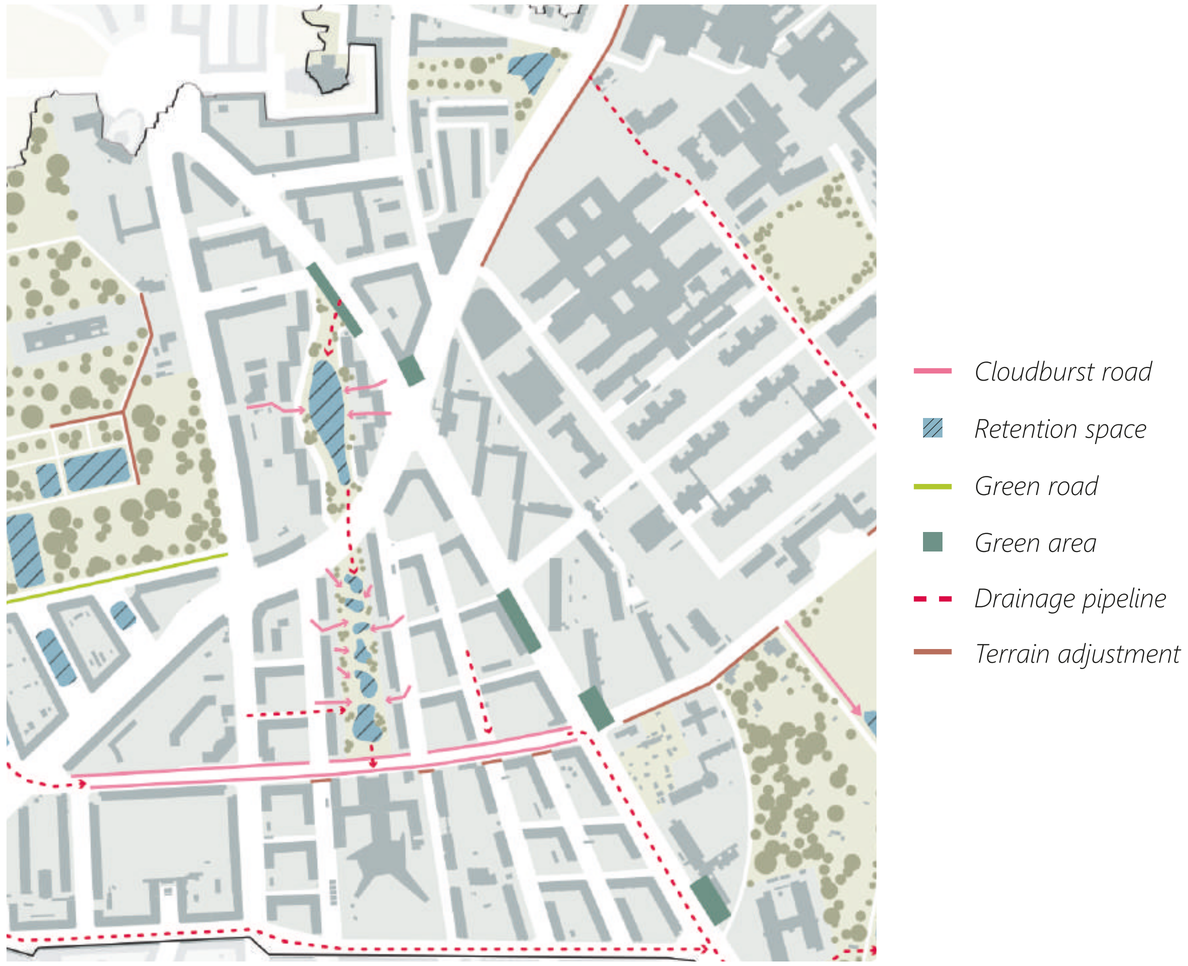


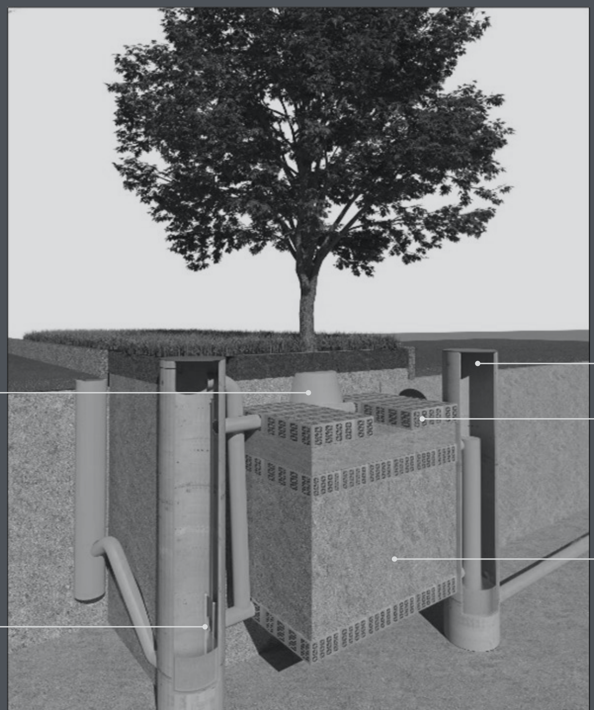
Figure 30:
Zoom in Bispeparken quarter cloudburst projects.



BOX 2: CLIMATE PLATFORMS

Climate platforms are infrastructure implemented in the city's largest streets which, according to the CMP, is planned to be transformed into retention roads. Climate platforms are an excellent example of how to achieve maximum synergy from the implementation of individual projects, in this case in the improvement of infrastructure for public transport traffic and stormwater management along the city's roads. The technology associated with the climate platforms performs a triple function: they improve accessibility to public transport, provide sustainable and green solutions for the city, and help manage water during ordinary and extraordinary events by exploiting planting and underground collection infrastructure. The project involves the creation of bus stop shelters equipped with one or more trees under which cloudburst tanks have been installed.

The mecanism:
Rainwater is channelled through gutters and kerbs into the irrigation system, which consists of a loader with capillary wicks that keeps the soil moist by using capillary rise. Excessive amounts of rain (cloudburst events) are conducted into the cloudburst tank under the platform by a system consisting of a water brake. The brake is designed to gradually empty the tank over 24 hours, preventing accumulated water from affecting the drainage system during cloudbursts.
The underground tank is connected to an irrigation system for the tree that keeps the soil moist. The roots absorb the water contained in the soil during the warm seasons. In winter, when the tree does not consume much water, rain mixed with salt flows through the soil without causing damage to the plant. It has been calculated that planting 1 tree with this type of technology is equivalent to disconnecting 25 m2 from the sewage system. Climate platforms thus reinforce the green expression of the city, reducing the effect of urban heat and the load on the sewage system. (Trafik, 2020).



Climate platform operation diagram
Source: Trafik, 2020

The cloudburst solutions should be integrated into the park space and create added value for the area, shaping themselves as soft depressions that contribute to the landscape experience and contain recreational elements. In this way residents can experience the cloudburst solution as a resource for their lives and that of the neighbourhood. All the rain that flows through the park downstream flows along Hovmestervej, a small road that separates the park from Tagensbo School, a key school building in the area. Hovmestervej is a road with little traffic as it is used almost exclusively to reach the school.

It is currently in a crumbling state and blocks the direct connection between the park and the school. A connection that would allow the park to be used as a play and learning area for the students. For this reason, the cloudburst project involves transforming the roadway into a cloudburst road, i.e., a road along which water is conducted and transported through elements at different heights. In this particular case, barriers are put in place, through the renovation of pavements, along the roads leading south from Hovmestervej. This blocks the flow of water and directs it completely along the cloudburst road, on which two lateral channels are provided to carry the water. In the event of a cloudburst, surface water is expected to accumulate but at a level where the road can be used (about 10 cm). In order to limit the amount of water flowing into the road and sewer, the school in Tagensbo was designed with green roofs in order to handle most of the rainwater locally without discharging it directly into the road. In addition, Hovmestervej will also have to accommodate the water delayed and conveyed to the reservoir at Gravervænget from the cemetery to the north. The combination of all these measures should stop the rain runoff from this area towards Lygten and direct it instead towards Lersøparken.

In order to further counteract runoff generation in the Lygten drainage, specific measures have been planned to involve the transformation of Tangensvej. Beside this, Tangensvej is one of the busiest access routes to the city and therefore its functionality must be preserved even during stormwater events. The proposed project involves the construction of several green water retardation areas, conceived as raingardens, merged with bus stops in order to manage the first rainwater but also to collect the accumulation of rain related to more intense events. The climate platforms are part of a drainage system separate from the sewage system and connected to the Lygten Kanal project, a tunnel under Tangensvej that carries accumulated water on Hovmestervej directly to Lersøparken. The construction of the Lygten Kanal makes it possible to disconnect many buildings on Tangensvej

LERSØPARKEN & LERSØ PARKALLÉ

Lersøparken is the central focus of the Masterplan as it is the conveyor point for all cloudburst management projects contained in the branch. As previously mentioned, this area is the lowest point in the branch and as a large green space it is an ideal basin to harvest and manage large volumes of water. Since it is the downstream element of the Masterplan, the solutions that need to be designed mainly concern stormwater harvesting mechanisms to prevent stormwater from reaching too high levels and flowing into the districts further downstream. This area is identified as the end point of the flow from which all accumulated water must be removed by using a cloudburst pipe for drainage into the sea. The watershed associated with Lersøparken includes the green area of the park and the plots belonging to the Garden Associations. It also includes a part connected to the cloudburst branch Haraldsgadekvarteret, beyond the railway. Within this analysis, the projects in the Haraldsgadekvarteret branch will not be discussed, while the remaining hydraulic basin connected to the Lersøparken branch considers two groups of projects related to the Lersøparken area itself and the section of Lersø Parkallé that runs under the railway.

Figure 31:
Lersøparken area flooded areas and flow accumulation.
Source: SCALGO Live

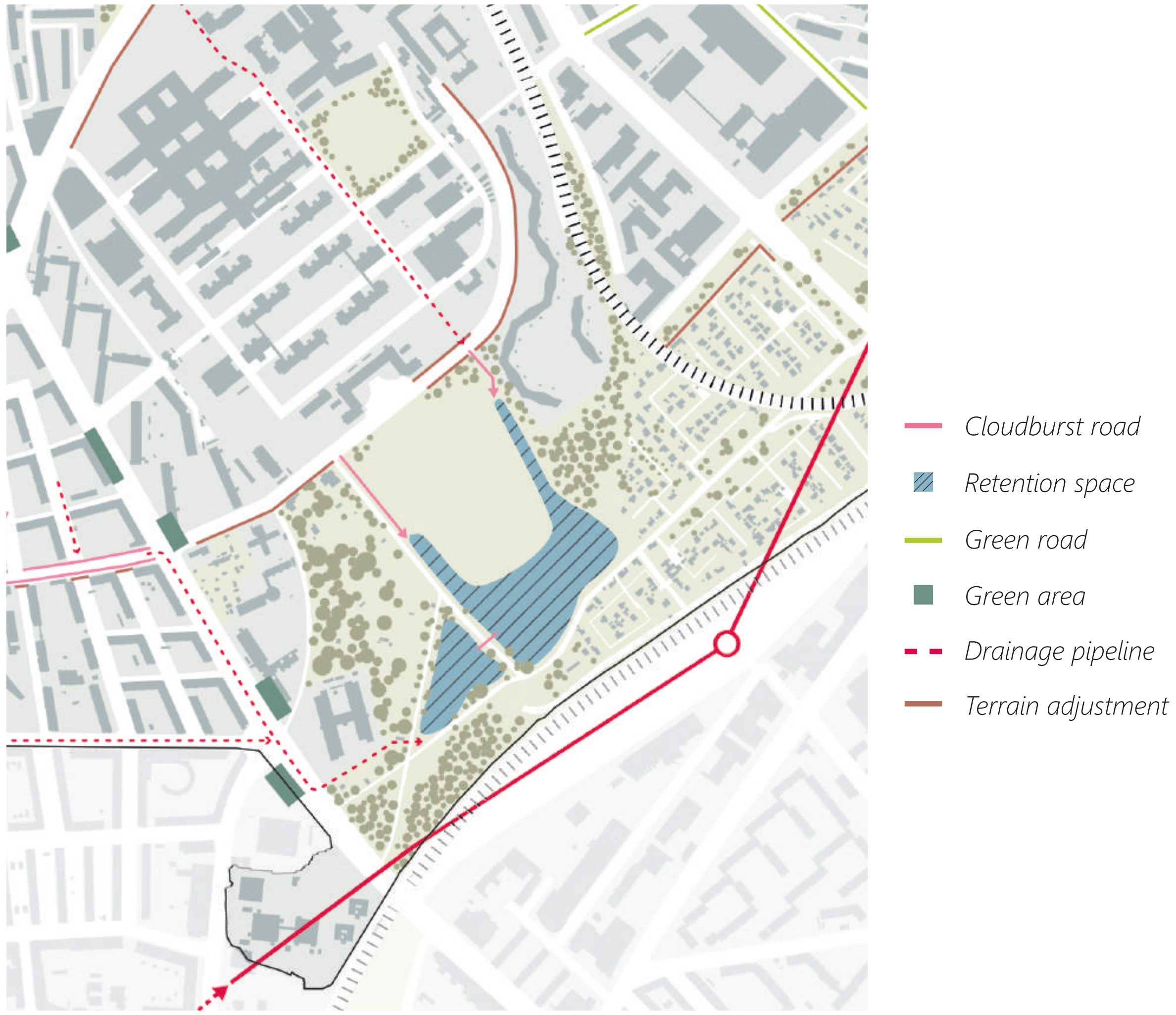
2,07 km² *Area*

40% *Pervious surface*
60% *Impervious surface*

Considering the scenario presented in the flood map (Figure 31) it is possible to see that all the rain connected to the Lersoparken watershed accumulates down a long strip that constitutes the lowest area of the whole branch. The presence of the railway breaks the depression into two areas hydraulically connected by the presence of subways which rains accumulates and flows from one side to the other.

During cloudbursts the area is almost completely flooded and tends to discharge into the lowest point, the subway at Lersø Parkallé, where also flows part of the water from the Nordvest district . The objective of the project is therefore to create safe rainwater collection and delay points in Lersøparken and at the green areas in the Garden Association, which will contain the accumulation of large amounts of water and counteract the flooding of surrounding roads and built-up areas. Because of the high risk associated with this area, accumulated rain must be drained away quickly using large-scale engineering infrastructure.

Figure 32:
Zoom in Lersøparken cloudburst project.



The masterplan provides for the establishment of two large wetlands that can manage the stormwater, partly accumulated naturally in the green areas of the park and partly coming from the 11 already described projects.

The park is a key green element for the whole city of Copenhagen as it is part of the concentric green arcs in the Finger Plan. In addition, the location of the park makes it an extremely attractive place because around its perimeter there are various activities and services such as: the hospital in the north, schools, nursing homes and spaces for culture and work.

Of the two planned basins, the smaller one is planned as a pool, located in the western part of the park. The lower part of the basin contains a permanent water level that receives everyday rain, while the upper part is filled by collecting water drained from the areas west of the branch via the Lygten Kanal. Polluted rain runoff is thus collected and filtered by the wetland in the park. At the end of the rainfall, the excess and treated water is conveyed into the cloudburst tunnel and drained into the sea. The construction of the Lygten Kanal allows the water coming from the north to be drained and discharged directly into the wetland at Lersoparken through an underground pipeline and an open channel that gives the water visibility within the project.

The second one is conceived as a dry basin in the eastern part of the park, where today there is a football field. This basin should only come into operation during cloudbursts and flood to contain the water coming from Bispebjerg Bakke and the pipeline draining the rain in the areas north of the watershed. The two basins are connected by an overflow structure that allows water to be transported from the smaller basin directly into the larger one during excessive water accumulation.

The rainwater flooding the second basin comes from Bispebjerg Bakke, a road north of the park that separates it from Bispebjerg Hospital. The road is designed as a cloudburst road so that the rain is channelled into the roadway and directly into the park. By raising the pavement it is possible to direct the flow of rain from the road to two open channels running laterally to the park. These are designed as green swales, delaying the runoff velocity and partially filtering polluted rain from the street. To the north of the larger catchment area, a ground alteration creates a barrier whose purpose is to preserve the park's recreational areas from flooding the catchment area.

The operation of this system is associated with the construction of the Svanemøllen Skybrudstunnel, one of the four large cloudburst tunnels responsible for draining water into the sea during cloudburst events. The purpose of building this tunnel is to avoid overload of the sewer and thereby avoid overflow phenomena.

One of the retention basin in Lersøparken

A dedicated project concerns the securing of Bispebjerg Hospitalsgrund, which is located on a lower ground than Tuborgvej, running north. This causes water to accumulate in the northern part of the hospital with a high possibility of flooding and damage to the entire facility. In addition, water accumulation along Tuborgvej itself must be avoided in order to keep the road accessible for ambulances in all weather conditions. For this reason, a raised kerb at the boundary between the hospital and the road is planned. Raising a barrier will not allow the natural flow of water towards the south, but its accumulation on the road. Therefore, an underground drainage line leading surface water directly to the catchment areas in Lersøparken must also be provided. Some of the water on Tuborgvej can be collected and delayed in the green area of Jensens Klints Plads. The green area is limited in size so it is designed in such a way that it can handle a volume of water corresponding to a daily event. In this way the use of the drainage channel under the hospital is limited to storm events.

Regarding the accumulation of rain towards Lersø Parkallé, the main cause of the inodation in this area is due to the flow of rain from the sub-basins of the Lundehus church and the northernmost areas of Strødamvej and Emdrupvej. These areas are connected to the cloudburst branch Lyngbyvej, of which however 1/3 of the rain ends up in the Strødamvej areas.

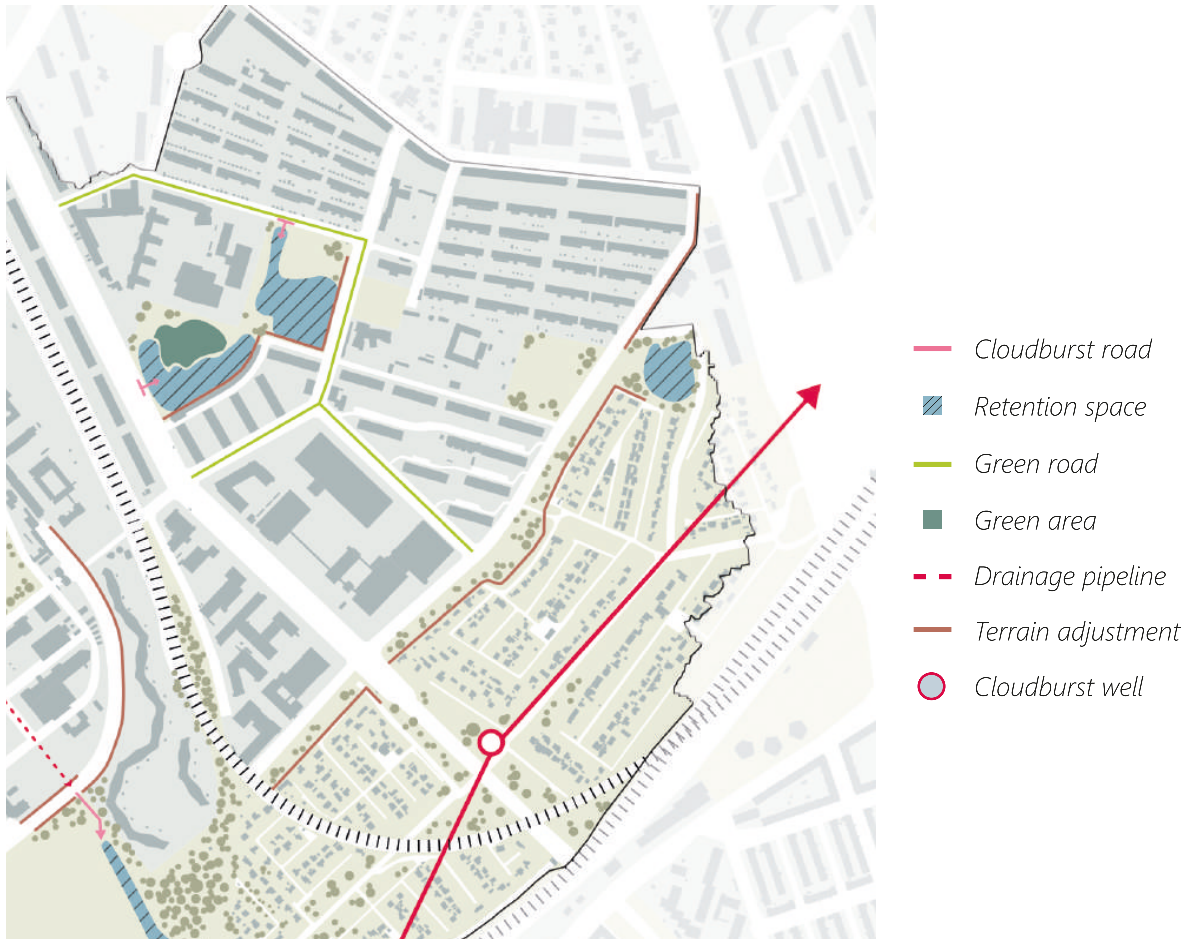
For this reason, the solution principle adopted is to install a series of delay points along Strødamvej and a larger storm basin in the park below the church in Lundehus in order to retain water upstream of the natural depression in the ground. Along Strødamvej, the delay points combined with the elevation of the ground should ensure that rain does not flow and accumulate at the Association's buildings.

In this way the barriers set up protect the buildings and direct the water partly to the basins in Lersoparken and partly to the pool in the church grounds. The church area is located in the middle between two cloudburst branches and consequently needs to be sized to accommodate extra rainwater from the branch beside it. As the church park in Lundehus is too small to model a pond large enough to collect the volume of water predicted by the hydraulic analyses, part of the water has to be retarded along the green belts between the gardens of the Garden Associations and Strødamvej by raising the barrier up to 80 cm (Figure 33). The water accumulated in these strips must be managed by infiltration or evapotranspiration, without conveying it into the cloudburst pipes.

Considering water storage under Lersø Parkallé, the solution proposed in this case, because of the specificity and particularity of the site, is the construction of a well directly connected to the Svanemøllen Skybrudstunnel. The insertion of a pure hydraulic facility makes it possible to maintain a maximum surface water level of 15 cm in the event of cloudbursts whose intensity corresponds to an event with a 100-years return time.

Alternative proposals are described in the masterplan, but in their overall assessment, the installation of a well is the most cost-effective action. To decrease the water, load downstream, other projects are described in the masterplan. These solutions concern the orthogonal roads to Strødamvej that conduct rainwater superficially to the area of the Garden Associations and contribute to the flooding of the area. The transformation of these areas will include green elements to handle the first 30 mm of rain so that it does not flow into the sewer or generate runoff. The streets already have green elements that can be extended and improved by modelling the street elements such as kerbs or pavements. The water flowing along these streets and in particular along Fruebjergvej and Keldsøvej, comes from the Lundehus School and park around it. The solution principle is to build a surface project to confine and collect stormwater such that it does not flow into the more vulnerable southern areas. The retention basin will accommodate the water along Lersø Parkallé north and Bredelandsvej. This is confined to the school grounds through the construction of a barrier along the south-eastern perimeter. The pool will be designed to handle the daily rainwater by infiltration or evaporation, but the volume of accumulated lag is sized to also cope with larger amounts of rain in the event of cloudbursts. In this case emergency drainage systems will be provided to empty the area within 24 hours of the event.

Figure 33:
Zoom in Lersø Parkallé and Lundehus School cloudburst project.



3.6 Considerations on Copenhagen Formula

From the evidence reported in this chapter, it is possible to understand how proper spatial planning can lead to the implementation of innovative solutions that adapt urban space to support extreme climate events such as cloudbursts. Among the policies adopted by the collaboration between HOFOR and the Municipality of Copenhagen, great space is given to decentralised urban drainage infrastructures (defined in the first chapter as Sustainable Stormwater Management solutions). SSMs are seen as a valid alternative to conventional rainwater management methods. In fact, the main problem related to the flooding phenomena in Copenhagen is connected to the drainage system, a mixed-type network whose design is nowadays undersized compared to the current and future amounts of rainfall. Moreover, the city is going through a period of strong urban growth that does not favour the natural processes of rain infiltration and produces an increase in surface runoff phenomena.

Both HOFOR and the Municipality agree that managing stormwater entirely with decentralised solutions is still a utopian vision, even for a city as advanced as Copenhagen in terms of water management policies and practices. In addition, the very structure of the city hinders the project of securing cities from 100-years rain events, making it extremely dependent on urban drainage infrastructure. The lack of sufficient green areas in the city centre and the presence of physical barriers, such as the railway or traffic roads, do not allow the development of a connected network of green and blue infrastructure to manage stormwater in an effective and integrated way. Despite this, the adoption of alternative solutions is seen as an opportunity for the growth and development of a more climate proof city. Indeed, the implementation of water-sensitive strategies are considered to prolong the lifetime of conventional infrastructure, contribute to the sustainable growth of the city, counteract climate phenomena and transform stormwater into a resource for the city.

Consideration of the associated benefits in the implementation of the CMP is absolutely necessary, as both the CCAP and the CMP are not binding planning instruments. Thus, the plans are accompanied by numerous analyses of the costs of deployment and the related benefits to people, the city and above all the economy. In addition, what identifies an effective cloudburst solution is the capacity of integration into the urban context through collaboration with conventional drainage infrastructure, achieving synergy effects together with other ongoing development projects and increasing the economic and social value of the city. For this reason, the primary goal of the Copenhagen climate proof strategy is to take advantage of the opportunities presented by climate change to strengthen the economy, improve the environment, enhance the natural resources and increase the involvement of inhabitants with their city. The planned actions in the CMP do not only seek to protect the city from flooding but also contribute to the creation of beautiful and recreational structures that respect the urban water and nature.

By adopting a plan to rethink urban space with water as a priority, Copenhagen has invested in a long-term project whose expected benefits are not immediately visible. Nevertheless, the proposed formula sets an example and a warning for many other international realities, so that the implementation of alternative and decentralised solutions for urban water management becomes an increasingly common practice and allows for a more "sensitive" development of the cities of the future. It is fundamental to underline that the proposed model is not perfect and even less can be slavishly replicated in other contexts.

As a matter of fact, the economic and political conditions and, above all, the Danish planning structure and tools, have favoured and encouraged the adoption of a model capable of facing different criticalities by combining urban design with hydraulic engineering. Many of the solutions proposed in the Cloudburst Management Plan are difficult to replicate or implement in other contexts. For example, the discharging of floodwater to the ocean through the construction of huge underground tunnels is unthinkable in inland cities or in geopolitical contexts lacking the economic resources for engineering works of this size. However, the approach, the methodology used and the coherence in the objectives to be pursued proposed by Copenhagen, can inspire other realities to adopt similar strategies though commensurate with the context in which they are inserted.

COPENHAGEN FORMULA	POLICY	ECONOMY	TECHNOLOGY	PLANNING
Cloudburst pipe			■	
Cloudburst road			■	
Co-financial scheme	■	■		
Combined drainage solution				■
Conveyance solution				■
Data analysis			■	■
Decentralized stormwater project				■
Drainage system to harbour/lake				■
Environmental and social value				■
Evaluation of economic benefits		■		
Financial plan		■		
Green road			■	
Hydraulic modelling			■	
Improvement of green space				
Increased employment		■		
Institutional cooperation	■			■
Integration with ongoing project		■		
Inter-organisational collaboration				
Local climate adaption plan				■
Local cloudburst plan				■
Long term vision	■	■	■	■
Private investment on flood protection	■	■		
Public involvement	■			
Retention basin			■	
Retention road			■	
Rise of properties value		■		
Sewer disconnection				■
Socio-economic assessment		■		
Stakeholders involvement	■			
Surface water limitation				■
Terrain and hydraulic model			■	■
Water charges funding		■		
Water sectoral confrontation				■
Urban context analysis				■
Urban risk assessment		■	■	

4.

PADUA WATER SENSITIVE CITY

The final chapter deals with the analysis of the planning tools and their implementation in the battle against flooding events in the city of Padua, which have characterised the entire territory for years. The investigation aimed at verifying the current state of the city regarding the management of meteoric phenomena to evaluate, even though in a different territorial and administrative context, the possibility of replicating or transposing solutions and strategies adopted in Copenhagen.

4.1 City and Water

The city of Padua lies at the eastern end of the Po Valley and in the centre of the Veneto Region. Due to its strategic position, it has always been a very important commercial hub for the territory, a factor that has allowed it to develop significantly from the industrial revolution until today. Currently, the Municipality of Padua has a territory of 93 km² and a population of about 210,000 inhabitants (padovanet, 2020), a value that classifies it as a medium-size urban area (Data.OECD.org, 2020).
According to the Koppern-Geiger climate identification, Padua falls under the humid subtropical climate areas. However, it is necessary to highlight that the geographical position sets the city in a transitional climatic band between the Mediterranean climate and the typical continental climate linked to the hilly-mountainous areas. This peculiarity has a particular influence on the temperature and especially the rainfall throughout the year. In fact, the average annual temperature is around 13 °C with cold, wet winters and hot, muggy summers (Data.OECD.org, 2020), while the rainfall pattern is intermediate between the sublittoral Alps and the Apennines. The average annual rainfall is about 850-900 mm/year, which tends to be more concentrated in the spring and autumn and relatively dry winters (Comune di Padova, 2009).

From a morphological point of view, the flat area on which the city stands is characterised by an alluvial bed that varies according to the area and which changes composition towards the south as it approaches the coastal area, from a more gravelly composition near the hills and foothills. Corresponding to the change of the alluvial bed material from gravelly to clayey-loamy, there is the band of resurgences that feed the main rivers of the area and constitute one of the main sources of water supply (Comune di Padova, 2009). The subsoil of Padua area is inserted in this particular hydrogeological system characterized by an alternation of permeable and impermeable levels typical of the transition area between high and low plain. The geological composition of the soil therefore determines the presence of a shallow aquifer with a modest flow rate that is recharged by infiltration of meteoric water. The height of the water table decreases from north to south but has an average depth of about 2 metres, which makes the groundwater particularly susceptible to pollution from surface infiltration. The altimetrical variation of the territory on which Padua stands is almost linear from north-west to south-east, with the presence of morphological humps formed over the years due to ancient floods or anthropic interventions. Indeed, the area that includes the historical centre is at higher altitudes (about 17-18 masl) due to multiple reconstructions, made on the rubble of ancient buildings (Comune di Padova, 2014).

The distinctive element of the City is its relationship with water, highlighted both by the territorial hydrographic context and by the historical evolution of the urban area. The hydraulic node has been one of the main elements that have characterised the urban and economic growth of the city until today (Zanetti, 2013). Padua lies on a territory washed by two waterways: the Bacchiglione and the Brenta. The Bacchiglione river, of resurgent origin, springs from the pre-Alps of Vicenza and, with a basin of 1300 km^2 flows downstream through the southern suburbs of the Municipality of Padua, and then continues towards the sea. The Brenta river, which has a larger basin of 1600 km^2, originates on the slopes of Monte Grappa at 60 km from Padua and flows in the city keeping north, meeting the Muson dei Sassi river and then continuing towards Venice and joining the Bacchiglione before flowing into the Adriatic Sea (Mel, 2020).

Around the thirteenth century the two main rivers were connected by the construction of several waterways, with the aim of facilitating navigation in the territory and the river connection with the Venetian lagoon. Besides being used for commercial purposes, the canals were dug to exploit the river waters for productive ends, using them as motive power for the agricultural and industrial machinery of the time (Zanetti, 2013). In this way, the Bacchiglione was first connected to the Brenta through the digging of the Brentella canal, west of the city and, later, divided into two different sections close to the city walls. Moreover, the artificial canal, called Battaglia, connects the city with the commercial centres of the lower Po Valley (Rovigo and Mantua), while the natural riverbed completely crosses the city under the name of Tronco Maestro (Autorità di Bacino dei Fiumi Isonzo, Tagliamento, Livenza, Piave, Brenta-Bacchiglione, 2012). Over the years, the Tronco Maestro has been connected to various secondary canals that cross the city centre, offering new navigation routes and bringing water to various productive areas of the city. These include the Naviglio Interno, the Canale di Santa Chiara, the Canale di Santa Sofia and the Alicorno. In addition, there are also small artificial canals, now almost completely tombed, which flow into the San Massimo canal near the eastern city walls, outside of which it rejoins the natural continuation of the Bacchiglione. A little further south of the river's branch from the artificial canal, the Bacchiglione continues its natural course, joining the San Massimo canal just outside the city walls. At this point, the river takes the name of Roncaiette, until its final confluence with the Brenta near the mouth into the sea (Zanetti, 2013).

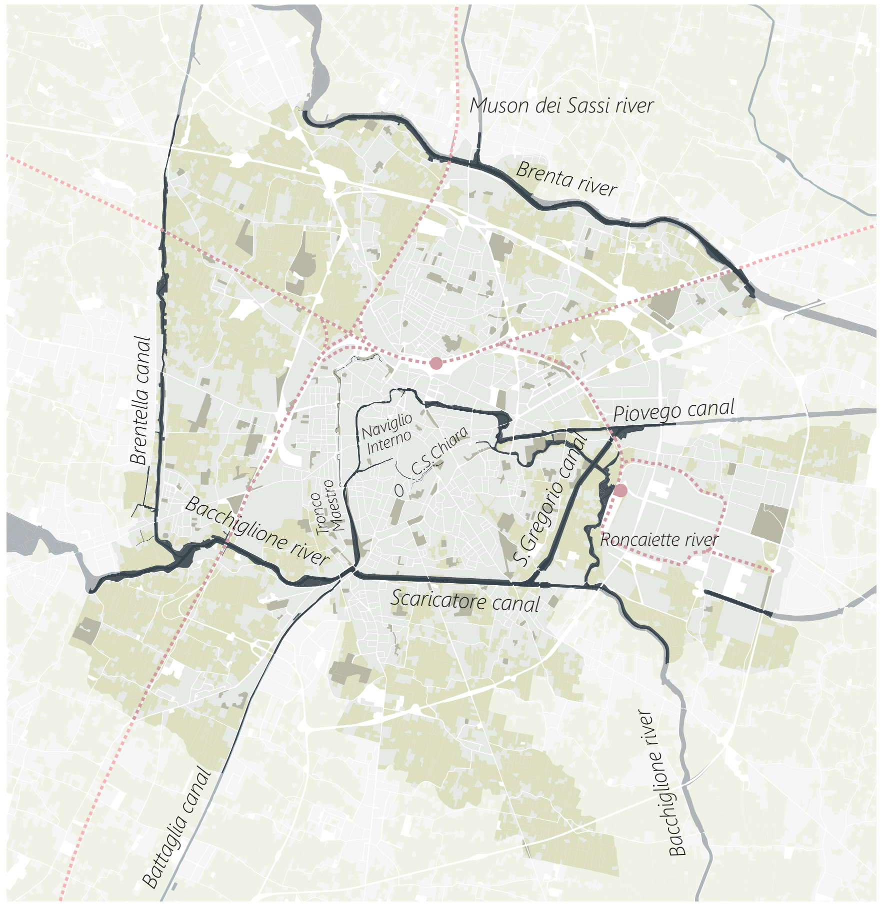


Figure 34:
Map of Padua hydraulic node.
scale 1:125000

However, this intricate river system, built to exploit the enormous potential of water for the economic development of the city, has created problems in the management of flooding phenomena in several urban areas over the years (Mel, 2020). Around the 19th century, it was decided to dig a new canal to solve the water management problems due to the increase in flooding. Thus, the Scaricatore canal was born, directly connecting the Bacchiglione with its natural prosecution (Roncaiette), linearly cutting the territory south of the city centre. In this way, during flood events of the Bacchiglione river, the city was able to drain large quantities of water directly downstream of the city, thereby avoiding flooding of the more densely inhabited area (Zanetti, 2013). Unfortunately, due to design errors, this canal was not able to discharge the flood waves upstream of the Bacchiglione River and therefore it was necessary to build a second artificial canal connecting the Scaricatore with the Piovego Canal north of the city. In this way, part of the waters of the Bacchiglione were also discharged into the river Brenta through the San Gregorio and Piovego canal system (Zanetti, 2013). Today, Padua's hydraulic node remains a complex network of canals outside and inside the city that regulate and divert the waters of the two main rivers Brenta and Bacchiglione in an attempt to keep the city safe from flooding.

When talking about water and the city, it is limiting to refer only to the river network that covers the territory. The most correct distinction would be between rainwater (or surface water) with its natural cycle (precipitation, infiltration, evaporation) and piped water, which is typical of the urban water service consisting of aqueduct, sewerage and purification systems. The fluvial waters described above which form the hydraulic node of Padua, are therefore part of the rainwater, but they come from different territorial contexts and so are more specifically defined as 'foreign waters'. These waters are distinguished from the 'indigenous' ones, which refer instead to rainfall falling in the proximity of the reference context. Generally speaking, water knows no physical or administrative boundaries, so the distinctions made are sometimes outdated.

As a consequence, besides the main hydrographic network, Padua has a dense network of canals and conduits that define the management network of 'piped waters' (Figure 35). The city was built on top of a dense network of drainage canals that form a minor water framework designed to convey and remove indigenous rainwater. This network of canals, historically open built, weaves within the urban fabric carrying surface stormwater directly into the main canals and rivers (Compagno, 2019). In addition, and in support of the drainage 'ditches', the city has a sewerage system that, as part of the integrated water service, allows the removal of wastewater produced by human activity (black water, grey water and industrial water). The sewerage system varies according to the different areas: the historical centre and some eastern districts have a separate sewerage system, while the rest of the city is served by a combined system which collects all wastewater (black, white, grey and industrial water) into a single type of network (AcegasApsAmga, n.d.).

View of the Tronco Maestro from the San Leonardo bridge.
Source: Author

Figure 35:
Map of drainage networks and hydraulic flow.
Source: Comune di Padova, 2009

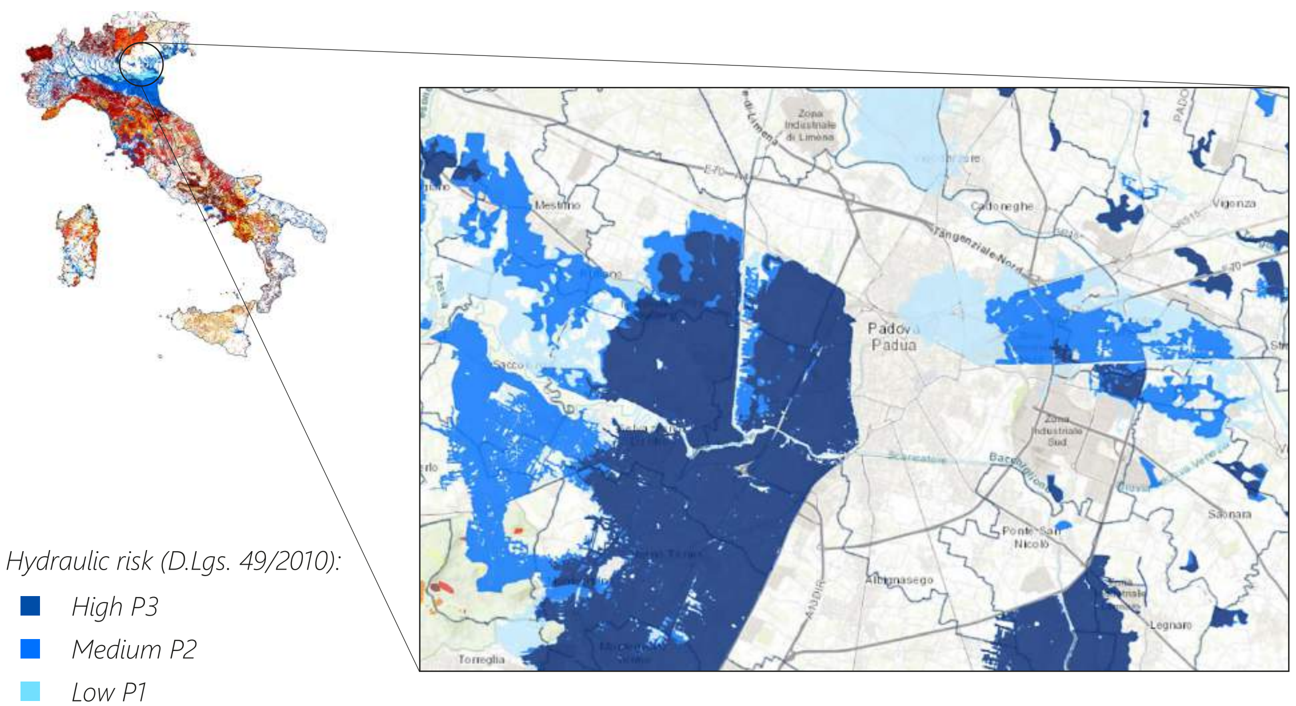
4.2 Padua hydraulic issue

If we specifically analyse the dynamics related to Padua and its integration The hydraulic risk definition refers to the phenomena of exodus or flooding of the main river network but, in reality, flooding phenomena can also occur due to superficial accumulations of rain or overflows of the sewerage network. Given the complexity of the relationship between Padua and water, it is more accurate to speak of flood risk or hydrogeological risk[8] , which includes the hydraulic risk related to major rivers and that connected to the drainage mechanisms of surface waters.

If we specifically analyse the dynamics related to Padua and its integration in the territorial context of the Po Valley, it is more correct to refer to a multitude of flood risks. Considering the particular hydrogeological and climatic context of the area, it is possible to identify risks linked to ordinary meteorological events that persist for days, putting the drainage channels under stress. Risks linked to river flooding phenomena, connected to the management of foreign waters that are difficult to regulate at a local level. Lastly, risks linked to extreme climatic events that heavily affect the city for a short time (Zanetti, 2013). These scenarios are worsened by the issues of the urban drainage system, which has been subjected to significant negative changes over the years. The continuous and intense urban development has determined the increase of soil sealing and the worsening of the already existing hydraulic vulnerabilities. These refer not only to flooding phenomena but also to the hygienic conditions of the watercourses, aggravated by the transport of dissolved pollutants in the water.

[8] *Definition at www.protezionecivile.gov.it*

Figure 36:
Map of hydraulic risk in the Padua area.
Source: www.idrogeo.isprambiente.it



However, the hydraulic issue can be summarised in two main problems: on the one hand, river waters, on the other hand, waters within the city.

4.2.1 Flood phenomena in the main hydrographic network

The problem of river inundations has always characterised the history of Padua, which over the years has carried out important hydraulic works to protect the city from new floods. Nevertheless, the flooding phenomenon is impossible to contain completely and, in fact, recent events (e.g. flood in 2010) have shown how the strategies adopted over the years have failed to solve the problem but instead have simply shifted the area of influence downstream, in the south-east of the city. As it is possible to see also from the thematic maps of the Piano Generale di Bonifica e Tutela del Territorio (PGBTT), the territory of Padua still presents a certain level of hydraulic vulnerability connected to river overflows (Consorzio di Bonifica Bacchiglione, 2010). While it is impossible to regulate the volumes of water transported during a flooding phenomenon since these are influenced by the regimes upstream of the watercourse, it is also necessary to underline the impossibility of enlarging the riverbeds to increase their capacity, since the nearby territory is strongly cemented. In addition, it is necessary to highlight how the maximum transport capacity of the two large rivers tends to progressively decrease downstream, constituting a potential risk for the surrounding areas (Mel, 2020).

In addition to hydrological problems, it is necessary to consider those related to the secondary drainage network, whose delivery point is the river node of Padua. In order to overcome the various problems related to the removal of surface water, over the years water pumps have been built to speed up the drainage of wastewater into the network of canals inside the city. Given the extreme vulnerability of the historic centre, defined by a dense building fabric, the level of water flowing through it must remain low and controlled at all times. This is currently guaranteed by hydraulic structures built to keep river water outside (Compagno, 2019). It is highly probable that a hydraulic risk will arise even in the apparently safe internal areas of the city, considering the variation of the expected precipitation regimes in the different climate scenarios and the continuous construction of water drainage structures to solve the dimensional problems of the drainage network.

Finally, it is necessary to consider the vulnerability linked to all those areas of recent urbanisation that have arisen close to the riverbanks, in areas recognised as unsuitable for construction because they are subject to flooding or water stagnation (Comune di Padova, 2014). Many of these areas did not exist when the two artificial canals were dug, and therefore do not fall within the vision of safety that the engineers wanted to ensure by channelling the water along these routes.

Breach of the Bacchiglione-Roncaiette embankment near Ponte San Nicolò (PD)- Flood of 2010
Source: Compagno, 2019

Flooding of the Bacchiglione river near the Paltana area, Padua - Flood of 2010.
Source: www.radioclub103.it

4.2.2 Internal water management and minor drainage network

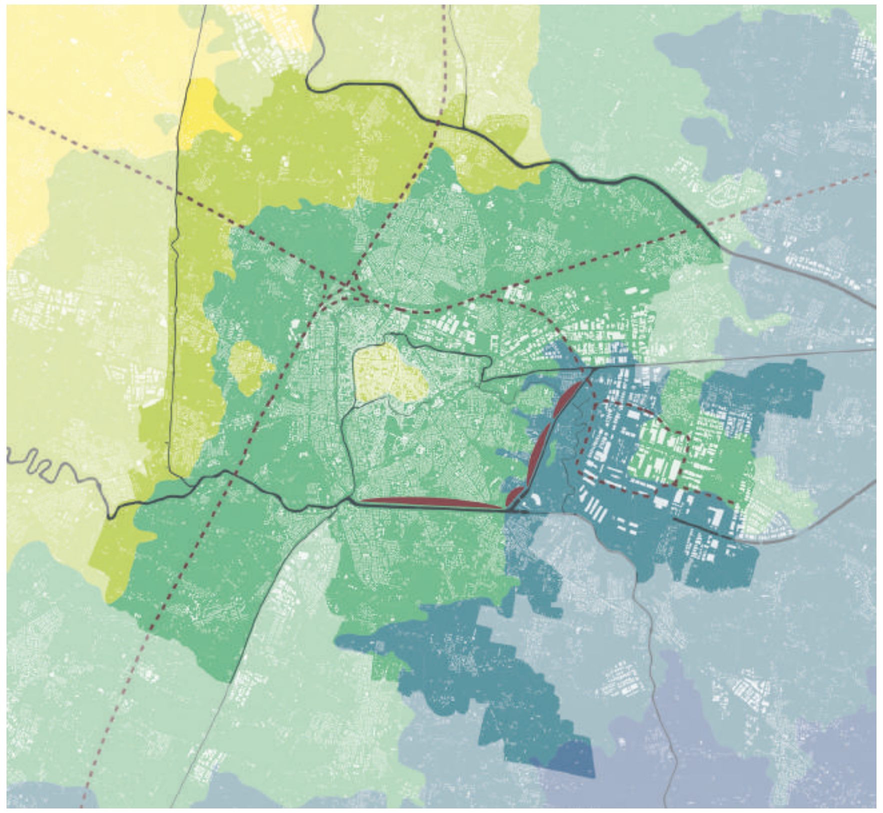
A secondary problem in flood management policies and practices is urban stormwater drainage. The main causes of flooding are to be found in the growing urbanisation process which, in the case of Padua, has seen the city expand outside the Venetian walls. The increase in built-up land reduces the ability of water to infiltrate the ground, causing a reduction in flooding volumes. The first consequence is an increase in the surface runoff coefficient and a decrease in the runoff time, which accelerates runoff and the accumulation of rain on impervious surfaces. The increase in surface runoff leads to a greater demand on the urban drainage system, which, however, is unable to accommodate ever greater volumes of rain due to its progressive sealing (Compagno, 2019). Indeed, the growth of the city has led to the coverage of almost all the drainage channels responsible for the removal of rainwater. This process has reduced the cross-section of the canals affecting their flow and making them less efficient in handling large volumes of wastewater. Problems of this kind can be seen in the Arcella and Montà districts, where the drainage system has repeatedly proved incapable of collecting rainwater from exceptional events, resulting in the flooding of many areas. In fact, almost one third of the urbanised area of Padua (about 3200 ha) drains rainwater into a single consortium canal (Fossetta canal) whose size is not commensurate with the current level of urbanisation (Zanetti, 2013). This phenomenon is accentuated by the combined structure of the sewerage system, which uses the same network of conduits to collect and remove wastewater from individual buildings and water from roadways.

The problems of water accumulation are compounded by the morphology of the land (Figure 37). The low variation in the average gradient of Padua's terrain favours the stagnation of stormwater in the most depressed areas, thus accentuating the problem of urban infrastructures which create insurmountable barriers. This problem has been further aggravated by the changes made to the area over the years to improve the city's hydraulic structure. The construction of the Scaricatore canal and later of the San Gregorio canal created a barrier to the natural flow of water along the axis of the south-eastern slopes. This has resulted in the formation of new runoff accumulation basins at the upstream areas of the left banks of the canals, causing considerable damage to the built-up environments (Compagno, 2019).

Figure 37:
Padua altitude profile and barrier

16-19 masl
13-15 masl
10-12 masl
5-9 masl
<5 masl

Water flow barriers:
Railway
Canals

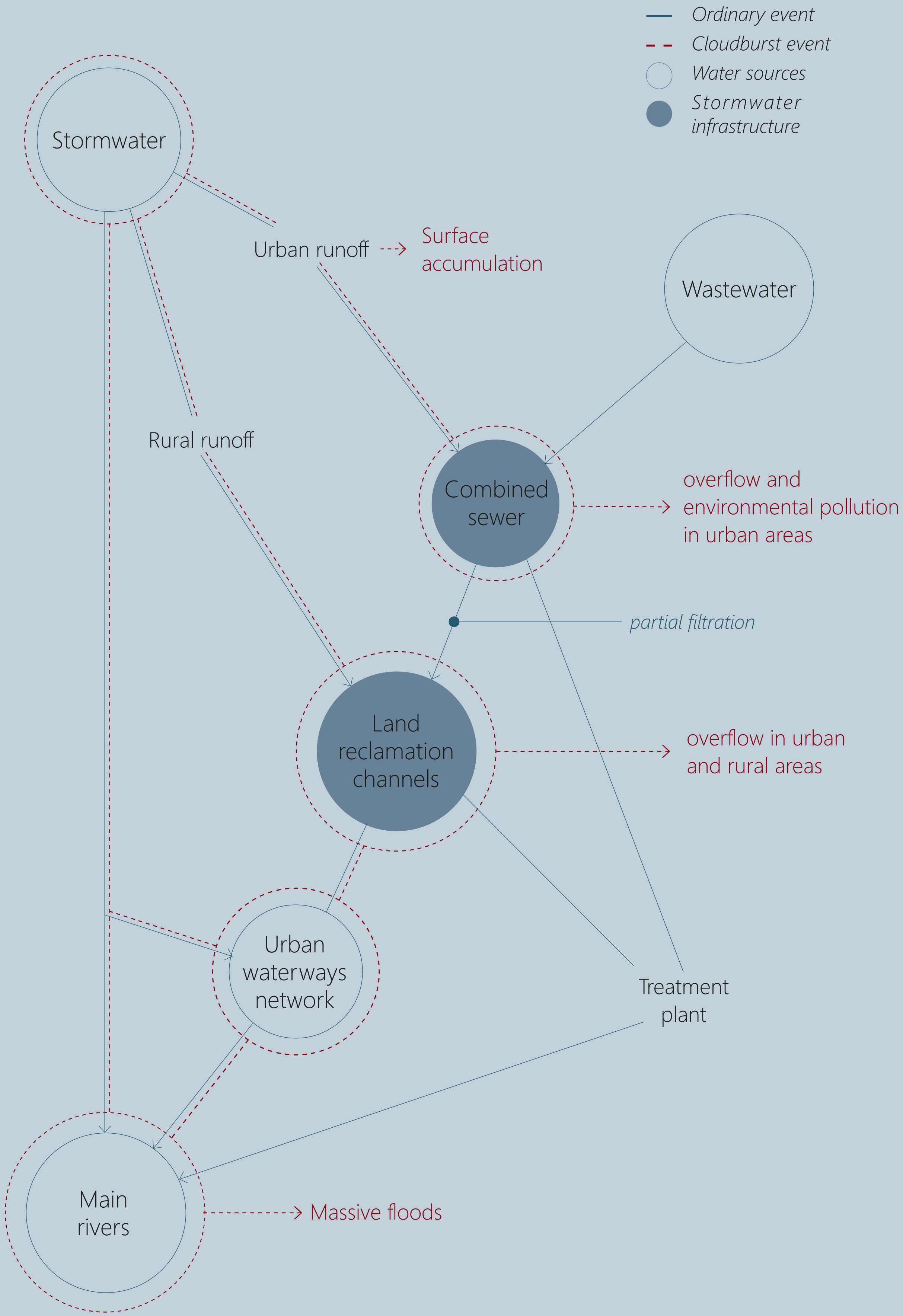


4.2.3 Cross-cutting themes

Among the transversal issues to the flood risk there is certainly the pollution and the hygienic-sanitary safety of the territory. Where the city is crossed by a combined sewer system (as in the most of Padua), the network simultaneously receives sewage water from building drains and possibly industrial water. As a consequence, in the case of excessive water accumulation, overflowing of the network causes the surface leakage of polluted water, whose uncontrolled management risks worsening the hygienic conditions of the city (Comune di Padova, 2009).
Referring to Padua, the water drainage channels, designed for rainwater drainage or to facilitate irrigation, becoming part of the urban fabric and the combined network, have become real sewerage collectors.

Generally, sewers are equipped with purification systems capable of filtering only black water during dry periods or wastewater with a predetermined degree of dilution. For this reason, wastewater discharged into canals that are still open to the sky significantly compromises water quality and pollution, affecting the environmental quality of the city. Such problems can be found in the Fossa Bastioni and the Piovego canal which cross an important portion of the city from west to north. In addition, water contamination inside the city is accentuated and aggravated during low water periods, when water scarcity causes less water dilution, hence water stagnation (Comune di Padova, 2009). This matter further highlights the inadequacy of a combined sewer system and the seriousness linked to a poor management of urban drainage.

Figure 38:
Diagram of Padua hydraulic network



4.3 Flood management tools

In the presentation of the Padua water context, attention has been paid to what is commonly referred to as hydraulic risk or more broadly understood as flood risk. Flood risk management requires different tools to control and reduce the hazard, ensuring a certain level of safety. Some differentiate these tools into *structural* and *non-structural* measures.

- The former concern all those practical solutions that act physically in the mitigation and limitation of the hydraulic or flooding problem.
- Non-structural measures, more commonly referred to as Plans, on the other hand mean the adoption of management or regulatory tools to regulate and define the practices and operations necessary for risk reduction (Mel, 2020).

In general, the plans can and should be adopted in support of structural measures to facilitate their implementation and verify their efficiency.

4.3.1 Plans

The national regulatory framework which describes the hydrogeological risk management instruments is divided into two types of instruments: sector plans and spatial planning system The Italian regulatory framework generally provides that the spatial planning falls under regional competences, which adopt sectoral and general strategies aimed at guiding the proper planning of lower administrative levels.

As regards the sectoral instruments relating to the hydraulic and hydrogeological issue, the State instructs the various Regions to provide for a series of sectoral plans through specific regional laws. These include the Piano di Assetto Idrogeologico (PAI), the Piano di Tutela delle Acque (PTA), and the Piano Generale di Bonifica e Tutela del Territorio (PGBTT). In addition to the national plans, there are two new plans derived from the implementation of two European directives. Specifically, the first is the Floods Directive 2007/60/CE[9] and with the D.Lgs. 49/2010 the State designates a new supra-regional body, the Distretto di Bacino, responsible for drafting the Piano di Gestione del Rischio Alluvioni (PGRA). This Plan gathers all the information necessary to adopt a planning activity aimed at the hydrogeological defence of the territory focused on the reduction of the risk that flooding phenomena cause to society, the economy and the cultural and environmental heritage of the country (ISPRA, n.d.). Moreover, with the implementation of the Water Directive 2000/60/CE through the D.Lgs 152/2006, the Autorità di Bacino is responsible for the drafting of the Piano di Gestione delle Acque aimed at quantifying the impacts and pressures exerted on the water bodies of the Distretto. The plan does not report information related to the action of natural events but draws up a complete picture of the health status of the territorial water resource (Autorità di bacino distrettuale delle Alpi Orientali, 2015).

[9] *Directive text at www.eur-lex.europa.eu*

The introduction of the PGRA among the spatial planning system poses a new question concerning the relationship with other plans, in particular with the PAI of the reference basins. The PGRA is not accompanied by implementation rules, so its adoption does not constitute an automatic variant of the PAI (which remain the main reference for urban planning tools and land management at local level) but, given the strong synergy of the areas of action, the drafting of PGRA led to the adoption of variants to existing PAI in order to build a coherent and harmonized administrative framework (Regione Veneto, 2021a).

As far as regional plans are concerned, they describe in a general way all the necessary indications for a correct planning, inserting the different issues related to the territory at a more adequate scale. Among these instruments are the Piano Territoriale Regionale di Coordinamento (PTRC) and the Piano Territoriale di Coordinamento Provinciale (PTCP), which report strategic lines of intervention and development of the regional and provincial territory to which subordinate local plans must refer. This category includes the Piani Regolatori Generali (PRG) administered by Regional Law 11/2004. PRGs are divided into the Piano di Assetto del Territorio (PAT), which contains the structural provisions on which urban planning is based, and the Piano degli Interventi (PI), which contains the more operational indications (Regione Veneto, 2021b). The law 11/2004, previously mentioned, also identifies a inter-municipal planning tool aimed to unify the interests shared by several municipalities under a common instrument of action, the Piano di Assetto del Territorio Intercomunale (PATI).

A detailed picture of the sector and spatial planning system related to the issue of hydrogeological risk and problem related to the reality of Padua is schematically reported below, in order to report the general normative context of reference, currently in force.

PGRA | PIANO DI GESTIONE DEL RISCHIO ALLUVIONI

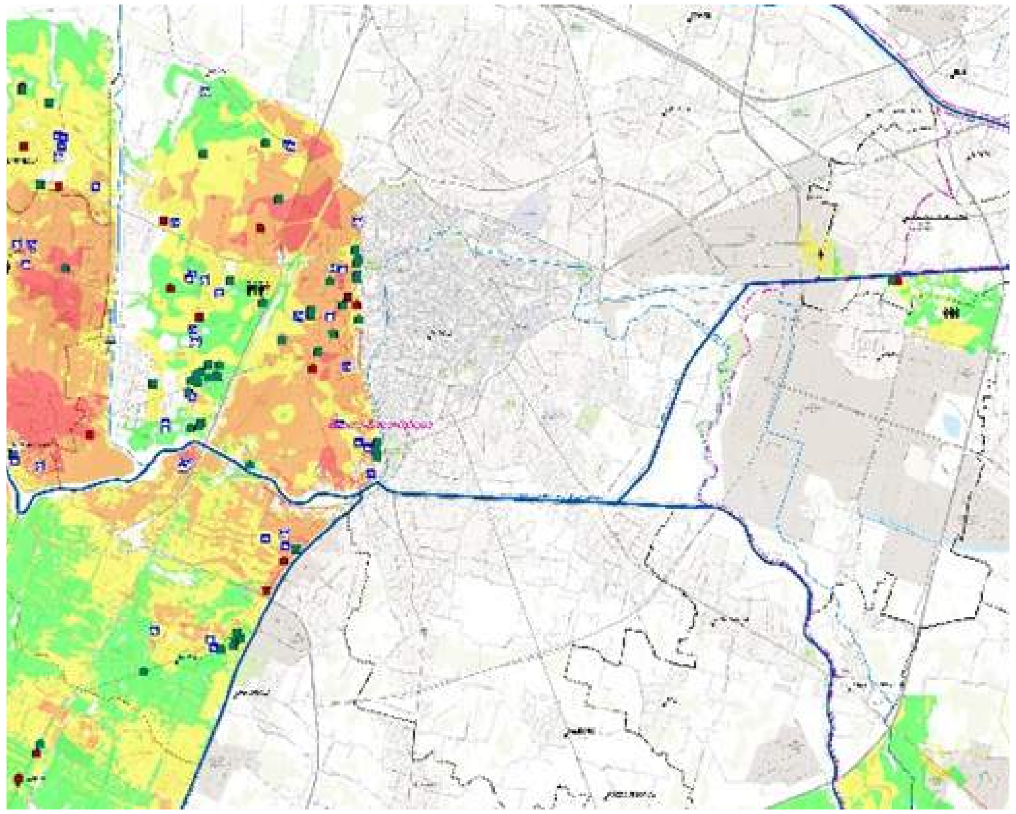
The Municipality of Padua belongs to the competence areas of the Distetto delle Alpi Orientali, which approved in 2015 the first 6-year Piano di Gestione del Rischio Alluvioni[10]. The Plan contains a series of information aimed at ensuring the correct synergy between the management disciplines of the Protezione Civile and those inherent in the planning of the basin, considering that both entities act on the same issues but on different space-time horizons. The information contained in the plan concerns the prevention of vulnerability, protection against flooding phenomena, preparation that reduces exposure factors and restoration, which is fundamental in planning actions following the event. The measures are divided into:

- A mapping of floodable areas and risk classes in different territorial contexts (fluvial, lake, marine, afferent to the secondary hydraulic network of the plain and the secondary hydraulic network of the hills and mountains), subdivided into three scenarios of different frequency/gravity (rare, infrequent, frequent event defined according to return times of 300,100 and 30 years) and the dynamic characteristics of flood waters.

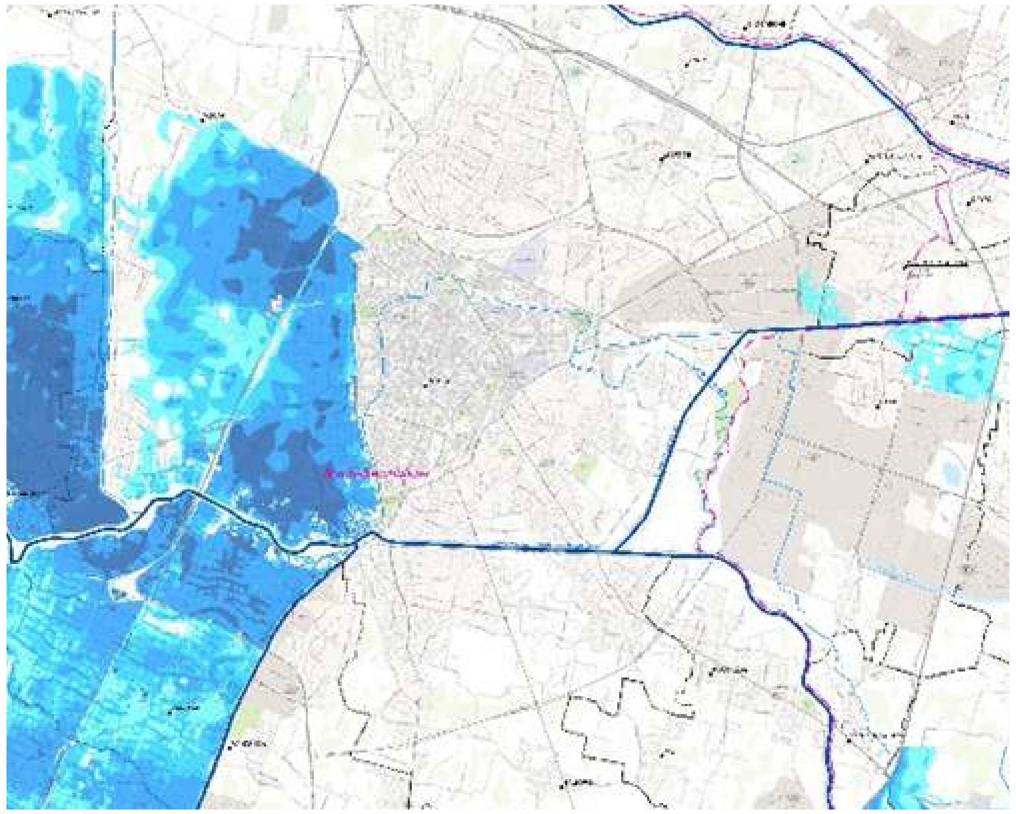
- Plan measures covering all aspects of characterisation and mitigation of flooding, related damage and risk, already foreseen or not yet used. These refer both to structural measures, active and passive, intensive and extensive, as well as to non-structural preparedness and prevention measures associated with land use restrictions, in order to deal efficiently with possible flood events.

[10] *Details on the structure and information contained in the PGRA-Alpi Orientali at www.alpiorientali.it*

Figure 39 & 40:
PGRA - Maps of flooded areas, high probability scenario (T=30 years)
Source: PGRA-Alpi Orientali



Risk classes:
- *Low (R1)*
- *Moderate (R2)*
- *High (R3)*
- *Very high (R4)*



Water levels:
- *0-0.5 m*
- *0.5-1 m*
- *1-2 m*

PAI | PIANO DI ASSETTO IDROGEOLOGICO

In accordance with the Legge Quadro on Soil Defence n. 183 of 18 May 1989, now merged in the codice ambientale, D. Lgs. 152/2006, the Autorità di Bacino are established, and their activity is managed within the limits of hydrographic basins[11]. Padua is part of the Autorità di Bacino dei fiumi dell'Alto Adriatico, which includes the basins of the Isonzo, Tagliamento, Livenza, Piave, Brenta and Bacchiglione rivers. Specifically, the activity of the PAI consists in offering a cognitive, normative and technical-operative tool through which actions and rules of use are planned and programmed for the conservation, defence and valorisation of the soil for all aspects related to the hydrogeological hazard of the territory (Autorità di Bacino dei fiumi Isonzo, Tagliamento, Livenza, Piave, Brenta-Bacchiglione, 2012). With this instrument, in a hydrographic basin:

- The dangerous areas due to landslide, avalanche and flood phenomena are identified, delimited and classified according to three classes of increasing dangerousness (P1, P2, P3).
- Structural (works) and non-structural actions and interventions are planned and programmed to mitigate the hazard and risk.
- The behavioural norms necessary to reduce the hazard and risk on the territory are indicated, combining these aspects with the territorial and socio-economic development needs of the area.

As far as the Brenta-Bacchiglione basin is concerned, within which the Municipality of Padua belongs, the mapping of the hydraulic hazard focuses mainly on the phenomena of river flooding. Indeed, urban drainage is considered as a secondary problem, limited to the northern districts of the city and the areas south of Ca' Nordio, served by channels that are undersized for the extension of the urbanised area. As a demonstration of this, the mitigation solutions reported within the plan concern only direct actions on river bodies with the aim of improving their safety and protection (Autorità di Bacino dei fiumi Isonzo, Tagliamento, Livenza, Piave, Brenta-Bacchiglione, 2012). These are indicated above all for the artificial canals Scaricatore, San Gregorio-Piovego and foresee:

- The adaptation of the riverbeds to the maximum flows according to the return time assigned to each class of works.
- The moderation of flood flows to reduce them to acceptable limits for the current state of the rivers.
- The combination of the two above.

[11] The territory from which rainwater or meltwater from snows and glaciers drains to the surface and collects in a given watercourse directly or by means of tributaries, and the territory which may be flooded by the waters of the same watercourse, including its terminal branches with their mouths in the sea and the sea coast opposite; where a territory may be flooded by the waters of several watercourses, it shall be deemed to fall within the water catchment area whose mountainous catchment area has the greatest surface area. (D.Lgs 152/2006 at www.normattiva.it)

Figure 41:
PAI - Map of hydraulic criticism
Source: Autorità di Bacino dei fiumi Isonzo, Tagliamento, Livenza, Piave, Brenta-Bacchiglione, 2012

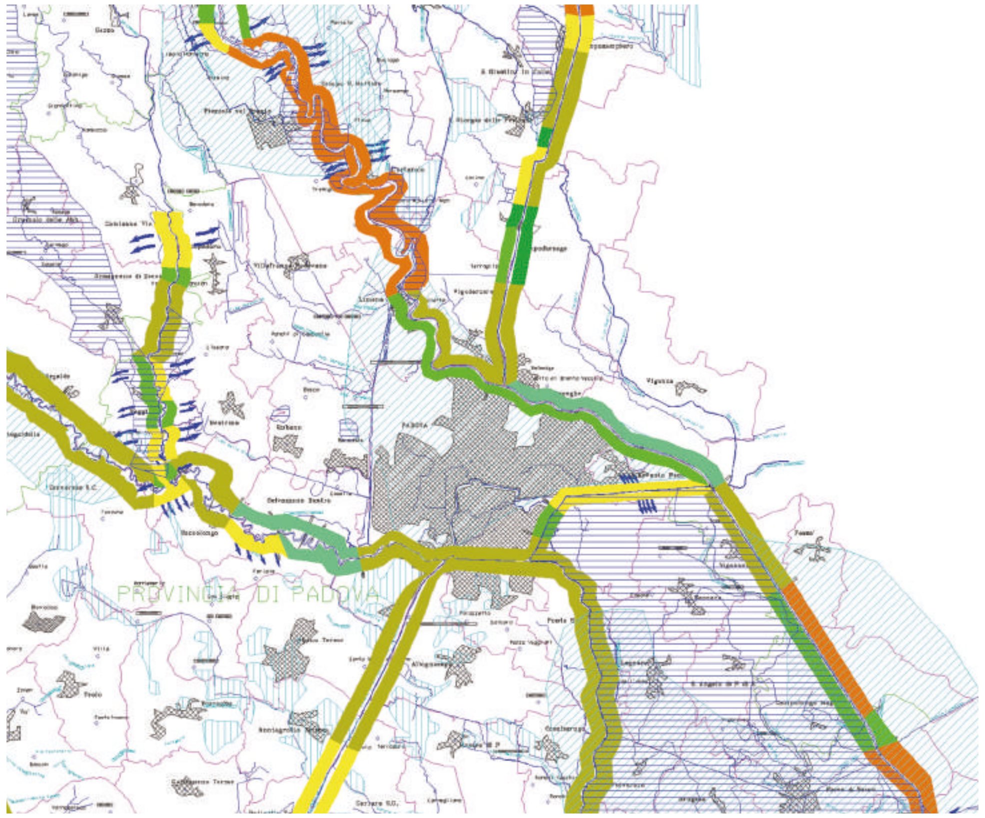


Figure 42:
PAI - Map of hydraulic risk
Source: Autorità di Bacino dei fiumi Isonzo, Tagliamento, Livenza, Piave, Brenta-Bacchiglione, 2012

PTA | PIANO DI TUTELA DELLE ACQUE

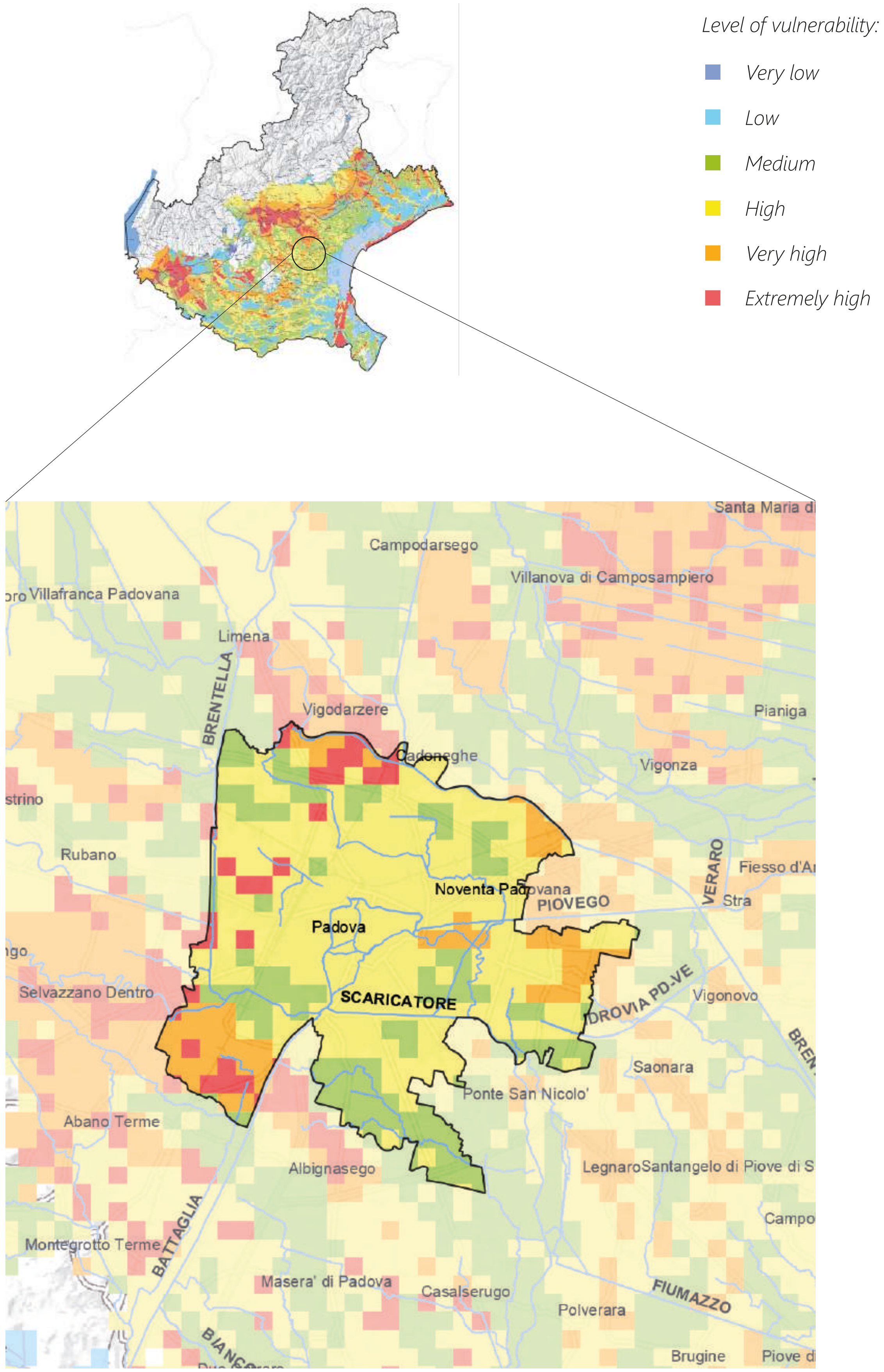
In addition to the previous plans, there is the Piano di Tutela delle Acque, a regional instrument provided for by article 121 of D.Lgs 152/2006. The PTA[12] drawn up by the Veneto Region is a document that identifies the precise regulatory apparatus that governs the individual activities and authorisation procedures relating to the protection of water resources in the territory. In the PTA we find:

- Summary of the cognitive aspects: summarises the cognitive base and its subsequent updates and includes the analysis of criticalities for surface and underground waters, by hydrographic and hydrogeological basin.
- Plan guidelines: contains the identification of quality objectives and the actions envisaged to achieve them: the designation of sensitive areas, vulnerable zones from nitrates and phytosanitary products, areas subject to soil degradation and desertification; the measures relating to discharges; the measures relating to river regeneration.
- Technical Implementation Standards: list of regulations to be followed to achieve quality objectives. These include measures for rainwater and runoff management.

The information and the reference cartography of the Plan are functional to classify and monitor the quality levels of regional water bodies, a factor not directly related to flooding problems but that in association with these can worsen the consequences on the health of cities and their citizens.

[12] *More information at www.regione.veneto.it/web/ambiente-e-territorio/tutela-risorsa-idrica*

Figure 43:
PTA - Map of intrinsic groundwater vulnerability
Source: regione.veneto.it



PGBTT | PIANO GENERALE DI BONIFICA E TUTELA DEL TERRITORIO

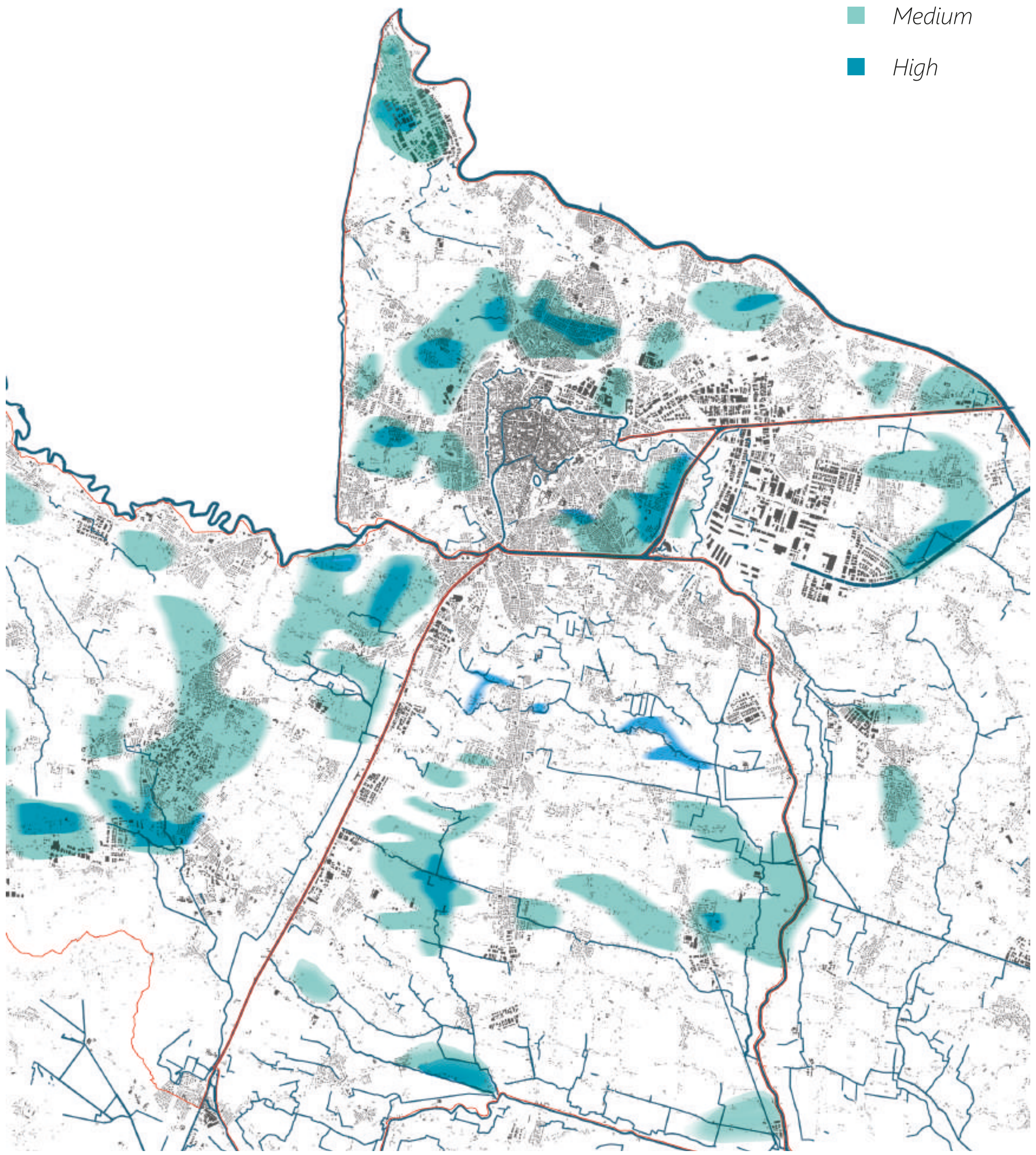
In reference to the sectorial planning of regional competence, we find among the land management tools the Piano Generale di Bonifica e Tutela del Territorio. The PGBTT, provided for by the regional law 12/2009, indicates the Consorzio di Bonifica as authority responsible for the drafting of a specific plan aimed at the management and administration of minor water courses within the limits of the competence district. The perimeter, in which the competence of the Consorzio acts, is established by the Region according to the evaluation of the homogeneity of the hydrographic and functional profile in relation to the needs of coordination and growing of the land reclamation activity[13] .

In general terms, the PGBTT contains a series of indications related to the division of the district by homogeneous levels of hydraulic and hydrogeological risk, the determination of public works necessary for the protection and enhancement of the territory and other proposals regarding the management of water bodies addressed to other public authorities of competence (Consorzio di Bonifica Bacchiglione, 2010). In order to manage more effectively the hydraulic problems of the territory, which extends over several municipalities crossed by the Bacchiglione river, the Consorzio has divided the drainage basin into sub-basins according to the existing infrastructure network and its relationship with the main and secondary river system. The Municipality of Padua is affected by four sub-basins: the Colli Euganei, Zontà-Portello, Patriarcati and Sesta Presa basins (Zanetti, 2013).

The basic cartography of the PGBTT concerning the areas recognised as hydraulically hazardous is associated with an informative cartography, drawn up by the Consorzio, which describes the morphological-territorial characteristics of the sub-basins that make up the administrative limits of the Bacchiglione basin.

[13] *Contents of the regional law available at www.bur.regione.veneto.it*

Figure 44:
PGBTT - Map of flooding areas
Source: Consorzio di Bonifica Bacchiglione, 2010



PTRC | PIANO TERRITORIALE REGIONALE DI COORDINAMENTO

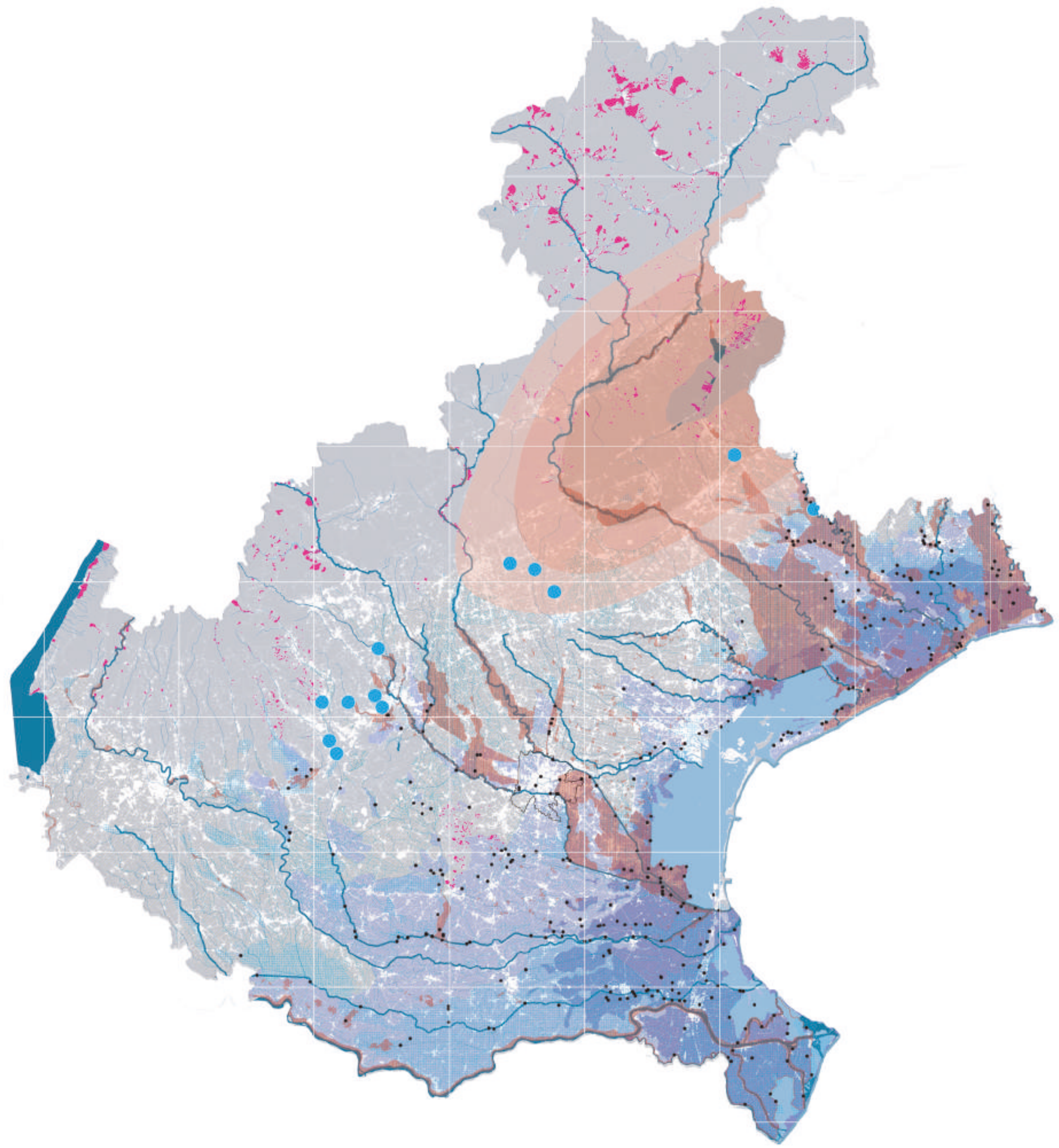
The Piano Territoriale Regionale di Coordinamento (PTRC) is the planning and management instrument for the territory at regional level, constituting the reference urban planning tool for the lower administrative levels. The PTRC lays down the rules and strategies for territorial development, establishing the thematic bases to be developed at the various local planning levels.

Among the numerous themes of the Plan, the issue of soil consumption is the most important one, also in relation to the consequences of climate phenomena. The Region's intention in compiling the PTRC is to highlight an increasingly evident breakdown in the relations between ecosystems and the territory, understood as an infrastructure and resource system to be used. This entails a loss of biodiversity but above all of those primary functions of ecosystems, including the maintenance of the hydrogeological balance. In fact, the Plan contains guidelines referring to the management of hydrogeological risks and the protection of the territorial hydraulic network, which introduce prevention and monitoring processes through the integration of basin planning and the construction of important hydraulic infrastructures. Given the thematic connection, the hydrogeological risk analysis is reported among the cartographic maps related to land use where the regional areas presenting hydraulic, geological and seismic hazard are marked[14].

Figure 45:
PTRC - Map of land use - hydrology and seismic risk
Source: PTRC-regione.veneto.it

Veneto hydrologic system:

- *Hydraulic risk area*
- *Geological hazard area*
- *Area under the medium sea level*
- *Basins subject to mechanical lifting*
- *Dewatering pump*
- *Retention areas*



[14] Plan documents can be found at www.regione.veneto.it/web/ptrc/ptrc-2020

PTCP | PIANO TERRITORIALE DI COORDINAMENTO PROVINCIALE

The provincial planning instrument provides the reference framework for local planning and deals within it with various issues, including soil protection, protection and enhancement of the environment and water resources as well as the prevention of disasters. The plan documents include the Carte dei Vincoli e Fragilità, which refer to the PAI information on the perimeter of hydraulic risk areas[15].

Among the technical documents that make up the plan there is also the Carta Idrogeologica where the different basic information of the hydrogeological structure of the Province are reported and the areas subject to periodic flooding phenomena are also identified. The hydrogeological information is referred to in the urban planning instruments of the lower levels.

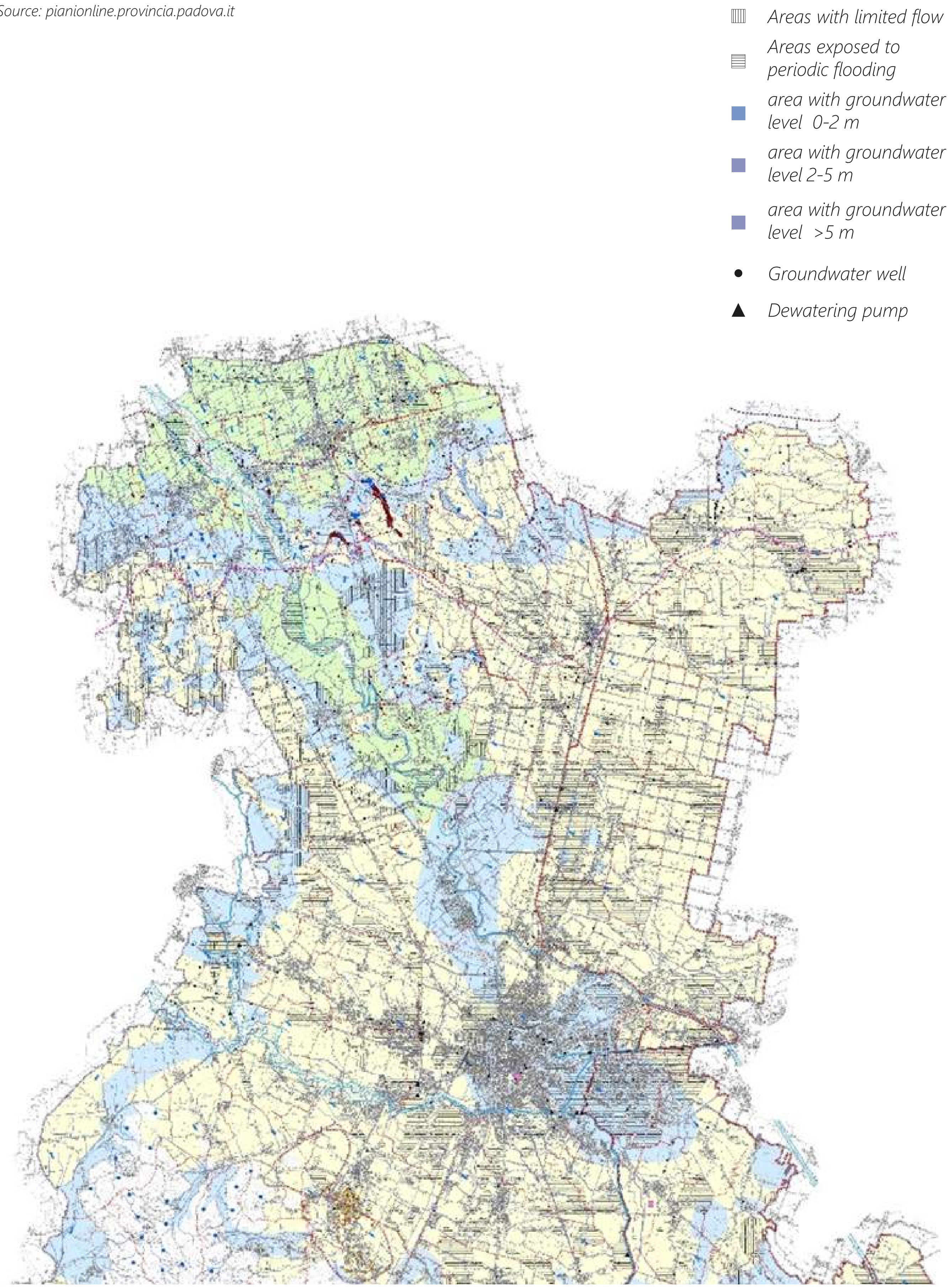
Among the documents produced, the Urban Planning Sector of the Province has recently published a text entitled *Linee guida per la stesura di progetti preliminari di gestione delle vie d'acqua di pioggia e di programmazione delle opere necessarie a mettere in sicurezza idraulica il territorio comunale / Intercomunale* (Guidelines for the drafting of preliminary projects for the management of rainwater ways and the programming of the works necessary to make the municipal/inter-municipal territory hydraulically safe),more briefly Piano delle Acque. The plan reports the necessary indications for the drafting of a Municipal or Inter-municipal Piano delle Acque. In particular, the structure of the Plan is articulated in four points that focus on the management practices of the rainwater ways and the works necessary to make the territory hydraulically safe with reference to the urban water ways and not belonging to the main network[16].

At present, the Municipality of Padua has not yet elaborated the Piano delle Acque, according to the provincial indications.

[15] *The Province of Padua plan at www.pianionline.it/elaborati-tecnici-del-ptcp*

[16] *All the information about the Piano delle Acque for the Province of Padua at www.pianionline.provincia.padova.it*

Figure 46:
PTCP - Hydrogeological map
Source: pianionline.provincia.padova.it

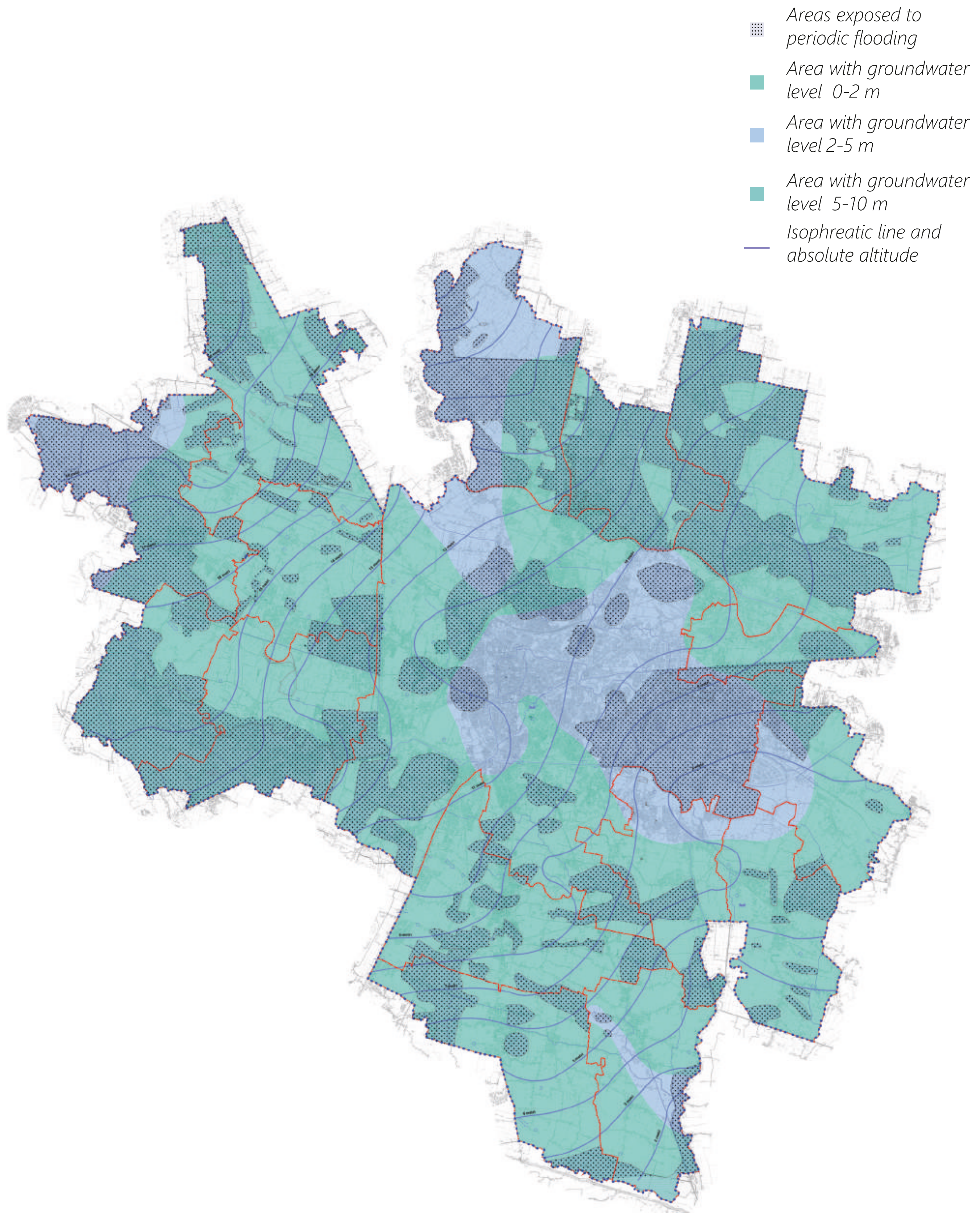


PATI | PIANO DI ASSETTO DEL TERRITORIO INTERCOMUNALE

The Piano di Assetto del Territorio Intercomunale is the main reference basis for the structure of the PAT of each Municipality included in the Comunità Metropolitana di Padova (CO.ME.PA) and aims to regulate the development of homogeneous territorial areas from the settlement-structural, geomorphological, historical-cultural, environmental and landscape points of view[17]. Among the objectives of the PATI is the concept of intergenerational equity in the use of natural resources, but also the need to act to protect the territory and its inhabitants from the consequences of hydrogeological instability.

With specific reference to the hydrogeological issue, the PATI cartography shows a map of the hydrogeological characteristics of the Padua metropolitan area and among the project documents, the Carta delle Fragilità. These documents define the areas at greater risk of hydrogeological instability, the areas at risk of flooding and the areas of difficult drainage. In the technical report of the Plan, on the other hand, the guidelines and general prescriptions for urban and building transformation interventions in urbanised areas or areas to be urbanised are specified, with the need to refer to the technical maps to identify the related dangers and risks.

Figure 47:
PATI - Hydrogeological map
Source: pianionline.provincia.padova.it



[17] *All the PATI documents available at www.pianionline.provincia.padova.it*

PAT | PIANO DI ASSETTO DEL TERRITORIO

The Piano di Assetto del Territorio of Padua represents the main instrument concerning the strategic planning objectives of the municipal territory with respect to the superordinate governmental instruments. The measures indicated in the Plan are articulated in directives, prescriptions and constraints in order to regulate in a clear and transparent way the urban planning activities of the consolidated city, implemented through the Piano degli Interventi (Comune di Padova, 2014). The Plan is organised in a general report, the cognitive framework, the graphic tables and the technical implementation rules. Entering in the specifics of the issues related to urban water planning and hydrogeological risk mitigation, the Carta delle Fragilità is the main reference to be considered. This map summarises the soil and subsoil investigations and establishes the constraints and methods for land transformation interventions. The drawing of the Plan provides indications on the classification of the territory to which the Norme Tecniche di Attuazione are linked, which specify the methods of intervention for building.

In addition, the theme of water is taken up in the document "La Città che Respira", one of the additional graphic documents that the Municipality has decided to add to the Plan in order to better specify the future development line of the city. The table proposes the general strategies for the realisation of the local ecological network, through an organic system of connections between the hydro-geographical network, the existing and planned urban parks and the new networks of environmental connections to be maintained, safeguarded and created[18].

In order to manage the frequent problems of hydraulic instability in cities, the Veneto Region has introduced with the D.G.R. of Veneto 3637/2002 (replaced by 1841/2007) the Valutazione di Compatibilità Idraulica (VCI), a report to be attached to every new urban planning instrument aimed at transforming the territory. The purpose of the VCI is to ensure that any intervention foreseen by the urban planning instruments does not aggravate the existing level of hydraulic risk and if this is not possible, the specific intervention must foresee a series of additional compensatory measures. In short, the VCI presents the hydrogeological, morphological and pedological characteristics of the Municipality, the hydraulic problems existing on the territory and summarises the conclusions about the possible causes and the possible solutions to contain these problems[19].

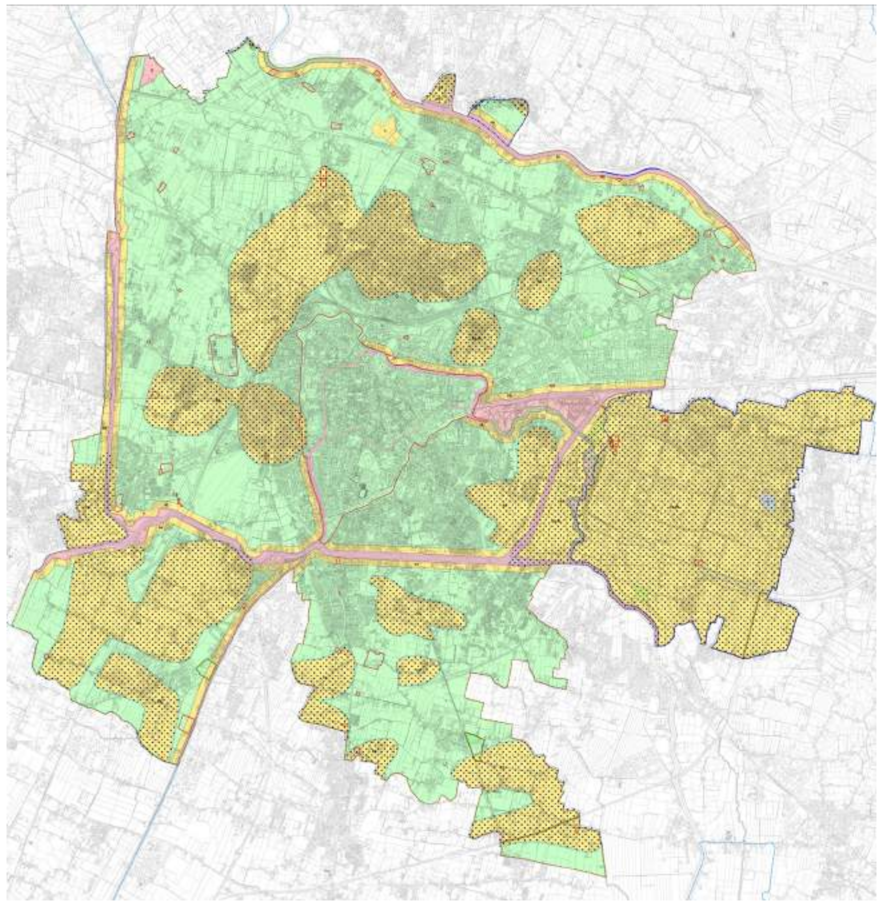


Figure 48:
PAT - Carta delle Fragilità (map of weaknesses)
Source: padovanet.it

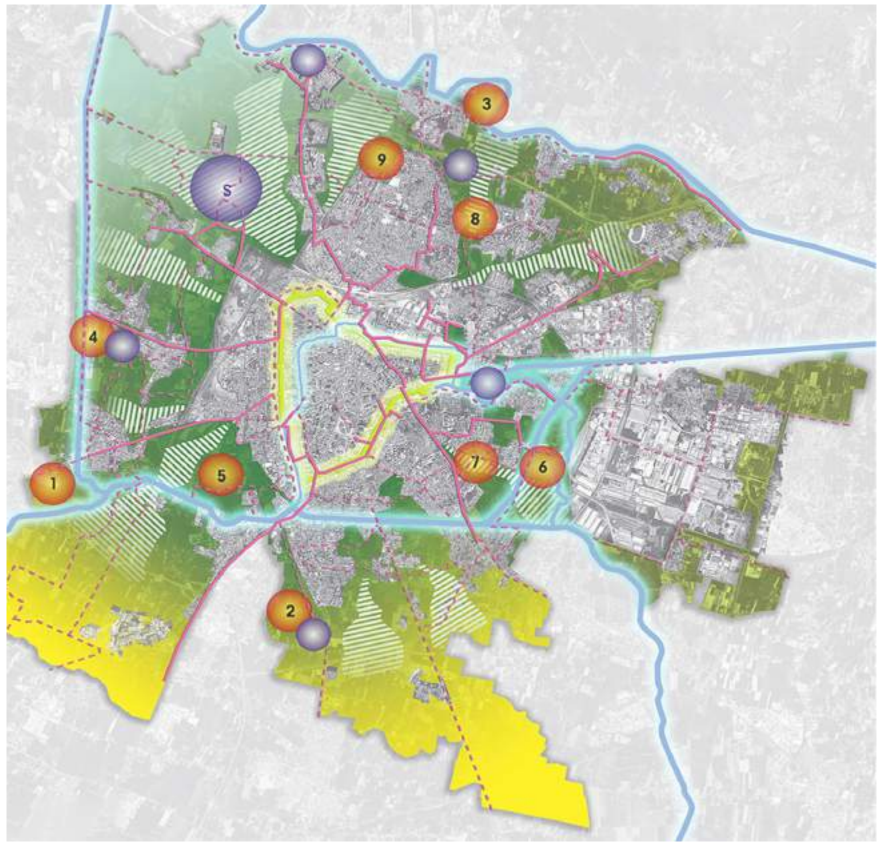


Figure 49:
PAT - La Città che Respira (The City that Breathes)
Source: padovanet.it

[18,19,20] *More information about the PAT e PI at http://www.padovanet.it/urbanistica*

PI | PIANO DEGLI INTERVENTI

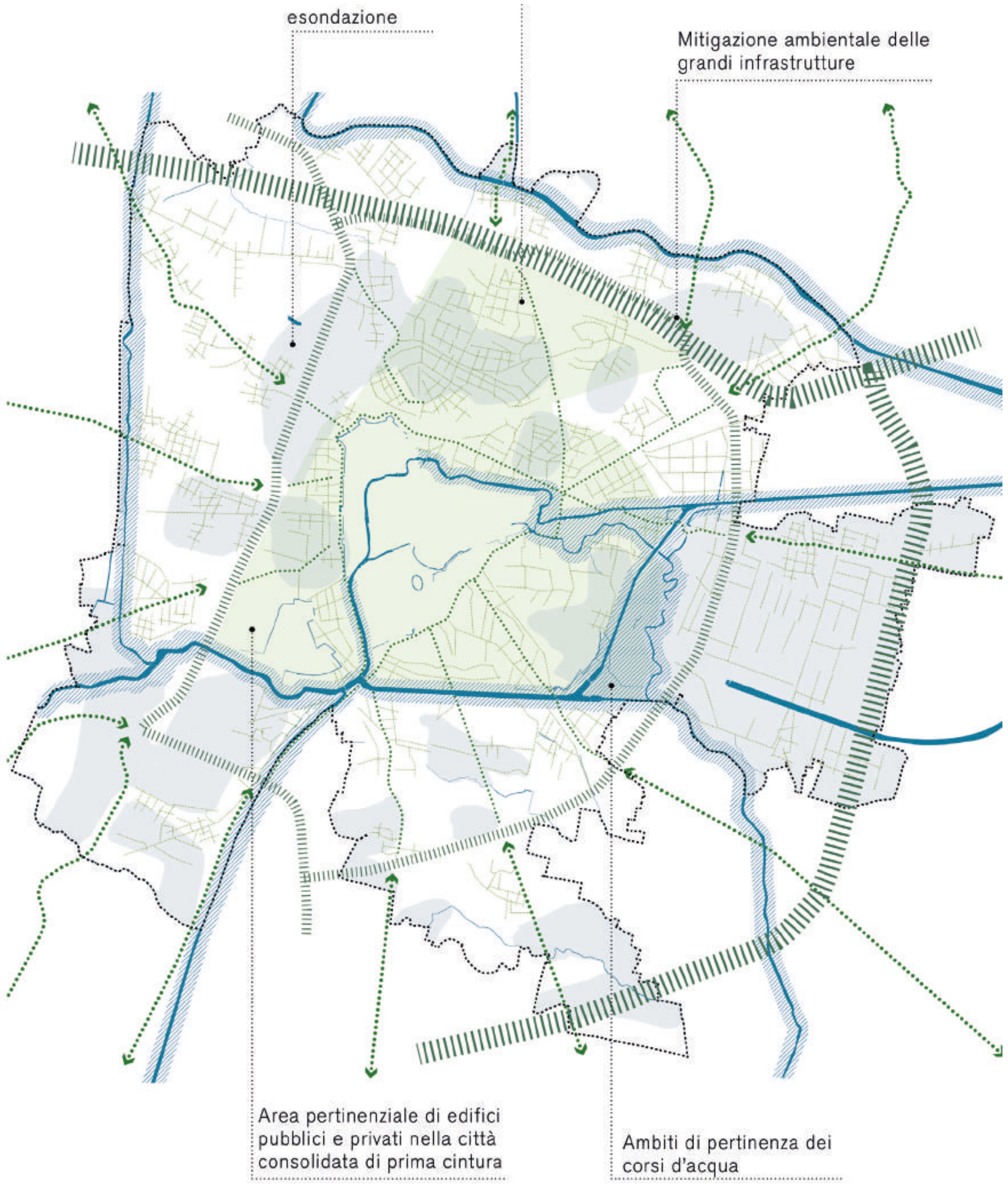
In the Piano degli Interventi (PI), the topics listed in the PAT are translated into a strategic design that guides the city's development practices. According to what is indicated in the regional law 11/2004, the PI has been conceived as a programmatic tool through which the municipal administration, in line with the measures indicated in the PAT, outlines a strategy and the objectives to be implemented in the short and medium term[20].

Inside the PI the specific development objectives of the city are reported, which is divided and analysed as a set of different territorial systems. The division of the themes into systems allows to analyse the criticalities and potentialities of each sector in order to define a complete and targeted action framework. Within the environmental system of the PI of Padua there is the subcategory of *Rischio idrogeologico e la Qualifica del drenaggio urbano* (Hydrogeological Risk and Urban Drainage Qualification). In this section, the issues related to water and climate change are discussed in depth, proposing guidelines for the reduction and mitigation of flooding phenomena.

The need to improve the efficiency of the existing urban drainage network is then stressed, as well as the application of the recent tool of hydraulic invariance[21] to subordinate transformation interventions to the realisation of infrastructures for stormwater management. In addition, the need to increase the permeability of the urban fabric by contrasting the phenomenon of cementification is underlined, and the hydraulic potential of the completion of the Padua-Venice hydroway is recalled (Comune di Padova, 2020).

[21] In areas subject to hydrological land-use change, which are hydrographically "upstream" of other areas without hydraulic problems, it must at least be ensured that the intervention does not increase the risk; this can be done, also in the light of the atomisation of land modification action (Comune di Padova, 2009).

Figure 50:
PI- Environmental System-Hydrogeological Risk and Urban Drainage Qualification
Source: padovanet.it

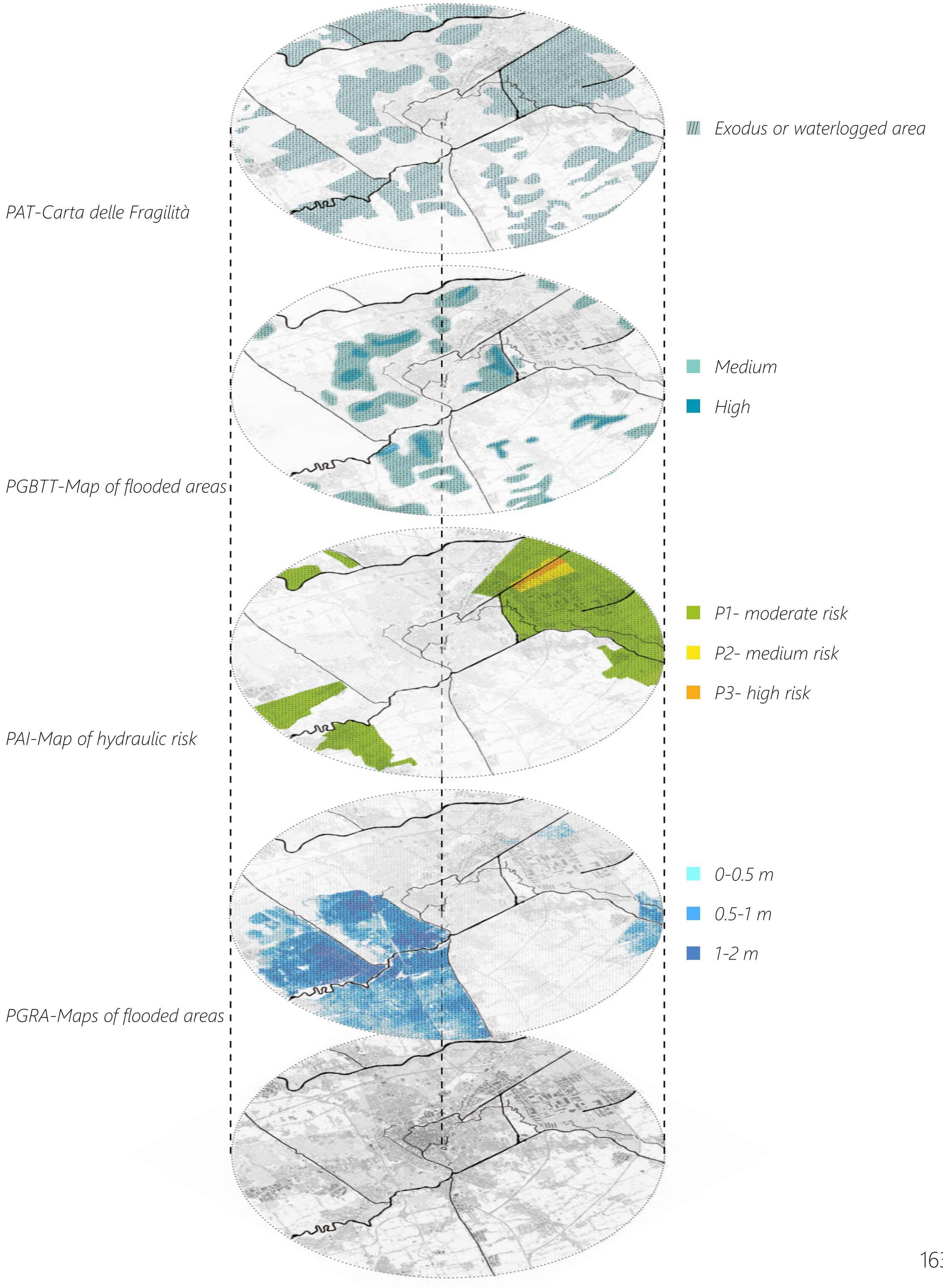


Comparing the existing hydrogeological risk maps, produced by different authorities, it emerges how unclear and conflicting the information is. Indeed, some areas highlighted as critical are overlapping, while others vary according to the map considered. These inconsistencies do not provide a clear picture of the problems present in the area, leaving practitioners free to interpret the risks and problems to be considered. The inconsistency between the various land management tools denotes the lack of a unitary and shared vision of the hydraulic problems, a vision that must form the basis for undertaking a path of change (Figure 51). A precise and transparent analysis of the water dynamics governing the territory makes it possible to plan efficient hydraulic solutions in the long term and, above all, to adapt to future uncertain climate scenarios.

The lack of a project aimed at the management of flooding phenomena is also evident in the local urban planning tools and in particular in the Piano degli Interventi (PI). As far as the theme of hydrogeological risk reduction is concerned, the PI limits itself to suggesting guiding intervention strategies aimed at strengthening the existing system, limiting land use and ensuring the realisation of interventions (compatible) with the current level of hydraulic safety. The lack of a specific plan for the management of flooding phenomena that accompanies the already existing local urban planning instruments does not allow the implementation of projects aimed at risk reduction and fortification of the territory against increasingly violent climatic phenomena.

In this way, the vertical hierarchical structure connecting the different territorial planning tools presents a weak point concerning the hydrogeological risk that does not allow a continuity between strategic planning, specific planning and final implementation of the measures.

Figure 51:
Comparison between different hydrogeological risk maps.



4.3.2 Structural measures

The framework presented so far summarises in a exhaustive way the planning tools supporting the management of hydrogeological risks related to flooding phenomena. Moving the attention on how these tools are adopted in the defined “structural measures”, it is necessary to indicate which are the Authorities responsible for the management and prevention of hydrogeological risk.

In the case of the territory of Padua we find the Genio Civile, the Consorzio di Bonifica del Bacchiglione, the Cosiglio di Bacino Bacchiglione and the Municipality of Padua which operate in different ways across the territory:

- The Genio Civile is a regional office that operates on a provincial basis for the protection and safeguard activities of the main hydrographic network with main hydrographic network with its pertinent state-owned facilities. The Genio Civile has to guarantee all the ordinary and extraordinary maintenance operations, emergency action and protection of the territory in the event of natural disasters (Regione Veneto, n.d.).

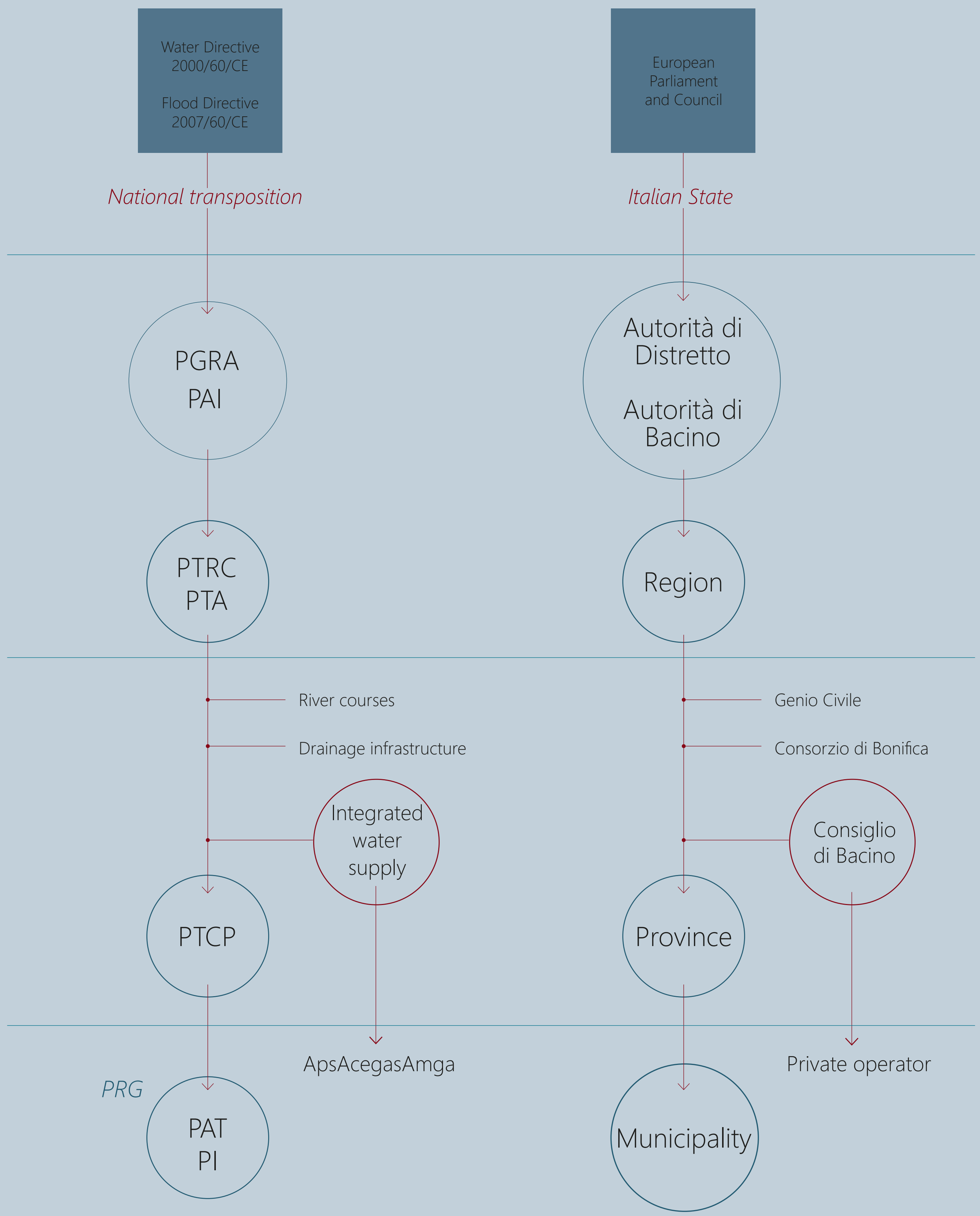
- The Consorzio di Bonifica del Bacchiglione, previously mentioned with regard to the PGBTT, is responsible for the implementation of all drainage and stormwater management infrastructures at supra-municipal level. The action of the Consorzio is focused on land reclamation channels and hydraulic structures responsible for the regulation of water levels in periods of flood and low water (Consorzio di Bonifica Bacchiglione, 2010).

- The Consiglio di Bacino (AATO) is responsible for overseeing the integrated water cycle for the territory under its jurisdiction. As far as the water service in Padua is concerned, this has been given in concession by the Consiglio to AcegasApsAmga, which is responsible for the public services of collection, adduction and distribution of water for civil uses, sewerage and wastewater treatment (Cosiglio di Bacino Bacchiglione, n.d.).

- Lastly, the Municipality is responsible for the planning and implementation of public works throughout the territory. Among these, the Documento Unico di Programmazione reports the support to the above-mentioned competent bodies in the realisation of risk mitigation interventions such as the renaturalisation of some urban drainage canals or the completion of river infrastructures such as the hydroway between Padua and Venice. The Municipality is also acknowledged the financial contribution for the realisation of lamination reservoirs for rainwater retention (Comune di Padova, 2020).

This division of competences but intermingling of common interests creates a complex and chaotic framework for action that makes it difficult to efficiently manage stormwater as a resource but above all as a land-shaping element (Figure 51).

Figure 52:
Scheme of tools and institutions involved urban stormwater management.



Over the years, numerous works and interventions of different nature and extent have been carried out to manage flooding phenomena, with the aim of making Padua and its territory safer and more flood-proof (Figure 53).

The interventions carried out by the Genio Civile have mostly involved maintenance works on the main river courses through the restoration or consolidation of the embankments. The Genio Civile operates to protect and secure the territory from flooding phenomena through hydraulic regulation structures along the rivers which regulate the volume of water in transit. Specifically, in the event of adverse weather events, the Civil Engineer completely closes the inner canals by operating on the infrastructure near the Bassanello bridge, San Gregorio counter-bridge (1), management of water levels at the San Massimo bastion (2) and control of the outflow at the Voltabarozzo junction between the Scaricatore and S. Gregorio canals (3). The control of water levels in the river courses is also managed in ordinary situations to safeguard public hygiene, controlling the derivation of water from irrigation canals or for industrial use (Zanetti, 2013).

The first mitigation initiatives refer to the control of flooding phenomena of the Brenta and Bacchiglione and they are imputed to the action of the Consorzio di Bonifica del Bacchiglione. The Consorzio has actually undertaken a campaign of interventions aimed at equipping the city with several hydraulic substructures capable of isolating the urbanised area of the historic centre from the waters of the major rivers (Compagno, 2019). These substructures have been realised in correspondence with the division of the Bacchiglione river in Tronco Maestro and Canale Scaricatore (4) and in correspondence with the diversion of the Brenta into the Brentella canal. Other counter-braces were positioned at the inflow of the Roncaiette Superiore river into the Bacchiglione and to the north before the confluence of the Piovego and S. Gregorio canals, with the aim of avoiding backflow phenomena due to excessively high water levels. A strategic node for the operation of these flood control systems is certainly the Voltabarozzo-Ca' Nordio area (5). Here the control system realized through a regulating support allows to control the outflow of water that is diverted to the S. Gregorio-Piovego (SGP) system and that which continues to flow in the natural continuation of the Bacchiglione (Mel, 2020).

With the frequently increase in problems related to surface water accumulation, a number of works have been carried out to strengthen the urban drainage system. Among these, the most important are certainly the lifting infrastructures (dewatering pump) built near the intake of the land reclamation channels into the main river network. Thanks to the dewatering pumps, it was possible to quickly transport larger volumes of water to the bodies, overcoming the inability of the drainage system to handle increasingly amount of rainwater (Compagno, 2019). Some of the most important of these are the Saracinesca (6), San Lazzaro (1) and Voltabarozzo (7).

Figure 53:
Scheme of tools and institutions involved in urban stormwater management.

[22] A mechanism enabling a canal to intersect a watercourse without confusing its flows. Under the banks of the main channel the lower channel flows through one or more tunnel barrels. If the difference in level between the two courses is relatively small, the underground channel is called a siphon barrel due to the hydraulic mechanism of operation (Zanetti, 2013).

Surface flooding also occurred in the proximity of depressed areas close to the canal embankments, the construction of which constituted a real barrier. The problem has been solved over the years through the installation of siphon barrels[22] capable of draining stormwater below the riverbeds. This type of construction has been carried out at the Voltabarozzo Bridge, in Terranegra and in the San Lazzaro area (Mel, 2020). Where, due to the urban context, it was not possible to build hydraulic structures such as dewatering pumps or barrels, the sewerage network had to be modified and adapted through the construction of new conduits (for example in the district of Montà) (Compagno, 2019).

Among the key engineering projects is the construction of the lifting plant at Ca' Nordio (8), whose operation allows the internal waters of Padua to be expelled when the city is isolated by river floods. In addition, the draining power of the plant allows to regulate the water level of the internal canals of the historic centre, preventing them from reaching too high an altitude for the benefit of special situations such as the preservation of the Cappella degli Scovegni (Zanetti, 2013).

The most recent project is the realization of the Limenella-Fossetta spillway (9), a 2 km long rectangular reinforced concrete culvert directly connecting the Fossetta manifold (undersized with respect to the incoming hydraulic loads) with the Brenta river in the north. Its construction should ensure the safety of almost one third of the urbanised area of Padua, solving the critical issues related to the frequent flooding of the Arcella neighbourhood (Compagno, 2019).

Other projects include the upgrading of existing stormwater lifting and pumping systems in the most vulnerable hydraulic districts and sub-basins. Increasing the frequency of maintenance work on the drainage network and hydraulic structures. The repair and reinforcement of portions of embankments and the installation of a monitoring system to facilitate the execution of emergency manoeuvres and the control of flood volumes. The latter are conducted in cooperation with the Genio Civile.

Although stormwater management does not come under the specific competence of the authorities responsible for managing the integrated water service, in the case of Padua, AcegasApsAmga has shown interest in the recent years in improving drainage, due to the intermingling of floods with the operation of the sewerage system.

One example of such an approach is the recent study carried out on the Forcellini sub-basin and potential measures to make the area safe from sewer overflow phenomena. The Forcellini district has a high hydraulic vulnerability, recognised by the various plan maps previously analysed, linked to the lack of a sewerage system. The study carried out by AcegasApsAmga concerns the risk assessment of the Forcellini sub-basin and the identification of possible mitigation measures (AcegasApsAmga, 2018).

After the construction of maps of the risk, damage and hydraulic hazard in the sub-basin for events with 10-year return times, some possible design solutions were identified. In the analysed area the construction of a new white water collector linking the northern area of Forcellini directly with the Roncaiette river is already in progress. Besides, the impact of the construction of a stormwater collector or of two collectors intercepting the Forcellini land reclamation canal was evaluated.

For each solution, a cost-benefit analysis was carried out to assess the most effective intervention from a technical and economic point of view. From the results obtained it can be seen that the construction of even one collector to support the Forcellini canal apart from the conduit already in place, would reduce the hydraulic risk by a factor of 0.4 (Figure 54).

Figure 54:
Hydraulic risk map dimensioned for a 10-years event

(a) State of art
(b) After the new manifold

Risk:
R1 *R2* *R3* *R4*

The same analysis was repeated for climatic events with return times of 20 years, even though scenarios of this type are covered by the Consorzio. Although the starting scenario is worse than the previous case, the results nevertheless show a considerable reduction in damage (Figure 55).

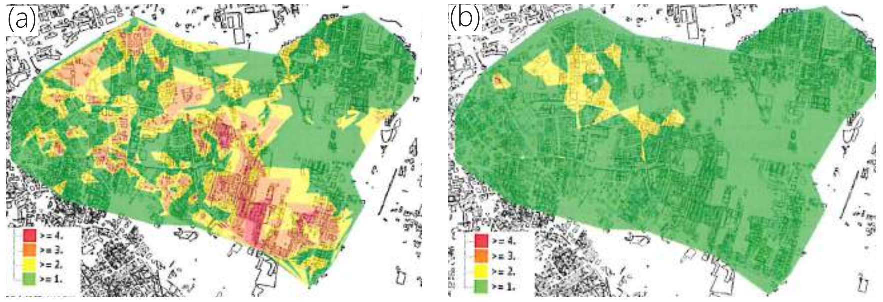


Figure 55:
Hydraulic risk map dimensioned for a 20-years event

(a) State of art
(b) After the new manifold

Risk: *R4*
R1 *R2* *R3*

Under the responsibility of AcegasApsAmga is the management of the treatment plant at Ca' Nordio, a fundamental centre for the purification of wastewater before it is released into the Bacchiglione River. The plant receives all the water drained by the sewage system and land reclamation channels.

From the overall picture presented it is clear that there is a lack of an organic framework of the works to be carried out, a concerted shared vision for the hydraulic future of the city and above all a coordination tool for the implementation of the works. Up to now, the planning of hydraulic risk reduction works has been carried out by the various bodies according to their specific competences and budget forecasts, leading to the realisation of contingent and punctual interventions.

BOX 3: POTENTIAL OF THE PADUA-VENICE HYDROWAY

The discussion on possible solutions to prevent flooding phenomena involving the Brenta and Bacchiglione rivers includes the Padua-Venice hydroway. According to the opinion of some experts, such as Professor L. D'Alpaos, the completion of the canal between Padua and the Venetian lagoon would significantly contribute to the reduction and relief of flooding phenomena, to the benefit of areas that are still extremely vulnerable (D'Alpaos, 2006). In particular, the hydroway could receive and convey towards the Venetian lagoon a water flow higher than the one normally diverted towards the Brenta via the San Gregorio-Piovego canal. This would relieve this stretch of canal and increase the fraction of flow normally diverted by the Bacchiglione. Indeed, conveying part of the water directly into the hydroway would reduce the hydrometric height at the Piovego-Brenta junction in Strà, a factor that would allow the transport of greater volumes of water through the San Gregorio channel (Mel, 2018). The overall effect is a reduction of the hydraulic hazard in the entire Brenta-Bacchiglione basin downstream of Padua and the ability to exploit the Scaricatore more effectively and S. Gregorio canals to the benefit of the whole City.

The hydroway therefore proves to be a functional intervention not only for the navigable connection between Padua and the Lagoon but as a real infrastructure for the management of flood phenomena (Mel, 2018). Moreover, further studies have shown how the controlled supply of freshwater and river sediments within the lagoon can counteract the erosive phenomena that are altering its morphology and balance (D'Alpaos, 2006).

View of the regulation structure on the Padua-Venice hydroway
Source: corrieredelveneto.it

5.

CONCLUSIONS

The previous chapters highlight that to deal with future uncertainties and climate challenges, sustainable water governance measures are needed to facilitate a change of perspective. The answers that must now be sought are those that seek to understand whether, compared to the Copenhagen model, other realities might be in the position to undertake a path of change towards more water sensitive urban models.

Does the city of Padua have the necessary tools or the potential to become a more water-sensitive city regarding stormwater management?

5.1 A new vision for Padua

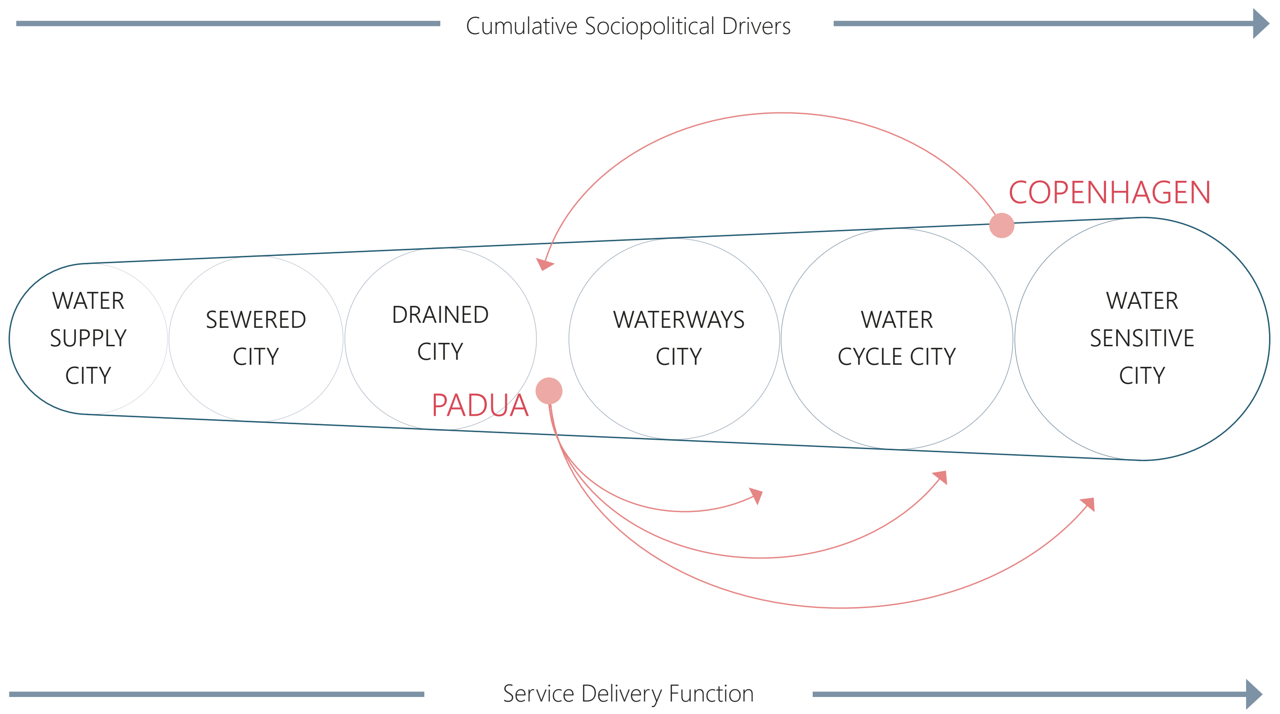
Referring to Brown's Urban Water Management Transition Framework presented in the first chapter (see section 1.1.1), Padua can be placed in an intermediate stage between the Drained City and the Waterways City (Figure 56). As a matter of fact, about the need for protective measures against flooding phenomena typical of a Drained City, Padua has been able to adopt over the years a dense drainage and channelling system capable of diverting rain towards the main water bodies. However, considering the socio-political factors that define a Waterways City, the policies undertaken by the administrators have not been able to promote social wellbeing, a good level of health of the river courses and the appropriate tools to protect the environment.

Besides, the strategies contained in the government instruments and the solutions implemented have not been able to adapt the urban space to the consequences of climate change and to guarantee the principle of intergenerational equity concerning the available natural resources.
These factors, together with a well-known hydraulic vulnerability, pollution problems of the environment and the rigid mentality of the institutions, not open to more innovative alternative solutions, make Padua a case with great potential and necessary to undertake a transition towards a more water-sensitive urban model.

Innovation and change of the urban stormwater management system could promote not only a sustainable development of the city but also limit the economic and social impacts of not acting in adaptation to hydrogeological disasters.

As repeatedly underlined in the literature, the transition path of a city towards greater water sustainability and resilience includes the reorganisation of the infrastructural and institutional system and the existing criteria concerning urban water management.

Figure 56:
Padua and Copenhagen relative stage in Urban Water Management Transition Framework.



For this reason, learning from models and best practices, such as the case study of Copenhagen, provides a benchmarking tool to assist other local governments. In this way, it is possible to assess the opportunities for shaping urban space according to a new balance between water and the built environment. Although the focus of this paper is on issues related to flooding and rainfall management practices, Copenhagen is an example of a city integrating all elements of the natural water cycle into its planning tools.

A process of changing is not easy to undertake. Despite development of innovative integrated urban water management approaches and the availability of appropriate tools and technologies contributing to sustainable urban water services, the progress of implementation is slow and major barriers remain. The main factor hindering the transition to a Water Sensitive City concept is the inability of Padua's decision-makers to see rain as a potential resource and not as a threat. In response to flooding events, public spending on flood defence and maintenance of waterways is increasing. However, the impression is that the city suffers from flooding rather than adopting proactive measures that would help to adapt to climate change and bring economic, social and, above all, environmental benefits.

The inability of institutions to see the positive aspects of a change in perspective is referred to in the literature as 'silo mentality' or 'silo-thinking'. Such an approach describes one-dimensional and sectoral decision-making and operational process in which the actors involved do not reflect on cross-sectoral linkages or interrelationships between different scales in natural resource management (Covarrubias et al., 2019). Practically, the entities involved in the urban drainage sector do not see the adoption of innovative and different solutions as a significant development opportunity for the sector but even more so for the economy and life within the cities. If urban water management practices have always been associated with the engineering of hydraulic works, the new hydrological scenarios require solutions capable of managing water not only at ground level but also at surface level, inserting it into urban space and activities. This new perspective makes conventional infrastructures inadequate to the task of managing stormwater and requires a new approach and set of actions capable of operating as both technical and social infrastructure. A multi-sectoral and multi-functional approach is opposed to silo-thinking, which leads experts to operate only within their field of experience without combining different experiences and perspectives.

Although Padua has not overcome the "silo mentality", as happened in other international contexts (see section 2.2), it is still possible to see a change in the formulation of some technical solutions. For example, in the last years, the Consorzio di Bonifica del Bacchiglione has decided to introduce different water management solutions such as the provision of flooding areas or retention basins in correspondence with canals or drainage ditches.

These green spaces are indicated by the Consorzio as areas necessary for the retention of flood peaks, located to achieve, in addition to hydraulic purposes, also landscape, environmental and recreational ones (Compagno, 2019). Despite the attempt to design a new type of multifunctional space, the result obtained does not reflect the design intentions, as it is still strongly linked to hydraulic functionalism rather than fulfilment the socio-recreational needs typical of urban parks.

To better understand how said, a comparison is made between a retention basin built by the Consorzio di Bonifica del Bacchiglione near Abano Terme (PD) and a water management park in Alicante (Spain). The basin in Abano Terme (Figure 57) is a large unplowed area connected to a drainage channel that safely overflows into the basin during a flood event. On the other hand, the project for La Marjal park in Alicante (Figure 58) concerns the recovery of an undeveloped area close to the urban centre, rethought as an attractive park capable of collecting occasional stormwater runoff from upstream areas (Jodar-Abellan et al., 2018).

Figure 56:
Retention basin of the Poggese drainage canal at Monterosso di Abano Terme (PD).
Source: Compagno, 2019

Figure 57:
The floodable park "La Marjal", Alicante (ES).
Source: Jodar-Abellan et al., 2018

The success of the Alicante project depends on the ability of the authority responsible for water management to combine engineering knowledge for drainage and stormwater management with expertise in urban design and planning. Examples such as Alicante show how, even Countries with a tradition in land management closer to the Italian system, have embarked on a different approach to innovation and design, aligning themselves with the policies presented by models such as Copenhagen.

The impossibility of constraining water management within precise administrative limits and bodies results in a lack of clarity regarding the competencies in the hands of the different authorities working in the water sector. The emergence of a mixture of practices and sometimes conflicts of interest shows how the inability to introduce innovative solutions in water management is a matter of institutional affiliation for which has to be identified a leadership and coordination figure.

Still, regarding the case of Padua, the institutional issue concerns mainly AcegasApsAmga, the Consorzio di Bonifica and the Municipality, responsible for public works. The institutions in charge of urban water management, even if they have different competencies (see section 4.3.1) very often find themselves managing issues that are not related to their respective fields. The overlapping of competencies does not allow free action by the two authorities, who consider it inappropriate to invest in innovative practices that are still not widely used. Besides, there is the inability of the City Council to play the role of a link between the different institutions by remaining outside the issue. For this reason, a new approach to sustainable stormwater management is considered a waste of time and resources, with no guarantee of concrete results. Such an institutional set-up encourages inertia and inhibits the possibility of undertaking alternative development paths, consolidating a siloed mentality.

In addition to the obstacles mentioned, it is necessary to mention the difficulty in combining planning and action tools. Despite the existence of instruments and prescriptions aimed at reducing the hydraulic risk and of bodies specialised in flood protection practices, the two aspects have never gone hand in hand, leading to ineffective solutions and a failure to solve the problems. First, they built, then they thought about the drainage network, and only after the occurrence of floods were hydraulic safety works planned. The result is an inability to avoid or in any case mitigate water problems in urban contexts, leading to the containment of emergencies without solving the problem at the root, imposing a coexistence suffered.

This difficulty in reconciling the planning tools with the structural measures depends also on the ambiguity proposed by the different plans (see section 4.3.1, figure 51) which leads to a fragmented and contradictory analysis of the problems and vulnerabilities present in the territory and at the local level.

In conclusion, it can be said that the challenges for the transformation and adaptation of stormwater management practices do not only include overcoming the technological backwardness but mainly concern the development of new working and planning procedures involving different actors and eventually the complete water cycle, including drinking water and wastewater.

5.2 The proposal

The final considerations expressed so far show that a change for Padua is possible through a mutation of vision, policy, design and urban planning culture. These mutations can be induced by transposing the concepts expressed by the Copenhagen Formula (see section 3.6) into the context of Padua water management. The framework for a Padua Formula could be articulated in different phases:

- The definition of the VISION, a clear image that describes the city in its transition path and that requires:

    1. Undertake a process of public sensitization on the need to rediscover the relationship between the city and water, recognising in stormwater an opportunity to improve the liveability and amenity of urban space. It is also essential to raise the awareness of stakeholders involved in the water sector, who must be comforted and informed about the advantages of implementing new and innovative solutions.

    2. Launch a process of innovation in the field of urban drainage by incorporating alternative solutions into current practice through pilot projects. These demonstrate the effectiveness and convenience of different solutions compared to the use of conventional solutions.

    3. Promote institutional cooperation, favouring the exchange of ideas, knowledge, technologies between direct responsible bodies and territorial support organisations such as universities, companies and industries. The concept of cooperation does not only concern the technical aspect but also largely includes the administrative aspect, encouraging the overcoming of socio-institutional barriers through the introduction of contracts and legislative measures.

    4. Proper planning of the area to get over a cohesive approach to planning in favour of a unified and integrated vision capable of satisfying multiple benefits.

- In order to make this vision a reality, an ANALYSIS process is needed to highlight Padua's vulnerabilities but especially its potential in terms of stormwater management. The analysis is fundamental for the construction of a solid information system to support the identification of the TOOLS that will direct the practice of the described vision.

    These two phases must:

    1. Taking into account the economic aspects in terms of costs and benefits related to the implementation of a more water sensitive city. Through economic analysis it is possible to assess the feasibility of different solutions according to the resources available. From the analysis it is then possible to establish an action plan and eventually ask for extra funds.

    2. Analysing the impact and benefits on the urban space to improve liveability and social aggregation, based on the balance between the nature and city. From the analysis of the context, it is possible to understand the real needs of the natural and social environment. In this way it is possible to size the action tools in such a way that they follow the highlighted needs without creating new problems.

    3. Define the technologies needed to achieve the objectives, favouring decentralised water management solutions. Crucial is the use of innovative technological tools capable of predicting future scenarios by showing the most likely level of risk and vulnerability. Appropriate technologies are needed to provide tools that act more locally over a longer time horizon.

    4. Provide a legislative apparatus that incentives the operability of some measures over others. Without the support of specific laws, it is complicated to act towards the achievement of climate-sensitive development. For this reason, the existing regulatory apparatus must be able to evolve, embracing the principles of the circular economy and sustainability.

- Through the analysis and definition of specific tools it is possible to translate the pre-established objectives into an ACTION or PLAN able to outline which and how many measures are to be adopted, the actors involved and the necessary implementation processes.
  A planning process is structured in different phases, which in the specific case of Padua would concern:

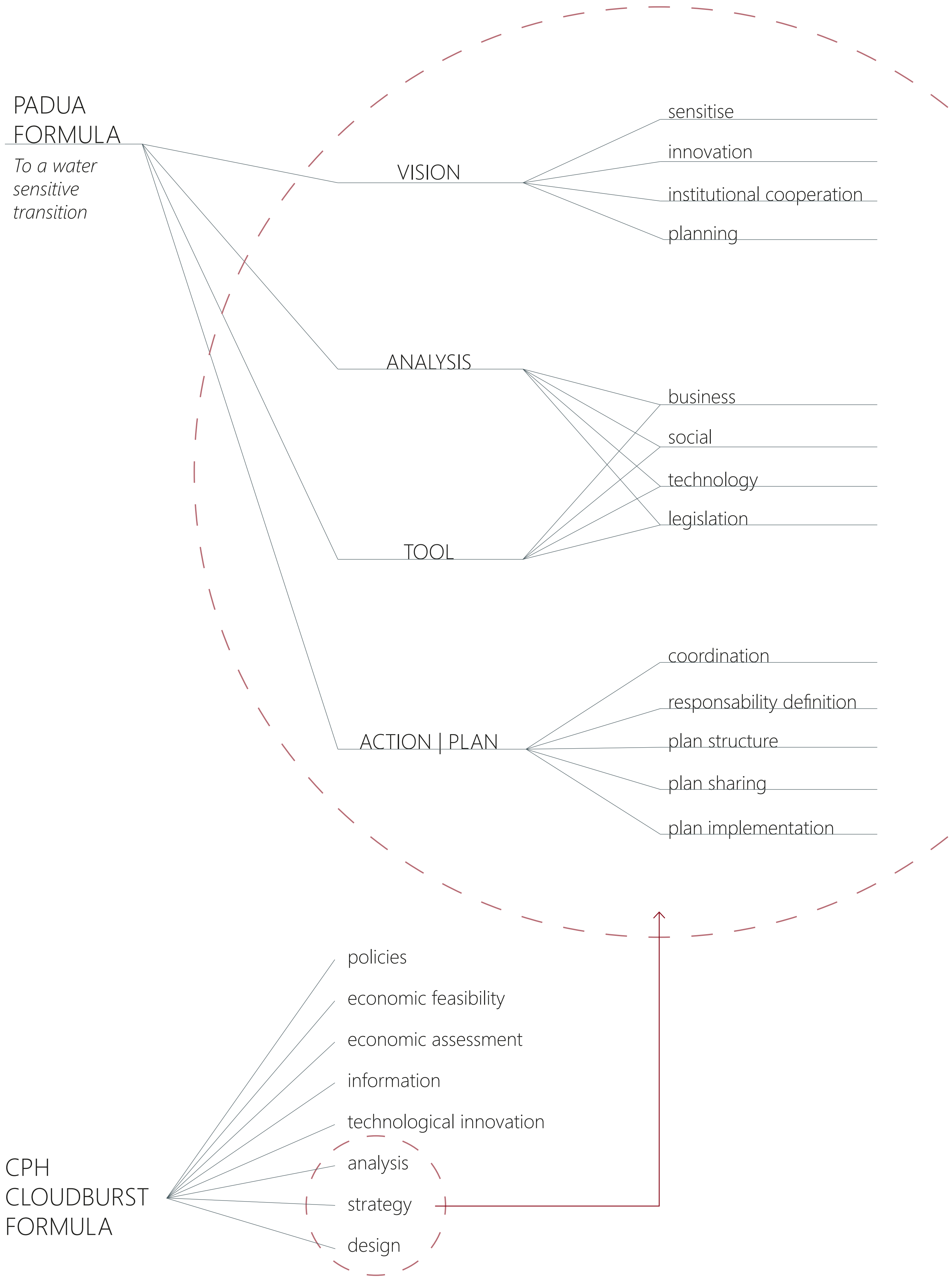
  1. Coordination among the authorities involved in stormwater management and planning, i.e. the drafting of special contracts or partnership that favour a more synergic action.

  2. The definition of competencies, a fundamental process to guarantee the enforceability of the plan. The different stakeholders have to act individually or jointly on specific areas of relevance, implementing both underground and surface hydraulic projects. Moreover, they have to cope also with bureaucratic issues, coordination and subsequently maintenance.

  3. Conceive a plan to merge surface urban design solutions with underground engineering infrastructure. Surface projects should act in support of the drainage network, promoting infiltration processes, natural filtration, delay of surface runoff and retention of rain in places where it causes minor damage.

  4. The involvement of citizens in the planning process would be crucial once the measures are defined. Indeed, planning according to the participatory approach has several positive aspects. Firstly, it raises public awareness of the problems associated with flooding, demonstrating that the consequences of climate change are real and affect everyone. Secondly, it allows the planner to get to know in more detail the needs of citizens and any problems not highlighted in the analysis and design phase. Finally, it increases consensus and collaboration in favouring the implementation of innovative and unconventional solutions that may sometimes appear unnecessary and excessively expensive.

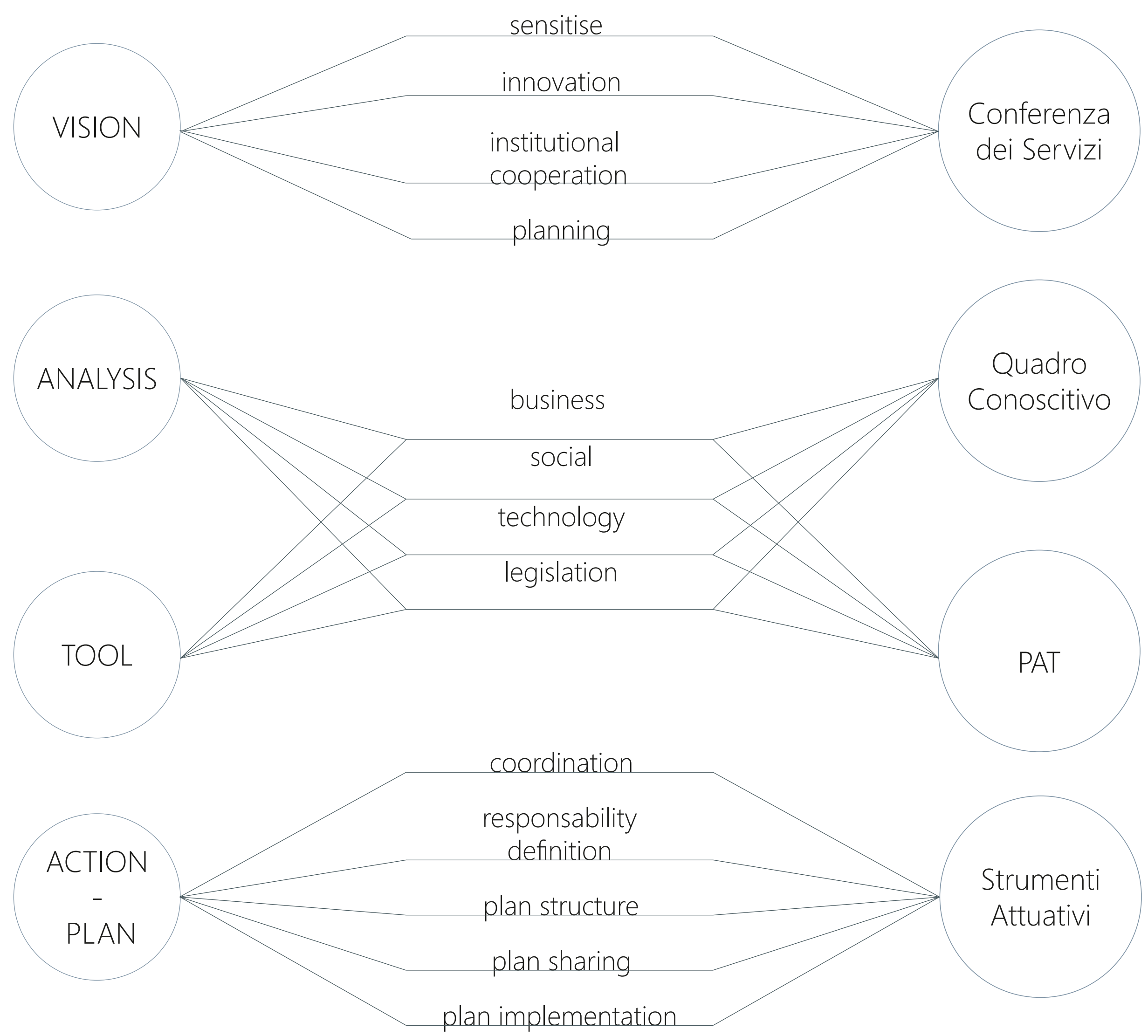
  5. The participatory process makes it possible to revise and improve the constructed draft plan and then proceed to the implementation phase. The involvement of the population in the drafting of plans is a process already widely used, but not very present in the Padua context.



In a situation where the cultural debate on water-related issues is constantly evolving and where there is a lack of a clear political vision at national level, the local political debate is not yet capable of implementing conscious management tools such as those proposed by Copenhagen. Therefore, assuming that the implementation of the proposal outlined in the diagram is still an ideal scenario, a more concrete alternative would be to attempt to integrate the key concepts highlighted in the existing instruments. Then:

- The VISION as presented could involve a moment of confrontation and discussion through a Conferenza dei Servizi between the different bodies involved in the water sector and the municipal administration. The aim would be to stimulate joint action in imagining a more innovative and sensitive city model with regard to water issues.
- The ANALYSIS could favour the updating and integration of the information bases contained in the Quadro Conoscitivo of the territorial urban planning tools. This would complete and standardise the information on hydrogeological issues and introduce an additional set of data to support more resilient strategies focused on climate change issues.
- The TOOLS instead should integrate the strategies contained in the Piano di Assetto del Territorio (PAT), integrating its contents with a section dedicated to new water management practices, increasing knowledge on adaptation measures to flooding phenomena and expanding the rules and guidelines on which the PI must be based for a more conscious management of urban stormwater.
- If it is not possible to implement it in a specific plan, ACTION could be included in the themes of the implementation tools (PI, PUA or Accordi esecutivi di pianificazione) to favour the integration of water-sensitive technologies in urban and architectural projects in the different areas of the city.

The model presented here gives a first idea of how to introduce a new sustainable stormwater management approach in Padua. Future developments of this research could deepen in a more exhaustive way the different phases of the Padova Water Sensitive Formula, introducing a more direct and participated dialogue with the responsible sector stakeholders and the political actors of the City Council.



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5. CONCLUSIONS

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ANNEX

Annex 1: Methodology of literature review

The purpose of this literature review is to analyse critically a segment of a published body (i.e., Water Sensitive City) of knowledge through summary, classification, and comparison of prior research studies, reviews of literature, and theoretical articles. The aim is to provide a replicable tool to foster any kind of research in order to locate own research within the context of existing literature, identify the global understanding on the topic and reveal any deficit in the literature.

The methodology followed to write the literature review about SWC is structured by 3 phases, each of them articulated in 4 stages, towards which it is possible to dig into scientific database and, starting from a basic knowledge level and through a working progress refinement of the research, it will be collected a sufficient number of peer articles that provide a comprehensive overview of the issue.

BASIC SEARCH

Through a preliminary reading of the topic, it is possible to identify the principal keywords which characterized the body of the research. In this case, the concept of Water Sensitive City (WSC), which in-deep study has been stimulated by works of Intergovernmental Hydrological Program (IHP) by UNESCO. The search has been carried on two scientific databases: Scopus and ScienceDirect. This first phase is structured in 4 stages, by which a first analysis of the articles is accomplished.
Stages:

1. *SEARCH KEYWORDS*: In this step is relevant to decide the term of the research. The terms should be relevant, and they can be organized into thematic groups, covering the various aspects within the topic (e.g water, sensitive, city, urban, sustainable, design, management)

2. *CRITERIA SELECTION*: Through the advance settings, the research criteria can be decided and fixed. In the subsequent phases, these settings can be modified, refined, or confirmed.
   - field of search= article title, abstract, keyword
   - data range= 2008-present
   - document type=articles and review (the articles have to be peer-reviewed)
   - access type=all
   - language= English

3. *KEYWORDS COMBINATION*: Using Boolean tools, it is possible to combine the different keywords to specifically direct the search. The principle Boolean tools are AND, OR, AND NOT: (a) AND is used when both terms must appear on results; (b) OR is used when one term must appear at least; (c) AND NOT is used when specific terms must be eliminated from the result.

   e.g:
   Water AND Sensitive AND cit* (the use of a wildcard as truncation extends the research to all the different version of the marked word).

Search results: **1842 articles**

The number of results is excessively wide, so it is necessary to refine results and eliminate those not relevant. The refine is taken through the inner tools of databases:

- Author name (if the field of research is largely profound by a specific author)
- Subject area=Engineering, Environmental Science
- Sorting=It is possible to sort the search by different criteria depending on own preferences. (e.g most cited, most recent, authors)

Refine results: **1064 articles**

Results are still too wide. Limit the research adding another research term which specified more the topic. Many articles could be generally related to your keywords, so it is possible to add additional research words to focalize and bounder the results.
To search for an exact combination of words, enclose the quotation marks = urban AND design

Refine results: **139 articles**

After a preliminary screening of titles, abstracts and articles' keywords (using subjective criteria) it is possible to select the most relevant publications: **25 articles**

DATA STORING: (using a spreadsheet document)
Build a specific spreadsheet to collect data from the first search. The spreadsheet's structure includes title, author, year, number of citations, note, publisher.

	number	title	author	year	cited	note
scientific literature	1	A strategic program for transitioning to a Water Sensitive City	Joshua Floyd, Benjamin L. Iaquinto, Ray Ison, K.Collins	2014	22	-
	2	Configuring transformative governance to enhance resilient urban water systems	T. H. F. Wong and R. R. Brown	2016	21	-
	3	Evaluation of Water Governance Processes Required to Transition towards Water Sensitive Urban Design	R. R. Brown, N. Keath and T. H. F. Wong	2019	232	-
	4	Initiative Urban water studies at Depok, Peri-Urban City - Toward the implementation of Water Sensitive City concept	-	-	-	-
	-	-	-			

4. PRE-READING AND REVIEW: By reading the abstracts of the 25 selected articles it is evident that selected papers are not comprehensive of Urban Water Metabolism concept so that it is important to review the procedure: (a) revise the search criteria initially used; (b) cross-check if the results are truly important and relevant to the topic; (c) collect more articles.

INTERMEDIATE SEARCH

The procedure leading the Intermediate Search is based on the previous framework. Depending on the range of research field it may be necessary to do multiple reviews of the methodology to search additional articles with a connected topic to the central one or to check the accuracy of the previous search. To correctly structure a refine review the following four stages have to be considered:

1. NEW COMBINATION OF KEYWORDS: From the keywords list of preliminary the phase, choose and combine different words to extend the search and include some articles that it may not be considered in the first step.
2. EXTRA CRITERIA SELECTION: Based on the acquired knowledge from the basic search, it is suggested to change, whether is necessary, the criteria used to sharpen the analysis.
3. SELECTION OF THE NEW ARTICLES: With the same selection methodology used in the previous phase, select new articles and cross check about the previously selected articles.
4. PRE-READING AND REVIEW OF METHODOLOGY: Through the abstract and keywords select the articles.

With the new combination of keywords and the extra criteria selection, it has been gained the following results:

- <u>Water AND Sustainable AND urban*AND manage*</u> =**6 articles**
- <u>Water AND sensitive AND plan* AND urban</u> = **5 articles**

In this specific case, the results are not so wide because most of the articles had already been selected during the basic search. Add all the results in the spreadsheet dividing the articles based on the different steps.

FINAL SEARCH

The final search is structured in the following four stages:

1. COMBINATION OF ARTICLES: Combine the articles found through the previous two phases and collect them in the previously created spreadsheet. **36 articles** have been collected but the further selection is needed to choose the most relevant articles.
2. READING OF ARTICLES: Read the entire articles to deeply understand the relevance and eventually discard part of them. In many cases it may help read introduction and conclusion to understand briefly whether the subject matter is of interest to the research topic.
3. ANALYSIS OF ARTICLES: The articles have to be analysed and it is useful to take some note about the contents. The final refinement consists of reading the references of the selected articles to: (a) check if selected articles are mutually cited; (b) look at missed articles. **5** more **articles** have been identified and add to the previous articles.
4. SELECTION OF FINAL ARTICLES: Finally, it is necessary to skim the results to remove some articles that can be too specific or not useful to the final review. Hence, to a clear understanding of the articles, it may help read both introduction and conclusion. From 41 articles, 11 have been discarded.

   Results: **30 articles**

   Last step read the entire articles to deeply understand the relevance.

   Final selected articles: **20 articles**

The same methodology was followed for articles on the concept of Water Sensitive Urban Design and Sustainable Stormwater Management.

WSUD results: **12 articles**
SSM results: **9 articles**

Annex 2: Revision of WSC index used by The Cooperative Research Centre for Water Sensitive Cities (CRCWSC)

There is already a WSC Index, recognised in the literature, through which it is possible to assess the performance of a city in being water sensitive. This index developed by a group of researchers from the CRCWSC (The Cooperative Research Centre for Water Sensitive Cities) aims to provide a strong and comprehensive tool to diagnose the strengths and weaknesses of cities as a function of their aspiration to be more water sensitive. The index is divided into 7 goals which in turn contain a total of 34 indicators that comprehensively describe all the goals contained in the WSC theory (Rogers et al., 2020) (Table 1).

These 34 indicators analyse water-related issues through societal, biophysical and ecological dimensions typical of a water sensitive city. Examining this index in detail, it is easy to note the specificity of the analysis and information it requires. This specificity is not accessible to everyone but requires months of study and data collection in collaboration with different institutions of government and water management in urban contexts. For this reason, an attempt at simplification was required to reduce the complexity of the data in order to propose a new version of the WSC Index whose applicability can be immediate and within everyone's reach. In order to maintain consistency and linkage to the official WSC Index, it was decided to maintain the 7 main goals while slightly modifying the wording in order to eliminate terms such as "ensure", "increase", "improve" and "achieve", which are linked to quantitative information. In fact, using these categories of terms requires the acquisition of a whole series of data relating to the performance of a city in its water management, access to which is questionable. The new goals have been associated with a specific qualitative definition that summarises and encompasses the main characteristics and features that satisfy the strategy proposed by each goal.

Below are two diagrams showing the organisation of the WSC Index developed by the CRCWSC and the reworking carried out personally (Table 2).

It is necessary to underline how the simplification and reworking of the WSC Index does not allow the preservation of the specificity and authenticity of the original assessment tool but allows for a screening tool through which it is possible to preliminarily assess the potential and coherence of certain solutions or policies with respect to the philosophy associated with the WSC concept.

Table 1:
WSC Index goals, indicators and strategic objectives.
Source: Rogers et al., 2020

Goal 1: Ensure good water sensitive governance	
1.1 Knowledge, skills and organisational capacity	Strengthen the capabilities of individuals and organisations to adopt water sensitive practices through science, experimentation, learning and training.
1.2 Water is key element in city planning and design	Improve urban planning and design frameworks and processes to drive the implementation of water sensitive solutions through urban development.
1.3 Cross-sector institutional arrangements and processes	Encourage collaboration and coordination across organisations, sectors and levels of government to plan and implement water sensitive solutions.
1.4 Public engagement, participation and transparency	Communicate effectively with citizens and encourage their meaningful involvement in planning, decision-making and design processes.
1.5 Leadership, long-term vision and commitment	Articulate a water sensitive vision that links to broader city aspirations, and commit to delivering the vision through policy, strategic plans and investment.
1.6 Water resourcing and funding to deliver broad societal value	Invest in water sensitive practices that will deliver the highest community value, including consideration of externalities and non-market values.
1.7 Equitable representation of perspectives	Ensure inclusiveness and representation of a diversity of perspectives in governance arrangements and decision-making
Goal 2: Increase community capital	
2.1 Water literacy	Improve community knowledge about the water cycle and water issues so they can adopt water sensitive behaviours and participate in decision-making.
2.2 Connection with water	Foster pride and connectedness of people with water through improved understanding and appreciation of water's role in landscape.
2.3 Shared ownership, management & responsibility	Empower community to be an active participant in creating, operating and maintaining decentralised parts of the water system.
2.4 Community preparedness and response to extreme events	Support citizens to cope with and recover from impacts associated with storms, floods, drought and heatwaves.
2.5 Indigenous involvement in water planning	Recognise Indigenous water values and interests in water system planning and management and involve Indigenous people in water system governance.
Goal 3: Achieve equity of essential services	
3.1 Equitable access to safe and secure water supply	Provide safe, secure and affordable water supply services that meet the World Health Organization's (WHO) standards for drinking water quality.
3.2 Equitable access to safe and reliable sanitation	Provide safe, reliable and affordable sanitation services that meet the standards for sanitation defined by the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation.
3.3 Equitable access to flood protection	Manage flood risk in a way that is affordable, including reducing nuisance flooding and protecting citizens and infrastructure from major floods.
3.4 Equitable and affordable access to amenity values of water-related assets	Enhance amenity values associated with urban landscapes through water sensitive solutions and provide affordable access to water and water-related landscape features.
Goal 4: Improve productivity & resource efficiency	
4.1 Optimised resource recovery	Optimise the recovery of water, energy, heat and nutrients through circular design of water systems.
4.2 Low GHG emission in water sector	Maximise the use of alternatives to high carbon emitting energy sources in water system infrastructure.
4.3 Water-related business opportunities	Stimulate investment in new business opportunities through innovation in the water sector.
4.4 Low end-user potable water demand	Support low end-user potable water demand relative to the local scarcity or abundance of water.
4.5 Broad community benefits from water services	Stimulate beneficial outcomes of water-related services for other sectors beyond water.
Goal 5: Improve ecological health	
5.1 Healthy and biodiverse habitat	Design water systems to help protect, restore and create well-functioning ecosystems that contribute to ecological resilience.
5.2 Surface water quality and flows	Improve and protect the quality of surface waters and marine environments.
5.3 Groundwater quality and replenishment	Improve and protect the quality of groundwater-connected environments.
5.4 Protect existing areas of high ecological value	Protect existing areas of high ecological value from the impacts of catchment urbanisation.
Goal 6: Ensure quality urban space	
6.1 Activating connected green - blue space	Plan and design the urban form to create many distributed, connected and well-maintained green spaces and waterways.
6.2 Urban elements functioning as part of the urban water system	Plan and design the urban form (such as green walls, roofs, retarding basins in parks) to function as an integral part of the water system.
6.3 Vegetation coverage	Provide significant vegetation coverage (e.g. tree canopies) supported by the water system.
Goal 7: Promote adaptive infrastructure	
7.1 Diverse fit-for-purpose water supply	Provide a flexible and adaptive water supply system appropriate to the quality water and demand requirements of the end user.
7.2 Multi-functional water infrastructure	Provide multi-functional water infrastructure that seamlessly integrates into the urban landscape.
7.3 Integration and intelligent control	Optimise water system network performance through the use of intelligent control systems.
7.4 Robust infrastructure	Remove sensitivities and vulnerabilities in the water system network through redundancy measures and by-pass systems.
7.5 Infrastructure and ownership at multiple scales	Optimise water system performance through the integration of centralised and decentralised infrastructure.
7.6 Adequate maintenance	Improve maintenance policies and practices to ensure the long-term integrity of all water system infrastructure, including natural and green infrastructure assets.

Table 2:
Author revision of WSC Index goals

Goal 1:	
Water sensitive governance	Good water-sensitive governance is achieved through vertical cooperation of policies and plans regarding urban water management. In particular, there must be coherence with regard to the strategy to be adopted for water management at different levels of spatial planning. It is also necessary to stimulate collaboration between public and private as well as collaboration between the different actors involved in water management in an urban context.
Goal 2:	
Community capital	It is necessary to undertake a series of policies aimed at educating the community towards the importance of water as a resource and urban element. Awareness-raising among citizens must aim to support them in managing climate risks related to water, the impact on urban water resources and the construction of a more attentive and participatory community towards new scenarios and possibilities concerning water management and planning in the urban environment.
Goal 3:	
Equity of essential services	The provision of water services within the city must be equal for all, ensuring good water quality and quantity. Different water supply services must be provided to reduce the impact on potable use. Water quality must also be pursued for water basins, watercourses, and the sea in such a way as to ensure a healthy and pleasant space.
Goal 4:	
Productivity and resource efficiency	Energy efficiency and waste reduction solutions must be provided within urban water management. It is important to provide alternative and sustainable solutions within the drinking water treatment and management processes to reduce consumption and CO2 emissions. Take advantage of new opportunities for resource management and consumption to stimulate investment and new job opportunities.
Goal 5:	
Ecological health	Protect, restore, and create new water systems that can boost the development of new well-functioning ecosystems that contribute to the resilience of the city. Green and blue infrastructure is needed to connect disconnected part of cities and create ecological corridors within the city that promote biodiversity.
Goal 6:	
Adaptive infrastructure	The design of new blue infrastructure must be aimed at adapting the city to climate change. To operate according to an integrated approach that favours the inclusion of water on different scales within the city providing multifunctional solutions and removing sensitivities and vulnerabilities regarding extreme climate events.
Goal 7:	
Quality urban space	Planning and designing urban forms in order to provide pleasant and liveable spaces. It is fundamental to conceive multifunctional and adaptable solutions to optimize the use and supply of water, to guarantee liveable public spaces where to consume social dynamics and to favour the inclusion of green areas at all levels of design in order to guarantee ecosystem services.