BARCELONA RESILIENCE ACTION PLAN

RESILIENCE TO CLIMATE CHANGE WITH FOCUS ON URBAN WATER CYCLE

2020 – 2030

Barcelona City Council

BARCELONA RESILIENCE ACTION PLAN

Barcelona City Council

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ACRONYMS AND ABBREVIATIONS

100 RC	100 Resilient Cities project pioneered by the Rockefeller Foundation
1D/2D USM	1 Dimension/2 Dimensions Urban Stormwater Model
AS	Adaptation scenario
BASEMENT	Basic Simulation Environment
BAU	Business as Usual
BCASA	Barcelona Cicle de l'Aigua, SA
C40	Network of the world megacities committed to addressing climate change, initially with 40 cities
CBA	Cost Benefit Analysis
CC	Climate change
CEA	Cost-effectiveness analysis
COP21	Conference of Parties - United Nations Framework on Climate Change
CRPP	City Resilience Profiling Programme
Csa	Hot-summer Mediterranean climate (Köppen climate classification)
CSO	Combined Sewer Overflow
DPLAN	Distribution Planning
EAD	Expected Annual Damage
EPANET	Application for Modelling Drinking Water Distribution Systems
GDP	Gross Domestic Product
GIS	Geographic Information System
ICLEI	Local Governments for Sustainability global network
Infoworks ICM	InfoWorks Integrated Catchment Modelling
M x	Measure reference number x
MVA	Megavolt amperes
RAF App	Resilience Assessment Framework web-based tool
RAF	Resilience Assessment Framework
RAP	Resilience Action Plan
RCP	Representative Concentration Pathway
RESCCUE	RESilience to cope with Climate Change in Urban arEas

S x	Strategy reference number x
SIMGES	Simulation Model of Water Resource Management
SO	Strategies that use the strengths to exploit opportunities
ST	Strategies that exploit strengths to overcome any potential threats
SUDS	Sustainable Drainage Systems
SUMO	Simulation of Urban Mobility
SWMM	Storm Water Management Model
SWOT	SWOT analysis (or SWOT matrix) to identify strengths (S), weaknesses (W), opportunities (O), and threats (T)
TOWS	TOWS analysis to link the different components of a SWOT together to come out with clear actions (SO, WO, ST, WT)
Tx	Return period of x years
UCLG	United Cities and Local Governments
UNISDR	Presently UNDRR, United Nations Office for Disaster Risk Reduction
WO	Strategies that mitigate weaknesses, by exploiting opportunities
WT	Strategies attempting to minimise weaknesses to avoid the impact of threats
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

Barcelona is firmly committed to fight against climate change and the negative effects it can cause to its population. The city has been sensible to this problem for many years and has worked so much in the adoption of international and local commitments as in the approval of different measures or plans focused on mitigating the effects of or adapting to climate change. In 2018, Barcelona presented the Climate Plan, fulfilling the commitment made when signing the Covenant of Mayors for Climate and Energy (2017) and the COP21 Paris Agreements.

The Climate Plan's timeframe runs to 2030, and it includes both short term (2018-2020) and medium-long term (2021-2030) objectives and strategic measures. It has 4 strategic axes: mitigation, adaptation/resilience, climate justice and the promotion of citizen action; 5 areas and 18 lines of action that result in 242 different measures.

The Climate Plan becomes an opportunity to join forces making Barcelona a pioneer city, responsible for its contribution to climate change and that is prepared to be less vulnerable to its effects and more equitable and participatory. It has received several international distinctions as the certification of the network of cities for climate leadership C40, recognizing the high quality of the Climate Plan and its compatibility with the Agreement of Paris; and the award for the best initiative of major European cities by the Covenant of Mayors for Climate and Energy, becoming a fully complying city.

The RESCCUE project arose as an opportunity to enhance several aspects of the Climate Plan mostly related to the improved knowledge on climate projections, the development of sectorial and integrated models to better understand the behaviour and response of the main urban services and infrastructures in extreme weather events, with special regard for services interdependencies and cascade effects. The Resilience Action Plan developed within the RESCCUE project aims to update and complement the Climate Plan measures and strategies regarding the main results of the project.

This Resilience Action Plan (RAP) has been developed for its city boundaries (mainly urban and peri-urban areas). The present planning has a medium/long-term horizon, of 10 years, from 2020 to 2030, in articulation with the strategic planning horizons for Barcelona. In this sense, Barcelona RAP can be considered as a "living document" with decadal periodic updating. Notwithstanding, it refers to other information sources with a broader horizon, e.g. 2100, like the studies carried out within RESCCUE about climate projections, impact analysis and Cost Benefit Analysis of adaptation measures.

The scope of this plan is to improve the Barcelona urban resilience to climate change with special focus on the water sector and other main services potentially affected due to cascade effects.

According to the Climate Plan 2018-2030, the Barcelona vision is to be a proactive city that adopts a comprehensive approach to tackling the challenge of climate change and assume its responsibility in that regard; a city that can find opportunities in difficulties and adapt to new climate conditions intelligently, generating co-benefits for people and socio-economic activity; setting the pillars of a more sustainable Barcelona:

- A **socially fair Barcelona**, that takes the social, economic, gender, territorial and cultural diversity of its citizens into account when applying policies and measures.
- A **safe, habitable Barcelona** that enables people to live in comfort and social cohesion, with quality green areas, and generates safe, friendly spaces that are suitable for everyone.

- A **healthy Barcelona** that promotes active living, where you can breathe clean air and enjoy quality public spaces, and people´s health and well-being is guaranteed.
- An **efficient, renewable Barcelona** with sustainable mobility that makes good use of its resources and closes cycles.
- A **low-carbon, distributive** Barcelona that is not so dependent on fossil fuels for generating energy, nor products and services, and where economic benefits are distributed among its inhabitants.
- A **Barcelona that learns**, tries out solutions every day and never forgets, that moves forward and improves every day but is aware it still has a lot to learn.
- And some **committed Barcelonians**, men and women who know they can change the situation by their actions and protect the future for the generations to come.

The Barcelona mission is to reduce vulnerabilities, increase health, improve the quality of life of their inhabitants and become more responsible by:

- reducing Barcelona's contribution to climate change.
- anticipating climate risks to ensure the city continues to function and improve its response capacity.
- reducing the vulnerability of people to climate change by guaranteeing their health and well-being.

The objectives considered to assess and improve urban resilience to face with climate change, including the urban services and their critical infrastructures, are to achieve: city collective engagement and awareness of citizens and communities, leadership and management, preparedness for basic conditions, climate change, disaster response and recovery and build back, for the organisational dimension of the city; spatial risk management and provision of protective infrastructure and ecosystems, for the spatial dimension of the city; services planning and risk management, autonomy and preparedness for climate change, disaster response and recovery and build back for the functional dimension of the city; and safe, autonomous and flexible as well as prepared infrastructures for the physical dimension of the city.

The plan considers the interactions and contributions to city's resilience of the following strategic urban services: water supply, wastewater drainage and treatment, stormwater drainage, waste collection and treatment, electric energy supply and mobility.

The most critical climate-related hazards for Barcelona are coastal and pluvial flooding, drought, heat waves, storm winds and combined sewer overflows. Therefore, future climate scenarios were studied for sea level rise, cumulative rainfall, extreme precipitation and extreme temperature, among other weather variables.

The main concerns for the incoming years are, consequently, flooding, drought, sea level rise and heat waves due to temperature and precipitation extremes that always represented a threat to Barcelona's resilience and are expected to be aggravated by climate change (Pagani et al., 2018; Monjo et al., 2018). Barcelona intends to achieve the above-mentioned resilience objectives, particularly to reduce vulnerability to these hazards, prepare the population and the services for their occurrence and promote a better articulation between urban services coordination and response in critical cases of extreme weather-related events.

According to Barcelona Climate Plan (Ecología Urbana, 2018), 11 planned adaptation strategies are expected to have greater impact on the city adaptation to face with climate change. Moreover, in this plan, 4 new adaptation strategies (and the related specific adaptation measures) are defined, proposed and analysed in order to assess their efficiency to reduce climate-related hazards and impacts for future climate scenarios. These new adaptation strategies, developed within the RESCCUE project are focused on the reduction of the social, economic and environmental impacts related to flooding, Combined Sewer Overflows (CSOs), drought and water resource availability.

With this set of strategies, Barcelona aims to achieve most of its long-term resilience objectives regarding climate change, with focus on the urban water cycle.

1. INTRODUCTION

BACKGROUND

Located on the northeast coast of the Iberian Peninsula facing the Mediterranean Sea, Barcelona is the capital city of the autonomous community of Catalonia, Spain. The city is situated on a plain spanning and is bordered by the mountain range of Collserola, the Llobregat river in the southwest and the Besòs river in the north. Barcelona is the second most populous municipality within Spain. However, the population has increased slowly but steadily until the 1970's when the city reached its maximum population, thereafter it stabilizes and even decreases at the beginning of the 21st century, reaching the average population of 1.6 million inhabitants.

Barcelona's physical expansion has been limited by the mountains and the sea, resulting in a relatively high population density, among the highest in Europe. Within this context, Barcelona's major vulnerabilities are mainly attributable to the natural and environmental threats faced by the wider Catalonia region, as well as to a broader set of socio-economic strains brought by the 2008 financial crisis. Barcelona has a very dominant service sector, a growing proportion of which depends on tourism (Pagani et al., 2018). The resilience of the city to climate change can be highly related to its urban services' resilience, their interdependencies and cascade effects.

The Barcelona vision is to be a city responsible for its contribution to climate change and gearing itself up to be less vulnerable to its effects by focusing on people, because it directly affects their health and quality of life; by comprehensively transforming the city tackling the risks and turning them into opportunities; by speeding up efficiency, renovation and the introduction of renewable energies to achieve better adaptation; by approaching this through a process of co-production with city residents.

The Barcelona Municipality has already developed an intensive work towards resilience and it is proactively committed to increase Barcelona's resilience: from social exclusion to economic stresses, flooding, drought and heat waves. Barcelona's commitment to resilience started in 2008, proceeding with diverse initiatives, with establishment of Urban Resilience Boards, participation with UNISDR – within the Making Cities Resilient campaign's framework, the agreement with UN-Habitat to develop the CRPP, with 100 Resilient Cities, among others (Pagani et al., 2018).

The urban water cycle is the scope for this plan, due to the importance of meteorological and hydrological water-related risks in the functioning of the city. This resilience action plan (RAP) is a thematic plan that contributes to the city's climate planning and it is related with other building up resilience instruments in Barcelona:

- Climate Plan;
- Drainage Master Plan (BCASA with the support of AQUATEC);
- Special Drought Plan (Catalan Water Agency);
- Emergency and contingency city plans;
- Urban Resilience Boards;
- City's Services Operational Centre.

It is important to remark the active participation of the city in different resilience programmes and international networks such as:

- Resilient Cities Network (former 100 Resilient Cities Pioneered by the Rockefeller Foundation);
- City Resilience Profiling Programme (UN-Habitat);
- UNISDR Making Cities Resilient Campaign;
- Networks and associations (ICLEI, C40, UCLG).

ABOUT THE PLAN

Plan scope, focus and time horizon

This resilience action plan (RAP) has been developed for the city of Barcelona within the RESCCUE project framework, becoming a new instrument to tackle with the effects of climate change and complementing the Climate Plan strategic measures and the climate action pathway. The present planning has a medium/long-term horizon of 10 years, from 2020 to 2030, in articulation with the strategic planning horizons for Barcelona. In this sense, Barcelona RAP can be considered as a "living document" with decadal periodic updating. Notwithstanding, it refers to other information sources with a broader horizon, e.g. 2100, like the studies carried out within RESCCUE on climate projections, impact analysis and Cost Benefit Analysis of adaptation measures. The scope of this plan is the urban resilience to climate change (CC) with focus on the urban water cycle.

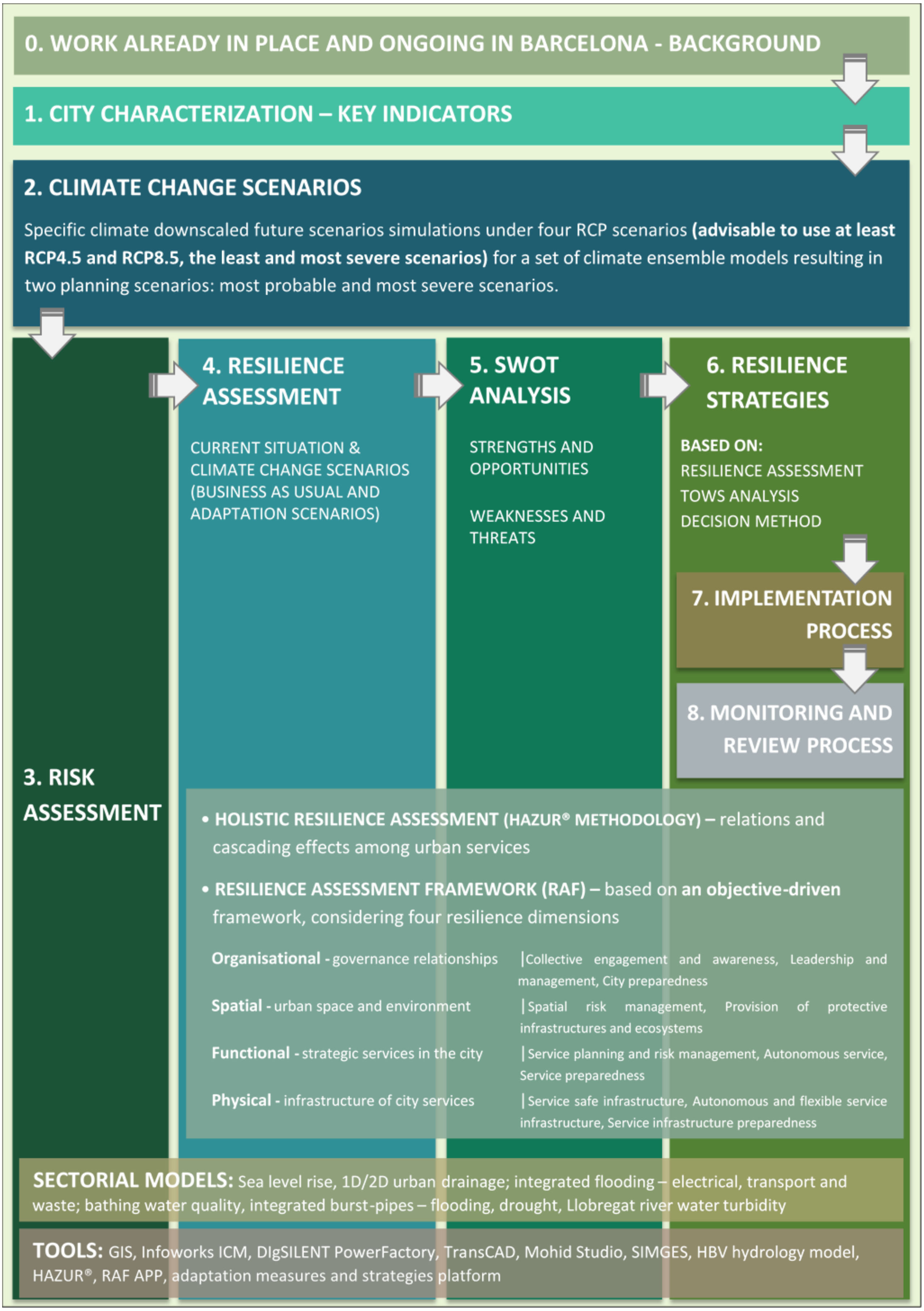
Geographical scope of the plan

Addressed urban services

The following urban services, their interactions and contributions to city's resilience are considered in the plan: water supply, water treatment, urban drainage (including wastewater and stormwater), waste collection, electric energy supply and mobility. These services are within the scope of this plan as they relate with the water cycle, either providing a water service, being affected by these services' performance or affecting their performance. Given its relevance, the effects of sea level rise in the beaches and the impacts of CSO on urban beaches were also considered in the plan.

In the resilience assessment, the services usually consider the whole urban and peri-urban area included in the administrative limits of the city.

Planning process



Document structure

This document provides a ten years' roadmap for resilience, defining a path to enhance resilience of the city and its services regarding climate change, with focus on the urban water cycle. It is based on the intense work and background already existing in Barcelona, the establishment of climate change planning scenarios, the characterisation of the city context and hazards, the risk and resilience assessment and on the development of the strategies that need to be implemented to enhance the resilience of the city to climate change with focus on water. It was supported on the RESCCUE's template, guidelines and results obtained using tools and approaches developed in this project (www.resccue.eu).

The plan is structured in 7 sections. This first introductory section provides the city background, an overview of the plan scope, focus, time horizon, planning process and structure.

In section 2, a brief characterization of the city and of the addressed urban services is provided, focusing on the plan scope.

In section 3, the climate change scenarios considered for the city in this plan are briefly presented, as well as the related hazards, risks and vulnerabilities.

The resilience assessment and a SWOT analysis are presented in section 4, followed by the description and planning of the adaptation strategies selected, in section 5.

In section 6, steps for plan monitoring and review are acknowledged and scheduled.

Section 7 presents the final remarks of the plan, with a brief list of identified benefits and future challenges, as well as any relevant acknowledgments.

Detailed or confidential information regarding the assessment or description of the strategies are included as confidential annexes.

2. CITY CHARACTERIZATION

CITY PROFILE

Located on the Mediterranean coast, northeast coast of the Iberian Peninsula close to the French border and south of the Pyrenees, Barcelona is on plain bordered by two rivers: the Llobregat in the south and the Besòs in the north. Due to its close proximity to the sea, Barcelona exhibits a Mediterranean climate with mild, relatively wet winters and hot, relatively dry summers. Barcelona is the second most populous municipality within Spain, the 6^{th} most populous in the European Union, continuing to expand the urban area beyond its administrative boundaries.

Within this context, Barcelona's major vulnerabilities are mainly attributable to the natural and environmental threats faced by the wider Catalonia region, as well as to a broader set of socio-economic strains brought by the 2008 financial crisis (Pagani et al., 2018). The city characterization focuses on the scope of this plan.

BARCELONA

GEOGRAPHICAL CHARACTERISTICS

Country: Spain

Altitude: 45 m

Metropolitan area: 636 km^2

Urban area: 101 km^2

- Coastal area
- Near to the sea
- Downstream a mountainous area

CLIMATE

Climate type: Hot-summer Mediterranean climate (Csa - Köppen climate classification)

Average temperature:

annual	hottest month	coldest month
16.5°C	27.1 °C	6.1 °C

Average rainfall:

annual	wettest month	driest month
600 mm	207.6 mm	4.6 mm

Sea level – Max tidal amplitude: 0.30 m – 0.99 m

Local mean (Barcelona port): 31/10/2013

One heat wave every 4 years

POPULATION

Urban population density: 16 142 inhabitants/km^2

Urban permanent population: 1 619 337 inhabitants

Urban population – floating: 9 065 650 tourists

Population of the metropolitan area: 3 200 000 inhabitants

ECONOMY & GOVERNANCE

GDP: 72 291 000€

GINI index: 29.1 (city), 32.5 (metropolitan area)

Political cycle: 4 years

BUILT AND NATURAL ENVIRONMENT & INFRASTRUCTURE

Services in the city: Water supply, urban drainage (including wastewater and stormwater), waste, energy, mobility (road, train, water, air based)
Protected areas in the city: Ecological or sensitive, cultural or historical heritage
Ecosystem services: Besòs river fluvial park, Collserola natural forest park, Montjuic mountain, the urban parks and gardens grid, beaches

EXISTING CLIMATE-RELATED HAZARDS IN THE CITY

Flooding – Rainfall, sea level, storm surge
Drought – Temperature and rainfall
Heat wave – Temperature
Combined sewer overflow (CSO) – Rainfall
River turbidity - Rainfall

HISTORICAL RELEVANT EVENTS AND TIME SCOPE OF ANALYSIS

Looking at historical relevant events:

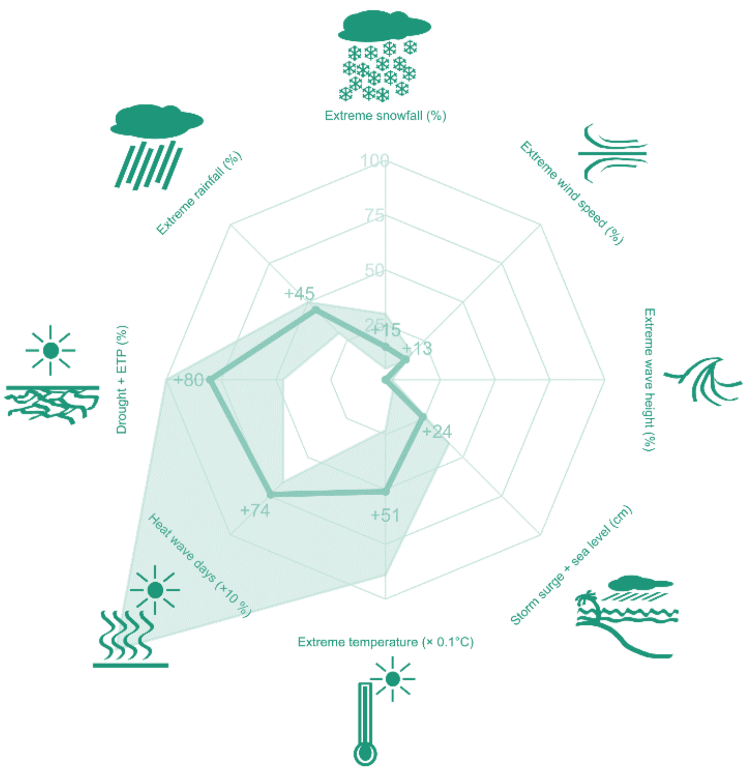
- Regarding drought impacts: the most severe and recent disruptive event hitting the urban area occurred between 2004 and 2008. During that period, four years of scarce precipitation in the Llobregat and Ter rivers' headwaters, coupled with an increased evaporation rate due to high temperatures, culminated in the Spring 2008 water crisis affecting over 5.5 million people in the broader Catalonia (Pagani et al., 2018). In January 2018, the city declared the pre-alert level of the Drought protocol after three consecutive years of low rainfall.
- Regarding flooding events: the city is affected every year by an average of three intense rainfall events and one extreme flooding event every five years, although these frequencies are increasing in the last years. Due to the variability of rainfall it is difficult to establish a trend. As an example, during 2018 the city suffered ten intense rainfall events and four extreme rainfall events, one of

them categorised as a T300 (return period of 300 years) rainfall event, according to records of the rain gauge network.

— Regarding heat wave events: historically, Barcelona has to tackle with one heat wave every four years, but this trend is increasing notably in the latest years. In 2003, a heatwave that lasted 13 days increased in more than 40% the average mortality. Last heat wave event occurred in summer 2018 with 7 days long and causing up to 10 direct deaths.

Looking at historical data records used in the RAP analysis, they refer to the last 70 years.

EXTREMES COMPASS ROSE FOR BARCELONA



Maximum change in climate extreme events along the century (return periods between 2 and 100 years) have been estimated within RESCCUE (Monjo et al., 2018).

The edge corresponds to an increase of 100%. For heat wave days, the most critical border of the uncertainty region reaches an increase of 10 times the number of heat wave days (+1000).

Median scenario

Uncertainty region (5-95%)

Note that this RAP focuses on flooding, drought and heat waves hazards in Barcelona and, consequently it considers only the related weather variables affecting the city and its services.

PLAYERS AND STAKEHOLDERS

Given this resilience plan’s thematic scope and focus (climate change and water cycle), all the players and stakeholders involved in this resilience process are identified. Several players from very different areas - both public and private - participate in the management of the services and infrastructures and several stakeholders are involved in strengthening Barcelona’s resilience-building efforts (Canalias et al., 2017).

Chief resilience officer	Ares Gabàs
Actors	**Acronym and full name**
RESCCUE partners	Barcelona City Council AQUATEC, Proyectos para el Sector del Agua S.A. (SUEZ Group) CETAQUA – Water Technology Center FIC – Fundación de Investigación del Clima UNEXE – University of Exeter LNEC – Laboratório Nacional de Engenharia Civil BCASA – Barcelona cicle de l'aigua IREC– Institut de Recerca en Energía de Catalunya ENDESA UN-Habitat

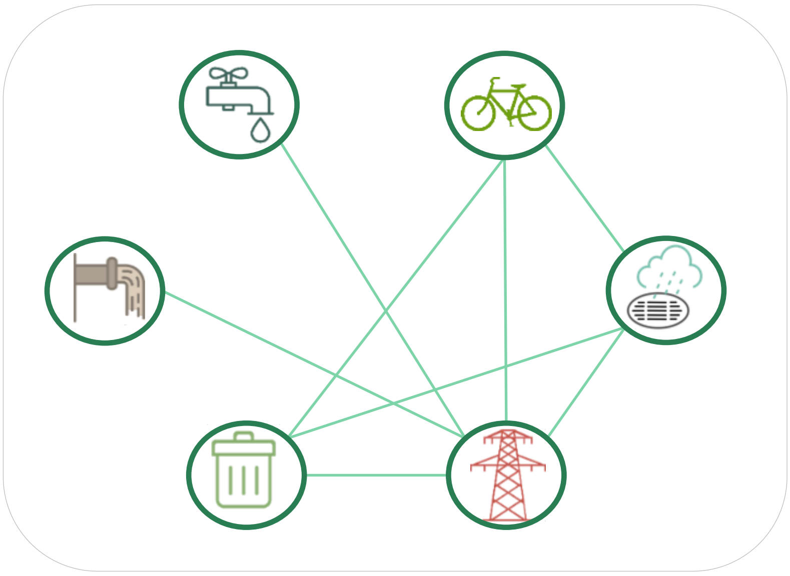
Other stakeholders

AB – Aigües de Barcelona (Water management, water treatment, water supply and wastewater treatment)
ACA – Agència Catalana de l'Aigua (Regional water resource management)
AMB – Àrea Metropolitana de Barcelona (Management of main metropolitan urban services like Urban water cycle, Waste, Mobility, Beaches)
ATM – Autoritat del Transport Metropolità (Public transport management)
TMB – Transports Metropolitans de Barcelona (Transport operator managing Bus and Metro networks within Barcelona Metropolitan área)

SERVICE PROFILE

Urban services play a very relevant role in city's resilience. The services considered in this plan interact and face their specific challenges due to climate change. Their resilience contributes to Barcelona's resilience.

INTERDEPENDENCIES ANALYSIS FOR BARCELONA



ASSESSED SERVICES

SERVICES CONTEXT CHARACTERIZATION

	Water	Urban Drainage	Waste	Energy	Mobility	Beaches
Utilities No.	3	2	2	1	2*	3
Inhabitants covered	About 2.8 million people	1.6 million	1.6 million (collection - municipality) 4.8 million (treatment - metropolitan area)	-	1.6 million	3.5 million-users
Area covered (km²)	101	101	101 (collection - municipality) 2 500 (treatment - metropolitan area)	-	101	4.3 km-long
Relevant info.	162.5 l/(inhab.day) of water consumption	-	1.3 kg/(inhab.day) (collection) 353 600 kgCO_2/ton	9.75 MWh/(inhab. year)	1 017 620 ton CO_2 eq	Recreational value of a beach day per user: 16 €
Scope of analysis	Urban area	Urban area	Urban area	Urban area	Urban area	Urban area

* Urban mobility management, traffic management, local road network, urban freight transport; metro and bus management.

Given its relevance for Barcelona, the effects of sea level rise and CSOs in all the beaches of the cities have been analysed through a GIS model and an integrated urban drainage – bathing water quality model respectively.

SERVICE INFRASTRUCTURE

WATER

Total length of conduits (km)	4 107
Water abstractions (No.)	26
Pumping stations (No.)	65
Treatment plants (No.)	5
Storage tanks (No.)	72

URBAN DRAINAGE

Total length of sewers (km)	1 906
Pumping stations (No.)	29
Treatment plants (No.)	3
Stormtanks (No.)	10
Rainwater sewer overflows (No.)	31
Detention tanks (No.)	3
Combined sewer overflows (No.)	41

WASTE

Waste containers (No.)	40 835
Waste collection vehicles (No.)	1 350
Recycling centres (No.)	24
Transfer stations (No.)	4
Composting plants (No.)	3
Incinerators (No.)	1
Sanitary landfills (No.)	1

ENERGY

Total length of aerial network (km)	-
Total length of subterranean network (km)	-
Power stations (No.)	-
Installed power (MVA)	-

MOBILITY

Total length of road network (km)	1 368
Total length of cycling network (km)	233
Airports (No.)	1
Airport passengers (No.)	44 154 693

ASSESSED HAZARDS IN THE SERVICES

Water	Urban Drainage	Waste	Energy	Mobility	Beaches
Flooding - Rainfall	**Flooding** - Rainfall	**Flooding** - Rainfall	**Flooding** - Rainfall	**Flooding** - Rainfall	**Combined sewer overflows** - Rainfall, sea level and wind
Drought - Rainfall	**Flooding** - Sea level		**Flooding** - Sea level		
	Combined sewer overflows - Rainfall, sea level and wind				

3. CLIMATE CHANGE SCENARIOS AND RISK ASSESSMENT

HAZARDS SOURCES AND PLANNING SCENARIOS

Several hazards may affect the city, its services and infrastructures. In Barcelona, this RAP focuses on the flooding from intense precipitation, drought, sea level rise and heat waves from extreme temperatures for the city. Water service considers flooding from intense precipitation and drought from the lack of precipitation. The urban drainage sector (involving wastewater and stormwater), waste and mobility services consider flooding from intense precipitation and from sea level rise. The energy service considers pluvial, river and coastal flooding, although in the last two cases, hazard maps were not provided by RESCCUE project and did not consider climate change updating. For the other hazards and related variables, climate change scenarios for impacts assessment were agreed within RESCCUE project (Monjo et al., 2018).

A planning scenario corresponds to a hazard condition, described by the characterization of its trigger variables by experts, for comprehensive assessment of the severity, probability of occurrence and its total impact. As a minimum, cities would ideally define two planning scenarios. The Most Probable relates to a hazardous event that causes disruption, assessed by experts to be the most likely to occur. The Most Severe relates to a hazardous event that causes greater disruption, assessed by experts to be the worst case to plan for (based on UNISDR, 2015).

CLIMATE CHANGE SCENARIOS FOR THE CITY AND SERVICES

ALL

PLUVIAL FLOODING – MAXIMUM RAINFALL INTENSITY

MOST PROBABLE PLANNING SCENARIO	1 year return period Increase of 9-18% to account for ensemble CC scenarios RCP4.5 and 8.5 and period 2071-2100
MOST SEVERE PLANNING SCENARIO	500 years return period Increase of 7-26% to account for ensemble CC scenarios RCP4.5 and 8.5 and period 2071-2100

CITY, URBAN DRAINAGE, WASTE AND MOBILITY

FLOODING – SEA LEVEL RISE

MOST PROBABLE SCENARIO	Expected mean sea level rise: = +20 cm Increase to account for ensemble CC scenario RCP4.5 and period 2071-2100
MOST SEVERE SCENARIO	Expected mean sea level rise: = +30 cm Increase to account for ensemble CC scenario RCP8.5 and period 2071-2100

WATER

DROUGHT – WATER RESOURCE AVAILABILITY

MOST PROBABLE PLANNING SCENARIO	Decrease of 0.38% to account for CC scenario RCP 4.5 and period 2071-2100
MOST SEVERE PLANNING SCENARIO	Decrease of 11% to account for CC scenario RCP 8.5 and period 2071-2100

CITY

HEAT WAVE – DAYS

MOST PROBABLE PLANNING SCENARIO	Increase of 30 days to account for ensemble CC scenario RCP8.5 and period 2041-2070
MOST SEVERE PLANNING SCENARIO	Increase of 42 days to account for ensemble CC scenario RCP8.5 and period 2071-2100

CITY, URBAN DRAINAGE

COMBINED SEWER OVERFLOW (CSO) – ANNUAL NUMBER OF RAIN EVENTS AND RAINFALL VOLUME

MOST PROBABLE PLANNING SCENARIO	Decrease of 2% in number of events and decrease of 4% of total rainfall volume to account for ensemble CC scenarios RCP4.5 and 8.5 and period 2071-2100
MOST SEVERE PLANNING SCENARIO	Same number of events and total rainfall volume Baseline Current scenario

CITY, WATER

TURBIDITY – AVERAGE CLOSURE EVENTS

MOST PROBABLE PLANNING SCENARIO	Decrease of 1% of average events with critical turbidity to account for ensemble CC scenario RCP8.5 and period 2071-2100
MOST SEVERE PLANNING SCENARIO	Increase of 2% of average events with critical turbidity to account for ensemble CC scenario RCP4.5 and period 2071-2100

CITY

EXTREME TEMPERATURE

MOST PROBABLE PLANNING SCENARIO	Increase of +3.8°C to account for ensemble CC scenario RCP8.5 and period 2071-2100
MOST SEVERE PLANNING SCENARIO	Increase of +5.1°C to account for ensemble CC scenario RCP8.5 and period 2071-2100

It is important to remark that climate projections show a rise of temperature up to +5.1°C by the period 2071-2100, with uncertainty from +2.3°C to +8.9°C in the worst-case scenario. Heat wave days will suffer a great increase of 750%, with little uncertainty below median but high above it, with the worst-case scenario pointing to an increase of up to 1500%.

BARCELONA CAN EXPECT CHANGES IN THE CLIMATE-RELATED EVENTS IN THE FUTURE. IN THIS PLAN:

Flooding

Flooding from **intense precipitation** could cause more damage to people, building and other facilities as well as infrastructures, increase the affectation on mobility and transport services disruption; overwhelm stormwater drainage systems; may cause other damages and collapses resulting in interruption of energy supply and waste collection and affect all other services and infrastructures' components.

Flooding

Flooding from **sea level rise** could cause loss of beaches and flooding of some coastal infrastructures like breakwaters and docks.

Drought

Drought from **reduced precipitation** could affect surface water levels as well as groundwater levels and affect water volume availabilty and quality with impacts on people, services, green infrastructures, economy and health.

Heat wave

Heat waves from **extreme temperatures** could impact the electricity generation capacity, cause heat stress on outdoor workers and machinery, diseases on population and increase peak of energy consumption and water demand.

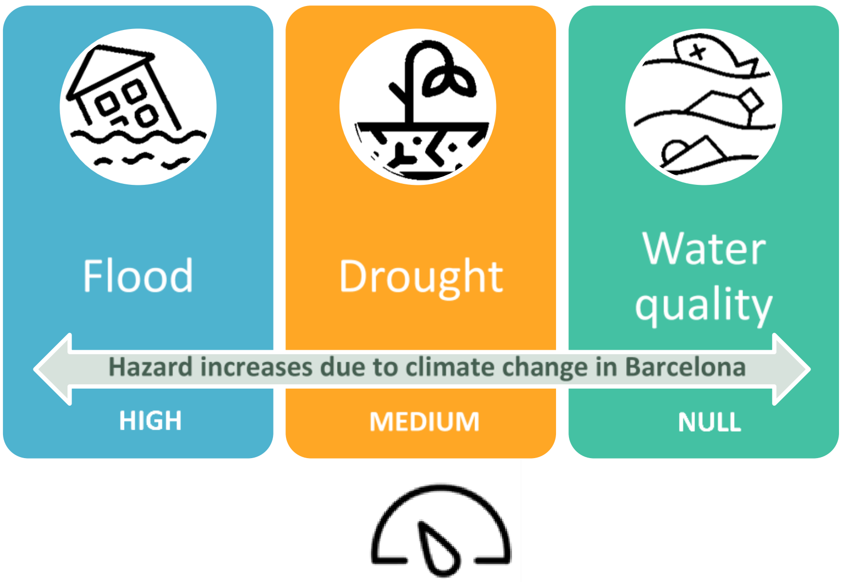
CSO

Combined Sewer Overflows (CSO) from moderate and heavy storm events could impact on beaches, affecting people health and the environment and on the related leisure and business activities.

Turbidity

Water turbidity produced by heavy rainfall and soil erosions could produce the closure of the abstraction facility of Water Treatment Plants with decrease of the availability of water resources.

A summary of the multi-hazard assessment and comparative analysis of the Baseline vs. Business as Usual (BAU) scenario for Barcelona research site is illustrated next.



RISK ASSESSMENT

SECTORIAL MODELS IN THE CITY

Sectorial and integrated models used in Barcelona were calibrated and validated using historical data. Simulations of current and future scenarios including projections provided a thorough characterization of the urban services and their relations with climate variables, a detailed analysis of interdependencies and the elaboration of multiple-hazards and risk maps.

Mathematical modelling was performed using a large set of software packages and tools (GIS, Infoworks ICM, DIgSILENT PowerFactory, TransCAD, MOHID Studio, SIMGES, HBV hydrology model). The scope of the modelling simulations was the whole Barcelona municipality area, including part of the surrounding municipalities and regions. Mathematical modelling and multiple-risk assessment regards water resources, urban drainage and the affected services of waste, electricity and mobility in case of flooding were performed to achieve a comprehensive multiple-hazards and risk assessment (Evans et al., 2020b; Forero-Ortiz et al., 2020; Martínez-Gomariz et al., 2020; Sánchez-Muñoz et al., 2020). An integrated urban drainage – water quality model was also used to assess of socio-economic impacts of CSOs for current and future scenarios. (Russo et al., 2019). Finally, a turbidity model was also developed to analyse the water quality of Llobregat river in case of rainfall events. Interaction between heat waves and electrical systems or energy consumptions have not been fully treated in RESCCUE.

Water resources analysis shows that future water availability scenarios for Barcelona central water sources indicate a mean decrease close to 11% in comparison with the period 1971–2015, considering the representative concentration pathway 8.5 (RCP8.5) climate change scenario in the year 2100.

For the period 2019–2050, the drought models average predicts 9% decrease in surface water volume availability of the reservoir system. However, for 2019–2100, due to precipitation reduction and temperature rise (warming-enhanced evaporation Climate Change effects), the models average predicts an 11% decrease with a remarkably high consensus among analysed models for the RCP8.5 scenario.

The effects of floods in a potential context of climate change for the city have been assessed through a multi-risk approach and the results of this assessment, in terms of tangible and intangible impacts, have been presented in terms of hazard, vulnerability and qualitative and quantitative risk maps for several return periods and considering both current and future scenarios (including BAU and Adaptation Scenarios) (Evans et al., 2019, Evans et al., 2020a). These maps can be visualized in https://csis.myclimateservice.eu/studies. As a representative case of intangible impact, the flood maps for pedestrians and vehicles are presented next.

The results of the flood simulations demonstrate that Barcelona could suffer a significant increase in these impacts due to climate change in case of adaptation measures are not adopted. For example, it was demonstrated that, increments of maximum rainfall intensity of 12-16%, may increment more than 25-30% in terms of social impacts (f. e. intangible damages like the increase of areas classified with high hazard conditions in case of pluvial flood events) and economical losses (tangible direct and indirect damages) expressed in terms of monetary terms through the concept of EAD (Expected Annual Damage). More details can be found in Russo et al. (2020).

Model	Type of impact	Current vs future climate conditions**	
		Indicator	**Variation (%)**
EAD/2D USM Urban drainage model	Intangible	Increase of high flood risk area for pedestrian and vehicles	Pedestrians: +30 (T10), +34 (T50), +32 (T100), +30 (T500) Vehicles: +38 (T10), +42 (T50), +34 (T100), +25 (T500)
1D/2D USM + Damage model	Tangible	Increase of EAD* (including properties, vehicles and indirect damages)	42
1D/2D USM + Traffic model	Tangible & Intangible	Increase of km of closed roads; EAD* due to travelling time rise	+31 (T10), +60 (T50), +66 (T100), +116 (T500); + 0.18 M€
1D/2D USM + Electric model	Tangible & Intangible	Increase of the number of flooded electric infrastructures; related EAD*	+13 (T10), +12 (T50), +11 (T100), +10 (T500); +0.012M€
1D/2D USM + Waste model	Intangible	Increase of the number of unstable waste containers	Empty: +27 (T10), +28 (T50) 50% full: +28 (T10), +32 (T50) 100% full: +28 (T10), +36 (T50)

* EAD - Expected Annual Damage

** see scenarios and Russo et al. (2020)

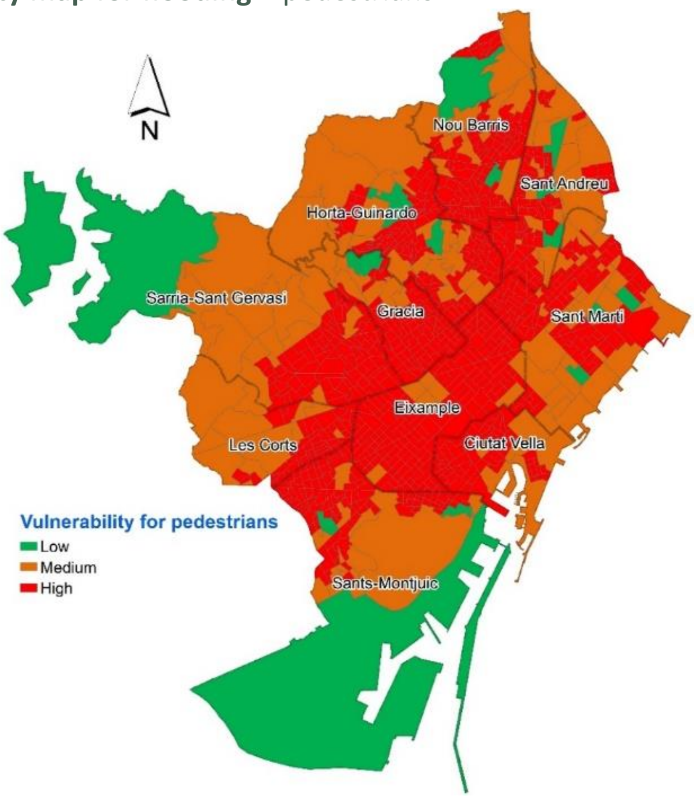
Water quality in bathing and Llobregat rivers should not be exacerbated by climate change scenarios, although their socio-economic impacts are and will be significant.

FLOOD RISK-RELATED MAPS FOR PEDESTRIANS AND VEHICLES (CURRENT AND FUTURE SITUATIONS)

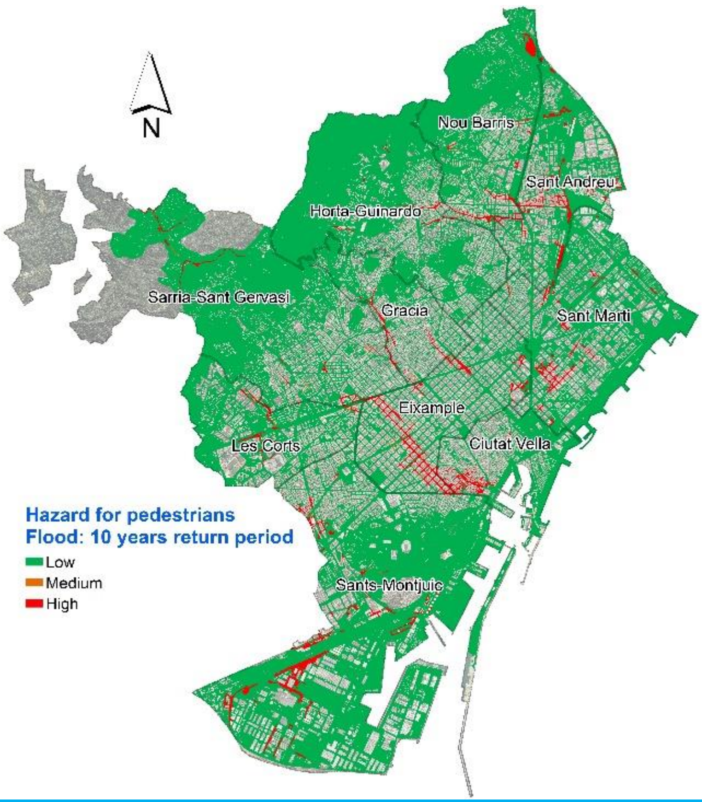
Besides the risk-related maps herein presented, additional maps may be visualised in https://csis.myclimateservice.eu/studies.

CURRENT CLIMATIC SITUATION

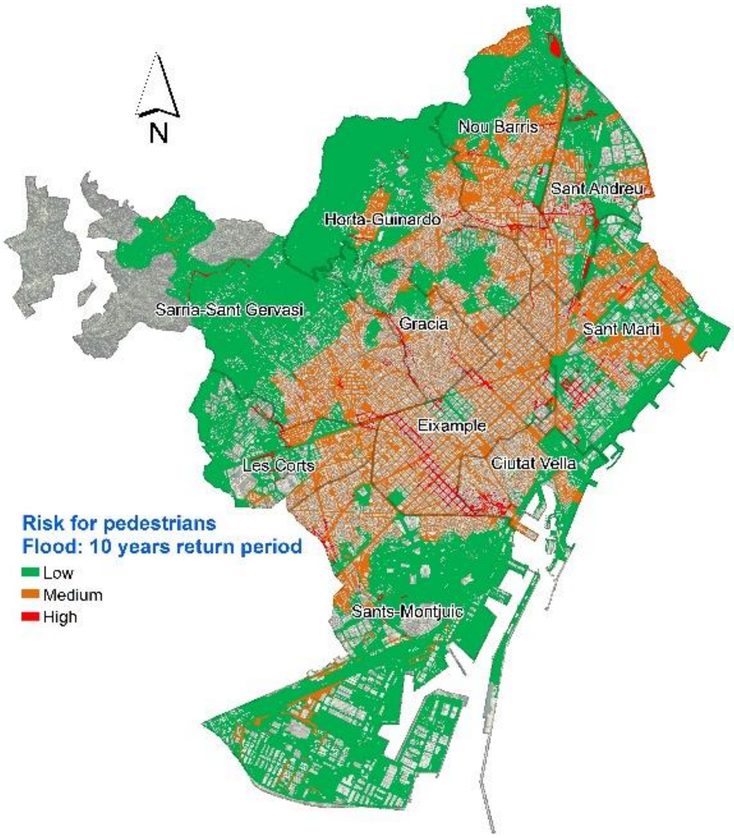
Vulnerability map for flooding – pedestrians



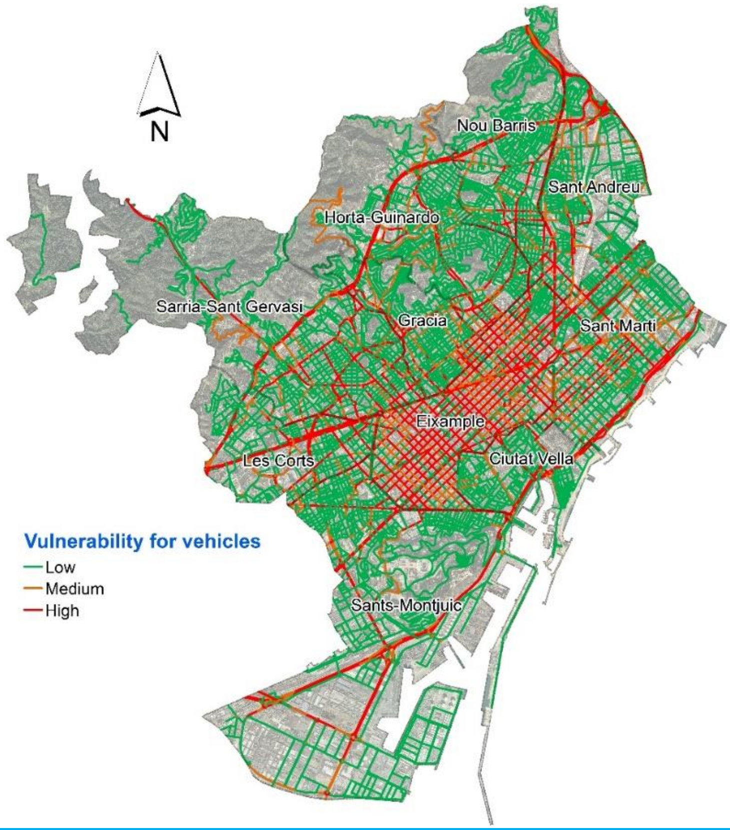
Hazard map for flooding (10 years return period) – pedestrians



Risk map for flooding (10 years return period) – pedestrians

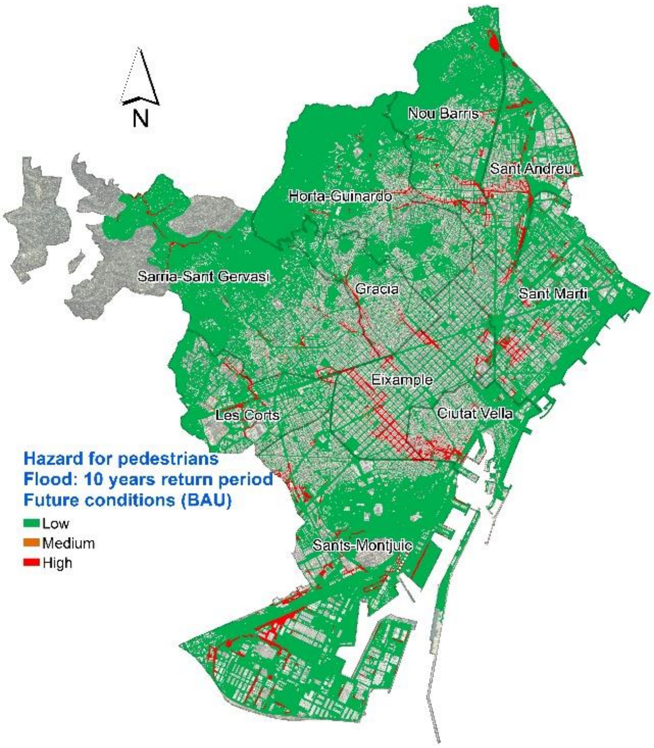


Vulnerability map for flooding – vehicles

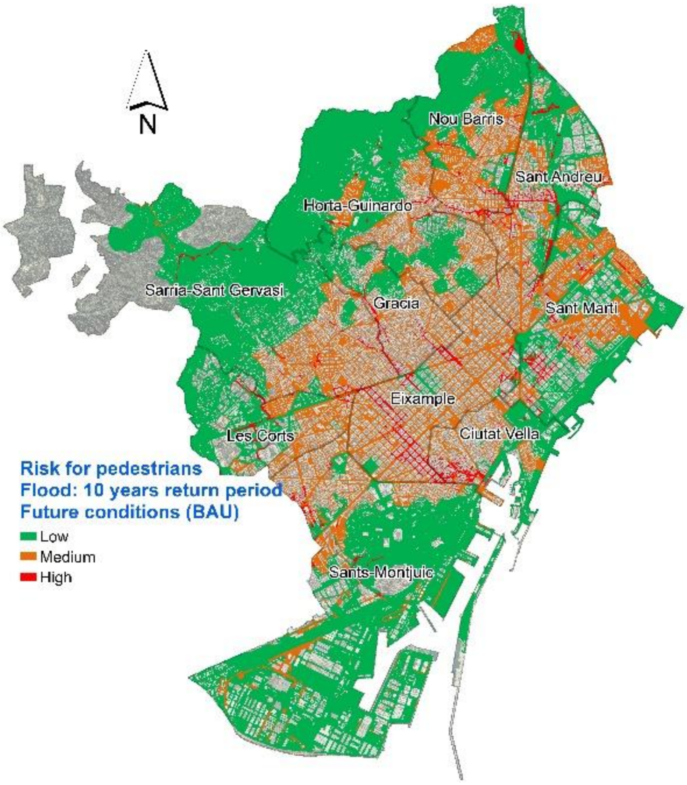


FUTURE CLIMATE SITUATION*

Hazard map for flooding (10 years return period) – pedestrians



Risk map for flooding (10 years return period) – pedestrians



* see scenarios and Russo et al. (2020)

4. RESILIENCE ASSESSMENT AND SWOT ANALYSIS

RESILIENCE ASSESSMENT

Resilience assessment enables to highlight where Barcelona and the urban services stand today (reference situation), regarding resilience to climate change, and to identify the most critical aspects to be improved, taking into account both the reference situation and the expected impacts of climate change scenarios. The integration of the resilience assessment results provided by all sources of analysis is presented in the SWOT analysis. This supports the identification of resilience measures and strategies for this RAP to implement in the city and services.

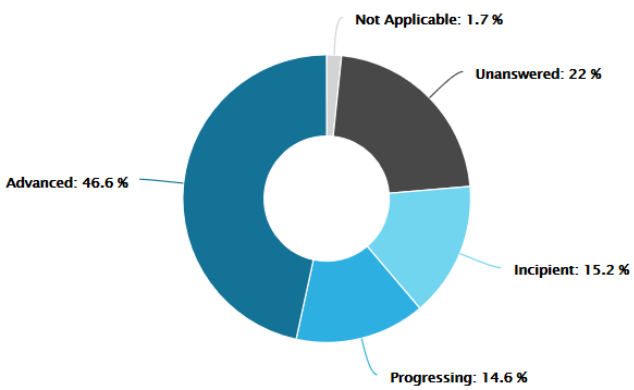
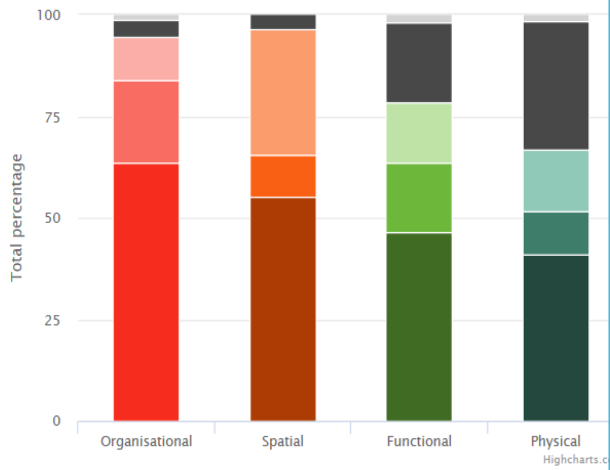
HOLISTIC APPROACH ASSESSMENT IN THE CITY

The holistic approach for resilience assessment was implemented using the HAZUR® methodology and tool. It analyses the cascading effects that have collateral impacts on other strategic urban services and the city. The identification of players, the description of the water related services and infrastructure, the dependencies, the hazards and impacts on recovery time were considered (Canalias et al., 2017). This was a result of collaborative workshops and a collection of historical data and data from the sectorial models.

BARCELONA OVERALL ASSESSMENT– RESILIENCE ASSESSMENT FRAMEWORK

An overall resilience to climate change was assessed based on an objective-driven framework, considering four resilience dimensions for climate change, with focus on the urban water cycle: organisational, spatial, functional and physical. The resilience assessment framework (RAF) applied to Barcelona, including the services, was the RESCCUE RAF (Cardoso et al., 2018; Cardoso et al., 2020a) supported by RAF App tool (Cardoso et al., 2020b). These provide the percentage of assessment metrics assigned to a resilience development level – incipient, progressing or developed (represented respectively from a lighter to a darker colour) – as well as those without information, that were not answered, and the ones not applicable to the city. The following results illustrate the overall assessment for flooding. Similar results were obtained for heatwave and drought.

In Barcelona, overall resilience development in the city is advanced in nearly half of the aspects assessed. Organisational resilience is overall the most advanced resilience dimension, followed by the spatial dimension. The physical dimension presents the highest percentage of metrics that were not answered, followed by the functional dimension what, may be due to data that is not easily applicable to the metrics provided in the RAF, in some cases, and to lack of information in other cases.

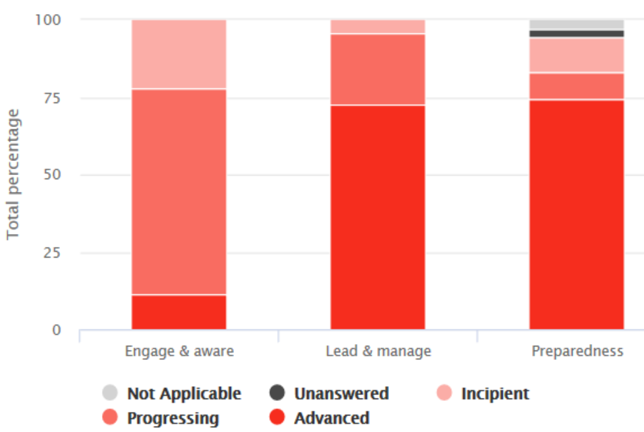
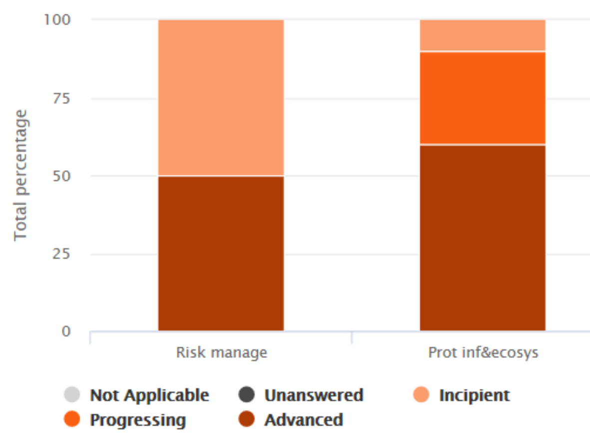
OVERALL RESILIENCE DEVELOPMENT LEVEL IN THE CITY	RESILIENCE DEVELOPMENT IN EACH DIMENSION
	

RAF ASSESSMENT FOR THE ORGANISATIONAL AND SPATIAL RESILIENCE DIMENSIONS

Organisational dimension focuses on city level, analysing governance structures, the stakeholder's involvement and the city's resilience engagement and preparedness for climate change.

Spatial dimension also focuses on city level, analysing herein the urban space, protective infrastructures and ecosystems.

DETAILED DEVELOPMENT LEVEL FOR THE CITY

ORGANISATIONAL	SPATIAL
	

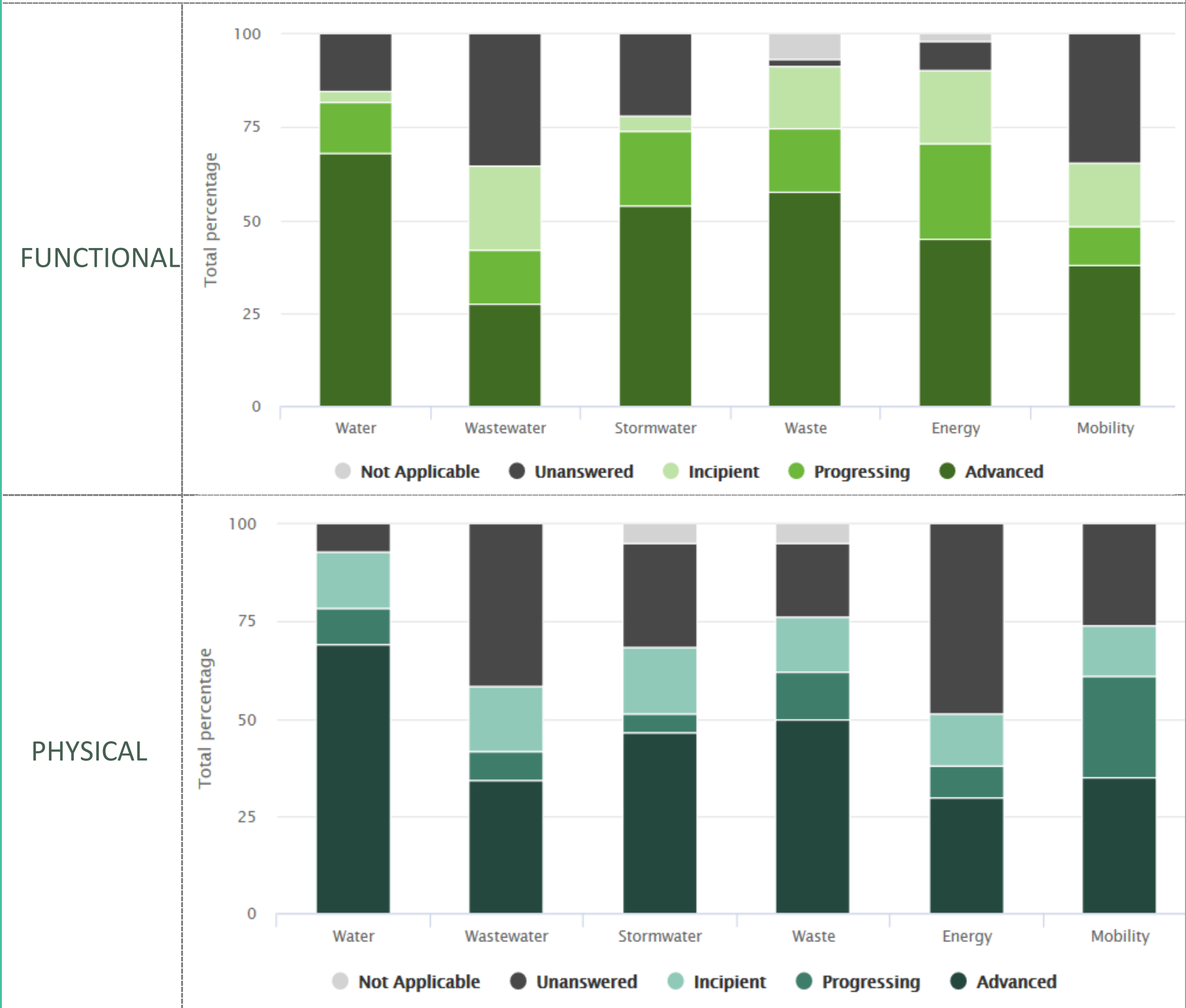
In the Organisational dimension, the overall resilience development level of both the Leadership and Management and City Preparedness objectives is significantly advanced. The Collective Engagement and Awareness objective is the one presenting a lower advanced level, while the progressing development level is the most expressive. Overall, this dimension still presents some opportunities for improvement.

In the Spatial dimension, both objectives Risk Management and Protective Infrastructures and Ecosystems are advanced in around half of the aspects assessed, while also presenting significant opportunities for improvement, particularly the former mentioned.

RAF ASSESSMENT FOR THE FUNCTIONAL AND PHYSICAL RESILIENCE DIMENSIONS

Functional dimension emphasizes each urban service management, autonomy and preparedness for CC. Also, for each urban service, the **Physical dimension** attends infrastructure resilience regarding its safety, autonomy and preparedness for CC. These dimensions also inform about the contribution of each service to Barcelona's resilience.

DETAILED DEVELOPMENT LEVEL FOR EACH SERVICE – Services contribution to city resilience



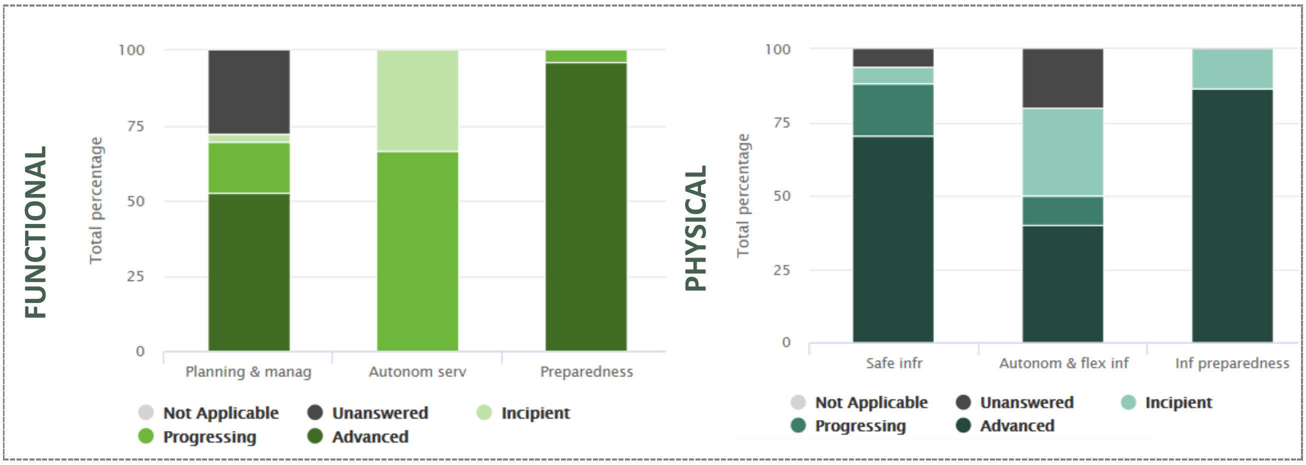
Functional resilience of all services, except wastewater and mobility, is advanced in about half of the aspects assessed. The wastewater, stormwater and mobility services, in general, translate significant percentage of metrics that were not answered, may be due to data that is not easily applicable to the metrics provided in the RAF, in some cases, and to lack of information in other cases.

Physical resilience is significantly advanced for the water service, in about two thirds of the aspects assessed; it is advanced in about half of the aspects assessed for the stormwater and waste services, while wastewater, energy and mobility present about one third of advanced metrics, the lowest percentage. The progressing development level in the mobility service is evident. This is the dimension presenting higher percentage of metrics that were not answered, namely regarding the wastewater, stormwater, energy and mobility services, for the same reasons described above.

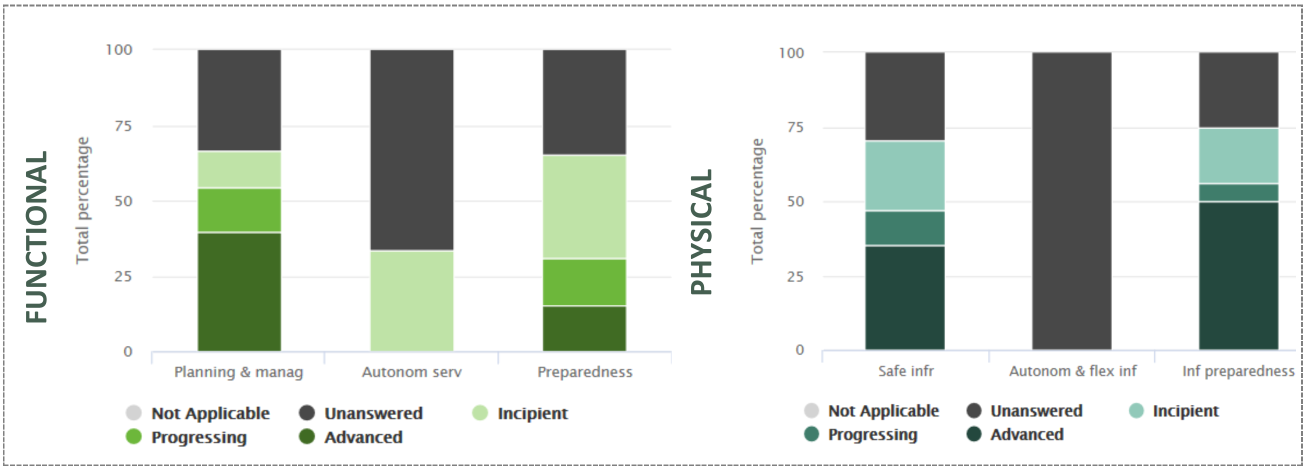
The main data gaps identified by the application of the RAF in the city of Barcelona are related to the definition of the metrics to be applied and the differences in the way how these metrics are calculated. Most of the time, the indicators did not fit the ones the city already determines and it would entail a noteworthy effort to address the requested specifications. The limitations to answer to a given set of indicators within a specific criteria or objective may not allow an accurate assessment of the points of view related to such criteria or objective. Without assuming harm, this gap identification also means an opportunity to improve a new approach to measuring the different aspects of resilience in the city.

A more detailed assessment for these two dimensions for each service is presented.

WATER

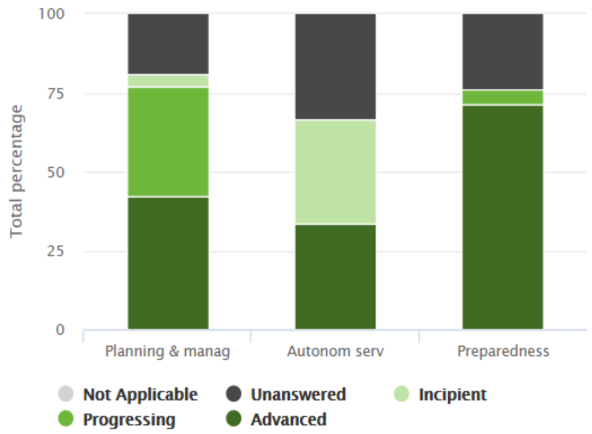


WASTEWATER

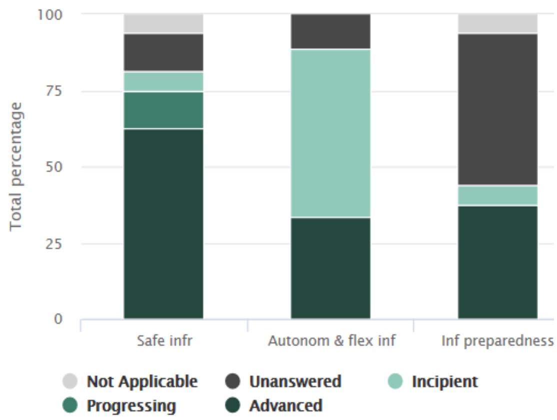


STORMWATER

FUNCTIONAL

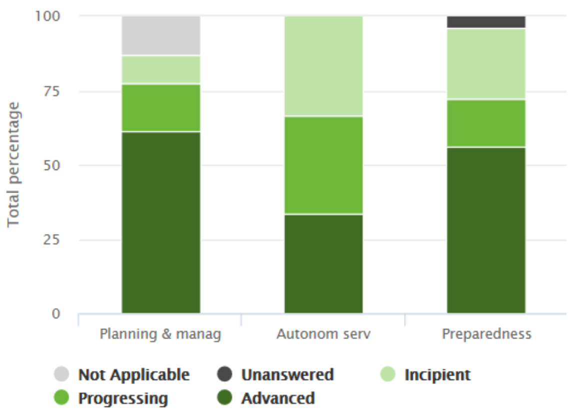


PHYSICAL

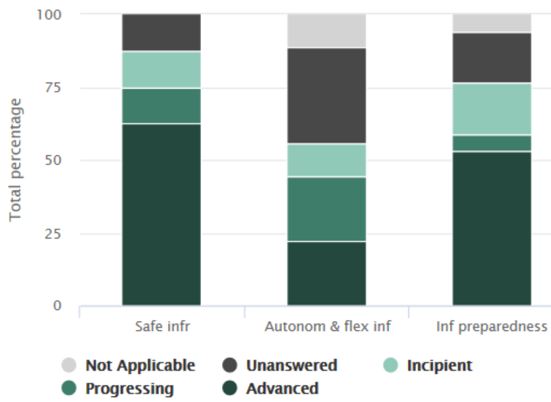


WASTE

FUNCTIONAL

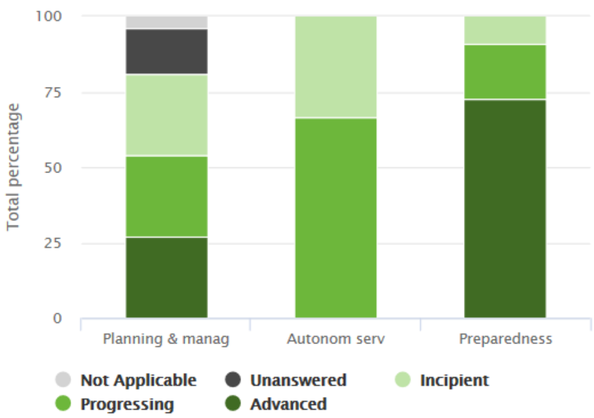


PHYSICAL

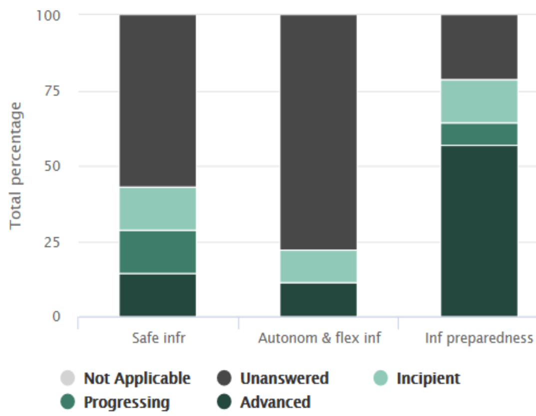


ENERGY

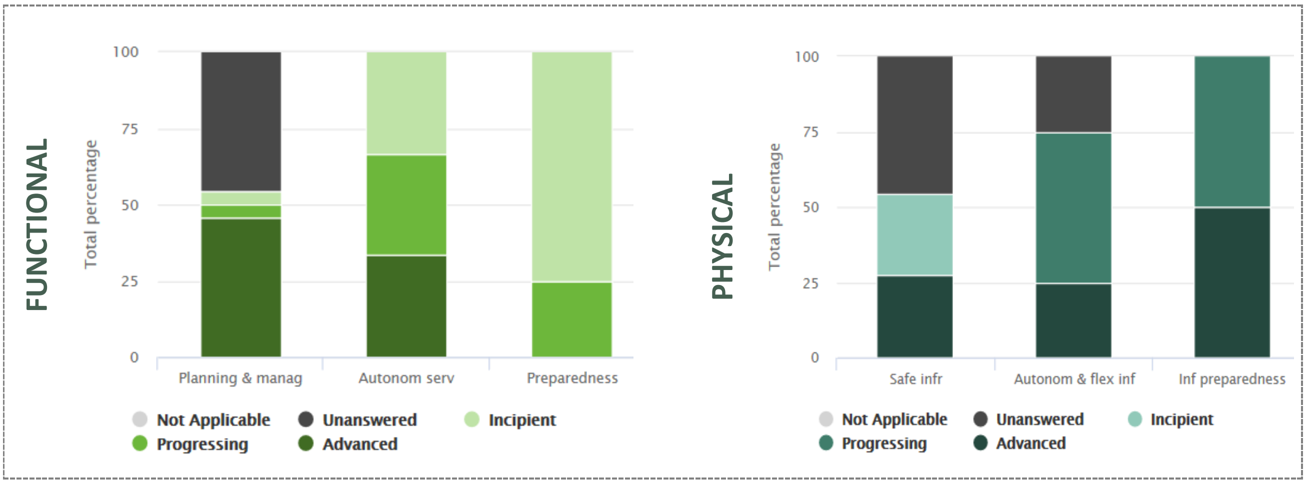
FUNCTIONAL



PHYSICAL



MOBILITY



More complete graphical analysis for each objective, namely by assessment criteria for each urban service, is presented in a confidential annex.

A more detailed analysis of all dimensions and also for each service is described in the SWOT analysis, linking the most advanced objectives to the city's main strengths, and the most incipient to the main weaknesses. Other information was also integrated in the SWOT, coming from the different assessments carried out, as well as from the analysis of context.

SWOT ANALYSIS

The diagnosis includes the integration of the resilience assessment results provided by all sources of analysis (Russo et al., 2018, Russo et al., 2019, Evans et al., 2018, Evans et al., 2019, Canalias et al., 2017, Pagani et al., 2018, Cardoso et al., 2020a,b). Aligned with objectives, a SWOT analysis (Strengths, Weakness, Opportunities and Threats) summarizes this information by identifying the city's and the service's internal strengths and weaknesses, as well as the external opportunities and main threats (McClinton, 2015), following the planning process presented before, as proposed in Cardoso et al. (2020a). As mentioned, in this analysis the most advanced objectives assessed in RAF are related to the city's main strengths, and the most incipient to the main weaknesses. From a resilience to climate change perspective, a SWOT analysis for Barcelona is presented. This SWOT analysis, whenever referring to detailed hazards assessment, applies overall to flooding, heatwaves and drought. Whenever any of these hazards analysis results into a different assessment, such hazard is specifically mentioned. A more detailed SWOT analysis is presented in the confidential annex.

SWOT ANALYSIS FOR BARCELONA FROM A RESILIENCE TO CLIMATE CHANGE PERSPECTIVE

This SWOT table identifies the aspects related to the city's main strengths and main weaknesses, in the respective columns. To illustrate the interpretation, existing *significant background in resilience and historical records of meteorological events* constitutes main strengths in the city, related to the organizational dimension; for the functional dimension, the main weaknesses are related to the *mobility service preparedness* for climate change and with *energy service autonomy in drought situation*. Those that are underlined are included in the TOWS analysis that follows.

MAIN STRENGHTS	MAIN WEAKNESSES
- Significant background in resilience and historical records of meteorological events	
- Leadership and management - City preparedness	- Collective engagement and awareness
- Spatial risk management, regarding general hazard and exposure mapping - Provision of protective infrastructures and ecosystems	- Spatial risk management
- Water, wastewater, stormwater, waste and mobility planning and risk management - Water, stormwater, waste and energy services preparedness - Mobility service autonomy for drought	- Mobility service preparedness for climate change - Energy service autonomy for drought - **Data gaps for RAF assessment**, regarding services: water, wastewater, stormwater, energy and mobility services planning and risk management; wastewater and stormwater service preparedness; wastewater and stormwater service autonomy
- Safe water, wastewater, stormwater and waste infrastructures - Autonomous and flexible water infrastructure - Water, wastewater, waste, energy (for flooding) and mobility infrastructures preparedness	- Stormwater infrastructure autonomy and flexibility - **Data gaps for RAF assessment**, regarding infrastructure: wastewater, energy and mobility infrastructures safety, wastewater, waste and energy infrastructures autonomy and flexibility; stormwater and energy infrastructure preparedness

OPPORTUNITIES	THREATS
- Coastal area may provide conditions for economic development such as tourism and industry development (e.g. food, water, shipping and ports, recreational activities such as bathing, water sports, raw materials, including salt and sand).	- Coastal area, highly exposed to sea level rise and storm surge, consequences of climate change
- High percentage of daily commuters provides positive impact in economic activities and employment (e.g. work, food, entertainment, transport).	- High percentage of daily commuters provides increasing of health risks related to air pollution, of resources needed to prepare for a disruptive event and damages and losses.
- Financial opportunities given the national and international recognition and awareness of resilience to CC emergency , such as the development of European financing programmes	- Socio-economics crises
- National and international recognition and awareness of resilience to CC emergency	- Heat waves related to climate change
- Low range of altitude	- Changes in rainfall patterns (decrease in summer precipitations but increase in rain intensity) related to climate change
	- Sea level rise related to climate change
	- Water scarcity related to climate change
	- Drought related to climate change
	- Temperature increase by 2050 related to climate change

5. RESILIENCE STRATEGIES

IDENTIFICATION OF STRATEGIES

The identification of the strategies that reduce Barcelona's threats (**T**), overcome weaknesses (**W**) and exploit strengths (**S**) and opportunities (**O**) was supported by a **TOWS** analysis (Weihrich, 1982), following the planning process presented before, as proposed in Cardoso et al. (2020a). The topics addressed are underlined in the SWOT table, previously presented, to facilitate identification. In order to address these aspects, the city aims to exploit its strengths to both take advantage of its opportunities and face its threats, by planning the SO and ST strategies to be implemented. It is also aiming to minimise its weaknesses in order to avoid the impact of threats, by planning WT strategies. These strategies are targeted to the different hazards considered in this plan (see Chapters 2 and 3).

TOWS ANALYSIS FOR THE CITY FROM A RESILIENCE TO CLIMATE CHANGE PERSPECTIVE

SO

STRENGHTS/OPPORTUNITIES

a) Exploit the existing significant background in resilience, the city's preparedness for disaster response as well as the safe wastewater infrastructure, **to take advantage** of Barcelona being a coastal area with significant touristic uses.

b) Exploit the strong leadership and management, the city's preparedness for CC and the developed urban services planning, **taking advantage** of the national and international recognition and awareness of resilience.

ST

STRENGHTS/THREATS

c) Exploit the existing protective infrastructures and ecosystems, the strong stormwater planning and risk management as well as the prepared stormwater service, to **overcome threats** related to changes in rainfall patterns, water scarcity and temperature increase.

d) Exploit the developed water service risk management and preparedness for CC as well as the flexible and prepared water infrastructure, **to overcome threats** related to changes in rainfall patterns, water scarcity and temperature increase, droughts and heat waves.

WO

WEAKNESSES/OPPORTUNITIES

- Not identified for this RAP

WT

WEAKNESSES/THREATHS

e) Minimize the weaknesses regarding collective engagement and awareness, spatial risk management, as well as those related to the energy service autonomy, mobility service preparedness, and stormwater infrastructure autonomy and flexibility, **to avoid the impact of threats** related to climate change and high percentage of daily commuters.

As **SO** strategies that exploit strengths to take advantage of opportunities (a and b in the table), it was identified respectively **"Environmental improvement of receiving water bodies"** and **"Guarantee security of services supply".**

As **ST** strategies that exploit strengths to avoid threats (c and d in the table), it was identified respectively **"Flood impacts reduction in a context of climate change"** and **"Not a single drop wasted. Alternative water resources".**

As **WT** strategy that minimises weaknesses and avoid threats (e in the table), it was considered **"Guarantee security of services provision"**.

Some challenges identified in the SWOT table, previously presented, are still to be addressed in the future, namely related to data gaps weaknesses identified in the RAF assessment.

STRATEGIES TO IMPLEMENT

DESCRIPTION

The strategies to implement are further detailed in the following tables, supported by information from Martínez-Gomariz et al. (2017), Martínez-Gomariz et al. (2019), and Guerrero-Hidalga et al. (2020).

S001 – Flood impacts reduction in a context of Climate Change

DESCRIPTION

Measures to reduce the impacts of flooding events identified for Barcelona in the framework of RESCCUE project. It includes structural measures, non-structural measures and nature-based solutions.

The morphology of Barcelona presents areas with high gradients and flat areas near to the Mediterranean Sea. These characteristics, added to the typically heavy Mediterranean rainfalls with high intensities and short duration, leave the city in a prone situation to be flooded. Moreover, the land of the municipality was strongly urbanized during the last decades. All these aspects facilitate urban flash floods in several critical areas with significant economic damages and high hazard conditions for pedestrian and vehicular circulation and for the urban assets.

Typology: NBS and ecosystems services; Infrastructural construction or rehabilitation

TOWS perspective: ST

Implementation: New

Timeline: 2100

Hazard: Flooding

Variables: Rainfall

Institution: Aquatec

Players: Barcelona City Council

Services:

Urban drainage

Costs:

Short-term: 809 250 000 €

Mid-term: 10 000 000 €

MEASURES:

Improvements of surface drainage system (New inlets)
Increase of sewer system capacity (I) (New pipes)
Increase of sewer system capacity (II) (New detention tanks for flooding protection)
SUDs (green roofs, infiltration trenches, detention basins)
Early Warning System
Self-healing algorithm implemented in the electrical distribution grid
Ensure the stability of waste containers

CO-BENEFITS: Relevant contribution | Slight contribution

ECONOMIC	SOCIAL	ENVIRONMENTAL
Cost savings Reduced energy losses **Job creation** **Increased labour productivity** **Increased economic production** **Increased property values**	**Reduced mortality impacts** **Reduced health impacts** **Reduced mortality from diseases** **Enhanced public amenity** **Reduced impacts on vulnerable groups** **Reduced number of householders, businesses forced from homes, places of work**	Improved air quality **Reduced aquifer depletion** **Reduced water pollution** **Reduced land contamination** **Improved biodiversity and ecosystems** **Maintained and increased green space** Reduced environmental impacts through associated awareness Increased biodiversity and ecosystem services **Effective/uninterrupted water collection and security** **Erosion control**

Other resources	Ecosystem services valuation techniques were used in order to include in the assessment the benefits provided by nature in related measures, such as SUDS.
Relevant info.	Additional information on risk assessment is displayed in https://csis.myclimateservice.eu/studies

RISK REDUCTION ASSESSMENT

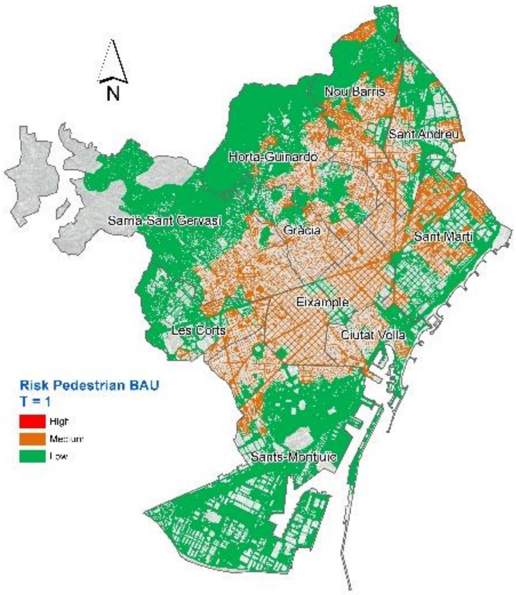
A detailed risk assessment (see Chapter 3) was carried out to compare BAU scenarios with adaptation scenarios. The last ones consist in different combinations of adaptation measures. This allowed to understand the potential for risk reduction under different settings, including climate scenarios. Following there is an example of the hazard maps developed to display the risk variation on pedestrian stability under different climate conditions for different return periods (T1, T10 and T500) and adaptation scenarios (BAU, and with structural and SUDS measures implemented). Additional information on risk assessment impacts may be visualised in https://csis.myclimateservice.eu/studies.

RISK-RELATED MAPS FOR PEDESTRIAN STABILITY

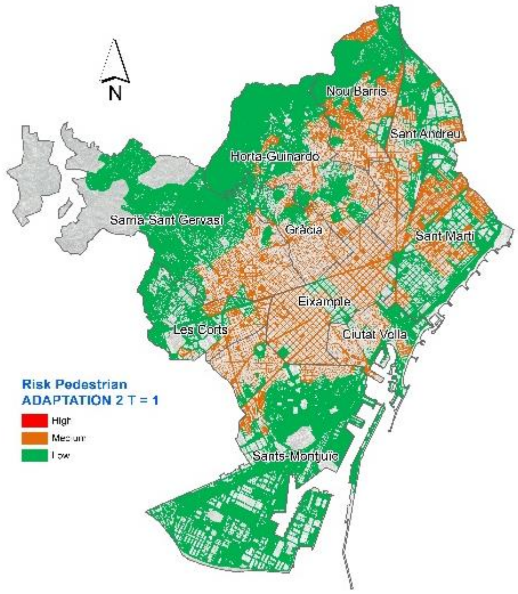
Risk map for rainfall induced flooding

Most probable scenario (T1)

BAU SCENARIO



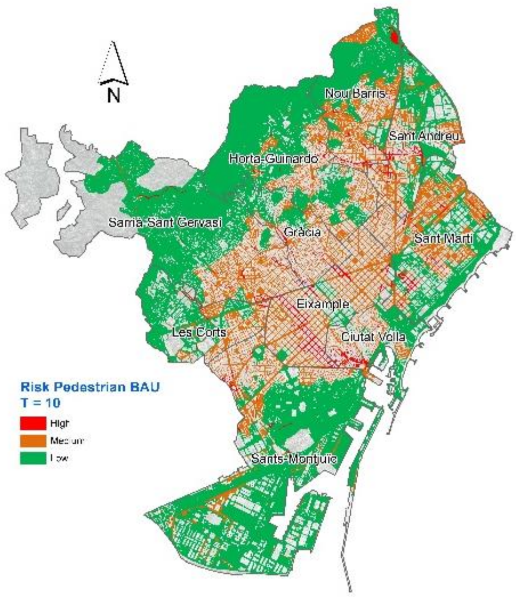
STRUCTURAL MEASURES + SUDs MEASURES



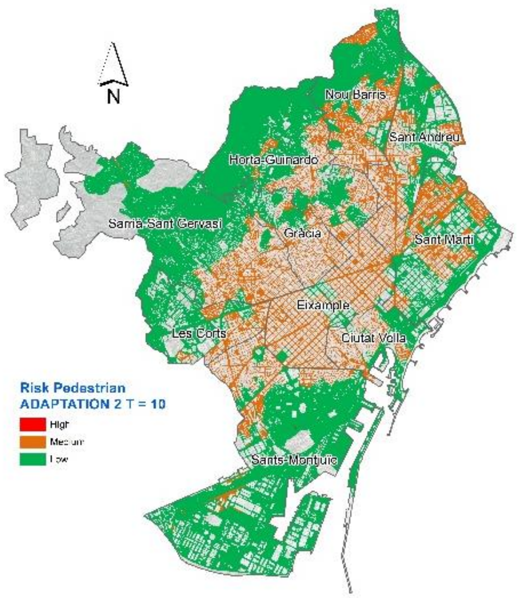
Risk map for rainfall induced flooding

Design scenario (T10)

BAU SCENARIO



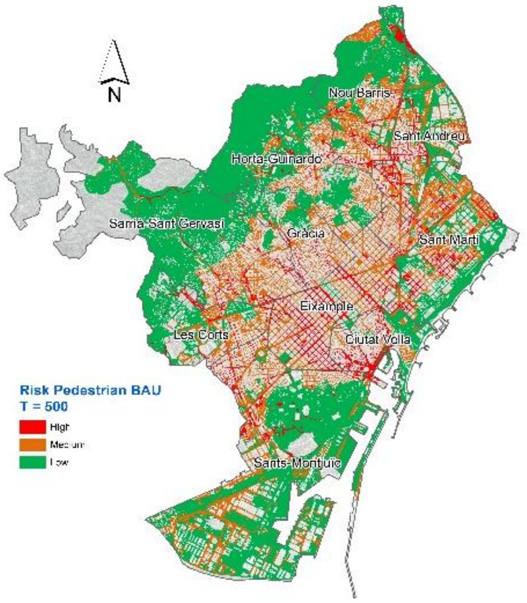
STRUCTURAL MEASURES + SUDs MEASURES



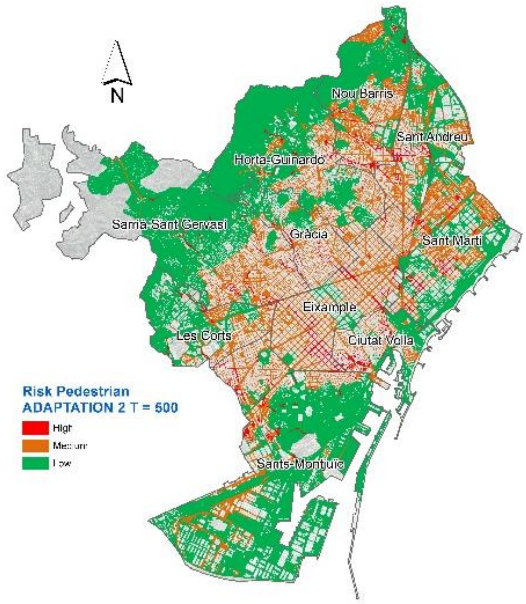
Risk map for rainfall induced flooding

Most severe scenario (T500)

BAU SCENARIO



STRUCTURAL MEASURES + SUDs MEASURES



S002 – Environmental improvement of receiving water bodies

DESCRIPTION

Measures to decrease the impacts of combined sewer overflows (CSOs) by: limiting the entrance of stormwater into the sewer system, increasing the retention capacity of the urban drainage/sanitation system during storm events or anticipating preventive actions through early warning.

During storm events, in combined sewer systems, the hydraulic capacity of the sewer system is exceeded and some overflows of untreated water (combination of stormwater and wastewater) occur, causing environmental impacts on receiving waters.

Typology: NBS; early warning system; Infrastructural construction or rehabilitation

TOWS perspective: SO

	O	T
S	**SO**	ST
W	WO	WT

Implementation: New

Timeline: 2100

Hazard: Combined sewer overflows

Variables: Rainfall, seawater pollution

Institution: Aquatec

Players: Barcelona City Council

Services:

Urban drainage

Wastewater treatment

Beaches

Costs:

Short-term: 502 000 000 €

Mid-term: 8 000 000 €

MEASURES:

SUDS (green roofs, infiltration trenches, detention basins)
Storage tanks for CSO prevention
Improvements of the capacity of sewer interceptor and WWTP
Early Warning System
End of pipe CSO treatment

CO-BENEFITS: Relevant contribution | Slight contribution

ECONOMIC	SOCIAL	ENVIRONMENTAL
Cost savings	**Reduced health impacts**	**Improved water quantity**
Job creation	Reduced mortality from diseases	**Reduced water pollution**
Increased economic production	**Enhanced public amenity**	**Reduced land contamination**
Increased property value	Reduced number of householders, businesses forced from homes, places of work	**Improved biodiversity and ecosystems**
		Maintained and increased green space
		Increased biodiversity and ecosystem services

	Reduced impacts on vulnerable groups	**Effective/uninterrupted water collection and security**

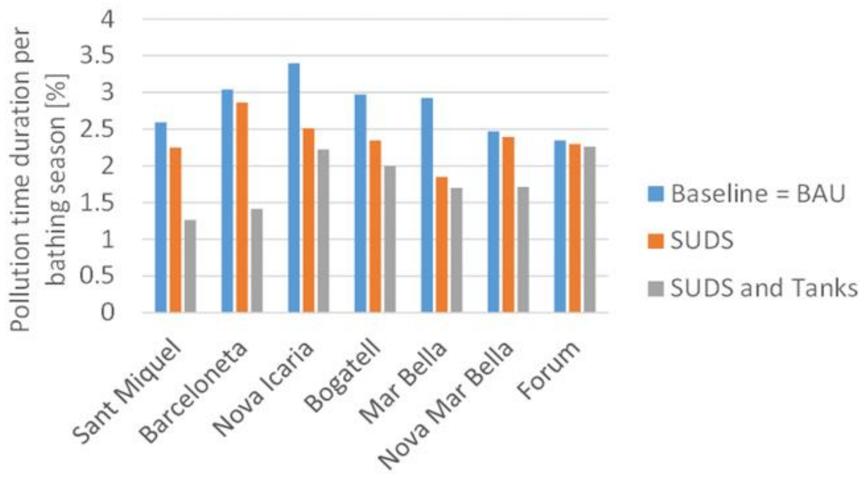
Other resources	Urban drainage and seawater quality models were developed for the assessment of pollutant hazard.
Relevant info.	Results of the water pollution model were given in hours of insufficient water quality. Indirect damage referred to potential business losses due to beach closure.

RISK ASSESSMENT

For the CSO spills reduction strategy, two detailed assessments were carried out to understand the impacts of the adaptation scenarios. Direct impacts on human health, are represented through the indicator of insufficient bathing quality time (in hours) during the bathing season. Specifically, pollutant hazard was assessed through a coupled urban drainage and seawater quality model that was developed, calibrated, and validated based on local observations.

Percentage of time during a bathing season with insufficient bathing water quality

Baseline and two adaptation scenarios: SUDS and combination of SUDS and detention tanks



Indirect impacts on business are represented by the potential economic losses as a consequence of closing related businesses (water sports, restaurants by the seaside, and fishing activities) due to bathing waters contamination. Estimations were obtained using revenues of the affected sectors and neighbourhoods where CSO spills occur. Indirect damage estimations on coastal economy under current scenario and adaptation scenarios proposed are presented next.

Adaptation scenario	Nº days per season of unacceptable bathing water quality	Estimated indirect damages per season	
		€/year	% variation
Baseline	3.22	1 643 260	-
SUDS	2.69	1 372 780	-16%
SUDS + Detention tanks	2.05	1 046 170	-36%

S003 – Not a single drop wasted. Alternative water resources

DESCRIPTION

Use of alternative water resources such as regenerated water, groundwater, greywater, rainwater or desalinated water to increase water availability and guarantee water supply during critical situations such as drought or turbidity episodes in water treatment and supply processes.

The higher frequency of drought episodes due to climate change makes municipalities to analyse alternative water resources to guarantee water supply. These alternatives must be optimized to each region to ensure its sustainability.

Typology: Alternative water sources; Infrastructural construction or rehabilitation

TOWS perspective: ST

	O	T
S	SO	**ST**
W	WO	WT

Implementation: New

Timeline: 2030

Hazard: Drought

Variables: Rainfall, water supply interruption

Institution: Aquatec

Players: Barcelona City Council and Catalan Water Agency

Services:

Water sourcing Water treatment Water supply
Water transportation

Costs:

Short-term: 82 000 000 € Mid-term: 82 000 000 €

MEASURES:

1. Optimize desalinization plant production
2. Promote the use of grey water in new housing developments
3. Continue reducing leakage in water distribution networks
4. Study the feasibility of producing regenerated water at the Besòs WWTP to feed the Besòs aquifer, to maintain the river's ecological flows and feed the purification plant
5. Exploit the Besòs aquifer resource as potable water and build a purification plant
6. Utilise regenerated water from the River Llobregat for the industrial uses of the Zona Franca Consortium and for recharging the aquifer
7. Promote rainwater collection and its reuse in buildings
8. Inter-basins connections
9. Increase the water cost for specific uses

CO-BENEFITS: Relevant contribution | Slight contribution

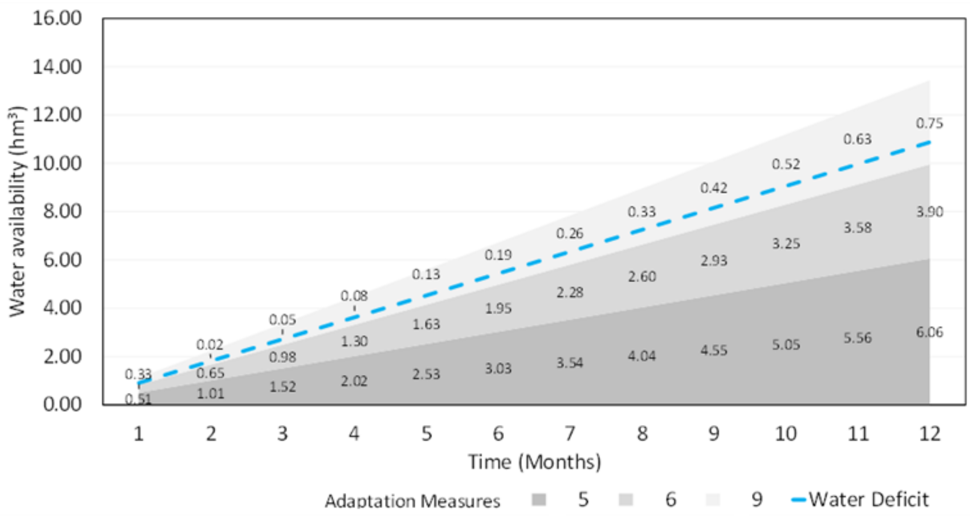
ECONOMIC	SOCIAL	ENVIRONMENTAL
Cost savings Reduced energy losses Job creation Possible reduction in prices Increased labour productivity Increased economic production Increased property values	Reduced health impacts Enhanced public amenity	**Improved water quantity** Reduced aquifer depletion Reduced land contamination Improved biodiversity and ecosystems Maintained and increased green space Increased biodiversity and ecosystem services Effective/uninterrupted water collection and security

Other resources	Water availability assessment

Relevant info.

Water supply potential under an adaptation scenario (AS) to handle drought

AS: Combination of measures 5, 6 and 9

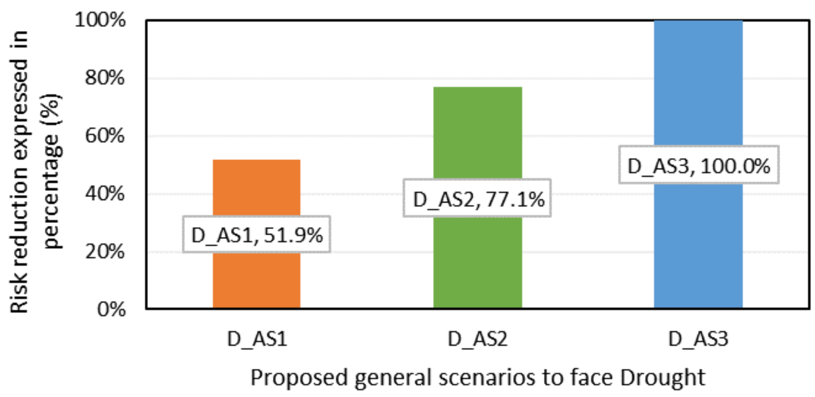


Proposed adaptation scenarios to deal with drought impacts

Strategy name	Adaptation Scenarios (AS)	Prioritization		
		Sectors impact studied	Risk reduction (time)	Cost (€)
Not a single drop wasted	AS1: Wastewater exploitation through regeneration processes, adaptation measures (4+6)	-	51.9%	1 643 260
	AS2: Integrated use of alternative resources + Optimization of water supply network, adaptation measures (1+2+3+5+7+9)	Social	77.1%	✓
	AS3: Water conveyance from another basin, adaptation measure (8)	-	100.0%	-

The capacity of the adaptation measures to close the gap between water demand and supply during the scarcity period (1 month) is represented as a percentage of the time that they are able to achieve. The maximum monthly potential per adaptation scenario corresponds to the maximum yearly potential divided by 12 months. It gives the water availability per month, which is the total yearly time of the drought period estimated herein. This monthly value over the total water deficit (i.e. 10.88 hm^3/year) provides the percentage of risk reduction. These adaptation scenarios are compared with the BAU scenario (water demand affected by future hydrological conditions), and risk reduction is identified as the percentage of time that the adaptation scenario replenishes this demand, as shown in the Table and following Figure.

Risk reduction expressed in the percentage of time (%) that the proposed adaptation scenario would cope with Drought



S004 – Guarantee security of services provision

DESCRIPTION

Measures intended to increase the resilience of urban services to critical events such as the ones caused by climate change. It includes a city resilience diagnosis) development of the resilience action plan (with its corresponding strategies to the city and its urban services resilience) and resilience management centre to rapidly respond during critical situations.

During critical situations such as the events caused by climate change (floods, droughts, sea level rise, etc.) the different urban services are affected with direct impacts on the society and its environment.

Typology: Planning	**TOWS perspective:** SO, WT
Implementation: New	**Timeline:** 2028
Hazard: Flooding, droughts, CSO, water service supply	**Variables:** Resilience, rainfall, environmental quality
Institution: Aquatec	**Players:** Barcelona City Council and urban services suppliers

Services:

Water	Wastewater	Stormwater
Waste	Energy	Mobility

Costs:

Short-term: 440 000 €   Mid-term: 120 000 €

MEASURES:

Perform a Resilience Diagnosis of the city by using RESCCUE methodology and tools

Elaborate a Resilience Action Plan for the city according to RESCCUE methodology

To locate a control centre and a situation room

CO-BENEFITS: Relevant contribution | Slight contribution

ECONOMIC	SOCIAL	ENVIRONMENTAL
Cost savings	Reduced mortality impacts	Improved air quality
Reduced energy losses	**Reduced health impacts**	Improved water quantity
Job creation	Reduced mortality from diseases	Reduced aquifer depletion
Possible reduction in prices	Enhanced public amenity	Reduced water pollution
Increased labour productivity	Reduced impacts on vulnerable groups	Reduced land contamination
Increased economic production	Reduced number of householders, businesses forced from homes, places of work	Improved biodiversity and ecosystems
Increased property values		Maintained and increased green space
		Reduced environmental impacts through associated awareness
		Increased biodiversity and ecosystem services

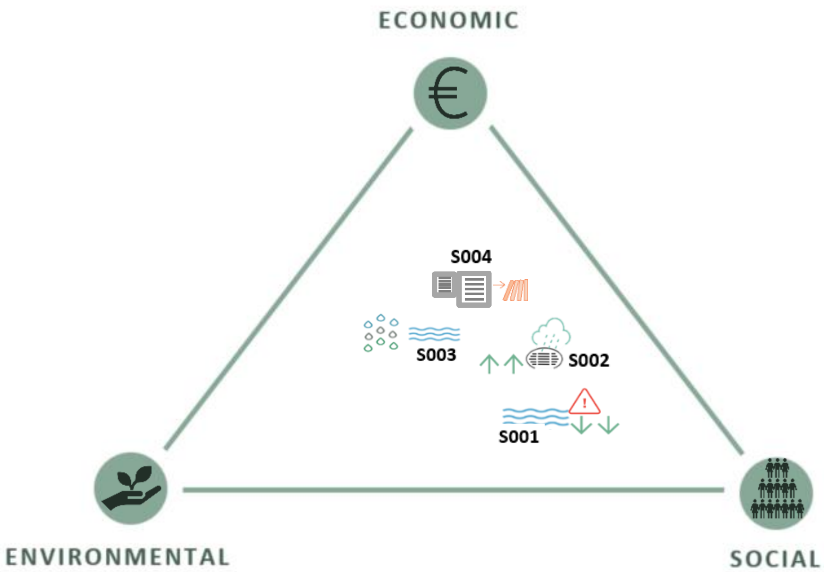
		Effective/uninterrupted water collection and security Erosion control Effective/uninterrupted water collection and security

Other resources	Existing Climate Adaptation Plan of the city
Relevant info. Effects on other services	Social, Transport, High Speed Roads, Streets, Landline Telephone, Mobile Telephone, Internet, Civil Protection, Fire, Medical Emergency, Local Police, Public Health, Green Infrastructures, Beaches, Schools, Natural Gas

CO-BENEFITS AND IMPACT ON RESILIENCE OBJECTIVES

CO-BENEFITS OF IDENTIFIED STRATEGIES

The identified strategies have several co-benefits, namely within the economic, social and environmental components. Within each component, the expected co-benefits contribute differently in each strategy. Depending on the relative contributions, the location of the strategy in the scheme below varies.



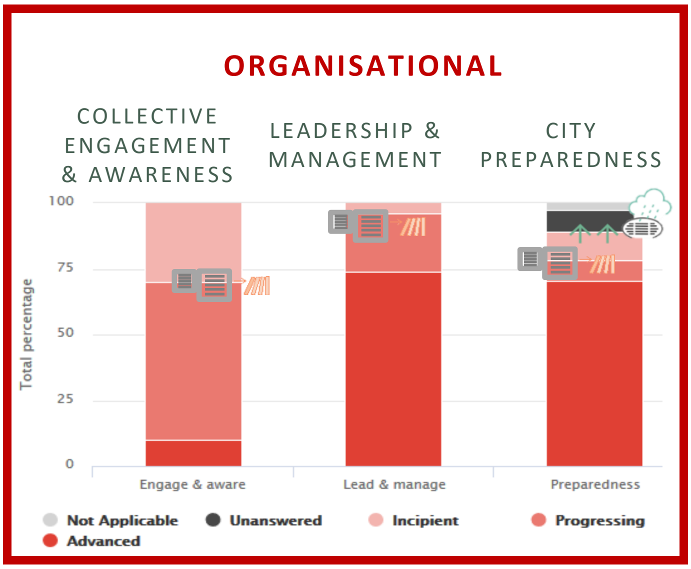
Strategy S001 – “Flood impacts reduction in a context of climate change” is more related to the social co-benefits and it also contributes to environmental aspects. Strategy S002 – “Environmental improvement of receiving water bodies” also relates mainly to the social co-benefits while contributing to economic aspects. Strategy S003 – “Not a single drop wasted. Alternative water resources” is more related to the economic aspects, considering also contribution to the environmental aspects. Strategy S004 “Guarantee security of services provision” is mainly related to the economic aspects while it also contributes in a balanced way to both social and environmental aspects.

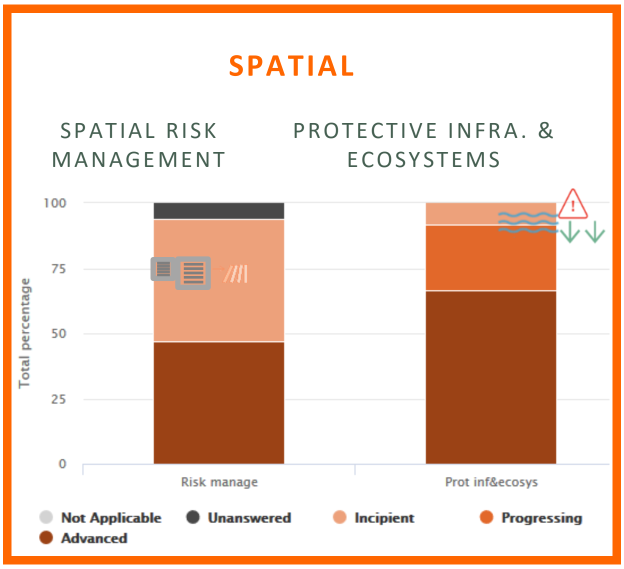
IMPACT OF IDENTIFIED STRATEGIES ON EACH RESILIENCE DIMENSION

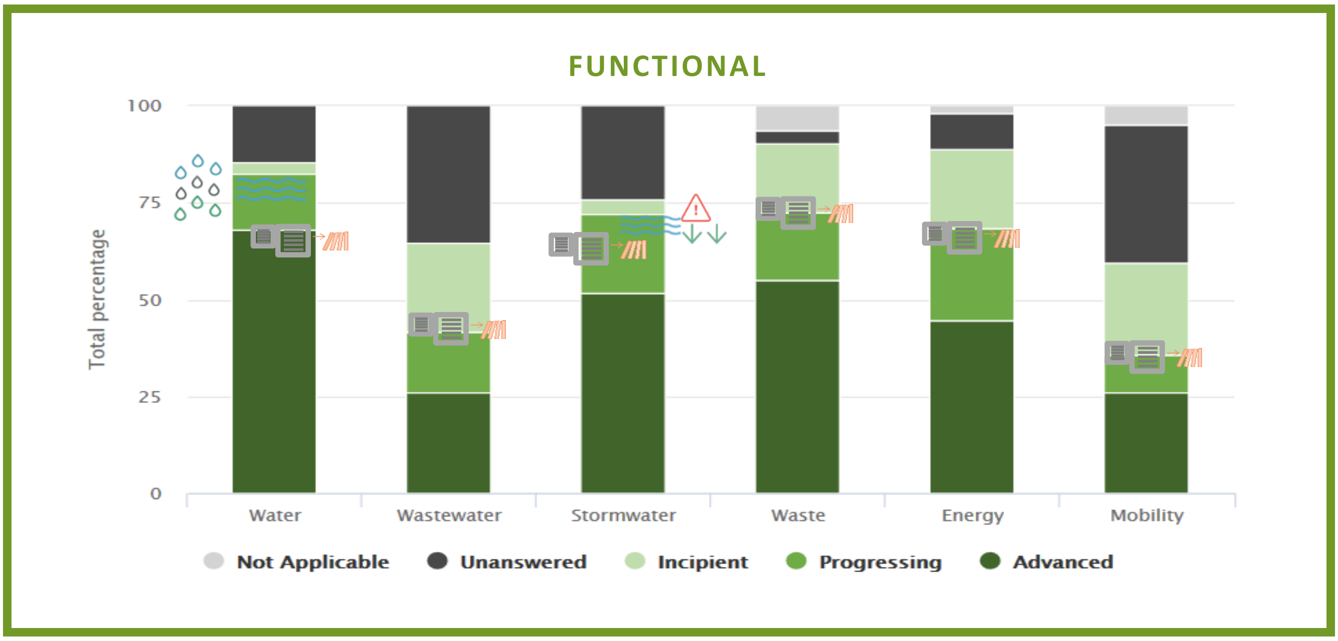
The impact of the identified strategies on the RAF resilience objectives for Barcelona is highly significant. The identified strategies address all the resilience dimensions and objectives as well as all services considered in this RAP.

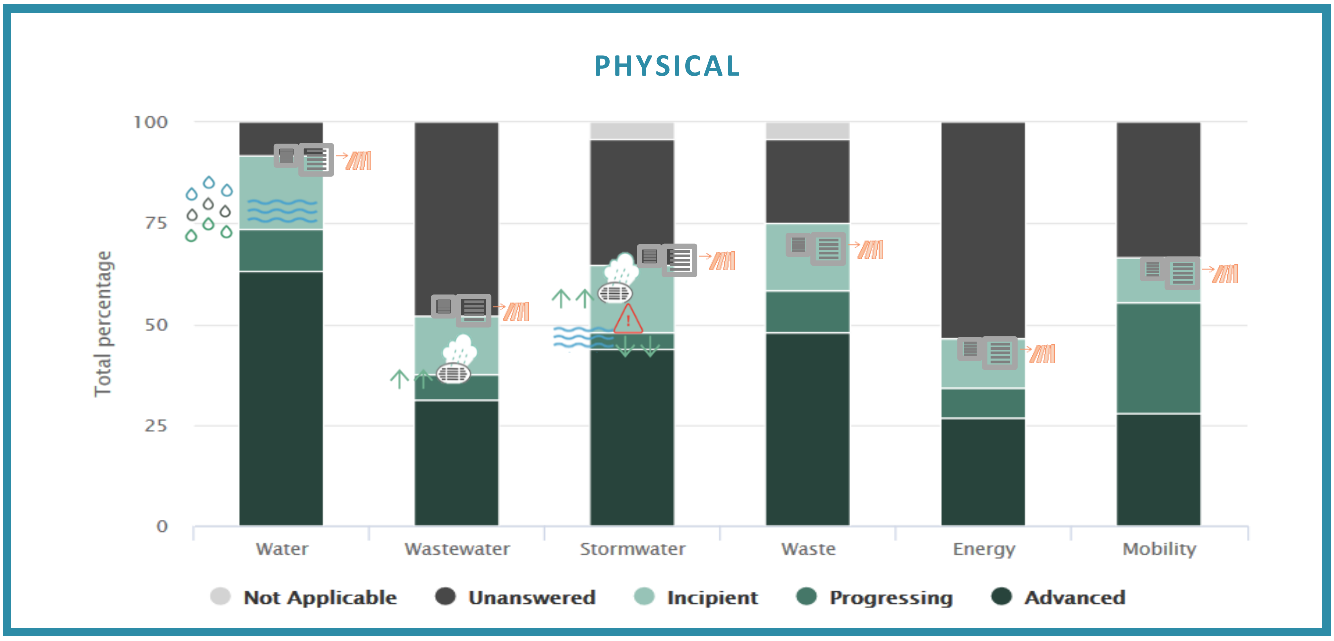
IMPACT OF IDENTIFIED STRATEGIES ON THE CITY’S RESILIENCE OBJECTIVES, FOR EACH RESILIENCE DIMENSION

STRATEGIES	
1. FLOOD IMPACTS REDUCTION IN A CONTEXT OF CLIMATE CHANGE	2. ENVIRONMENTAL IMPROVEMENT OF RECEIVING WATER BODIES
3. NOT A SINGLE DROP WASTED. ALTERNATIVE WATER RESOURCES	4. GUARANTEE SECURITY OF SERVICES PROVISION


ORGANISATIONAL
COLLECTIVE ENGAGEMENT & AWARENESS
LEADERSHIP & MANAGEMENT
CITY PREPAREDNESS
Total percentage
100
75
50
25
0
Engage & aware
Lead & manage
Preparedness
Not Applicable
Unanswered
Incipient
Progressing
Advanced


SPATIAL
SPATIAL RISK MANAGEMENT
PROTECTIVE INFRA. & ECOSYSTEMS
Total percentage
100
75
50
25
0
Risk manage
Prot inf&ecosys
Not Applicable
Unanswered
Incipient
Progressing
Advanced


FUNCTIONAL
Total percentage
100
75
50
25
0
Water
Wastewater
Stormwater
Waste
Energy
Mobility
Not Applicable
Unanswered
Incipient
Progressing
Advanced


PHYSICAL
Total percentage
100
75
50
25
0
Water
Wastewater
Stormwater
Waste
Energy
Mobility
Not Applicable
Unanswered
Incipient
Progressing
Advanced

FLOOD IMPACTS REDUCTION IN A CONTEXT OF CC

Strategy 1 - "Flood impacts reduction in a context of climate change" will contribute to improve spatial resilience, namely regarding the protective infrastructures and ecosystems services, and to improve stormwater service and respective infrastructure preparedness.

ENVIRONMENTAL IMPROVEMENT OF RECEIVING WATER BODIES

Strategy 2 - "Environmental improvement of receiving water bodies" will contribute to improve organisational resilience, regarding the city preparedness, and the physical resilience regarding wastewater and stormwater infrastructures.

NOT A SINGLE DROP WASTED. ALTERNATIVE WATER RESOURCES

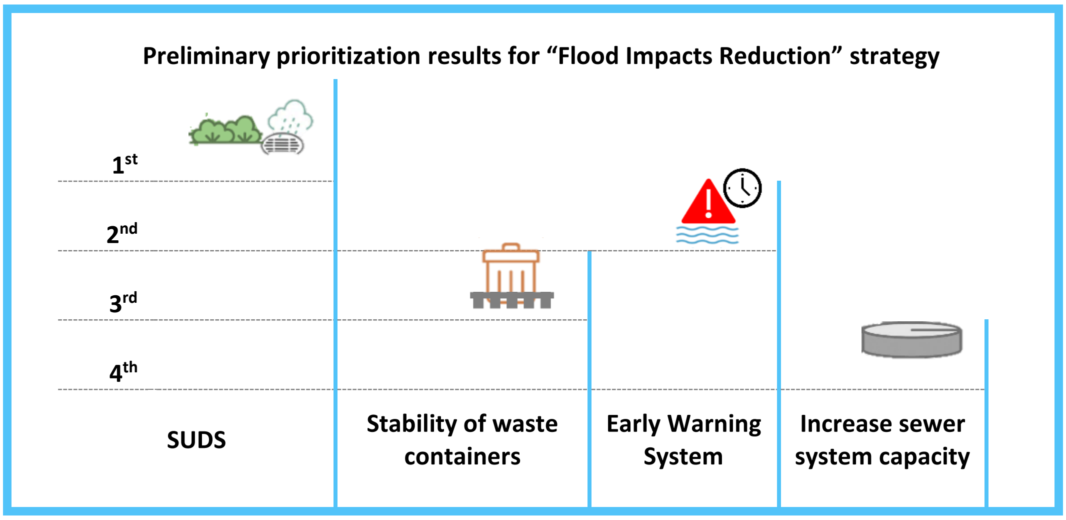
Strategy 3 - "Not a single drop wasted. Alternative water resources" is directed to the functional and physical resilience dimensions of the water service.

GUARANTEE SECURITY OF SERVICES PROVISION

Strategy 4 - "Guarantee security of services provision" is related to all services regarding functional and physical dimensions and will also contribute to improve all objectives of the organisational resilience (collective engagement and awareness, leadership and management and city preparedness), as well as the spatial dimension regarding spatial risk management.

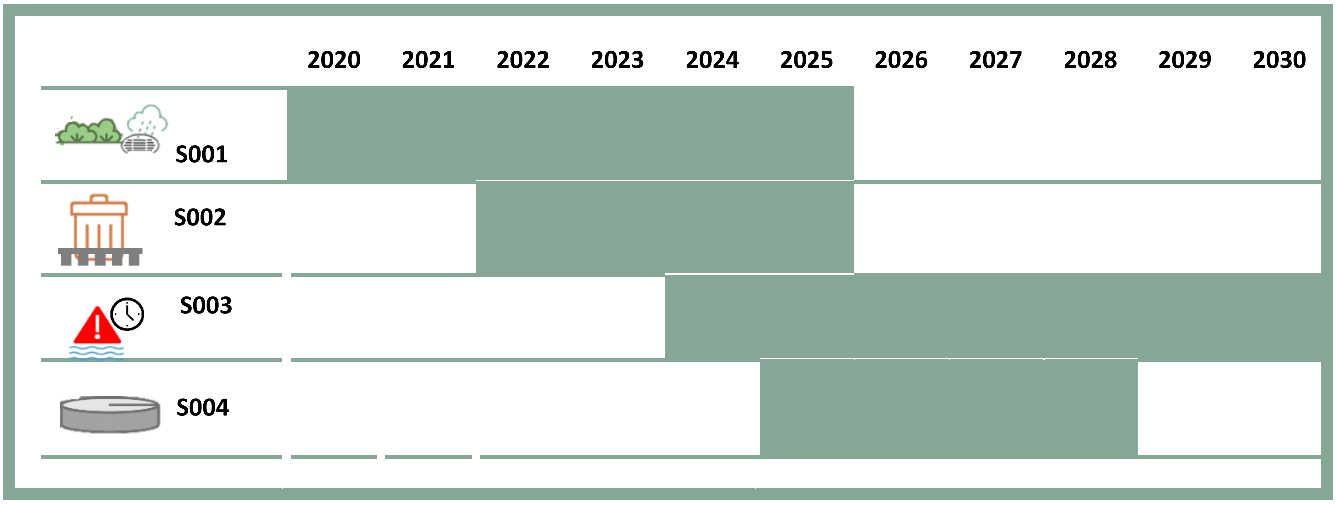
PRIORITIZATION

Prioritization of measures is mandatory whenever resources are limited or when different strategies compete for the same resources. As Barcelona is committed to implement the strategies "Flood impacts reduction in a context of climate change", "Environmental improvement of receiving water bodies" and "Not a single drop wasted. Alternative water resources", the measures contained in these strategies were considered for prioritization following the method identified in the planning process. The prioritization method was not applied to the "Guarantee security of services supply" strategy. The prioritization method consisted in 2 stages. The first stage – the preliminary assessment – used Cost-Effectiveness Analysis (CEA), scores of co-benefits and risk assessment to assess the sets of measures contained in each strategy. To provide more detailed information to decision-makers, a second stage assessment was carried out, using detailed risk assessment, Cost-Benefit Analysis (CBA). In addition, after conversations with stakeholders, measures were grouped in scenarios, in order to assess structural measures in different areas of the city and different prioritization criteria were used, namely avoided damage, net costs and risk reduction criteria. These inputs were extracted from the RESCCUE web-based platform for strategies and measures and from the projects' outcomes. Full methodology and results can be consulted in Guerrero-Hidalga et al. (2020) and Evans et al. (2020).



As an example, based on the results obtained for the first strategy assessed - "Flood impacts reduction in a context of climate change" - Barcelona considered to firstly implement the measure SUDS, followed by the fixation pieces to provide stability of waste containers, then the Early Warning System and lastly, to increase the sewer system capacity. The same exercise was carried out for the rest of the strategies, providing the city council with an index that considers more than only economic factors.

PROPOSED IMPLEMENTATION PLAN



6. RAP MONITORING AND REVIEW PROCESS

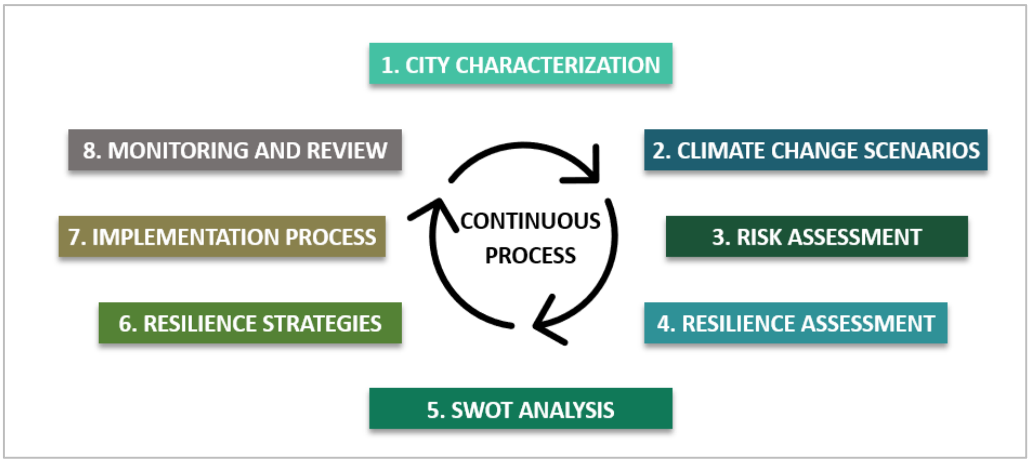
MONITORING

In order to trace the progress of the resilience strategies implementation, of resilience changes and to identify early deviations that may require corrective action, the RAP monitoring is planned as follows.

Periodicity	2 years
Responsibility	Andoni Gonzalez, Barcelona CC
Activities	Trace strategies implementation
	Acknowledge resilience improvements or setbacks
	Identify unexpected facts with impact on resilience

REVIEW

To continuously ensure the city resilience considering the city's dynamics, the RAP review is a crucial step requiring to review all the steps of the planning process, from step 1. In this plan some of the challenges within its scope that were identified in the SWOT are still to be addressed in the future, namely related to data gaps weaknesses identified in the RAF assessment.



Periodicity	10 years
Responsibility	Andoni Gonzalez, Barcelona CC
Activities	Analyse monitoring results
	Re-think SWOT
	Re-think TOWS
	Re-think previously identified and postponed strategies
	Evaluate updated knowledge on climate change

7. FINAL REMARKS

MAIN BENEFITS AND FUTURE CHALLENGES

The RESCCUE Project has brought a substantial improvement in the knowledge of the effects of climate change on the city of Barcelona. The city already had its own Climate Plan for the adaptation and mitigation of climate change since 2018, which was enhanced by the Climate Emergency Declaration in early 2020, both plans set the roadmap for the city to achieve a better future for all its inhabitants. Through different stages, RESCCUE has been able to provide new information in areas as important as the development of new climate projections which confirmed the trends of climate change presented in the Climate Plan, presenting a future for Barcelona where the effects of increased heat will affect it more intensely. Climate projections developed in RESCCUE show an increase of the medium temperature for the most probable and the most severe scenarios; by the end of the century, this increase may be boosted to 3,8 ºC and 5,1 ºC for the most probable and most severe scenarios, respectively, reaching +8,9 ºC in the worst case under analysis. Also, heatwaves will be triplicated and their duration in days will go from 30 to 42 days per year, depending on the considered scenario. If the expected increase of high temperatures intensity is added to those events, heatwaves become the main climate risk that Barcelona will face in the future. Regarding extreme rainfall events, those will increase its actual intensity, by 10 to 25% depending on the considered scenario, a fact that will increase the risk of suffering more severe pluvial floods. But improving knowledge about the future climate has also helped to develop new vulnerability analysis and new risk assessments through the development of defined sectorial models for the different hazards that may affect the city in the coming years. As RESCCUE project focuses on water related events, the main impacts analysed due to urban flooding show an increase of 30% in the city areas with high flood risk exposure, affecting main urban services as traffic, energy, waste and also the risks posed to city's inhabitants and assets, namely, risks related to pedestrians, vehicles and properties.

Those sectorial models developed facilitate the knowledge of those areas most exposed to hazards and sets off the basis for the definition of adaptation strategies to climate change. These strategies complement the climate action of Barcelona, focusing on those most important aspects facilitated through the prioritization methodology that allows the development of robust adaptation strategies which have been presented in this RAP to be implemented in the following years in the city of Barcelona. The proper implementation of the developed adaptation strategies will effectively reduce the risk exposure of the city to climate hazards, as shown in chapter 5, while at the same time mainly economic, environmental and social co-benefits are enhanced, contributing to the improvement of the climate action of Barcelona.

The following figure shows the main benefits and future challenges derived from the elaboration of the Barcelona's RAP.

BENEFITS	FUTURE CHALLENGES
• Current situation evaluation and Baseline setting. • Definition of multisectoral goals, indicators and targets • City resilience monitoring based on climatic scenarios • Increase of Barcelona stakeholders' involvement for strategies implementation • Dynamic process of continuous improvement • Deepen the knowledge of city services resilience	• Implement the strategies according to the plan • Address new data and information • Include other hazards • Monitor and review the plan • Development of actions to fill data gaps • Redefinition or adaptation of indicators to city's metrics

Acknowledgements

The authors would like to thank all the RESCCUE partners, as well as to all other organisations that collaborated directly or indirectly, mainly through the participation on local workshops and meetings. The works developed constitute an important step-up to the resilience assessment and improvement and represent a strong effort from all the involved stakeholders to achieve a better common future for the city of Barcelona and its citizens.

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Clarity portal, https://csis.myclimateservice.eu/studies

RESCCUE project, www.resccue.eu

RESCCUE tool kit, www.toolkit.resccue.eu

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Barcelona City Council

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RESCCUE

RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

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