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RESCCUE

RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

D2.1

IDENTIFICATION OF POTENTIAL HAZARD FOR URBAN STRATEGIC SERVICES PRODUCED BY EXTREME EVENTS

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Document history

DATE	VERSION	AUTHOR	COMMENTS
12/01/2017	V1	Salvador Vela	Pending Barcelona Telecommunications section.
28/02/2017	V2	Salvador Vela	Internal and External reviews have been included
30/05/2017	V3	Beniamino Russo	New edition according to standardized format
15/07/2017	V4	Patrick Goodey	New details about Bristol RS flood prone areas. New features about urban drainage sectorial model
06/04/2018	V5	Salvador Vela Beniamino Russo	Further amendments based on EC feedback added

1. **Changes with respect to the DoA**
   This deliverable has been considered as Public, as it was considered in the original DoA.

2. **Dissemination and uptake**
   Public

3. **Short Summary of results (<250 words)**
   Deliverable 2.1 "Identification of potential hazard for urban strategic services produced by extreme events" has been developed by Cetaqua within task 2.1 of WP2 "Hazards Assessment for urban services operation". For each one of the research sites of the RESCCUE Project (Lisbon, Barcelona and Bristol), a current state of urban water system and others important urban services (Energy, Transport, Waste and Telecommunications) has been exposed in detail, along with the other strategic urban services. The analysis of the research sites begins with an accurate characterization of the sites based on their main features, like climate, morphology, population, land use, urban systems and socio-economic activities developed in them. Moreover, the deliverable describe the main characteristics of strategic urban services and infrastructures and their behavior during extreme climate events. The main climate effects and natural hazards affecting strategic services and critical infrastructures are also underlined and specific matrices linking weather variables and critical services / infrastructures have been elaborated. These matrices have been used in the WP4 for the resilience holistic assessment and the interdependency analysis among strategic urban services and critical infrastructures.

4. **Evidence of accomplishment**
   This report

Table of Contents

Summary of tables

Summary of figures

RESCCUE
RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

1 Introduction and RESCCUE general framework

The present deliverable develops the first task of second Work Package (following WP2) dealing with the identification of potential hazards for strategic urban services as a consequence of climate change pressure. The WP2 will cover a complete hazard assessment for urban services operation for current and future scenarios.

The deliverable has been elaborated in the wide context of the RESCCUE Project. This Project concerns urban resilience to cope with climate change and, specifically, the potential impacts of extreme events on several urban services related to water cycle, transport, waste and electricity. The project will provide a framework enabling city resilience assessment, planning and urban services management.

According to this point of view, impacts caused by extreme events, as strong rainfalls, droughts, flooding, storm surge, will be characterized through detailed hazard (WP2) and risk (WP3) assessments by detailed analysis and tools. In this kind of framework, RESCCUE WP2 assumes a relevant importance in assess and reducing extreme hazards, with special regard to flooding that is the common threat of the three RESCCUE research sites.

Therefore RESCCUE assumes a significant importance in increasing urban resilience to a wide range of challenges, which can have physical, economic or social origin, being the natural ones, the treat of main concern in RESCCUE. In particular, this objective has to be achieved by implementing new tools and models, suitable for different kind of cities, characterized by several climate conditions and pressures. One of the most important contribution of the Project is the analysis of the relations among the several urban services and the impacts that climate change will generate on each one, giving particular relevance to effects of a failure in one sector and consequently also on the other ones. Specifically, RESCCUE aims to improve urban resilience of our cities through a set of models and software tools that, firstly, assess climate change impacts in several strategic urban sectors like water cycle (water treatment, water supply, urban drainage and waste water treatment), transport, energy supply, and solid waste, and then interconnects them to assess urban resilience for the current state and a wide range of potential future scenarios.

In this framework, the **detailed knowledge of the behaviour of our urban systems** during extreme climate events represents the initial basic piece of the whole process of the city resilience assessment. This site characterization in terms of description of the main features, potential hazards and vulnerabilities of the strategic urban services in the three RESCCUE city is the main objective of Task 2.1 and, therefore, of the present Deliverable 2.1. In this context, the use of **detailed models and software tools** (likely known as sectorial model within the RESCCUE project) is essential to analyse the **behaviour and the response of strategic services and critical infrastructures with respect to specific pressures and drivers related to climate change**, that are the aims of tasks 2.2 and 2.3 respectively. Moreover the outputs of these sectorial models will be used to **assess hazard (Task 2.2), vulnerability and risk levels (Task 3.4) related to the above mentioned pressures/drivers for current and future scenarios where a large set of measures and strategies will be simulated and evaluated** in terms of impacts reduction.

Once the detailed knowledge of each urban service has been acquired through available data, past experiences and simulation results, then **the interdependencies between them and the**

cascade effects due to failures or extreme climate events can be studied. This second step in RESCCUE is treated by two different approaches characterized by a different level of detail:

> In the **WP2 and WP3** (respectively focused on multi-hazard and multi-risk assessment**) the analysis of certain impact events could be achieved via the use of loosely coupled models and tools (integrated models)**. In this case, **adaptation strategies and measures** will be proposed and prioritized on the basis of hazard and risk reduction but, also, **through multi-criteria analysis providing an overview of other kinds of co-benefits** (like economic, social and environmental targets) (**WP5**).
>
> In **WP4 by using a holistic resilience assessment tool (HAZUR**), the **relations and the cascade effects among the different urban services can be analysed in the three RESCCUE research sites during crisis events**. In this case, adaptation measures and strategies will be focused on the recovery of the normal functioning of the city and, specifically, of its strategic urban services and infrastructures. This concept will be expressed by the concept of recovery time and the efficiency of the measures and strategies, in terms of decrease of recovery tine (**WP4 and WP5**).

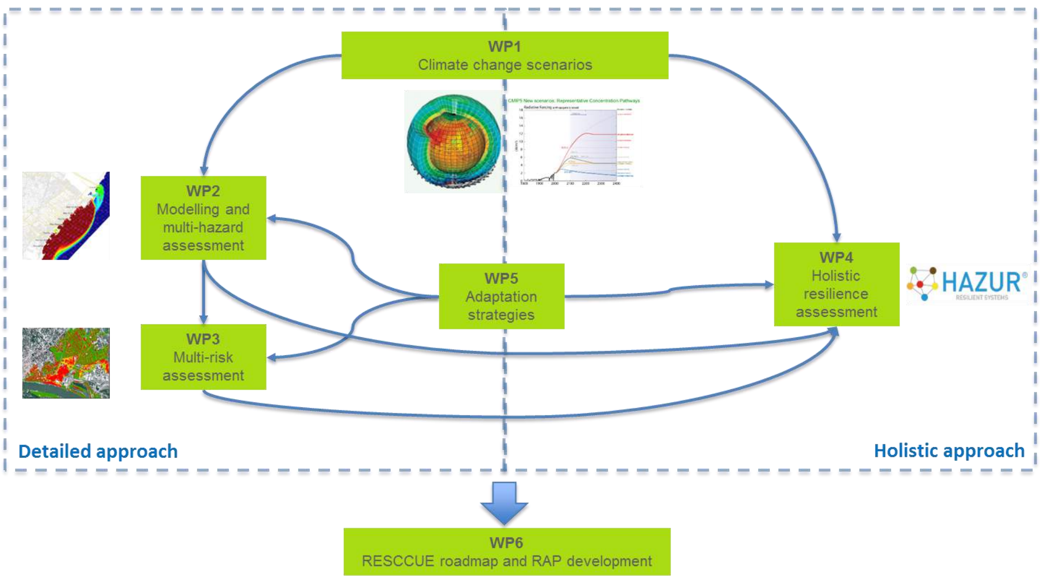


Figure 1: Summary of RESCCUE framework

The present deliverable deals with relations between climate variables and urban systems response. Mainly in this part of the project (WP2), potential hazards that characterize urban system have to be analysed and estimated in both cases of current and future scenarios. The development of hazard assessment models and tools for the different urban services selected in RESSCUE (defined as sectorial models) constitute one of the main important outputs of this work package. They allow to estimate the potential hazard related to several climate variables for current and future scenarios provided by WP1.

Within this global context**, Task 2.1 aims to identify the potential hazards for urban services in correspondence with potential climate change variable and pressures**.

Figure 2: Framework of the Task 2.1

In order to fulfil this task, previously it is included a brief literary review in which current knowledge about relation between climate variables and their impacts on cities has been explored. Then the analysis and evaluations of the three RESCCUE research sites, Lisbon, Bristol and Barcelona, have been reported and analysed in detail in this deliverable.

For each one of these research sites, a current state of urban water system has been exposed, along with the other strategic urban services. This description has considered the main feature of the services, the main hazards potentially affecting them, the vulnerability of these systems to failure (although vulnerability and risk assessments will be performed in Task 3.4) and finally the duplicity of features or redundancy measures to reduce hazard and impacts generated by extreme events.

Specifically, the analysis of the research sites begins with an accurate characterization of the sites based on their main features, like climate, morphology, population, land use, urban systems and socio-economic activities developed in them.

The deliverable focuses, with special devotion, on water cycle, by describing carefully all activities involved in that: water abstraction, water treatment, water distribution, urban drainage and waste water treatment.

The other important urban services follow. Electricity, Transport and Waste are common urban services analysed in all the RESCCUE research sites characterization while, for the only city of Barcelona, the additional telecommunication sector has been involved into the analysis. Each research site has been analysed according to their interests and involvement with the specifics public services.

In the end, potential interdependencies among urban services have been described focusing on the state of the sectorial models related to the urban services. This identification is the previous step in order to be completed by next tasks of the WP2 and WP3, through the development of integrated sectorial models and the impact assessment obtained by them, or WP4 through Hazur tool and the holistic approach.

2 Hazard and multi-hazard assessment in the framework of RESCCUE. Literature review on potential failures of urban systems

In the framework of WP2 of RESCCUE project, detailed sectorial models will be used to asses hazard for specific urban services and, in some cases, multi-hazards will be assessed using the integration of sectorial models obtaining outputs regarding several hazards (i.e. the use of drainage and marine models will provide hazard assessment concerning flooding but also CSOs in bathing water).

In any case, in order to achieve a complete risk assessment, it is necessary to take into account the **nature of the hazard** and the **factors** that affect the consequences (impacts). The extent of consequences are a complex function of the exposure, the susceptibilities of the elements exposed and the resilience of a system: *i)* the degree of exposure (measured by the number of the elements at risk or by their value), *ii)* the vulnerability of the system referring to the propensity of exposed elements to suffer adverse effects (damages) as a consequence of certain level or characteristic of the hazardous event (measured by the susceptibility of those elements to the risk, originated by their vulnerability) and on *iii)* the system resilience (coping and recovery capacity) (Rocha et al., 2017).

2.1 Urban services interdependencies

The extreme events related to climate change represents a potential critical threat for our cities (and their resilience), which are complex systems characterized by constant flow and are the result of a lot of dynamic variables that change in space and time (Da Silva, *et al.*, 2012). These events maybe generate a cascade of indirect effects, which cause disruption of socio-technical networks needed in order that city works correctly. Infrastructures and urban systems are often interactive and interdependent, so interactions among them might be affected by climate change and increase the hazard.

The report elaborated by U.S. Department of Energy "Climate Change and Infrastructure, Urban Systems, and Vulnerabilities" (2012) describes very well how climate change impacts affect the most important sectors of society. The paper considers Boston city in its analysis and defines the main climate change impacts in the interactions systems. They are reported in the following table (Table 1):

Affected sector / Affecting sector	Energy	Transport	Fluvial floods	Sea level rise	Water supply	Water quality
Energy	/	Losses of rail service, traffic signals, disruption of air traffic (summer)	/	/	Rise in cooling water need (summer)	Reduced water quality because of increased cooling water (summer)
Transport	Higher energy demand due to longer travels	/	/	/	/	/
Fluvial floods	Disruption in local supply	Decrease of travels and more delays	/	Increase of flooding impacts	Flood water can affect plants and wells	Flood water can affect wastewater treatment plants, more no-point scarce pollution.
Sea level rise	/	Decrease of travels and more delays	It can raise losses due to fluvial floods	/	/	Flood water can affect wastewater treatment plant and it can impact desalination plants
Water supply	Possible loss of local water supply because of lack of cooling water.	/	/	/	/	More water withdrawal and so less dilution
Water quality	Warmer water can cause reduction in local energy production	/	/	/	Need of more treatments	/

Table 1: Interactions systems by climate change hazards. (U.S Department of Energy, 2012).

The previous impacts imply more serious consequences for the most vulnerable communities, which are the poor people living in areas affected by high vulnerability, like floodplains, coastal lines, areas susceptible to landslides, low quality constructions, so areas that are characterized by low resilience.

Therefore, among impacts due to climate change, floods represent a threat for many sectors (social, economic, industrial, energetic), one of the most concerning according to *Koetse & Rietveld* (2009).

In recent times, urban floods that provoke major consequences increased considerably because of an effect known as "urban heat island", due to built surfaces, which are responsible for increase of storms and floods magnitude and frequency.

Furthermore, global warming intensifies significantly many water cycle subsystems and dust particles behave as nuclei in which clouds humidity condensates generating little water drops that can increase their size and provoke a storm.

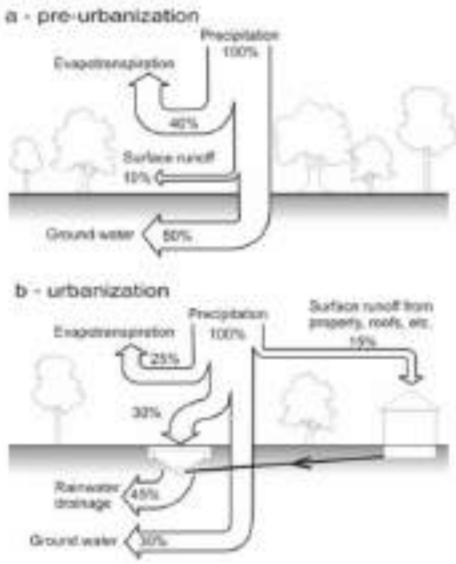


Figure 3: Influence of impervious surfaces in runoff. (WMO & GWP , 2012).

The variables that contribute to flooding events, according to *WMO & GWP*(2012) *and WMO & GWP,* (2008)*,* might be metheorological (rainfall, small scale storm, temperature, snowfall, snowmelt) and hydrological (soil moisture level, groundwater level before the storm, natural infiltration rate, impervious surface, channel cross section shape and roughness, over bank flow presence or absence, channel network, timing of runoff from various parts of the basin, imminent high water drainage).

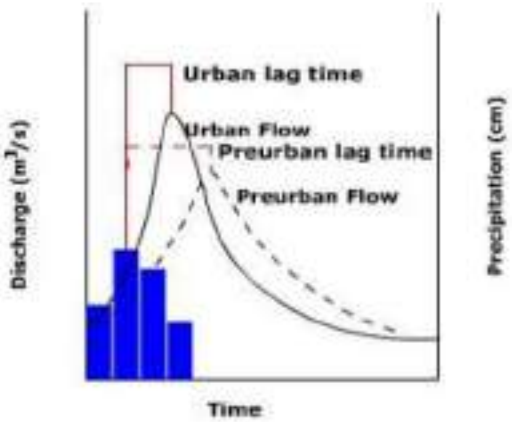


Figure 4: Discharge accentuation due to urbanization. (WMO & GWP, 2008).

Human variables deteriorate natural flooding risk by increasing hazard. Among the most significant ones, it is possible to cite: land use change (deforestation, increase of impervious surface), that raises runoff, occupation of floodplains, inefficiency or lack of maintenance of infrastructure, too efficient drainage of upstream area increases the peak flow, climate change affects magnitude and frequency of rainfall and flooding events, urban microclimate could lead to rainfall events.

Urban features that are relevant with respect to high flooding hazard are: concentrated population due to job opportunities, high impervious surfaces and buildings construction, concentration of solid and liquid waste without any formal removal system, clogged drainage system, intensive economic activities, high value of infrastructures and properties, informal poor people settlements outside the urban zone (often along rivers and floodplains), accommodation without hygienic standards, changes in areas around cities.

Damage magnitude depends on exposure, vulnerability and flooding type (water depths, flow velocity, water quality, duration and debris load).

Losses due to flooding events can be direct (result of direct contact with flooding water) or indirect (due to floods but they do not result from water direct contact). In both cases, there are two subcategories that are tangible losses (losses of things that have a monetary value) or intangible ones (they affect things that do not present a monetary value).

The main and relevant impacts regarding our field are reported in the following table:

	Losses due to flooding events	
	Tangible direct	**Tangible indirect**
Primary	Damages of: buildings, properties, infrastructures, crops, livestock	Losses or disruption of: crops and industrial production, communication (roads, rails, telecommunications), medical assistance, educational services, water, gas, electricity, food supply
Secondary	Flooding events cause fires, pollution, decrease crops productivity, provoke damages to electricity supply, damage the most delicate machines	Loss of value added in industry, increase of traffic and travel costs, workers disorder, water supply contamination, emergency service cost rise, losses of income, home expenditure increase
Tertiary	Higher rate of deterioration of the properties, rot and humidity, weaker structure in the following floods	Companies' bankrupt, lost export, gross domestic product reduction

Table 2: Losses due to flooding events. (WMO & GWP, 2012).

Among the most vulnerable sectors, affected by climate change and high hazard, the energy one was subject to many studies.

Extreme events, like storms, fires, landslides, floods and extreme temperatures, affect energy production and supply infrastructures, provoking disruptions in supply and affecting other infrastructures that depend on energy supply (International Energy agency, 2015). Energy infrastructures risk increases when extreme events frequency and intensity raise too.

Water shortage affects hydroelectric energy sector, biofuel production and any energetic sector that needs water for cooling (International Energy agency, 2015).

Furthermore, climate change generates heat waves and so reduces energy production because water or air input temperature is very high and, instead, temperature difference between steam in turbines and water used to condense it, has to be high. Therefore, if exterior temperature is very high, the energy station produces less electricity per fuel unit and rules are required to protect ecosystem. All this implies power outages and block of production (Davis & Clemmer, 2014).

Figure 5: Interdependencies between energy and other sectors. (U.S. Department of Energy, 2012).

Heat waves also affect energy distribution because transmission and distribution occur through networks that are very sensible to climate change and they lose efficiency when temperature is high (Aivalioti, 2015).

So, climate change increases significantly hazard and can produce high damage in this sector because high temperatures and droughts decrease hydric resources and production efficiency. *Bekoe & Logah* (2013) deals with this problem in Ghana and (*Provincial Government of Western Cape & department of environmental affairs and development planning, 2005*) talks about Western Cape situation where water is a necessary element for economy and tourism.

Moreover, sea level raise is dangerous for resilience because it affects coastal and off-shore energy infrastructures as well (International Energy agency, 2015).

Flooding events, extreme rainfalls and storms may also cause damages to energy infrastructures that are located in areas prone to flooding and affect energy transport because of transport systems disruptions.

The following list contains climate change variables that constitute a threat for energetic sector vulnerability and its resilience, according to *Asian Development Bank, (2012), Davis & Clemmer* (2014) *and U.S. Department of Energy,* (2015):

- Increase of water temperature (reduction of energy production efficiency)
- Raise of air temperature (reduction of energy production efficiency and increase of energy demand in order to cool accommodations, offices, etc.)
- Change in rainfall paths and runoff, increase of droughts frequency and intensity (reduction of water availability, necessary to generate hydroelectric energy and for cooling processes in other energetic sectors)

- Extreme climate events (they can reduce fuel supply and quality, cause damages energy infrastructures network and affect energy transport and supply)
- Quick changes of cloud cover and wind velocity (they affect stability of networks that receive renewable energy as input)
- Water level rise (it affects energy infrastructures)

Also the increase of fires causes higher vulnerability and hazard regarding to electric system efficiency, because the power transmission poles can be subjected to serious damages, while smoke and particles can ionize air, generating a path out of the transmission lines and so power outages (Davis & Clemmer, 2014)

Other indirect impacts produced because of climate change are: accentuation of existing stressors and enivronmental degradation (The White House, 2015), lake generation (GLOFs) because of glaciar retreat and these lakes are characterized by ah high potential to provoke floods (IPCC, Linking climate change and water resources: impacts and responses, 2008), serious water shortage in developing countries (Brown, Hammill, & McLeman, 2007).

2.2 Cascading effect and lifelines interdependency

Despite the fact cascading effect will be analyzed in detail on WP3 especially during Task3.3, some significant references have been consulted in order to have a wider framework about the identification and prioritization of potential cascading effects and to develop integrated models for the development of multi-hazard assessments in WP2 and multi-risk assessment in WP3.

A relevant study about sector interdependency have been carried out by EU-CIRCLE [1] project, in which is included an exhaustive review about sector interdependency (*D1.2 State of the art review and taxonomy of existing knowledge*) for Energy, Chemical Industry, Water System, Transportation, ICT networks and Public sector.

In the present deliverable, Energy, Water and Transportation dependencies review have been included due to the relevance for RESCCUE project scope.

[1] EU-CIRCLE's scope (Pan European framework for the strengthening critical infrastructure resilience to climate change) is to derive an innovative framework for supporting the interconnected European Infrastructure's resilience to climate pressures, supported by an end-to-end modelling environment where new analyses can be added anywhere along the analysis workflow and multiple scientific disciplines can work together to understand interdependencies, validate results, and present findings in a unified manner providing an efficient "Best of Breeds" solution of integrating into a holistic resilience model existing modelling tools and data in a standardised fashion.

Water

Water is a vital component of the majority of urban services and as such if the water system fails this impacts all other critical infrastructure (Peerenboom *et al., 2001*). Additionally, water assets are dependent to power supply and telecommunications and damages to these sectors affect the water infrastructure. For example, water is used for cooling purposes in electric power production and distribution and in telecommunications and requires both for control systems.

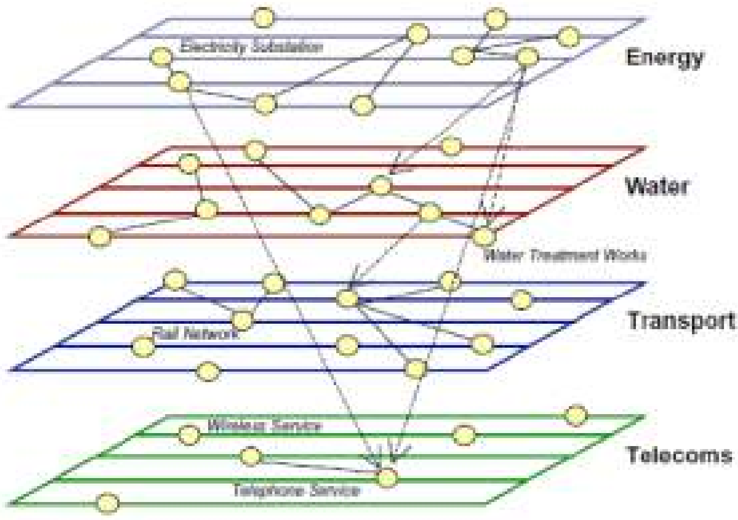


Figure 6: A schematic outline of some of the interdependencies between critical infrastructure sectors. (Pederson. *et al.,* 2006.)

An example of some of the interdependencies between critical infrastructure sectors is given in Figure 6 (Pederson *et al*., 2006*).* For example, a water treatment plant is dependent on an electricity substation, which is in turn related to the telephone service operation. Other sector's dependencies on water infrastructure presents the dependencies of the water infrastructure assets with the energy, transport and ICT sectors and the impacts of these sectors' damages to the water infrastructure (Table 3)

Sector	Dependencies on water infrastructure	Sector dependencies on water related hazards and availability of natural water resources	Impacts on water infrastructure
Energy	Water for cooling in power stations and fuel refining	Substations and local distribution networks are vulnerable to flood; Coastal power stations vulnerable to flood, and most power stations are dependent on natural water supplies for cooling	Dependent on energy for pumping and control systems
Transport	Drainage infrastructure to prevent flooding	Road and rail vulnerable to flood	Depend on transport to carry workforce to sites
ICT			Dependent on ICT for control systems; Increasing dependence on ICT for sensing and reporting the condition of the infrastructure

Table 3: Other sector's dependencies on water infrastructure. Royal Academy of Engineering, 2011.

Figure 7 (Peerenboom *et al., 2001*.) presents the interdependencies between different critical infrastructure sectors. More specific, the energy sector is dependent on water infrastructure state, for example, since lower lake and river levels may threaten the capacity of hydroelectric plants, while higher temperatures may increase water temperature making water too warm to cool coal and nuclear power plants, leading to power brownouts (Georgakakos*, 2014*.). Additionally, the collocation of water networks with roads, ICT infrastructure and gas lines are the main cause of indirect impacts with water networks creating more than twice damage to other infrastructure assets than being affected by them. (Zimmerman*,* 2004).

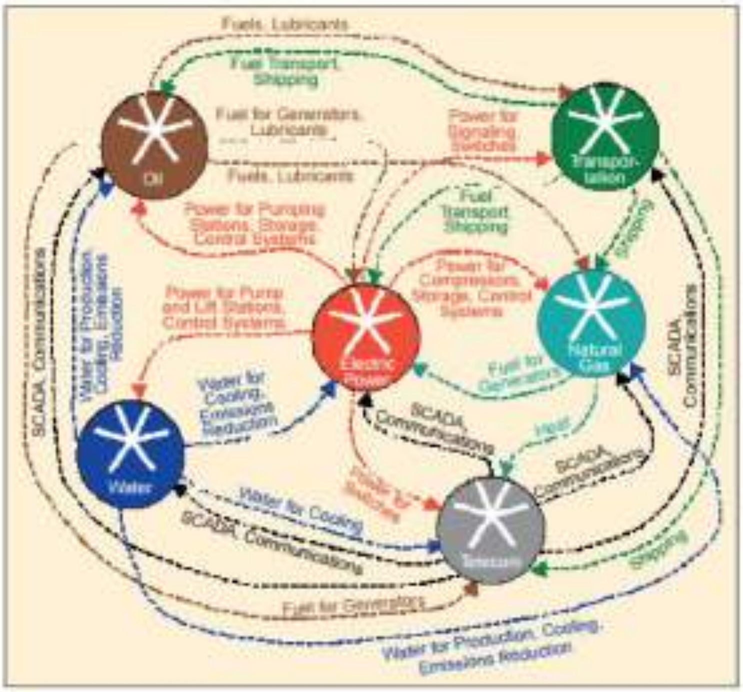


Figure 7: Example of infrastructure interdependencies. Peerenboom *et al*., "Identifying, understanding, and analyzing critical infrastructure interdependencies," IEEE Control Syst Mag , 2001.

Energy

Without energy, most of the other urban services cannot operate properly. A disruptive event may have impacts at different levels to a system of infrastructures and socioeconomic environments. Therefore, a sequence of disruptive events will follow with impacts to different sectors. According to (Luiijf *et al.,* 2009) energy is the only sector which initiates more cascades than any other sector. For instance, energy crisis in a region can disrupt many vital services propagated from the initial disruptions created in electric power generation.

There are many examples of interdependencies between different critical infrastructures. Power grids might be affected by communication system disruptions (Watts, 2003) giving the example of failures in the communication system affecting health sector. Following are some facts that have been reported and they give a clear image of what interdependencies are:

- The 2003 Northeastern America power blackout—about 50 million people in the Northeastern and Midwestern US and Ontario, Canada, lost electric power. This also shuts down water treatment plants and pumping stations. The urban water supplies in the affected areas lost water pressure contaminating urban water supplies. Major sewage spilled into waterways which forced the authorities to issue boil water orders affecting about eight million people (Wilbanks *et al*. 2013).
- The 2012 Hurricane Sandy in Northeastern US—caused massive failures in power supply, inundated tunnels and subway stations and streets, and stopped air transportation and financial services. About 8.7 million customers were affected by power outages causing serious damages to wireless and Internet infrastructure. Power outages also affected oil and natural gas production and transportation. Refineries were shut down and oil terminals, gas tanks and pipelines became inoperable due to power loss (Comes *et al., 2014*)

There are many models and simulation approaches to study infrastructure performance. One basic way to divide them is whether a single infrastructure or a system of interdependent infrastructure is being modeled. (Sieber*, 2011)*

Transportation

The major source of complexity in heterogeneous transport systems is defined by the way each asset affects the others as well as the intensity of that effect. All interdependencies can be categorized based on the medium which each connection utilizes in order to manifest itself. These categories are (Rinaldi *et al., 2001*):

- Physical Interdependency: Two networks / assets are physically interdependent if the state of one is dependent on the material output(s) of the other.
- Systems Interdependency: Two networks / assets have a systems interdependency, if its state depends on the properties of a system transmitted through another asset.
- Geographic Interdependency: Networks / assets are geographically interdependent if an incident in an asset may impact the state of assets in a defined spatial proximity.

- Logical Interdependency: Two networks / assets are logically interdependent if the state of each depends on the state of the other via a mechanism that does not fall into any of the above.

Other references about urban systems interdependencies

Other significant references have been consulted about interdependencies systems (Pescaroli *et al*., 2015; Pescaroli *et al.*, 2016*)* in which is studied the concept of cascading effects and paths for critical infrastructures. Different classes of cascade effects with a unifying theoretical framework (Lorenz *et al*., 2009; Motter et al.,2004) and analysis of the role of interconnectivity in catastrophic failures (Little, 2002; Comfort *et al., 2010;* Vespignani, 2010*;* Buldyrev*, et al.,* 2010) have been taken into account as a references for the present document.

3 Research site characterization: Lisbon site

3.1 Main features of the research site

Lisbon is a city that has been shaped by influences of a large number of cultures over time. With an extensive river front to river Tagus, the city enjoys a Mediterranean climate.

The Lisbon's Metropolitan Area is a metropolitan area which encompasses 18 counties of Greater Lisbon and Setúbal Peninsula. It is the metropolitan area more populous of the country (NUTS[2] 3), with 2 821 876 inhabitants (2011), and the second most populous region (NUTS 2), following the Northern Region (http://www.aml.pt/index.php).

Table 4 – Municipalities that comprise the Lisbon Metropolitan Area (Source: CML/SMPC, 2016).

Alcochete	Lisboa	Odivelas	Setúbal
Almada	Loures	Oeiras	Sintra
Amadora	Mafra	Palmela	Vila Franca de Xira
Barreiro	Moita	Seixal	
Cascais	Montijo	Sesimbra	

Figure 8 – Lisbon Metropolitan Area (AML) (Source: CML/SMPC, 2016).

[2] Nomenclature of territorial units for statistics

Figure 9 – Lisbon urban area (Source: CML/SMPC, 2016).

Lisbon has boundaries with three other municipalities (Table 5). Morphologically, the city is quite steep (average slope of 5.7º and maximum slope of 81º) with an average altitude of 76.3 meters, ranging from sea level to 216.4 meters

Table 5 – Lisbon main indicators. Source: Emergency Municipal Plan (PME)

Administrative boundaries	Cardinal points
Loures	N
Odivelas	NO
Amadora Oeiras	O
Tagus riverfront	S AND E

Aerial view. Source: CML

River front. Source: CML/SMPC

Figure 10 – Lisbon city. River front. Source: CML/SMPC

Lisbon city covers an area of approximately 100 km², of which 85.8 km² are continental area and 14.2 km² submersed areas. The area is classified as urban soil (100%), 90% is classified as consolidated area and 10 km² as urban forest (11.7%). There are 24 parishes (neighbourhoods). Other indicators include:

- Buildings: 52.496
- Lodgings: 323.076 (6 lodgings/building)
- Number of vehicles/day (2012): 648 615

Figure 11 – Lisbon´s boundaries, council and parishes (Source: CML/SMPC, 2016).

In terms of land use, indicators of the class's distribution are provided in

Table 6.

Table 6 – Lisbon main indicators.

	Lisbon's Council Soil Qualification (continental area)	Area (ha)	%
Class	Central space and residential consolidated	3256,41	37,92
	Central space and residential to consolidate	717,35	8,35
	Consolidated green space to framework the infrastructures	382,63	4,46
	Consolidated green space to protection and conservation	559,82	6,52
	Consolidated green space of pleasure and production	1052,98	12,26
	Green space of pleasure and production to consolidate	356,30	4,15
	Consolidated green riverside space	74,80	0,87
	Consolidated space to economic activities	75,02	0,87
	Economic activities space to consolidate	77,54	0,90
	Riverside space of special use consolidated	6,32	0,07
	Riverside space of special use to consolidate	24,59	0,29
	Facilities space of special use consolidated	1050,89	12,24
	Facilities space of special use to consolidate	139,71	1,63
	Facilities space with green areas associated of special use consolidated	103,31	1,20
	Infrastructures space of special use consolidated	709,63	8,26
	Total	**8587,30**	

Source: Lisbon's Master Plan (PDM adapted)

3.1.1 Population and economics

The population of Lisbon City, with 547.733 habitants (residents), is 19,3% Lisbon´s Metropolitan Region, with a density of 6.446 habitants/km^2. The population present during the day (people not living in Lisbon who goes there for different purposes during the day) is estimated in 1 million people.

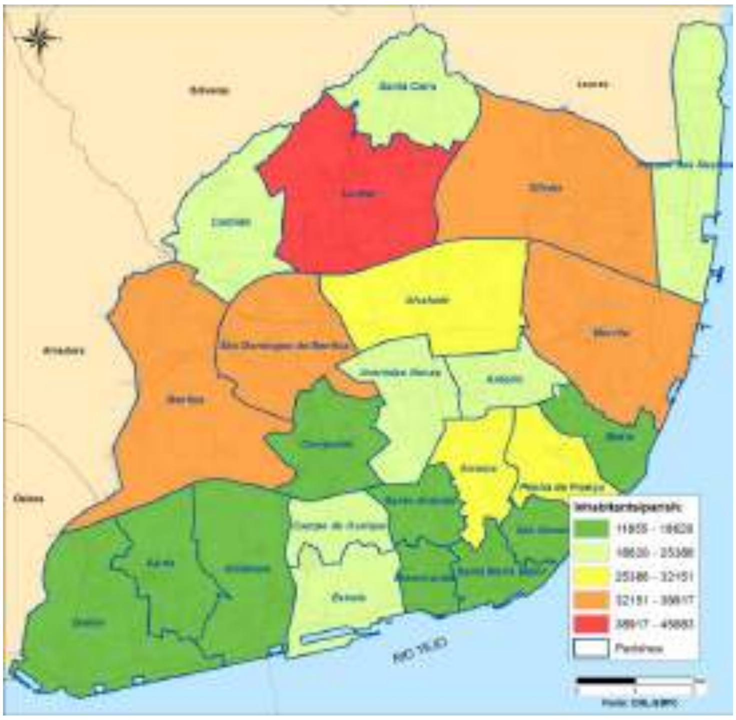


Figure 12 – Lisbon´s population density per parish. (Source: CML/SMPC, 2016).

In terms of gender distribution, 46% are male and 54% female. In terms of age, 12,9% of the population is less than 15 years old and 23,9% are 65 years old or more. It is estimated that 17,1 % is with one or more disability. It is estimated that 5,7 % are immigrants or have dual nationality. The literacy rate (% literate population) is 96.81%. In terms of economic indicators, values for broad indicators are given in the following tables (

Table 7; Table 8) for Lisbon region and Portugal.

Table 7: Lisbon and Portugal, Economic indicators (2013).

Economic indicators, 2013*			* Preliminary data
	Lisboa (region)	Portugal	Weight of region in the country (%)
GDP (millions euros)	63 902	171 211	37.3
Gross value added GVA (millions euros)	56 154	150 465	37.3
GDP per capita (thousands euros)	22.7	16.4	-
Apparent labour productivity (per person employed) (GVA/Employment, 2011)	41.7	32.3	-

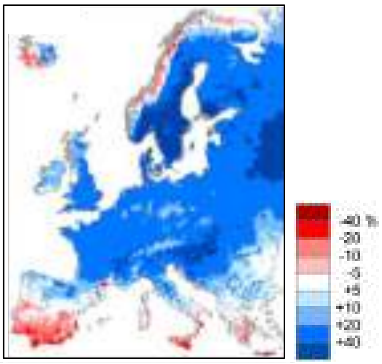
Table 8: Lisbon and Portugal, Employment indicators (2011). Source: http://www.cm-lisboa.pt/investir/investimento/lisboa-em-numeros/economia-de-lisboa-em-numeros; Data: INE, I.P., Contas Regionais.

Employment indicators, 2011*			*Preliminary data
	Lisboa (Região)	Portugal	Peso da região no país (%)
Employment (thousands persons)	1 385.8	4 776.7	29.0

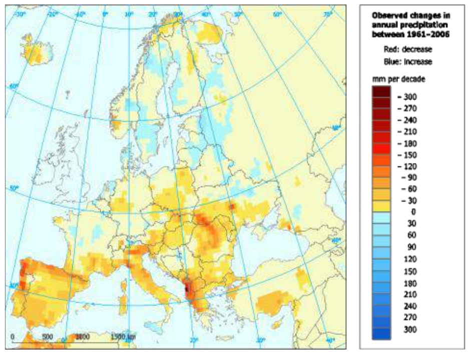
3.1.2 Climate and weather

Lisbon has a temperate climate, classified as Mediterranean climate, and is characterised by dry and hot summers and wet and fresh winter periods.

The climate change trends are average air temperature increase, decrease of annual and non-wet season rainfall, increase of wet-season rainfall and of frequency of intense rainfall events (Figure 13 – Changes in precipitation), average sea level rise, and increase of frequency of coastal floods.



Relative change in the seasonal precipitation amounts in Winter (DJF) (Dankers & Hiederer, 2008)



Observed changes in annual precipitation 1961-2006 (mm per decade) (ENSEMBLES (http://www.ensembles-eu.org), ECA&D (http://eca.knmi.nl))

Figure 13 – Changes in precipitation.

Climate description is supported by the surface weather stations from “Lisboa/Instituto Geofísico” and “Lisboa/Gago Coutinho” for the period 1971-2001 (Portuguese Sea and Atmosphere Institute - IPMA). In Table 9 to

Table 11 information of climate and weather is provided.

Table 9 – Surface weather stations.

Surface weather stations	Latitude	Longitude	Altitude (m)
Lisboa/Gago Coutinho	38°46’ N	9°08’W	104
Lisboa/Instituto Geofísico	38°43' N	9°09'W	77

Table 10 – Temperature. Source: Portuguese Sea and Atmosphere Institute (IPMA)

Average monthly values for: average, minimum, and maximum daily air temperature on Lisbon's surface weather stations in Celsius degrees.													
GAGO COUTINHO	JAN	FEB	MAR	APR	MAI	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
average	10,5	11,9	14,3	15	17,4	20,5	22,9	23,2	21,9	18,1	14,4	11,8	16,8
Maximum	14	15,4	18,5	19	21,5	25,3	28,1	28,3	26,7	22,1	17,5	14,8	20,9
Minimum	7,1	8,4	10	11,1	13,2	15,8	17,7	18	17,1	14,1	11,2	8,9	12,7
GEOFÍSICO	JAN	FEB	MAR	APR	MAI	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
average	11,3	12,6	14,3	15,3	17,3	20,3	22,7	22,9	21,7	18,4	14,8	12,4	17
Maximum	14,5	15,9	18,2	19,2	21,4	24,8	27,5	27,8	26,2	22,1	18	15,2	20,9
Minimum	8,1	9,2	10,4	11,5	13,3	15,9	17,9	18,1	17,3	14,6	11,5	9,5	13,1

Table 11 – Precipitation. Source: Portuguese Sea and Atmosphere Institute (IPMA).

Average monthly of the total precipitation quantity, quantity of daily maximum precipitation and average number of days with precipitation above or equal to 10mm.

Gago Coutinho	JAN	FEB	MAR	APR	MAI	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
total rainfall quantity (mm)	97,7	82,3	36,1	68,7	64,4	14,1	6	5,1	30,6	86	135,8	127,3	754,1
Daily maximum (mm)	57,1	56,4	42,2	41	36,3	49,7	36	14,5	50,4	98,3	126,6	51,3	126,6
Days with ≥ 10mm	3,4	2,8	0,8	2,3	2,3	0,3	0,2	0,1	0,9	2,5	4,3	4,5	24,4
Geofísico	JAN	FEB	MAR	APR	MAI	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
total rainfall quantity (mm)	96,8	90,2	51,2	64,7	55,6	17,2	6,1	6,8	28,5	79,8	107,1	121,8	725,8
Daily maximum (mm)	46,4	60,2	46	55	59,6	37,1	34	26,7	57,7	92,6	95,6	54	95,6
Days with ≥ 10mm	3,4	3	1,6	2,2	1,9	0,5	0,2	0,1	0,8	2,6	3,5	4,2	24

Table 12 – Maritime / Fluvial agitation, storm surge. Source: FCUL.

Astronomical Tide Forecasting Model FCUL (2011-2020)					
	high tide Max	high tide Average	NM	low tide Average	Low tide Min
Minimum	4.30	3.56	2.33	1.08	0.27
Average	**4.41**	**3.59**	**2.35**	**1.10**	**0.34**
Maximum	4.50	3.61	2.36	1.15	0.45

In Table 13, levels for warning for wind, rainfall, thunderstorm, fog and coastal events, based on specific parameter values are given.

Table 13 – Levels for warning and parameter values. Source: Portuguese Sea and Atmosphere Institute (IPMA)

Criteria for mainland						
Warning	**Parameter**	**Yellow**	**Orange**	**Red**	**Units**	**Notes**
Wind	Maximum Gust	70 to 90	91 to 130	> 130	km/h	
		90 to 110	111 to 130	> 130	km/h	In the highlands
Rainfall	Rain/Showers	10 to 20	21 to 40	> 40	mm/1h	Millimetres in 1 hour
		30 to 40	41 to 60	> 60	mm/6h	milometers in 6 hour
Thunderstorm Fog	Electric Discharges Visibility	a)	b)	c)		a) Frequent and scattered. b) Frequent and close together. c) Very frequent and excessively close together.
		*≥ 48h	*≥ 72h	*≥ 96h		* - duration
Coastal Event	Significant Wave Height	4 to 5	5 to 7	> 7	m	

3.2 Organisation of the city services management

3.2.1 Overview and structure

Lisbon city services are mostly managed by the Municipality and by Parishes. For specific services, such as energy supply, gas supply, water supply, public transports and infrastructures other stakeholders are responsible.

In terms of water management, the Portuguese Environment Agency is the national water authority. Regarding the land use planning and geographical information at national level, the Direção-Geral do Território is the national authority. For the metropolitan Lisbon region, the AML (Área Metropolitana de Lisboa) has a role in the decisions at multi-municipal level in the planning and management of issues of public interest, including essential services such as water supply, sanitation, wastes management, public transports, among others. Other stakeholders relevant for Lisbon area in terms of water management includes the Ports authority.

The following figure (Figure 14) indicates the main actors in terms of water. Natural water resources are under the scope of APA, including the planning for the Tagus River Management.

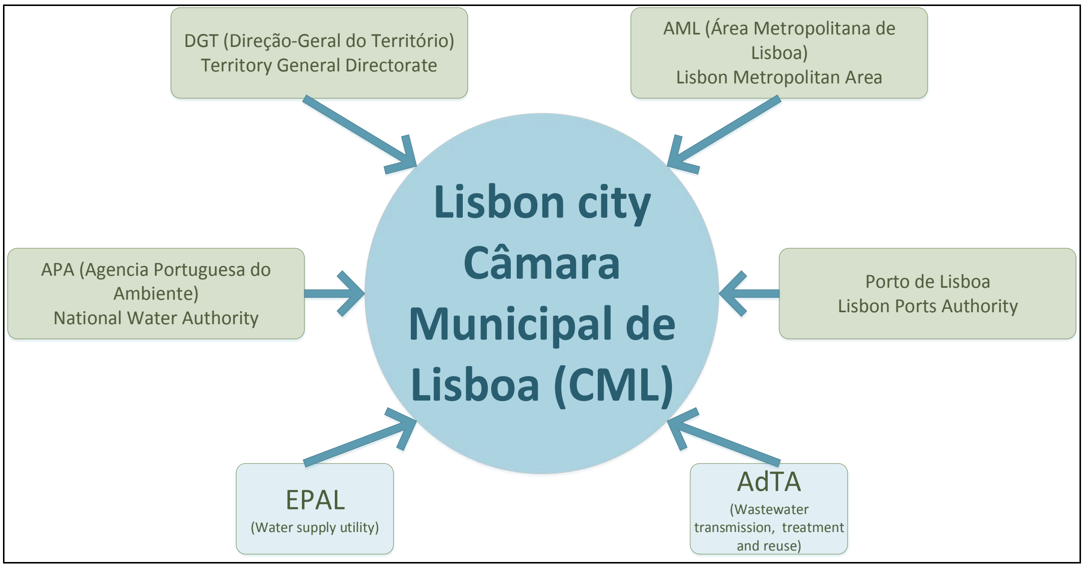


Figure 14: Main actors managing Lisbon urban services

In the following sections, a description for the main actors involved in the RESCCUE project (CML, EPAL-LVT, EDP Distribuição) and AdTA is provided.

3.2.2 Lisbon Municipality

The Lisbon City Council is the executive body of the municipality and its mission is to define and execute policies that may promote the development of the County of Lisbon in different areas. The City Council comprises 17 elected Councillors, representing the different political forces, of which one is the Mayor.

In Table 14 , the city council organisation is presented. A total of twelve territorial services, 60 transversal services and 32 sectorial services exist, with a total of approximately 9.000 employees.

Table 14 – Lisbon´s City Council Organization (CML).

City unit	Scope
Units of Territorial Intervention (Management of Private Buiding, Management of Public Space, Public Ilumination, Local Dinamization)	Territorial
Department of Mark and Comunication (events management, comunication)	Transversal
Directorate-Municipal of Finances (Budget and Management Control)	Transversal
Directorate-Municipal of Urbanism (Divisions: Municipal Master Plan, territorial planning, urban reabilitation, ...)	Transversal
Directorate-Municipal of Project and Construction (Infrastuctures, Public spaces and Drainage, Council residences, …)	Transversal
Directorate-Municipal of Property Management (cadastre and property management)	Transversal
Directorate-Municipal of Human Resources (Health, Hygiene and Safety in work)	Transversal
Department for Information Systems	Transversal
Lisbon Fire Brigade Regiment (RSB)	Transversal
Municipal Police, Forest Police	Transversal
Civil Protection Service of Lisbon City Council (SMPC)	Transversal
Directorate-Municipal for Habitation and Local Development (management of social residence, social intervention, local intervention, participation and citizenship, cohesion and youth.	Sectorial
Directorate-Municipal of Green Structure, Environment and Energy (cemetery management, animals house, green structure management, Monsanto Natural Park management)	Sectorial
Directorate-Municipal for Urban Hygiene (management of cleaning Lisbon and fleet management)	Sectorial
Directorate-Municipal of Mobility and Transports (Traffic and Mobility Management)	Sectorial
Directorate-Municipal of Culture	Sectorial
Directorate-Municipal of Economy and Innovation	Sectorial
Directorate-Municipal of Education and Sport (Management of facilities for sports and education)	Sectorial

3.2.3 AdTA

Águas do Tejo Atlântico (AdTA) is a leading company operating in the environmental sector in Portugal and its mission is to contribute to the pursuit of national objectives in the wastewater collection and treatment within a framework pf economic, financial, technical, social and environmental sustainability.

Águas do Tejo Atlântico has the responsibility to manage and operate the wastewater multi-municipality system of the Great Lisbon and West. The aims are guaranteeing the quality, continuity and efficiency of the public water services, in order to protect public health, populations' welfare, the accessibility to the public services, the environmental protection and economic and financial sustainability of the sector, in a framework of equity and tariff stability, contributing to the regional development and planning.

Presently, Águas do Tejo Atlântico manages a large system including 104 WWTP, 292 pumping stations and 922 km of main sewage system, and treats around 244 Mm^3/yr, serving a population of 2,4 million inhabitants in 23 municipalities (Alcobaça, Alenquer, Amadora, Arruda dos Vinhos, Azambuja, Bombarral, Cadaval, Caldas da Rainha, Cascais, Lisboa, Loures, Lourinhã, Mafra, Nazaré, Óbidos, Odivelas, Oeiras, Peniche, Rio Maior, Sintra, Sobral de Monte Agraço, Torres Vedras e Vila Franca de Xira) and an area of 4.145 km^2.

Águas do Tejo Atlântico undertakes R&D activities in partnership with other institutions, companies and universities in a wide range of subjects, including novel treatment processes and implementation of management and simulation tools for optimizing wastewater treatment and collection. R&D activities include participation in several national as well as in European projects.

3.2.4 EPAL

EPAL – Empresa Portuguesa das Águas Livres, S.A. is the oldest and largest water supply company in Portugal, operating for more than 145 years. EPAL is the successor of the centuries-old CAL (Companhia das Águas de Lisboa), the concessionaire for supplying water to the city of Lisbon from 2nd April 1868 to 30th October 1974, when the concession agreement reached its term. EPAL (Empresa Pública das Águas de Lisboa) was then set up. It kept this name until 1981, when it changed it to EPAL (Empresa Pública das Águas Livres).

On 21st April 1991, through Decree-Law no. 230/91, EPAL was converted into a Limited Liability company with exclusively state capital, which afforded greater flexibility regarding its management in order to carry out its strategic development and fulfil its mission. In 1993 it was included in the then created group - Grupo AdP – Águas de Portugal SGPS, SA.

EPAL – Empresa Portuguesa das Águas Livres, S.A. is currently a company belonging to the state corporate sector, 100% held by AdP – Águas de Portugal, SGPS, S.A., and subject to the legal framework inherent in this qualification, namely that set forth in Decree-Law no. 133/2013 of 3rd October.

Each day EPAL supplies over 550 million litres of drinking water to customer, along more than 2.100 Km of water mains, 41 pumping stations, 28 water tanks, 14 service reservoirs and about 83.000 service connections. EPAL is a reference company within the water sector in Portugal, with large expertise, substantial experience and modern technology, which it uses to maintain an exceptional level of services to customers.

3.2.5 EDP Distribuição

EDP (Energias de Portugal) is the largest Portuguese industrial group with strong activity in Portugal, Spain and other European Countries, and also in the USA and Brazil. It is the largest generator, distributor and supplier of electricity in Portugal, the third largest electricity generation company in the Iberian Peninsula and one of the largest gas distributors in the Iberian Peninsula. EDP is one of the largest wind power operator worldwide with windfarms for energy generation in the Iberian Peninsula, the United States, Canada, Brazil, France, Belgium, Italy, Poland and Romania, has capacity under construction in Mexico and is developing wind projects in the United Kingdom. Additionally, EDP generates solar photovoltaic energy in Portugal, Romania and the United States. In Brazil, EDP in the fifth largest private operator in electricity generation, has 2 electricity distribution concessions and is the third largest private supplier in the liberalized market. EDP has a relevant presence in the world energy landscape, being present in 14 countries, with 9.7 million electricity customers, 1.4 million gas customers and more than 12 thousand direct employees around the world. On December 31, 2015, EDP had an installed capacity of 24GW and generated 64TWh during 2015, of which 58% from renewable sources.

In Portugal, EDP group operates across the electricity value chain in the generation, distribution and commercialisation of electricity and gas.

EDP Distribuição (EDPD), one of the main companies in EDP Group, is the Portuguese Distribution System Operator (DSO), and distributes electricity to more than 6 million customers in Portugal, in a regulated business with clearly defined responsibilities, with a network of more than 224.500 km. EDPD has distributed around 44 TWh of energy in 2015, with a headcount of 3.316 direct employees, and as much outsourced, and managing assets worth of 2.5b€, including 419 HV/MV substations, 67.063 MV/LV secondary substations.

EDP Distribuição has low voltage (LV) concessions granted by the 278 Municipalities for a period of 20 years (next concessions are subject to public tender), and High/Medium Voltage (HV/MV) concession granted by the government until 2043.

EDP Distribuição mission focuses on three areas:

- Planning, construction and maintenance of the National Electricity Distribution Network under regulatory requirements;
- Operation of the National Electricity Distribution Network complying with Quality of Service and other regulatory requirements;
- Provide market support (switching, metering, ...).

3.3 Urban water cycle in Lisbon

3.3.1 Overview of water cycle related risks

Lisbon main issues (Figure 15) and challenges related with climate change are the following:

- Increase of runoff flows and associated risks;
- Flooding and overflows resulting from limited hydraulic capacity of the sewer network;
- Meteorological droughts that can severely impact drinking water consumption;
- Water quality deterioration in natural water bodies especially relevant for recreational uses resulting from sewer systems wet weather overflows and dry weather permanent discharges;
- Impacts on WWTP from I/I (undue inflows) increase reducing treatment efficiency.

Figure 15 – Examples of rainfall related problems in Lisbon.

Lisbon sewer system is very complex. It includes combined, separate and partially separate sewers, dendritic and looped sewer networks, and sewers of very different ages, dimensions and materials.

The water level in the Tagus estuary receiving waters is dominated by the ocean tide. During high tide, the downstream restrictions to flows in sewer networks increase the risks of flooding at the lower Lisbon areas, during rain events. This is also important since some urban areas in the Lisbon centre have elevations of just 0.20 m above the maximum high tide.

On the other hand, as the Tagus estuary is intensively used all over the year for recreational activities, such as sailing, water quality is a crucial issue, namely in terms of pathogenic concentrations and aesthetics.

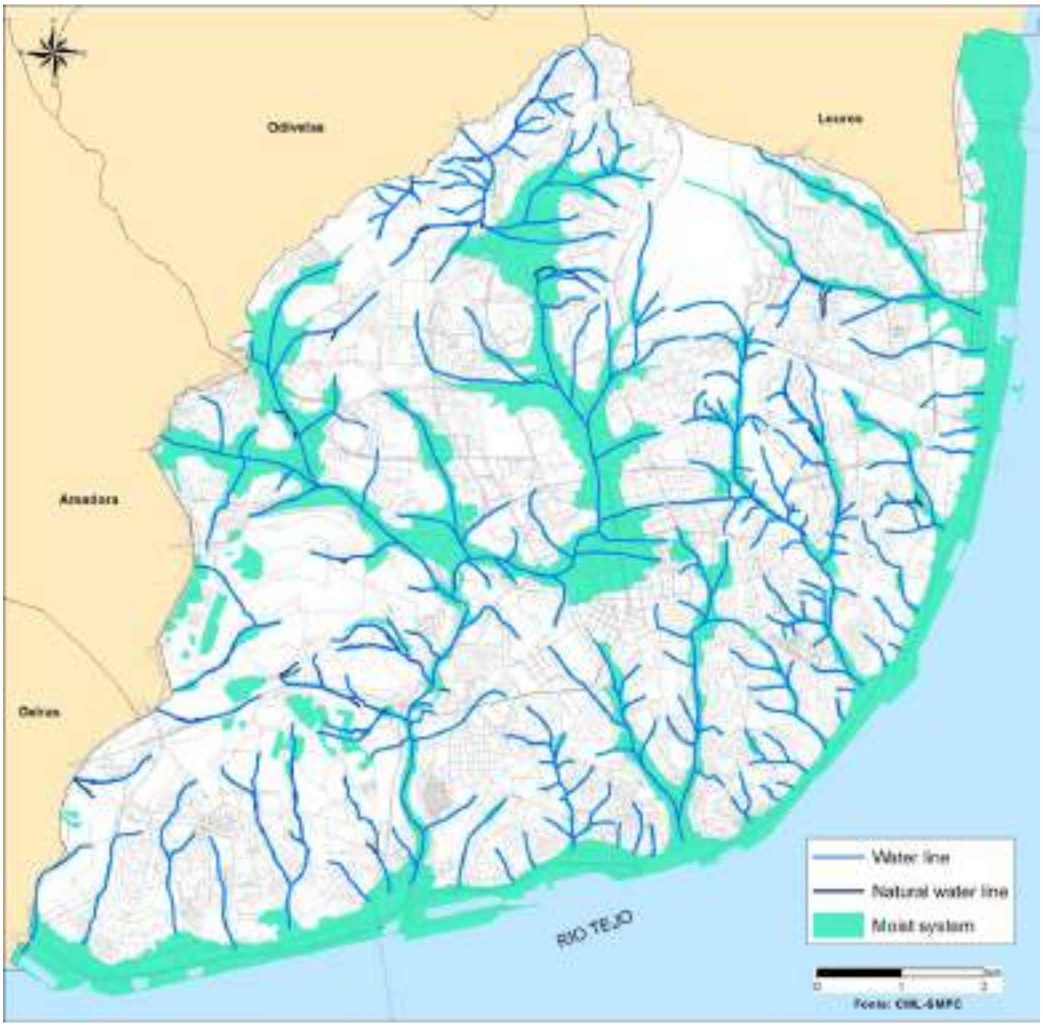


Figure 16 – Lisbon's water systems. (CML/SMPC, 2016).

The major risks associated with the Lisbon drainage system are flooding events which have been relatively frequent in the city of Lisbon in recent decades, with relevant economic and social consequences, but human losses did not occur. Figure 17 shows the vulnerability map for Lisbon regarding flooding and, in Figure 18, the areas with higher number of flooding events over the last decades.

Based on the list of areas prone to more frequent flooding and the latest news, the areas that currently show greater risk of flooding have been be identified (Figure 19 and Figure 20). Figure 21 shows some illustrative photographs of urban floods in Lisbon.

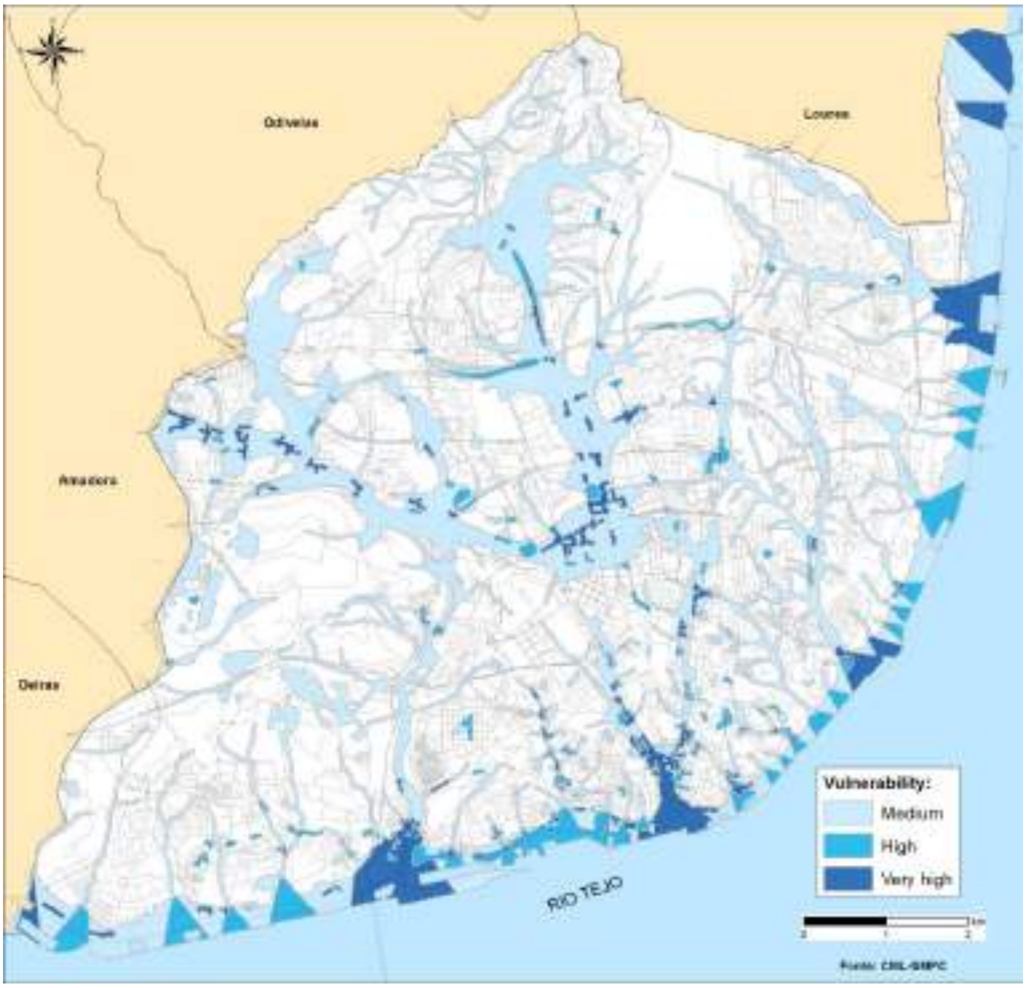


Figure 17 – Lisbon's flooding vulnerability map.

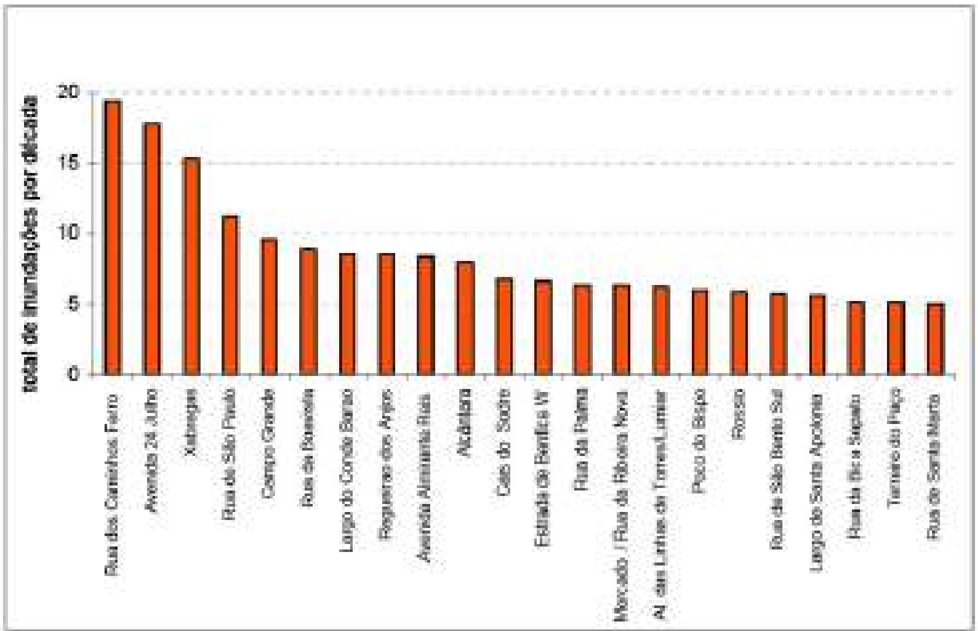


Figure 18 - Lisbon's area distribution which registered floods (Oliveira, 2005).

Figure 19 - Lisbon's area distribution which registered significant floods.

Figure 20 - Areas of particular risk of flooding.

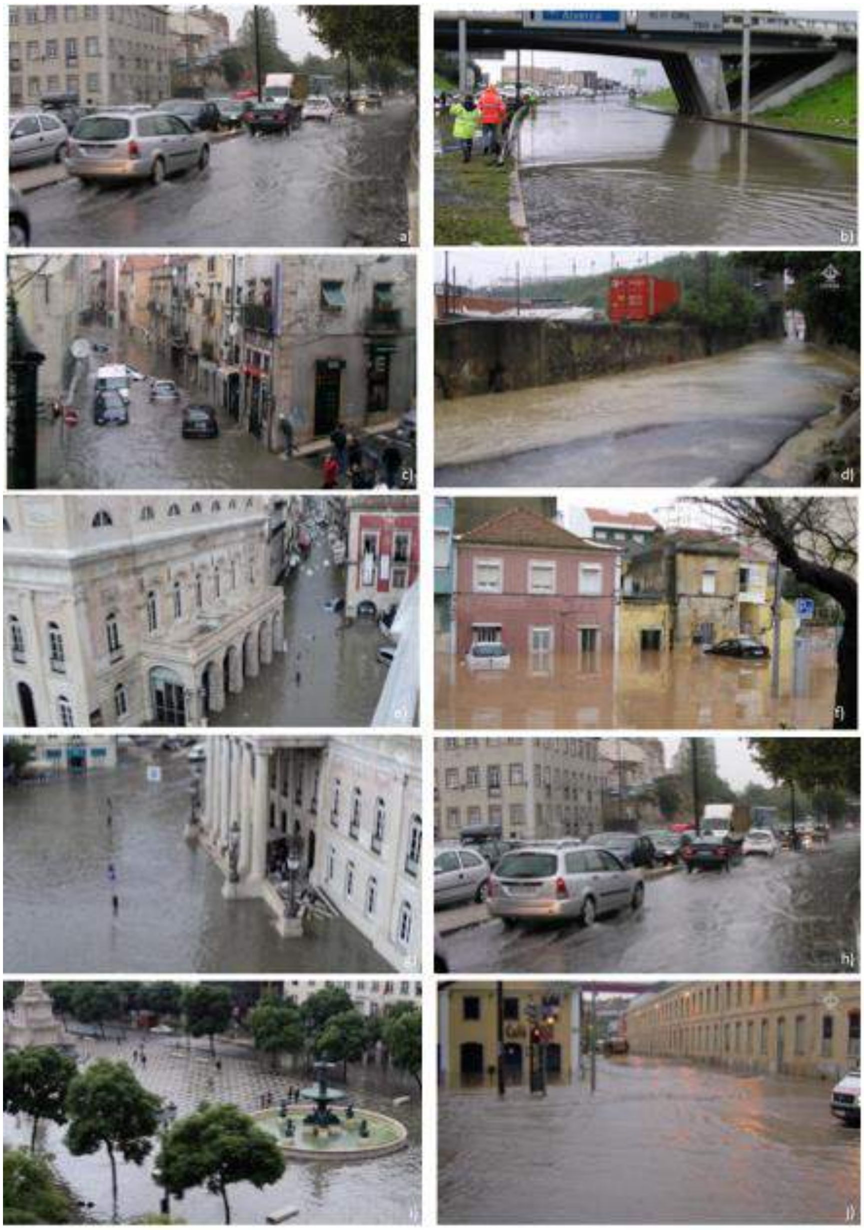


Figure 21 - Details of floods in Lisbon (Source: https://vimeo.com/132020170).

The final sections of the Lisbon sewer network, located in the lower areas, are particularly affected by the sea level. This is why these sewers have a reduced outflow capacity. Figure 22 schematically shows the susceptible areas in the municipality of Lisbon to the sea level.

Figure 22 – Areas exposed to sea level variations in the municipality of Lisbon.

Antunes and Taborda (2009) used data from the Cascais tide gauge to analyse the rise in average sea level during the last decade. This station has one of the longest time series and its result analysis of the 1990 and 2000 decades shows an increase in average sea level at a rate of 2.1 and 2.5 mm/year, respectively (Figure 23), which is in accordance with the IPCC's estimates associated to an increase in sea level (IPCC, 2014). This event, coupled with the IPCC's also anticipated increased frequency and magnitude in extreme precipitation events, will contribute to more severe pressures on the city's drainage system, resulting in an increased risk of urban floods.

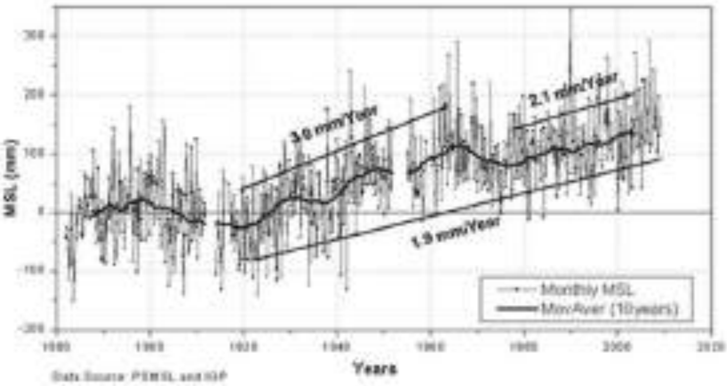


Figure 23 – Average sea level registered by the Cascais tide gauge (Antunes and Taborda, 2009).

The Lisbon municipal council (CML), aware of the city's vulnerability and the potential increase flooding risks in the future, has been developing several strategic, tactical and operational tools.

As an example, the Lisbon Drainage Master Plan (Plano Geral de Drenagem de Lisboa) 2016-2030, includes options to tackle the city's drainage problems, based on different types of structuring actions (flow diversion by means of tunnels, respectively around 5 km - Monsanto-Santa Marta-Santa Apolónia tunnel, and about 1 km - Chelas-Beato tunnel), complemented with a set of smaller scale actions or interventions and a more targeted focus. These urgent structuring actions are expected to be implemented by 2020.

3.3.2 Water supply

3.3.2.1 Water abstraction

Lisbon water supply comes from the Castelo do Bode reservoir, being the dam owned by EDP (the Portuguese Company of Electricity), located in the Tagus river basin. Water transmission is carried out by a number of mains as are schematised in Figure 24.

3.3.2.2 Water treatment

Water from Castelo do Bode reservoir is treated at Asseiceira Water Treatment Pan (WTP), following a scheme comprising pre-chlorination, mineralization, coagulation/flocculation, flotation, oxidation (ozone), filtration, pH adjustment and final disinfection (chlorine). This WTP, built in 1987 with a capacity to treat 500 000 m^3/day, was recently upgraded to treat 625 000 m^3/day, along with the introduction of flotation and ozone into the treatment process (Luís et al., 2014).

3.3.2.3 Water distribution

Each day EPAL supplies 650 million litres of drinking water from the sources to the customers' taps, through more than 2 100 kilometres of water mains, 43 pumping stations, 24 water tanks, 14 service reservoirs and about 80 000 service connections (Luís et al., 2014).

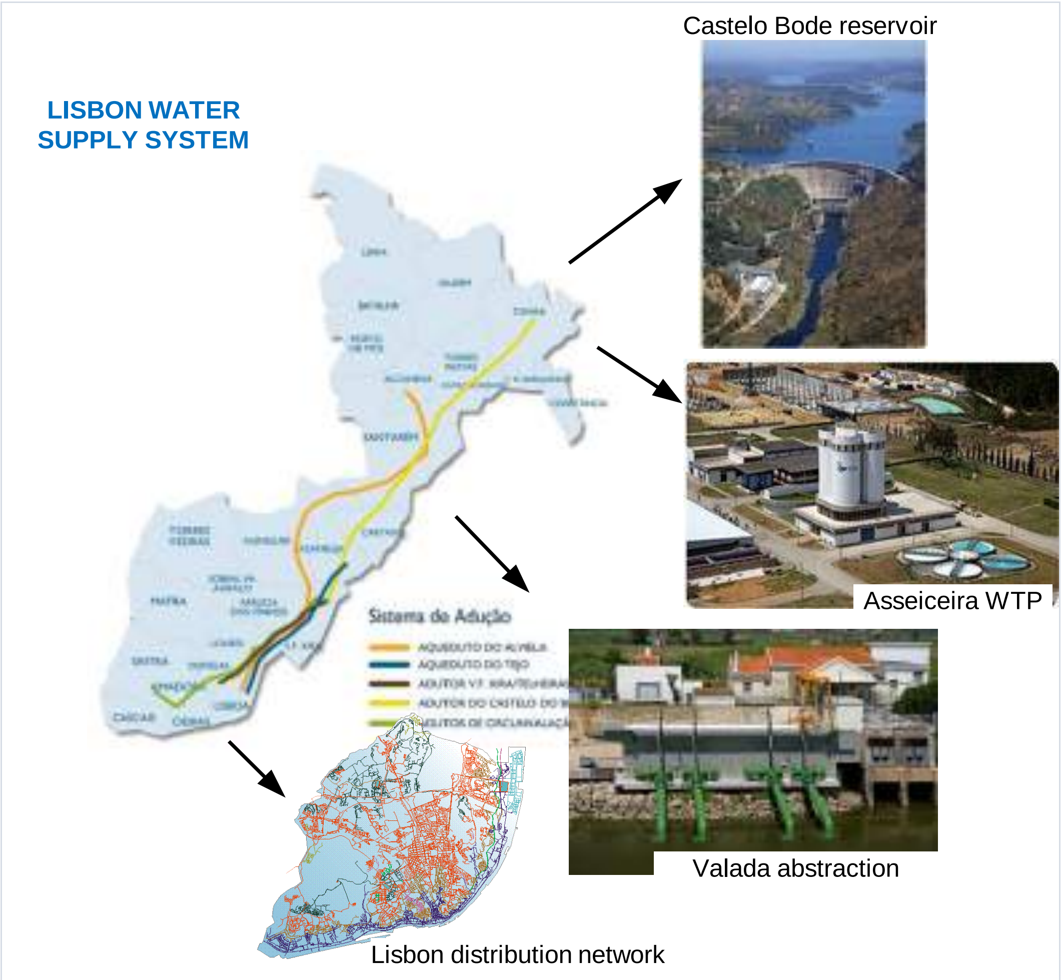


Figure 24 – Lisbon water supply system (Luís et al., 2014).

Main climate effects affecting resilience of water supply system

EPAL carried out specific studies to evaluate the impacts and adaptation actions of foreseen climate change trends, taking into account both climate and socioeconomic scenarios. The results of the study are as follows (Luís, 2014; Serranito, 2012):

- The foreseen socioeconomic changes are not expected to have significant impact in terms of the total water demand and competition for the resource for different uses;
- The expected reduction on water reserves in the main source (Barragem de Castelo do Bode, approximately 90% of supply) should not put at non acceptable risk the supply of the water demands. In a smaller abstraction system (Valada-Tejo) might be affected only in extreme drought periods;
- Increase in pollutants in surface water sources (higher concentration of pollutants) should be dealt with by Asseiceira water treatment facilities even if increasing operational costs.

The city of Lisbon has some alternative sources of water compatible with non-potable uses. One of the existing alternatives is provided by EPAL as treated wastewater compatible with reuse.

3.3.3 Urban Drainage

3.3.3.1 Sewer system description

A large part of Lisbon's sewer system is combined (Figure 25). However, especially since 1995, new developments have been planned with separate systems and today there is about 27% of the area with separate networks, being 12% separate domestic and 15% separate stormwater.

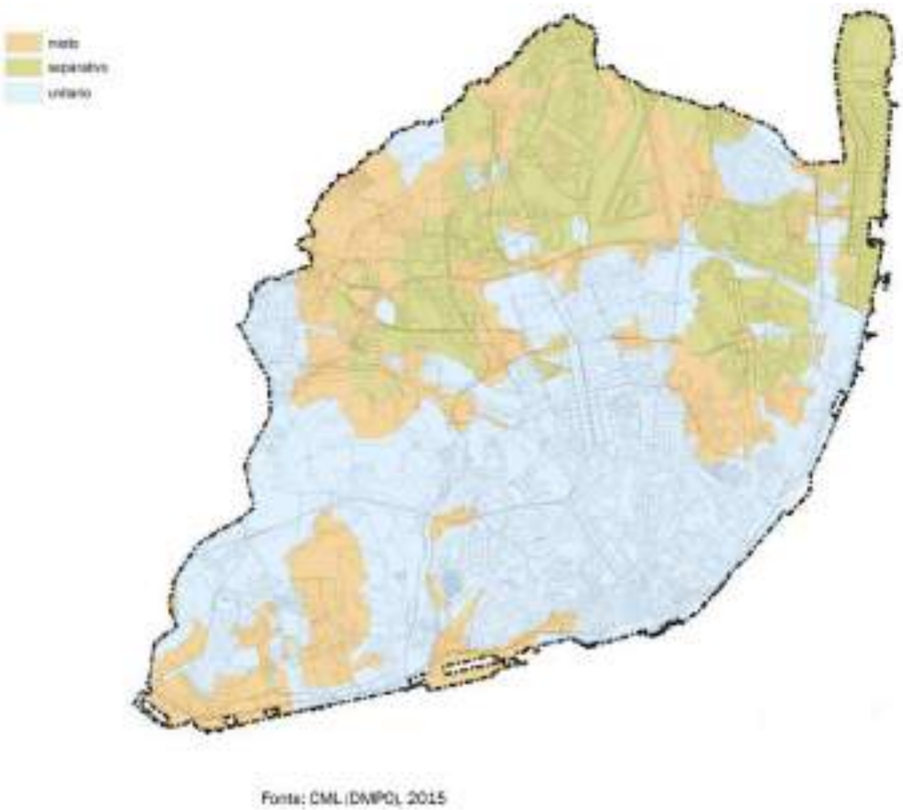


Figure 25 – Areas and predominant type of sewer system (REOT, 2016).

In the oldest parts of the city, mainly downtown, combined system has a higher expression, about 97%, especially in the sub-catchments of Terreiro do Paço and Cais do Sodré. In the upstream parts, with a more recent construction, as Benfica and Avenidas Novas, there is a higher incidence of separate systems but still connected to the downtown combined sewers. Many of these systems are really functioning as combined due to the large number of illegal or wrong connections to both stormwater and domestic sewers (Telhado et al., 2014).

Drainage system sub-catchments

Baixa Pombalina was the first part of Lisbon having a sewer network. It was completely rebuilt after the earthquake of 1st November 1755. The sewers of this area of the city, built by demand of Marquis of Pombal, prime minister of King Joseph I, are known as “saimel”, designation of the bricks built with limestone.

Lisbon’s sewer system is divided in three main systems, namely, Alcântara, Chelas and Beirolas (Figure 26). The conceptual Lisbon drainage system includes sixteen main catchment basins (referred to using letters “A” to “Q”). There are also 4 adjacent basins, “S”, “T”, “U” and “V”, which drain the domestic wastewater and rainwater from the city of Lisbon to other council areas (not considered in this study).

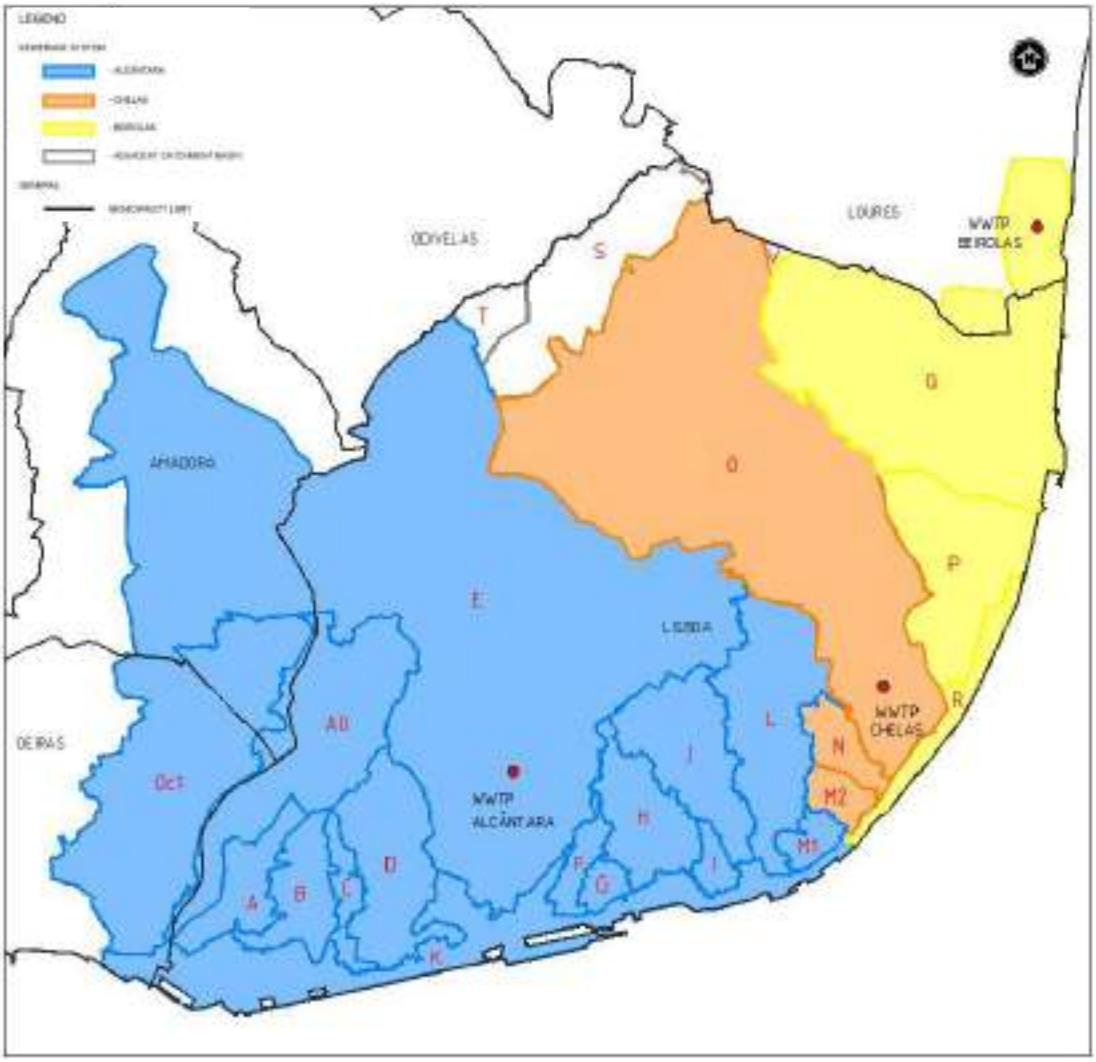


Figure 26 – Lisbon catchments and main systems.

The municipality of Lisbon, located near the estuary of the Tagus River, has a geographical position and topographical features that make centralisation of wastewater in a single location difficult, therefore the domestic wastewater drainage system of the city is divided into three drainage systems, namely Alcântara, Chelas and Beirolas, as follows (Figure 27):

- Alcântara system – includes catchments Oc1, A0, A, B, C, D, E, F, G, H, I, J, L, M1 and K and wastewater is conveyed to the Alcântara wastewater treatment plant (WWTP). The sewer network is mostly combined.

- Chelas system – includes catchments O, M2 and N and is served by the Chelas WWTP. Most sewers operate as combined, despite of having been designed as separate.
- Beirolas system –includes catchments Q, P and R and wastewater is conveyed to the Beirolas WWTP. The drainage network has areas with sewers operating both as combined and others as separate.

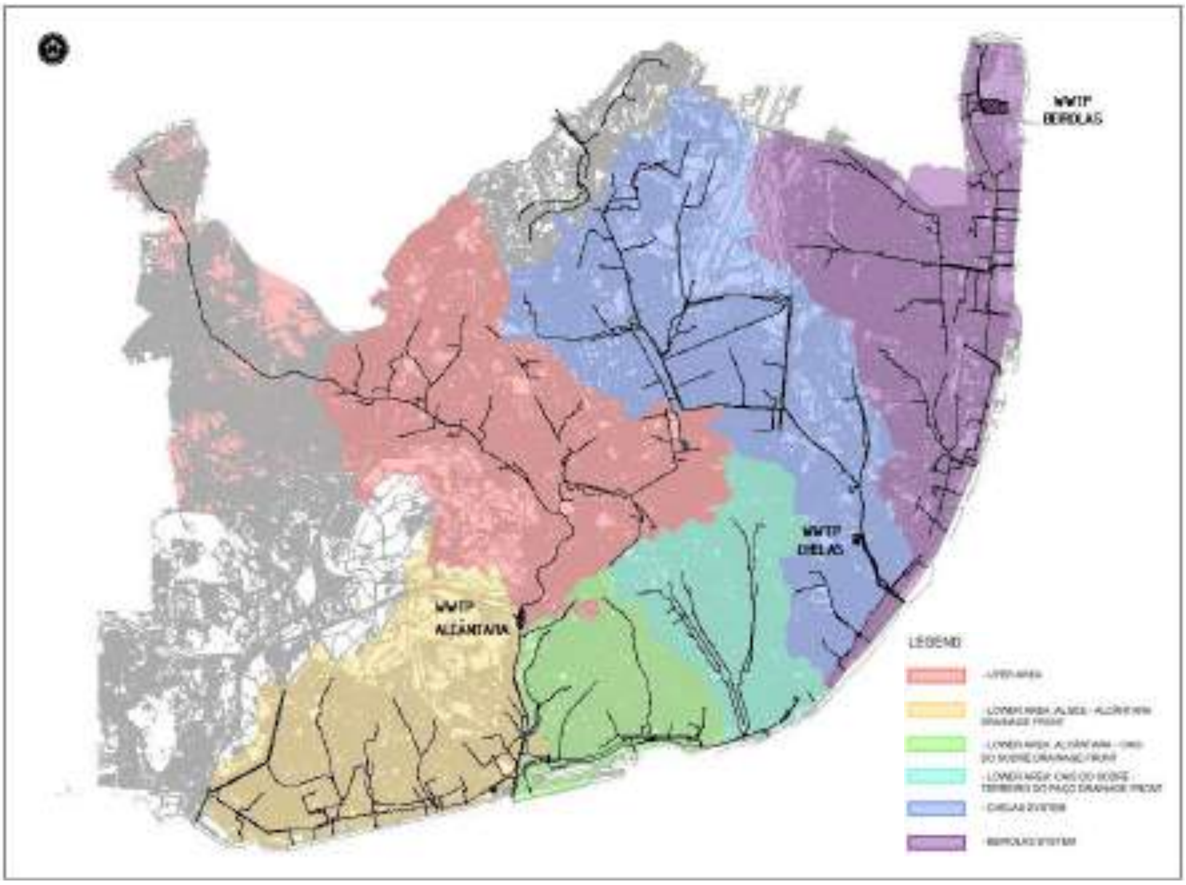


Figure 27- Lisbon drainage systems - catchments and main systems.

The city of Lisbon sewer system, with about 1400 km long, is very diverse and complex due to factors typical from old and coastal cities, such as:

- Co-existence of combined and separate sewers, some areas with mesh sewer networks, especially with higher flows.
- Lisbon sewer networks receive contributory areas from neighbouring municipalities, such as Amadora and Oeiras (Figure 26).
- Tidal influence in coastal boundary.
- Sewers with a variety of types of cross- sections, materials (stone masonry, brick, concrete, PVC, HDPE) and construction dates, complex links and intersections that hinder clear understanding of the integrated network operation.
- Lisbon system has several weirs and diverters, intended to divert the wastewater to the treatment systems, pumping systems and inverted siphons, and weirs that only

operate from a certain limit on so as to "relieve" the network and avoid superficial floods (storm or relief weirs), often possessing tidal valves.

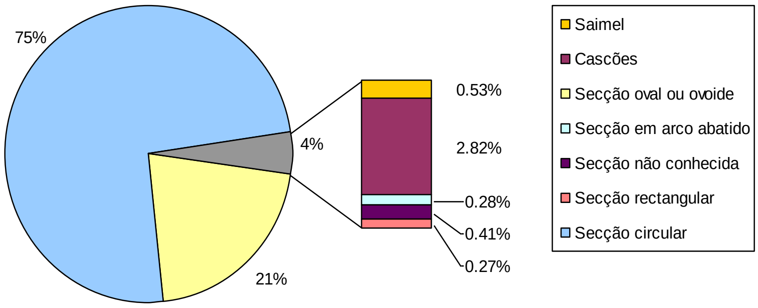


Figure 28 – Types of cross-sections.

Most of the existing sewers (about 75%) have circular cross section. The second more common cross section is the oval or ovoid cross section and often this type of cross section has a gutter, in some cases made of stoneware (Figure 28). Regarding the remaining cross section shapes, of about 4% of total length, only rectangular sewers have some representativeness. The sewers in "saimel" shape, characteristic of the Baixa Pombalina area, are less than 1%, generally have inverted U section or, in few cases, oval cross section.

Domestic sewers are mainly of stoneware ceramic while for stormwater sewers the majority are of concrete. Plastic materials such as polyvinyl chloride (PVC) and polypropylene corrugated (PP) have been used in the past 40 years in both stormwater and domestic sewers. Most of the sewers installed before 1950 are made of stone masonry or, less usual, of brick. After 1950's, the use of these materials is less frequent and usually are oval reinforced concrete sewers.

The majority of sewers, about 85%, are non-man-entry, having vertical dimension or diameter of less than 1800 mm. In terms of cross section size, the distribution is presented in Figure 29. Sewers with less than 500 mm in diameter or size are approximately 58% of the network and 28% have cross sections of 500 mm to 1000 mm, and only 0.6% is larger than 3000 mm in size.

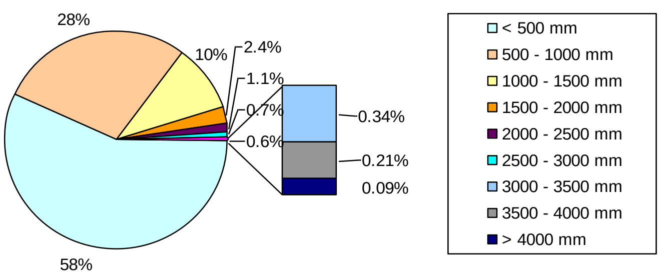


Figure 29- Size and total length of piping.

Alcântara system

The Alcântara system, with a total area of about 6225 ha, currently serves receives wastewater from Lisbon, Oeiras and Amadora municipalities, estimated in 756.000 inhabitants. The wastewater is transported to the Alcântara WWTP. Two sub-systems are considered: the upstream area where transport is by gravity and the downstream areas where wastewater is pumped to the treatment plant. The downstream area is sub-divided in the Algés-Alcântara, Alcântara - Cais-do-Sodré and Cais-do-Sodré - Terreiro do Paço drainage fronts.

The upstream sub-system serves an area of approximately 2747 ha and has densely populated zones as well as part of the Monsanto Forest Park. The main sewer caneiro de Alcântara is a channelized and covered stream, from the 1940's to 1960´s.

The caneiro of Alcântara is the main sewer of the Alcântara catchment and has approximately 10 km length, starting near Portas de Benfica and developing towards southwest, crossing the neighbourhoods of Benfica and S. Domingos de Benfica to the railway station of Campolide. At north of this site there is a confluence of a significant branch of Sete Rios, corresponding to a catchment contribution of 323 ha corresponding to the areas of Avenidas Novas, Entre Campos, Campo Pequeno, Hospital de S. Maria, Sete Rios e Praça de Espanha. Downstream this sewer develops to the south until the Tagus River near the Gare Marítima de Alcântara (Figure 30).

Figure 30 – Caneiro de Alcântara.

The caneiro de Alcântara is mostly made of concrete and with a purpose designed cross-section, consisting of a parabolic arch with 0.45-meter thickness supported on lateral walls, ending in two lateral blocks against which loads are transmitted to the support foundations. The invert has a 0.20 m thickness and has a central channel for dry weather flows, allowing man circulation during dry weather periods in the lateral benches (Figure 31).

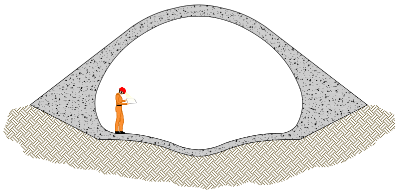


Figure 31 – Cross section of caneiro de Alcântara.

The cross section dimensions vary through eight types of sections. The smaller section is upstream (type VII), next to Portas de Benfica, has 4.66 m wide by 3.00 m high. The downstream sections, between Campolide and Alcantara railway stations (type I and II) have a width of 8.00 m by a height of 5.15 m (Telhado *et al.*, 2014).

The longitudinal profile has lengths with 0.0058 m/m gradient and transition ramps with 0.10 m/m slope. There are access galleries, with a semi-circular vault section of 1500 mm in diameter and a 2 m clear internal height on the vault crest.

This large sewer has been thoroughly inspected and rehabilitated gradually during the last decade as indicated in Figure 30.

In the downstream parts, the three drainage fronts are:

- Algés-Alcântara drainage front (2449 ha, 3 km network) – corresponding to the basins A, B, C, D and E, as well as part of the coastal areas (K). This front is made up of a diverter, variable in diameter between ϕ800 and ϕ1200 mm, including three main trunk sections and three pumping sections (EE1, EE2, EE3), eighteen diversion weirs (two with tidal valve) directed to the diversion system and several secondary sewers, variable in diameter between 200 and 600 mm.
- Alcântara - Cais do Sodré drainage front (about 310 ha, 2.65 km network) – from Cais-do-Sodré to Alcântara and incorporates part of the E basin, F, G, H and I basins and part of the coastal area basin. This front is made up of a diverter, variable in diameter between ϕ500 and ϕ1200 mm, three main trunk systems, buried (EE4, EE5, EE6), ten diversion weirs directed to the diversion system and several secondary sewers, variable in diameter between ϕ300 and ϕ800 mm. This drainage front connects to the EE3, which pumps the flow to the Alcântara WWTP.
- Cais do Sodré - Terreiro do Paço drainage front (about 660 ha, 4 km network) – it is also a part of the Terreiro do Paço Alcântara area, stretching from J, L and M1 basins, as well as part of the coastal area basin. This front is composed of five flow regulation chambers (three of which include tidal valves), a main circular diverter of ϕ1000-ϕ1200 and five pumping stations (EE) (Terreiro do Trigo, Fluvial, Agências, Santos and Rocha do Conde de Óbidos), connecting to the final diversion section of Cais-do-Sodré- Alcântara (at the intersection of Av. 24 de Julho and Rua Tenente Valadim) flowing to EE3.

Chelas system

The drainage sub-basins that make up the Chelas system (total area of about 1980 ha; 230 000 inhabitants) stretches from Santa Apolónia (bordering the Alcântara system) to Travessa do Grilo, where it borders the Beirolas system (O, M2 and N basins). This system also borders the basins that drain to the municipality of Odivelas, on the North, and the coastal area basin, on the south (Figure 26). Of the three systems serving the city of Lisbon, this is the only one that drains flows solely from the council area, excluding water flows from neighbouring municipalities, with a total drainage area of 26.18 km².

The sewer network which of Chelas system has, for the most part, combined sections, although there are also separate parts, particularly in the so-called Alta de Lisboa area (Ameixoeira, Charneca and Lumiar) and in Chelas. In addition, the infrastructure integrates, other components such as weirs intended to divert the domestic effluents of combined networks and carry them to the diverters (infrastructures belonging to the "upper" system) or to pumping systems (also belonging to the "upper" system), contributes to the great complexity of this basin.

The separate flows coming from the Alta de Lisboa area are drained to combined sewers in Alameda das Linhas de Torres and part of the rainwater flows to the upcoming Av. Santos e Castro. From here, these flows follow a trunk sewer to the combined sewers in Campo Grande, Entre Campos, Av. Estados Unidos da América and Vale de Chelas. Regarding Alta de Lisboa, it should be noted that the combined sewer "Nova II" in Al. das Linhas de Torres does not have the capacity to harbour rainwater flow of the area, therefore a 25 000 m³ capacity lake is planned for building, which will serve as a retention basin. The Chelas separate networks are also linked to combined infrastructures.

Upstream from the Chelas WWTP, there are weirs which separate the flows. The flows are carried by gravity to the diverter and from there to the WWTP, and the rainwater flows follow the river "pipings" and are discharged into the Tagus River. The Chelas WWTP also harbours flows through pumping systems belonging to basins M2 and N.

Chelas system includes the following main components (Figure 27):

- South of the WWTP: a) a diverter, variable in diameter between ϕ400 and ϕ700 mm; b) four main trunk systems, buried, (EE8, EE9, EE10, EE11); c) six domestic flow diverter weirs from the combined networks to the diverter system.
- North of the WWTP: a) a diverter varying in size from ϕ500, 0.80 m x 1.20 m ovoid, to ϕ1200; b) domestic flow diverter weirs from the combined networks to the diverter system; c) domestic flow diverter weirs from the diverter to the combined sewers (these weirs are usually not in operation, they serve only as a backup).

Beirolas system

The drainage basins of Beirolas system include not only civil parishes from the Eastern municipality of Lisbon, but also part of the council area of Loures (P, Q and R basins). This basin's total drainage area is approximately 29.70 km², 11.91 km² of which in the municipality of Lisbon, whose system serves approximately 213 500 inhabitants.

The sewer network has, for the most part, combined sections, although there are also pseudo-separate and separate sections, particularly in the areas of Olivais Norte, Olivais Sul, Encarnação and Parque Expo. The oldest parts of the municipality of Loures (Moscavide, Sacavém and Prior Velho) are mostly made up of combined networks.

These networks integrate in both municipalities (Lisbon and Loures), such as network pumping systems and weirs intended to divert the domestic effluents of combined networks and carry them to the diverters (infrastructures belonging to the "upper" system) or to pumping systems, also belonging to the "upper" system, contributes to the great complexity of this basin (Figure 27).

Generally speaking, separate networks are connected to combined sewers, with downstream weirs, where separation of domestic and rainwater flows is made, the first being carried to the Beirolas WWTP by the "upper" system and the latter discharged into the Tagus river. The only exception is the area of Parque Expo, as there are no weirs, because the domestic network is directly connected either by gravity or small pumping systems to the diverter system.

The Beirolas WWTP also harbours flows through pumping systems belonging to the "P" basin from the municipality of Lisbon. The Beirolas diverter system includes the following main components:

- In the municipality of Lisbon: a) a diverter, variable in diameter between ϕ400 and ϕ1200; b) six main trunk systems, buried, EE12, EE13, EE14, EE15, EE16 and EE17; c) sixteen domestic flow diverter weirs from the combined networks to the diverter system; d) a domestic flow diverter weir from the diverter to the storm sewer (this weir has no shut-down valve and therefore can easily begin operating); e) a siphon at the intersection of Alameda dos Oceanos and Avenida de Ulisses.
- In the municipality of Loures: a) a diverter, variable in diameter between ϕ400 and ϕ1200 mm; b) two pumping systems, EE6 and EE4; c) two domestic flow diverter weirs from the combined networks to the diverter system.

The domestic flows reaching the EE17, which is located on the border of the Lisbon and Loures municipalities, come from both council areas. There is also a storm weir in the municipality of Lisbon, whose affluent flow comes from Moscavide (municipality of Loures). It should also be noted that the diverter system in the Parque Expo area has two connections to the storm sewers, which work as a backup.

3.3.3.2 Wastewater treatment

Alcântara WWTP

The Alcântara subsystem is in charge of treating urban wastewater generated by about 756 000 inhabitants and it serves some of Lisbon's municipalities (Western area), Amadora and Oeiras.

The Alcântara WWTP has a capacity to handle 3.3 m^3/s in dry weather, with secondary level treatment and 6.6 m^3/s in wet weather, with physical-chemical treatment.

Treatment starts by screening and pumping using Archimedes' screw, and subsequently aerated grit chambers. Lamellar clarification chemical assisted for dry weather line and ballasted lamellar clarification for a dedicated wet weather line are used in wastewater primary treatment. Dry weather line also has biological treatment by means of biofiltration. For wastewater reuse a dedicated treatment is accomplished with microfiltration and ultraviolet lamps. The treated effluent is then discharged in the Tagus River.

The Alcântara WWTP has a unique configuration, particularly due to its vegetation cover (a hanging garden, with approximately 2 ha), which favours landscape integration, improves air quality, creates natural habitats and encourages biodiversity in an urban context, and reduces waterproof area, thus contributing to a lower surface runoff and consequent floods. This cover also locally reduces heating in the surrounding area, as it absorbs sun rays that would otherwise reflect, warming the atmosphere. At the same time, plants synthesise CO2 from the air, converting it into oxygen through photosynthesis. Due to green roof, Alcântara WWTP odour treatment have a capacity of 220 000 m3/h of polluted air.

http://ancv.webnode.pt/projetos/WWTP-de-alcantara-lisboa/

Figure 32 – WWTP Alcântara green roof.

Chelas WWTP

The Chelas WWTP was designed to serve a total population equivalent of 230 000 inhabitants, with a maximum flow of approximately 52 000 m^3/day. It includes the following operations and processes:

- Pre-treatment - screening followed by aerated grit chamber.
- Primary treatment – primary lamellar sedimentation.
- Secondary treatment - activated sludge (anoxic and aerobic) followed by rectangular clarifier.
- Advanced treatment - filtration and disinfection using ultraviolet radiation for wastewater reuse.
- Sludge treatment – gravity thickening of primary sludge, and flotation of biological sludge, anaerobic digestion and dewatering centrifuge.

Beirolas WWTP

The Beirolas WWTP was designed to serve a total population equivalent of 213 500 inhabitants, with a maximum flow of around 54 500 m^3/day.

The installed treatment programme includes the following operations and processes:

- Pre-treatment - screening followed by aerated grit chamber.
- Primary treatment – primary lamellar sedimentation.
- Equalization.
- Secondary treatment - activated sludge (anaerobic, anoxic and aerobic) followed by circular clarifier.
- Advanced treatment - filtration and disinfection using ultraviolet radiation for wastewater reuse.
- Sludge treatment – gravity thickening of primary sludge, and flotation of biological sludge, anaerobic digestion and dewatering centrifuge.

Wastewater reuse

Alcântara and Chelas wastewater treated is reused for street cleaning with approximate $2x10^6$ m^3 (2014 data).

3.3.3.3 Mathematical modelling of water systems

In terms of water supply, EPAL has mathematical models of the network that are used currently to address several issues.

For the drainage systems, by request of Lisbon Municipality, a model was set up by consulting consortia to analyse the hydraulic and environmental performance of the Lisbon drainage system and to evaluate the effectiveness of proposed measures to improve the system, during the development of Lisbon Drainage Master Plan (PGDL 2016-2030). The model focus was the main drainage systems on the abovementioned catchment basins E, J, L and O, and the program SWMM (Storm Water Management Model) developed by EPA (US Environmental Protection Agency) was used. This program is a 1D dynamic hydrology-hydraulic water quality simulation model and can be used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas.

Within PGDL (2016-2030) SWMM simulations carried out included rainfall events with different return periods and a quantitative analysis (flow and flow depth) was carried out, which allowed for assessing sewer hydraulic performance, sewer surcharge and node flooding. This simulation, through different scenarios, took into account the effects of climate change, notably the increased intensity of rainfall and the increase in the average level of seawater, effects already identified as relevant for Lisbon. The model was calibrated with monitoring results (flow level and velocity measurements) in critical parts of the system.

On the other hand, for the catchment basins J and L (Av. da Liberdade, Av. Almirante Reis and city downtown), basins rather vulnerable to floods and with several fundamental services for Lisbon, a 2D integrated model was developed and implemented to simulate urban flooding.

For this integrated simulation, MOHID Land and SWMM were combined into a single model, where MOHID Land was used to simulate all surface processes in the catchment basin (precipitation, infiltration and runoff) and SWMM was applied to simulate the flow in the sewers. Wastewater can "exit" MOHID Land model and “enter” the SWMM model by street inlets and if sewer surcharge occurs and water “exits” though manholes the wastewater can re-enter MOHID through runoff. Any interchange of wastewater between the models is calculated taking into consideration the hydraulic gradients.

This model has been validated under the CIRAC project ("Flood Risk and Vulnerability Mapping in Climate Change Scenarios", developed by the Portuguese Association of Insurers and the Foundation of the Faculty of Science, University of Lisbon), and additional tests (e.g. mass conservation tests) were carried out within the PGDL 2016-2030.

MOHID Land is a 2D mathematical model developed and maintained by the University of Lisbon in coordination with Action Modulers. This model allows to simulate a wide range of hydrological and hydraulic processes that can occur in catchment basins and it is used by hundreds of professionals in more than 40 countries.

Main climate effects and natural hazards affecting resilience of urban drainage and wastewater treatment

The climate variables with potential to have significant effects on these systems are as follows:

- Stormwater collection and transport – rainfall, wind, and sea water level combined with tides and storm surges. These variables have potential if aggravating to increase the risk associated with flooding, runoff velocity and water level as well as to limit conveyance capacity of networks;
- Pumping stations - rainfall, sea water level combined with tides and storm surges. These variables have potential if aggravating to increase the risk associated with flooding of facilities (equipment failure), and high salinity degrading mechanical equipment;
- Wastewater treatment - rainfall, sea water level combined with tides and storm surges. These variables have potential if aggravating to increase the risk associated with excessive inflows and dilution and of entry of salt water into the system leading to potential corrosion of materials. Temperature is also a variable affecting significantly the performance of treatment processes especially for biological processes.

Vulnerability varies throughout the city but information provided in previous sections provides a good indication of exposure. The main interdependencies identified are related with transportation systems, solid wastes components and some exposed energy equipment. Pumping and treatment systems are very dependent on energy supply but emergency systems are usually available to face energy supply failures.

3.4 Energy (Electric sector)

The National Electric Distribution Grid (NEDG) is composed by the High Voltage (HV) grid, which includes the HV overhead lines, HV underground cables, HV sectioning stations and by Medium Voltage (MV) grid, which includes MV overhead lines and underground cables, power substations (HV/MV and MV/MV) and MV sectioning stations (Figure 33).

The power network in High Voltage (HV) is ensured by the National Electric Transmission Grid (NETG) which assures the transportation from the production sites to HV substations which connects with the NEDG at designated injector's points.

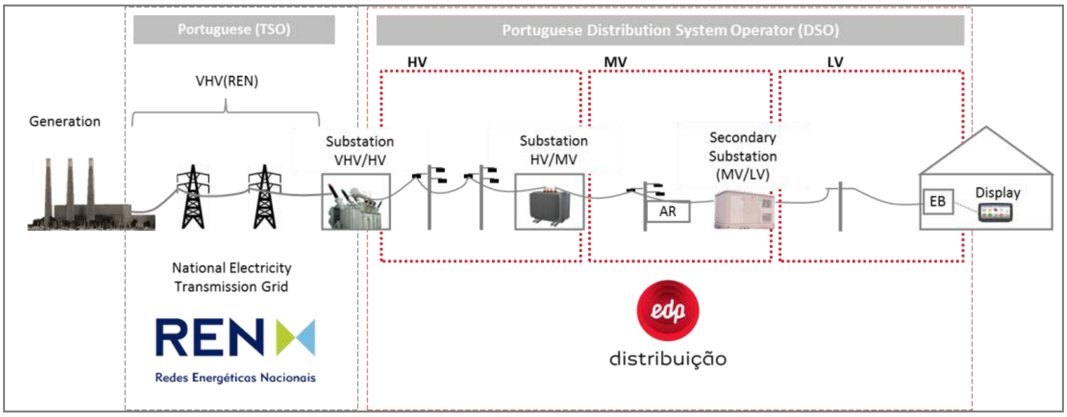


Figure 33 –Value chain.

The Medium Voltage (MV) grid is fed from the high-voltage lines or HV sectioning stations. The HV distribution is made at 60 kV, with only an HV line (132kV) in the north of the country, between the Lindoso hydro plant and Ruivães substation. The HV grid structure is mesh topology generally, and the operation performed in closed loop whenever possible and appropriate. Most of the HV network is composed by overhead lines. However, there is significant number of underground cables components in urban areas of Lisbon and Porto.

The typical configuration of the HV / MV substations assumes that they have the possibility of being fed from two HV lines, being endowed with HV bus bar and having two power transformers.

In high charge density areas, and for reasons of space limitations, there are substations without HV bus bar, constituted as a block (cable / transformer) protected by a single circuit breaker in the upstream switching station, being guaranteed the N-1 reserve to number loads. In lower density loads areas there are HV / MV substations with only one HV power or with a single power transformer, but its base configuration provides the possibility of future expansion; this may also occur in new substations in the early years of operation.

Table 15 – Distribution network indicators

Substation		2015
	# Substation	419
	# Power transformer	731
	installed capacity (MVA)	17.608
Electrical Lines (Km)		82.175
Overhead Lines		67.336
	HV (60/130KV)	8.904
	MV (<6/10/15/30KV)	58.443
Underground cables		14.839
	HV (60/130KV)	523
	MV (<6/10/15/30KV)	14.316

http://www.edpdistribuicao.pt/pt/rede/Pages/aRededeDistribuicao.aspx

To ensure the resource to the substations without N-1 reserve, EDP Distribuição has mobile substations, properly equipped and maintained as a reserve. The HV / MV substations are automated and remote controlled, which eases the network reconfiguration and electricity supply in case of an incident. Geographically, these facilities are more concentrated in higher density loads areas, where the reduction in the length average of the MT output and with the possibilities to create alternative electricity supply, allows to ensure a better quality of service to customers.

In the National Grid Distribution Map all substations in Portugal are represented and in Figure 34 the detail for Lisbon area is presented.

Figure 34 – National Grid Distribution Map: Lisbon area.
(http://www.edpdistribuicao.pt/pt/rede/Pages/aRededeDistribuicao.aspx)

The MV distribution grid is predominantly provided in 30kV, 15kV and 10kV voltage levels. The lowest levels are typically used in higher density loads regions and at coast, while the 30kV are used in greater dispersion regions. There are also MV/MV substations with the responsibility for lowering the MT distribution voltage of 30kV to 15kV or 10kV. Additionally, there are small networks at 6kV that have been substituted for higher voltage levels. The MV network is operated radially. In urban or semi-urban areas has a structure in zone or ring, being mostly underground; in these areas, most of the MT output of the substations have backup power.

In rural areas, the MV network has a structure essentially radial and composed mostly overhead lines. To facilitate operation and improve the quality of service, the overhead lines has remote controlled equipment cutting or other equipment having some kind of automatism (in Development and Investment Plan for the National Grid 2015-2019).

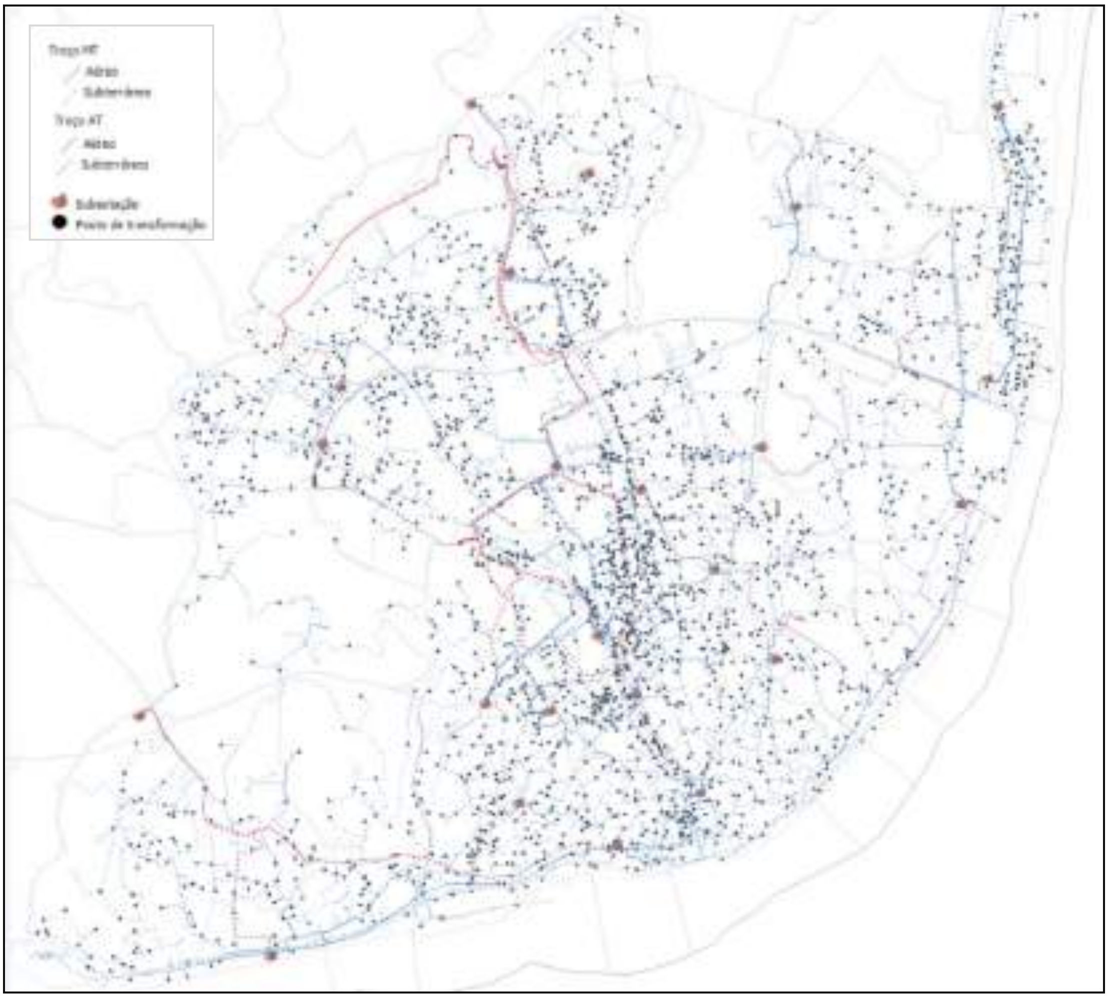


Figure 35 – Lisbon grid.

Mathematical modelling of energy systems

EDP Distribuição has internal technical models for simulation of the electrical distribution network, with the identification of dependencies in case of failure (DPlan software, geographic based integrated analysis and optimization system for distribution network). Possible developments are the simulation of climate scenarios taking into account existing infrastructures by the EDP Distribuição team.

Main climatic effects and natural hazards affecting the service and the critical infrastructures

The climate variables with potential to have significant effects on these systems are synoptic severe weather, heat events and local severe weather (heavy rainfall, wind). Depending on the type of component and climate event, the failures resulting include damages and collapse, eventually resulting in interruption on energy supply.

Regarding EDP Distribuição organizational structure, Lisbon city is included in the Lisbon Operacional Area (OA Lisboa) of the Lisbon Network and Customer Department (DRCL) (Figure 36), one of the six network and customer units of the company, which regionally ensures the energy supply services.

Figure 36- Lisbon network and customer department.

In the Table 16 energy data at DRCL scale is provided, including data on energy consumption and energy production under special regime, in order to define the scope of resilience challenges related to energy and for developing urban policies.

Table 16 – Data for Lisbon area (DRCL): energy consumption and energy production under special regime.

Energy Consumption 2015 (GWh)	
VHV	873
HV	1.560
MV	3.668
LV	5.386
Street Light	269
Total	**11.756**

Special Regime Producers 2015 (KVA)	
Biogas	15.806
Biomass	14.700
Cogeneration	327.192
Wind	109.944
Photovoltaic	71.188
Self-consumption production	165
Urban solid waste	6.300
Total	**545.295**

In Table 17 service continuity indicators for Lisbon Area are provided. (http://edp-distribuicao-continuidade.wntech.com/Indicadores/2015/115).

Table 17 – General indicators of service continuity.

Grande Lisboa | Lisboa | 2016

Indicadores Gerais de Continuidade de Serviço

	SAIFI AT (nº)	SAIDI AT (min)	MAIFI AT (nº)	TIEPI MT (min)	END MT (MWh)	SAIFI MT (nº)	SAIDI MT (min)	MAIFI MT (nº)	SAIFI BT (nº)	SAIDI BT (min)
Zona A	0	0	0	15,37	54,06	0,56	20,06	0,53	3,77	33,19
Zona B	0	0	0	0	0	0	0	0	0	0
Zona C	0	0	0	0	0	0	0	0	0	0
Concelho	0	0	0	15,37	54,06	0,56	20,06	0,53	3,77	33,19

These indicators are:

SAIFI - System Average Interruption Frequency Index (number);
SAIDI - System Average Interruption Duration Index (minutes);
MAIFI - Momentary Average Interruption Frequency Index (number);
TIEPI - Installed Capacity Equivalent Interruption Time (minutes);
END – No-Distributed Energy (MWh).

The electrical infrastructures, namely substations and secondary substations, are equipped with alarm mechanisms that allow early detection of risk events, such as fires, flooding and others. In the particular case of the most critical assets, such as transformers, they include a set of sensing devices alarms such as associated with the significant increase of temperature.

This mitigation equipment's integrate a systematic preventive maintenance plan of the company, thus allowing to minimize the impact caused by the occurrence of any disruptive event, such as flooding.

Vulnerability and exposure varies with the type of component, its location and other factors.

The main interdependencies identified are related with energy supply to other systems functions, but physical collapse of components can also have consequences in other systems such as transportation systems.

3.5 Transport

The road network assumes a crucial importance in the planning of the city. With heterogeneous and diverse characteristics, this network is classified in municipal and supralocal and allows different types of connections to and from the city on a daily basis.

According to the State Report of the Territorial Planning (REOT 2015), the road network is placed in a hierarchy in accordance with the functions and characteristics of the roads, being divided into five levels: structural, main distribution, secondary distribution, local distribution (net of proximity) and of local access (net of neighbourhood).

The road network has approximately 230 bridges and other structures, including tunnels and viaducts.

Figure 37 – Lisbon rail network and airport

As crucial points of this network, the interfaces of public transport stand out, being places constituted by a set of areas and facilities that provide the connection between two or more ways of transportation, which may or may not include the respective terminals. Through this network a number of several vehicles circulate, for transport of passengers and goods, managed by public and private operators.

In the scope of the implementation of the National Action Plan for Energy Efficiency, it was created in Portugal the program for electrical mobility, aiming the introduction and expansion of the use of the electric vehicle, whose mission is to contribute to a more sustainable mobility, maximizing the benefits and integrating seamlessly the electric power, resulting from renewable energies, in the functioning and development of the cities.

The network "Mobi.e" has on the public space about 500 stations of slow loading (charge the battery to 100% between 6 to 8 hours).

Figure 38 – Lisbon transport networks and interfaces

Operators of transport considered two major situations, by its relevance: (i) intrinsically urban flow and flow associates with those who make connections between Lisbon and other regions of the country.

The existing network rail in the council is managed by three organisations: (i) Infrastructures of Portugal S.A. managing the national rail network; Lisbon's Transports which includes the network of Lisbon's Metropolitan (ML) and the Company CARRIS (Companhia Carris de Ferro de Lisboa) with the network of trams and lifts. CARRIS also manages the public buses of urban and suburban areas.

The Lisbon's Metropolitan (ML) mission is the provision of public service of passengers' collective transportation, having transported in 2012 approximately 154 million of passengers. This underground network is currently comprised of four lines.

With the situation of the city through the waterfront of Lisbon, the waterway connection between Lisbon and the south edge of the Tagus River is of utmost importance for the populations, in particular for those who living in one of the edges and working in another, make daily a pendulum motion very expressive. During 2013, were registered at Cais do Sodré and Terreiro do Paço around 11 million passengers in each terminal and around 540 thousand passengers at the terminal of Belém.

The areas on the river edge in which are deployed the infrastructures of maritime and inland waterway transport are under the management of the Administration of Lisbon's Port (APL) and offer facilities for navigation, both for the large vessels as for the rest river traffic and nautical sports.

The harbour is equipped with three cruise terminals: the cruise terminal in Lisbon, registered in 2013, 353 cruise ships in scale that transported approximately 558,040 passengers.

The main infrastructure of aerial transportation in Lisbon is the International Airport of Lisbon is the Airport Humberto Delgado. In 2013 passed through this airport, more than 16 million passengers and about 142 thousand aircraft[3] movements. The complex of cargo from Lisbon Airport allows the processing of 100,000 tonnes/year.

Lisbon, result of their position and needs of domestic supply, is the crossing point and storage of numerous dangerous products. This transport is done by sea, road, rail, air and in one case or another by river.

In Figure 39 the AADT (Annual Average Daily Traffic), i.e. the average daily traffic on a roadway link for all days of the week during a period of one year, expressed in vpd (vehicles per day) is given for the period 2009-2013. For the same period, in Figure 40 the variation of the AADT is provided.

The Lisbon Intelligent Traffic Control monitors traffic in the central area of the city with the aim of improving traffic management and safety through a variety of subsystems, including centralized traffic light systems, TV cameras, radar gauges, traffic lights triggered by speed controllers and variable message boards. Other objectives of this system are to improve traffic conditions, speed up the maintenance of traffic lights, with the activation of alarms in case of detection of equipment failures, improving environmental conditions and reducing energy consumption.

The Operational Control Center concentrates all the information flow necessary to operate the systems that integrate it. The traffic management and control system is a centralized, real-time, modular and hierarchical system, assuming a central role in the city zones in operation.

[3] ANA Aeroports of Portugal – Management and Accounts Report (2013)

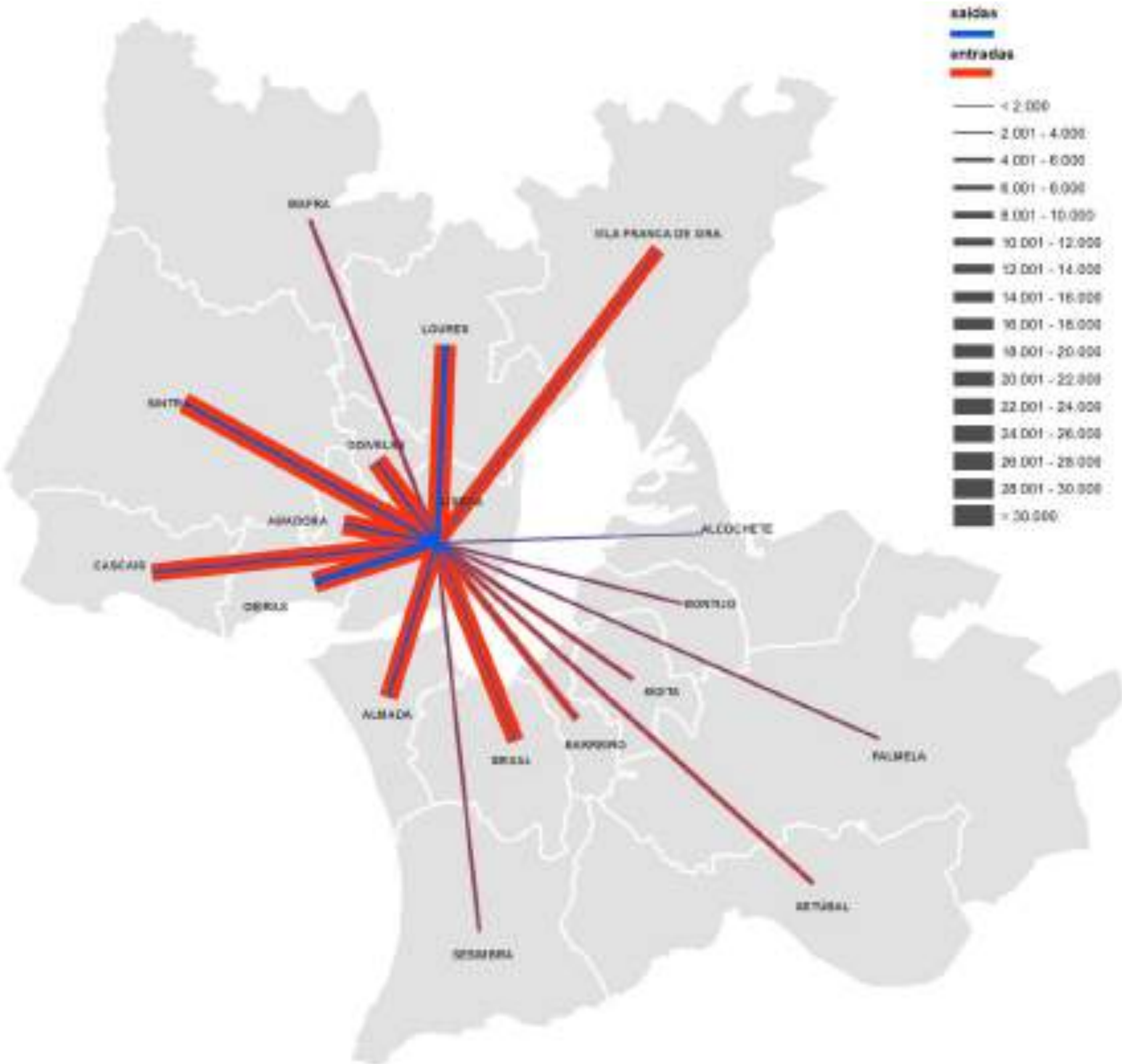


Figure 39 – Lisbon Metropolitan Area Annual Average Daily Traffic (vehicles per day).
Source: INE, Census 2011

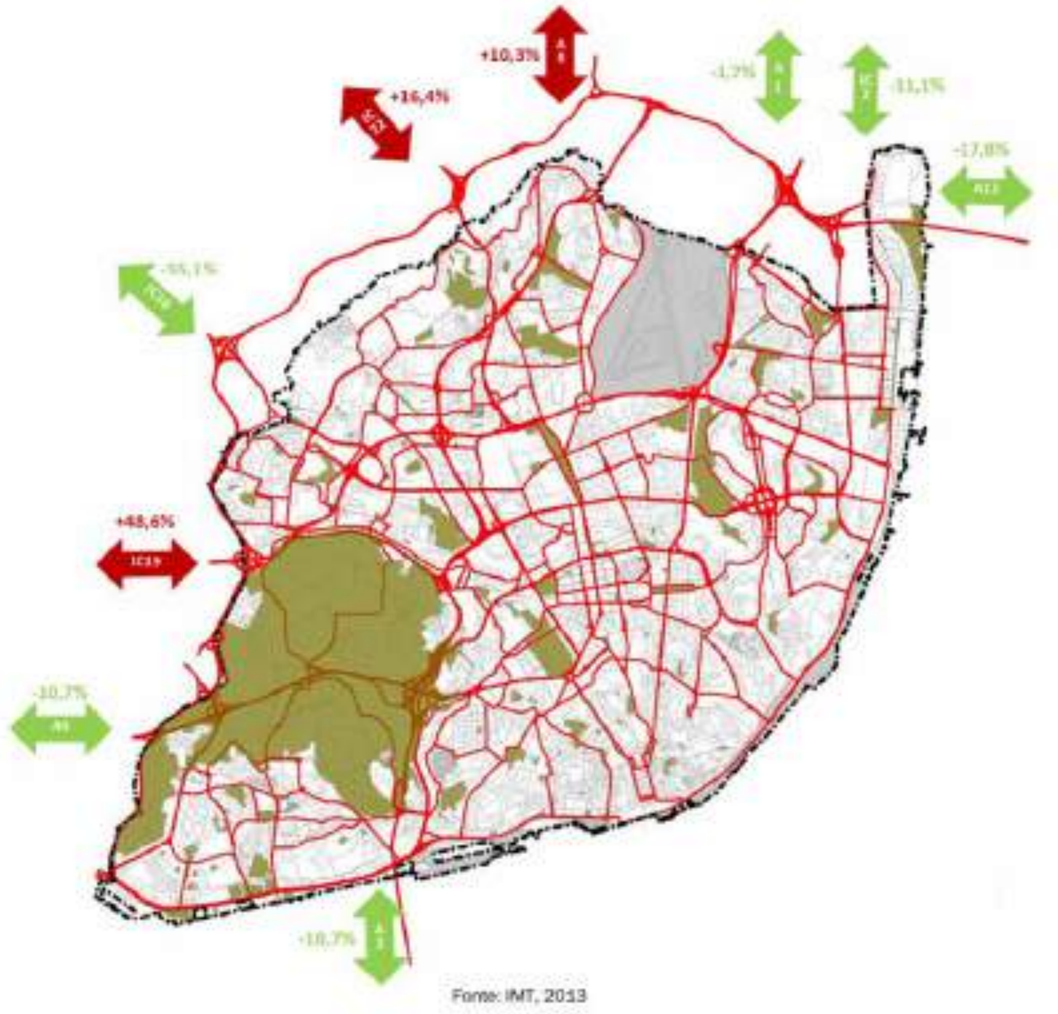


Figure 40 – Variation of Yearly Daily average traffic in main accesses to Lisbon (2009-2013, two ways, REOT, 2016).

Main climatic effects affecting the service and the critical infrastructures

The main climate variables with potential to have significant effects on transportation systems are rainfall, sea water level, tides and wind. Depending on the type of component and climate event, the failures resulting include Interruption of public and private transportation.

Vulnerability and exposure varies with the type of component, its location and other factors.

The interdependencies can be related with several urban services and several cascading events can occur. Parts of the infrastructure are significantly dependent from energy supply and, in some cases, provision of service is also dependent (e.g. trains). Physical collapse of other underground infrastructures, landslides and flooding can also have consequences in transportation systems.

3.6 Waste

The collection and transport of waste undifferentiated (trash) and recyclable materials produced in the city of Lisbon, as well as pest control and the population of pigeons are the council's responsibility. It is a continuous work, supported by human resources and mechanical means existing in the operating structures affected to various activities.

The fulfilment of national objectives until 2020 on reducing, reusing and recycling is included in the Action Plan of Lisbon's Council to the fulfilment of the Strategic Plan for Urban Solid Waste (PERSU) 2020, developed in partnership with the ValorSul Company and approved by the Portuguese Environment Agency in July 2015. It is up to the citizens participate in the reduction of waste production and recycling through the correct selective separation and use of containers/equipment available.

In the council, the management activity of solid waste is a public service of which the Regulatory Service of water and waste (ERSAR) is the entity regulatory. In terms of numbers according to data published by the Territory Planning State Report (REOT) 2014, the total amount of solid municipal waste collected was 228,984 tonnes of undifferentiated and 63,708 tonnes collected selectively. This value has increased annually.

At present, the number of dwellings covered by selective collection door to door is 184,217 (data at 2014) and the number of ecopoints, glass banks and batteries recycling containers is approximately 2000. In the case of large producers of waste (entities with average production per day of waste equal to or greater than 1100 liters), they are responsible for the management of waste that they produced, can hire the collection and treatment services of it by private operators, licensed for that purpose, or the municipal services.

Main climate effects and natural hazards affecting resilience of solid waste management services

The main climate variables with potential to have significant effects on solid waste management services are rainfall and wind. For instance, flooding or intense wind can result in damage, displacement and overturn of containers.

Vulnerability and exposure varies with the type of component, its location and other factors.

The interdependencies can be related with urban drainage, increasing the likelihood of obstruction of components (inlets, trenches, and sewers) and traffic, increasing, for instance, the likelihood of traffic accidents and obstructions, thus disturbing the fluxes of vehicles and people as well as economic activities.

3.7 Green Infrastructures

Lisbon concept sees green infrastructure as a tool to solve the most basic urban quality of life requirements, such as access to leisure and recreation areas, space for social integration, health standards, active mobility, and even local food production.

The approach of Lisbon Master planning, as part of the Lisbon Metropolitan Region, is based on a hierarchical ecological network where the concept of ecological or green corridors area the basis for a *continuum natural* between priority areas (REOT, 2017). The Municipal Ecological Structure develops this concept.

The Green Plan Measures (2008) incorporated in the 2012 Lisbon Master Plan defines the most sensitive ecological areas for preservation and promotes ecological sustainability, biodiversity and quality of green public spaces across the green corridors, soft drainage systems, pedestrian and cycle paths and an increase in permeable areas. The green infrastructure is a cross-platform in order to promote diversity and functionality, taking into consideration the inter-connexion within the green infrastructure of Lisbon Metropolitan Area.

Lisbon Master Plan - based on the assessment of natural and manmade threats - set the guidelines and objectives for targeted individual planning and local development founded on ecological principles, water cycle improvements and sustainable mobility, through the enhancement of the green infrastructure. Sustainability measures were included as specific targets, which includes several specific measures such as Urban Allotments, Green Structure Areas, Water Cycle improvements, among others (Mata, 2014). The International Society of City and Regional Planners honoured Lisbon with its Award of Excellence (2013) for innovative approaches to implementation that set the priorities for the municipal budget.

Figure 41: Lisbon: green corridors planning (2017)

From its inception in 2008, the setting of green corridors supports strategies for managing green infrastructure. The green infrastructure program basis is the idea of multifunctional systems and uses. This program considers benefits in terms of climate adaptation responses, improvement of the water cycle, urban climate regulation (e.g. heat Island effects) and decreasing soil sealing. The green infrastructure program comprises the implementation of 9 green corridors, including an urban allotment garden program, reinforcement of trees plantation, mostly street alignment trees and development of nature based solutions such as rainwater retention basins and rain fed biodiversity meadows. There is a growing investment in the environment, as shown by the doubling of the municipal budget in green infrastructure from 2015 to 2018.

Additionally, the use of nature based solutions in the Lisbon Drainage Master Plan (2016-2030) allows further promotion of combined drainage solutions with green areas.

Figure 42: Lisbon Urban Allotment Garden program (2016)

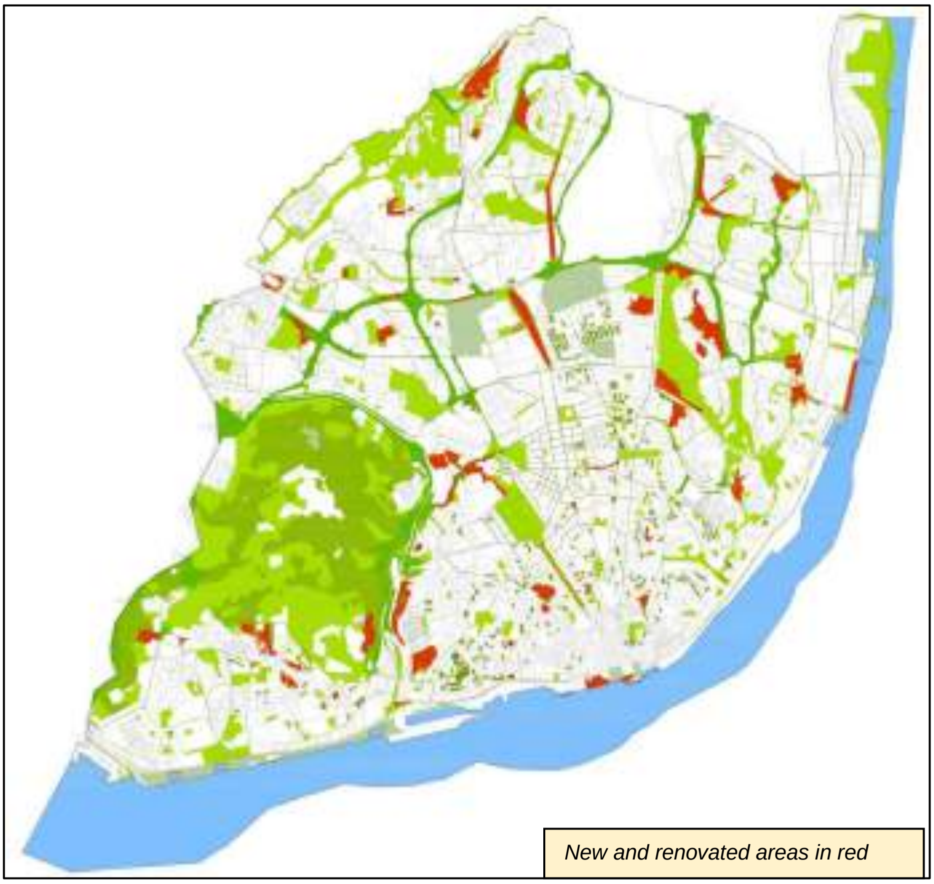


Figure 43: Enhancement of green infrastructure (2008-2017)

In terms of area, excluding green areas smaller than 1000 m^2 and private green areas, the total area of established and under improvement green areas is around 24 km^2, representing around 28% of Lisbon´s area. In terms of green area per inhabitant Lisbon has a value of 36,2 m^2/inhabitant (REOT, 2015). When considering all green areas these values are estimated as 32,1% and 46,8 m^2/inhabitant, respectively (Santos, 2009).

Main climatic effects and natural hazards affecting the service of green infrastructures

The main climate variables with potential to have significant effects on green infrastructures is wind specially related to the collapse of trees. Depending on the type of component and climate event, the failures resulting include interruption of public and private transportation.

Vulnerability and exposure varies with the type of component, its location and other factors. The interdependencies can be related with several urban services and several cascading events can occur. Cascading effects on urban drainage causing obstruction of components and surface flows; on energy causing damage to equipment and lines. Transport can be effected causing road and rail traffic disturbance and interruptions. Damage to equipment and lines on communication infrastructures also can be affected.

3.8 Lisbon matrix of exposure and direct impacts among extreme climate variables and failure in urban services

3.8.1 Exposure to natural hazards

According to the territory planning state report, the indicators of the exposure to natural hazards are those given in Table 18.

Table 18 – Territory Planning State Report (REOT Indicators).

INDICATORS		2014				
Exposure respect Natural Hazards		*Nº*	*Area (m²)*	*Area (%)(1)*	*N.º Residents (2)*	*N.º Buildings*
1. Soil's seismic	High		20775899.3	24.62	228556	19535
	Very High		13002418.9	15.41	140722	10616
	Total		**33778318.2**	**40.03**	**369278**	**30151**
2. Land mass movement	High		364692.10	0.43	32930	4340
	Very High		379876.41	0.45	20304	2878
	Total		**744568.51**	**0.88**	**53234**	**7218**
3. Direct tide effect (5m elevation)			5384599.29	6.38	18909	2317
4. Floods	High		3029983.86	3.59	110012	12448
	Very High		3388559.90	4.02	82161	8528
	Total		**11803143.05**	**13.99**	**192173**	**20976**
5. Maximum accumulation point	Basin > 5 ha and < 75 ha	30				
	Basin > 75 and < 500 ha	8				
	Basin > 500 ha	4				
	Total	42				
(1) Calculated values are referenced to the total council area (geographic shape measure 84374973,93 m²). (2) Data obtained from census 2011 (definitive results)						

Source: http://www.cm-lisboa.pt/fileadmin/VIVER/Urbanismo/urbanismo/planeamento/reot/

3.8.2 Identification of exposure and direct/indirect impacts from climate variables

The information collected in the section of this deliverables has been also used to create specific tables for each research site to relate climate variables and direct and indirect impacts of main urban services analysed in RESCCUE according to their level of exposure. These tables could be used in the WP4 for the elaboration of the interdependency matrix of each research site.

The first approach about identification of interdependencies for the city of Lisbon was carried out considering eight urban services even if it is not considered in RESCCUE to proceed with a detailed analysis through WP2 and WP3 tasks.

The critical elements are the components from the systems indicated that can be affected by the climate variable (hazard or risk factor). The climate variables are connected with those identified in WP1. The failures indicated are associated with the critical element under analysis and the services interdependencies are those services potentially affected by the failure (corresponding in the row).

RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

			CLIMATIC VARIBLE	Temperature	Temperature	Rain	Rain	Rain	Wind	
			HAZARD	Heat Wave	Sea level rise	Urban flooding	Drought	CSOs	Windstorm	
URBAN SERVICES	URBAN SERVICE CYCLE	SUBSYSTEMS	CRITICAL ELEMENTS	EXPOSURE						COMMENTS ABOUT POTENCIAL DERIVED RISKS / CASCADE FAILURES
Energy	Electricity	Power generation	Main station of power generation	✓	✓	✓	✓	✓	✓	
			Station of distributed generation	✓	✓	✓	✓	✓	✓	
		Electric Transportation	Substation	✗	✗	✗	✓	✓	✗	Damages, collapse, interruption of energy supply. Water supply cascading effects: failures regarding electromechanical and control systems. Urban drainage: failures iregarding pumping and control systems. WWTP: failures regarding electromechanical elements and control systems. Street light: failures regarding function and control systems. Telecommunication: cellulars towers, central offices and other critical communications used in monitoring and controlling the delivery of electricity.
			Overhead lines	✗	✗	✗	✓	✓	✗	
			Underground cables	✗	✗	✗	✓	✓	✗	
		Electric Distribution	Substation	✗	✗	✗	✓	✓	✗	Damages, collapse, interruption of energy supply. Water supply cascading effects: failures regarding electromechanical and control systems. Urban drainage: failures iregarding pumping and control systems. WWTP: failures regarding electromechanical elements and control systems. Street light: failures regarding function and control systems. Telecommunication: cellulars towers, central offices and other critical communications used in monitoring and controlling the delivery of electricity.
			Overhead lines	✗	✗	✗	✓	✓	✗	
			Underground cables	✗	✗	✗	✓	✓	✗	
Telecommunicatio		Network	Antennas	✗	✓	✗	✓	✓	✗	Damage/collapse, interruption of communication services. Cascadinf effects on several urban services affecting control and communication systems.
			Telecommunication network (fiber)	✗	✓	✗	✓	✓	✗	
			Telecommunication network (coppe	✗	✓	✗	✓	✓	✗	
		Nodes	Operational centers	✗	✓	✗	✓	✓	✗	
Urban water cycle	Water Supply	Water Distribution	Distribution network	✓	✓	✓	✗	✓	✓	Insufficient availability, limitation in supply
	Urban Drainage	Sewers system	Sewer network	✓	✗	✗	✓	✗	✓	Limited conveyance capacity, high street runoff (level and velocity), CSOs. Transport cascading effects: road and rail traffic disturbance and interruptions, flooding of underground infraestructures (metro, train, parkins). Solid waste: overturn, dragging and damage on wastes. Energy: Damage to equipment and lines. Other urban services: pedestrian ways, parking lotsplaygrounds, among others, untreated discharges, pollution of receiving water bodies.
			Pump stations	✓	✗	✗	✓	✗	✓	Electrical or mechanical failures due to flooding with consequences in terms of pumping lower capacity and CSOs. High salinity degrading mechanical equipment. Excesive inflows. Transport: Road traffic disturbances and interruptions.
	Waste Water Treatment	Waste Water Treatment Plant (WWTP)	WWTP	✓	✗	✗	✓	✗	✓	Excessive inflow anfd dilution generating lower treatment efficiency and CSOs. Entry of salt water into the system leading to potential corrosion of important infrastructures causing lower treatment efficiency due to Cl^-.
Waste	Solid waste	Solid Urban Waste Collection (SUW)	Pneumatic collecting plants	✓	✓	✓	✓	✓	✓	
			Pneumatic collecting network	✓	✓	✓	✓	✓	✓	
			Waste vehicles	✓	✓	✓	✓	✓	✓	
		Cleaning	Solid waste containers	✓	✓	✗	✓	✓	✗	Damage, displacement and overturn of containers. Cascading effects considered on urban drainage: obstruction of components and surface flows
		SUW Treatment	Waste treatment plant	✓	✓	✓	✓	✓	✓	
			Cleaning stations	✓	✓	✓	✓	✓	✓	
Transport	Roadways	Roadways	Main roadways	✓	✗	✗	✓	✓	✗	Flooding and stormwind can cause interruption of public and private transportation including underground infrastructures. Several urban services could be affected by cascading effects if maintenance or repair tasks are required during failures.
			Secundary roadways	✓	✗	✗	✓	✓	✗	
			Local roads	✓	✗	✗	✓	✓	✗	
			Traffic signals	✓	✗	✗	✓	✓	✗	Wind can generate failures of traffic control systems. Several urban services could be affected by cascading effects if maintenance or repair tasks are required during failures.
	Rail and Metro	Rail and Metro	Surface rail and metro network	✓	✗	✗	✓	✓	✗	Flooding and stormwind can cause interruption of public and private transportation including underground infrastructures. Several urban services could be affected by cascading effects if maintenance or repair tasks are required during failures.
			Surface rail and metro stations	✓	✗	✗	✓	✓	✗	
			Underground rail and metro networ	✓	✗	✗	✓	✓	✗	
			Underground rail and metro station:	✓	✗	✗	✓	✓	✗	
			Traffic signals	✓	✗	✗	✓	✓	✗	Wind can generate failures of traffic control systems. Several urban services could be affected by cascading effects if maintenance or repair tasks are required during failures.
Green infraestruct	Green infrastructures	Trees	Trees	✓	✓	✓	✓	✓	✗	Coilapse of trees. Cascading effects on urban drainage causing obstruction of components and surface flows. Cascading effects on energy causing damage to equipment and lines. Cascading effects on transport causing road and rail traffic disturbance and interruptions. Cascading effects on communication causing damage to equipment and lines.
Urban equipment	Urban equipment	Various components	Various elements	✓	✓	✗	✓	✓	✗	Cascading effects on urban drainage causing obstruction of components (inlets, trenches, sewers, etc.). Cascading effects on energy causing damage to equipment and lines. Cascading effects on transport causing road and rail traffic disturbance and interruptions. Cascading effects on several urban services if maintenance or repair are required.

✗	Exposed
✓	Not Exposed or Not Considered

Table 19 – Lisbon matrix of exposure and direct/indirect impacts from climate variables and failure urban services.

4 Research site characterization: Barcelona Site

4.1 Main features of the research site

Located on the Mediterranean coast 41°23’ N/02°12’ E, 166 km from the French border and 120 km south of the Pyrenees, Barcelona is on plain bordered by two rivers: the Llobregat in the south and the Besòs in the north. The Collserola ridge (part of the Serralada Litoral) borders the west side of the city, with pine and oak woodland, fields and meadows, as well as wetland vegetation. The city has five small hills (Monterols, Putget, Carmel, Rovira and Peira) and was once full of streams and small marshes. The promontory of Montjuïc is also by the coast, rising to a height of 191.7 meters.

Figure 44: Barcelona municipality boundaries.

The city’s climate is Mediterranean, with hot and humid summers and warm winters. Rainfalls occur mostly during spring and autumn reaching a total of 598 mm/year and the average temperature is about 16.5°C with 2,483 hours of sun and solar radiation of 1,502 kWh/sq m.

Barcelona is a dense and compact settlement: on a surface area of 100.4 square kilometres, a population of 1.619.337 inhabitants is established, which implies an average density of 15.873 hab/km2.

Its territory is divided into ten administrative districts: Ciutat Vella, Eixample, Sants-Montjuïc, Les Corts, Sarrià-Sant Gervasi, Gràcia, Horta-Guinardó, Nou Barris, Sant Andreu and Sant Martí, each of them being represented by its own district council. The roots of the current division can be found in the history of the city. The district of Ciutat Vella is the old centre of the city and the Eixample is the area where the city was expanded after the city walls were knocked down. The other districts correspond to municipal areas which were around the old city, outside the walls and which became part of Barcelona during the 19th and 20th centuries. Each district is divided into different neighborhoods.

Figure 45 Barcelona is organized in 10 administrative districts and 73 neighbourhoods.

4.1.1 Population and climate

The following table (Table 20) shows specifically population density for each administrative district. These values denote that the central zone of the city has the highest population density, while the districts of Sants-Montjuïc (where is located the Industrial zone) and Sarrià-Sant Gervasi (that includes an important area of the Collserola mountain) have a low population density.

Table 20: Barcelona Population density by districts.

	Population	Surface (ha)	Density	Net density
BARCELONA	**1.604.555**	**10216**	**157**	**619**
1. Ciutat Vella	100.115	437	229	775
2. Eixample	263.558	748	353	707
3. Sants-Montjuïc	180.757	2294	79	724
4. Les Corts	81.530	602	135	453
5. Sarrià-Sant	146.834	2009	73	321
6. Gràcia	120.401	419	288	601
7. Horta-Guinardó	166.559	1195	139	564
8. Nou Barris	164.648	804	205	700
9. Sant Andreu	146.494	657	223	761
10. Sant Martí	233.659	1052	222	841

Barcelona benefits from a classic Mediterranean climate, with gentle winters and even hot summers. The yearly average rainfall is 460 mm, but this value occasionally may be concentrated in a few storm events, heavy rainfalls of great intensity. These events, in combination with the morphological characteristics of the city, and the high percent of impervious areas, produce high flows in the sewer system. All these factors increase urban flood risk in the flatland areas of the city. Barcelona has rainfall data since 1927, from the Observatory Fabra, located in the Collserola mountain range. The pluviometer installed gives data of rainfall intensity. This long time data series allowed to creating the Intensity Duration Frequency (following IDF) curves of the city of Barcelona. The IDF curves were recently updated on the basis of these data series (81 years, from 1927 to 1992 and from 1995 to 2009), by Casas *et al*. (2010).

The new IDF curves, related to different return periods (T), are shown in the Figure 46. The numerical values for the rainfall intensities obtained are exposed in the Table 21. The values of intensity expressed on the Table 21 are currently used in local studies of the sewer network, and to design sewer networks in local areas.

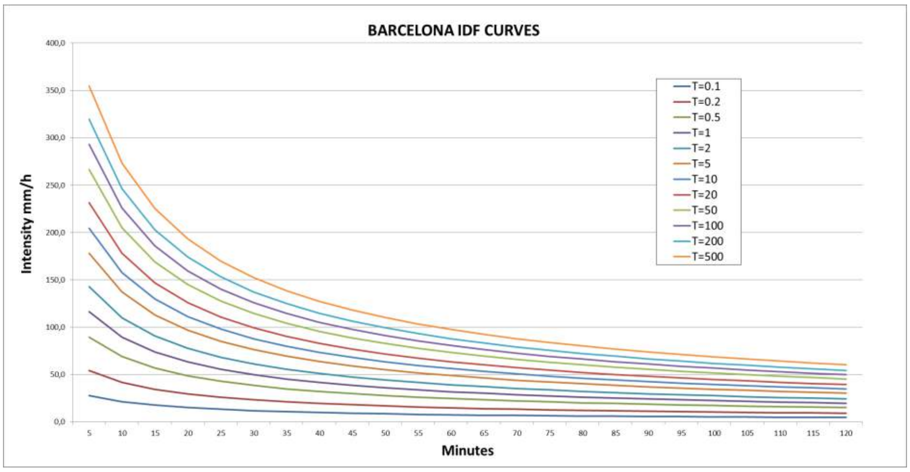


Figure 46: Barcelona IDF curves (Casas *et al*., 2010).

Table 21: Numerical values of rainfall intensities in mm/h for the new IDF curves relating T return periods (in years) with durations (in minutes).

		t (minutes)																							
		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	10	10	11	11	12
T	0,1	27,9	21,5	17,7	15,2	13,4	12,0	10,9	10,0	9,3	8,7	8,1	7,7	7,3	6,9	6,6	6,3	6,1	5,8	5,6	5,4	5,2	5,1	4,9	4,8
	0,2	54,5	42,0	34,6	29,7	26,1	23,4	21,3	19,6	18,2	16,9	15,9	15,0	14,2	13,5	12,9	12,3	11,8	11,4	11,0	10,6	10,2	9,9	9,6	9,3
	0,5	89,7	69,1	56,9	48,8	43,0	38,6	35,1	32,2	29,9	27,9	26,2	24,7	23,4	22,3	21,2	20,3	19,5	18,7	18,0	17,4	16,8	16,3	15,8	15,3
	1	116,3	89,6	73,8	63,3	55,7	50,0	45,5	41,8	38,7	36,2	33,9	32,0	30,3	28,9	27,5	26,3	25,2	24,3	23,4	22,5	21,8	21,1	20,4	19,8
	2	142,9	110,1	90,7	77,8	68,5	61,4	55,9	51,3	47,6	44,4	41,7	39,4	37,3	35,5	33,8	32,4	31,0	29,8	28,7	27,7	26,8	25,9	25,1	24,4
	5	178,1	137,2	113,1	97,0	85,4	76,6	69,6	64,0	59,3	55,4	52,0	49,0	46,5	44,2	42,1	40,3	38,7	37,2	35,8	34,5	33,4	32,3	31,3	30,4
	7	191,0	147,1	121,3	104,0	91,5	82,1	74,7	68,6	63,6	59,4	55,7	52,6	49,8	47,4	45,2	43,2	41,5	39,8	38,4	37,0	35,8	34,6	33,6	32,6
	10	204,7	157,7	129,9	111,4	98,1	88,0	80,0	73,5	68,2	63,6	59,7	56,4	53,4	50,8	48,4	46,3	44,4	42,7	41,1	39,7	38,3	37,1	36,0	34,9
	20	231,3	178,2	146,8	125,9	110,9	99,4	90,4	83,1	77,0	71,9	67,5	63,7	60,3	57,4	54,7	52,4	50,2	48,3	46,5	44,8	43,3	41,9	40,6	39,4
	50	266,5	205,3	169,2	145,1	127,7	114,5	104,2	95,7	88,7	82,8	77,8	73,4	69,5	66,1	63,1	60,3	57,8	55,6	53,5	51,7	49,9	48,3	46,8	45,4
	100	293,1	225,7	186,1	159,6	140,5	126,0	114,6	105,3	97,6	91,1	85,5	80,7	76,5	72,7	69,4	66,3	63,6	61,1	58,9	56,8	54,9	53,1	51,5	50,0
	200	319,8	246,2	202,9	174,1	153,2	137,4	125,0	114,8	106,5	99,4	93,3	88,0	83,4	79,3	75,7	72,4	69,4	66,7	64,2	62,0	59,9	58,0	56,2	54,5
	500	354,9	273,3	225,3	193,2	170,1	152,5	138,7	127,5	118,2	110,3	103,6	97,7	92,6	88,0	84,0	80,3	77,0	74,0	71,3	68,8	66,5	64,3	62,3	60,5

These new IDF curves were used to calculate a new project storm, with a return period of 10 years, named "Plubarna 2010" (Casas *et al.*, 2010). This synthetic storm, shown in the Figure 47, is currently used for the design of the sewer network of Barcelona.

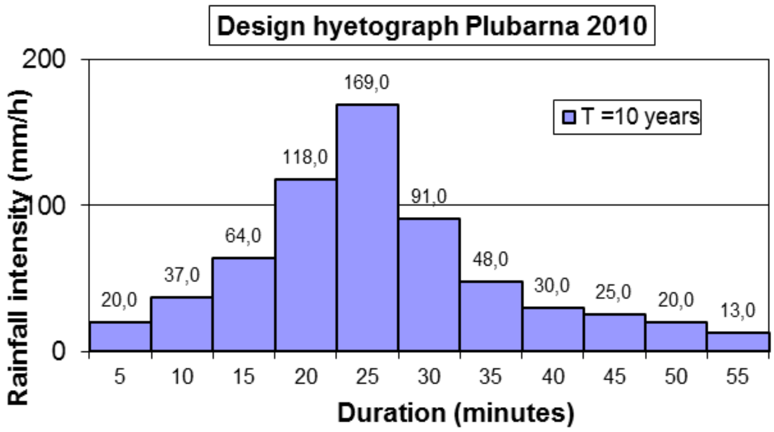


Figure 47: Design storm for T=10 years return period Plubarna 2010. (Casas M.C. *et al.*, 2010)

4.1.2 Morphology and land use

Because of the short distance between the Collserola range mountain and the Mediterranean sea, Barcelona presents some areas with high slopes (greater than 6%), and other areas, next to the coast and the rivers, with very small slopes (below 1%). This is represented on the Figure 48.

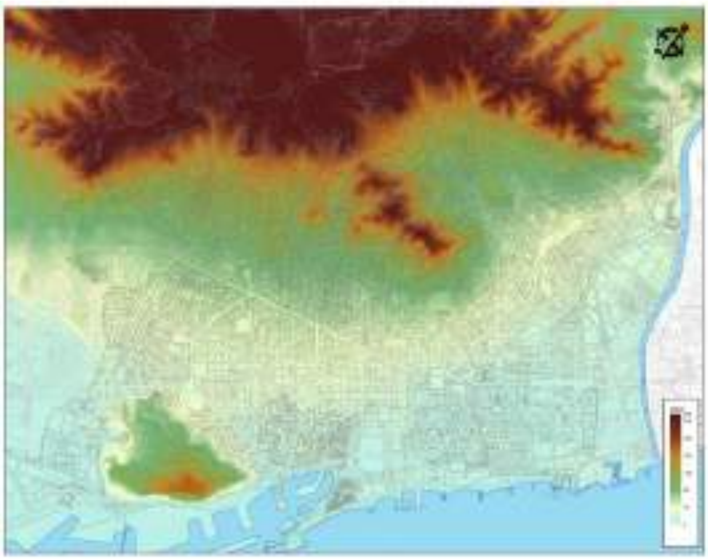


Figure 48: Topography of the city of Barcelona

This morphology causes that the catchment areas of the high zones of the city have a short time of concentration. As a result, in case of medium and heavy storm events, theses produces a quick storage of storm water in the flatland areas, turning into urban flash floods on these areas.

The land of Barcelona was strongly urbanized during the last century. Currently, the land use of the city has a 70% of impervious areas and a 30% of pervious areas. The spatial distribution of the land use is represented in the next figure Figure 49.

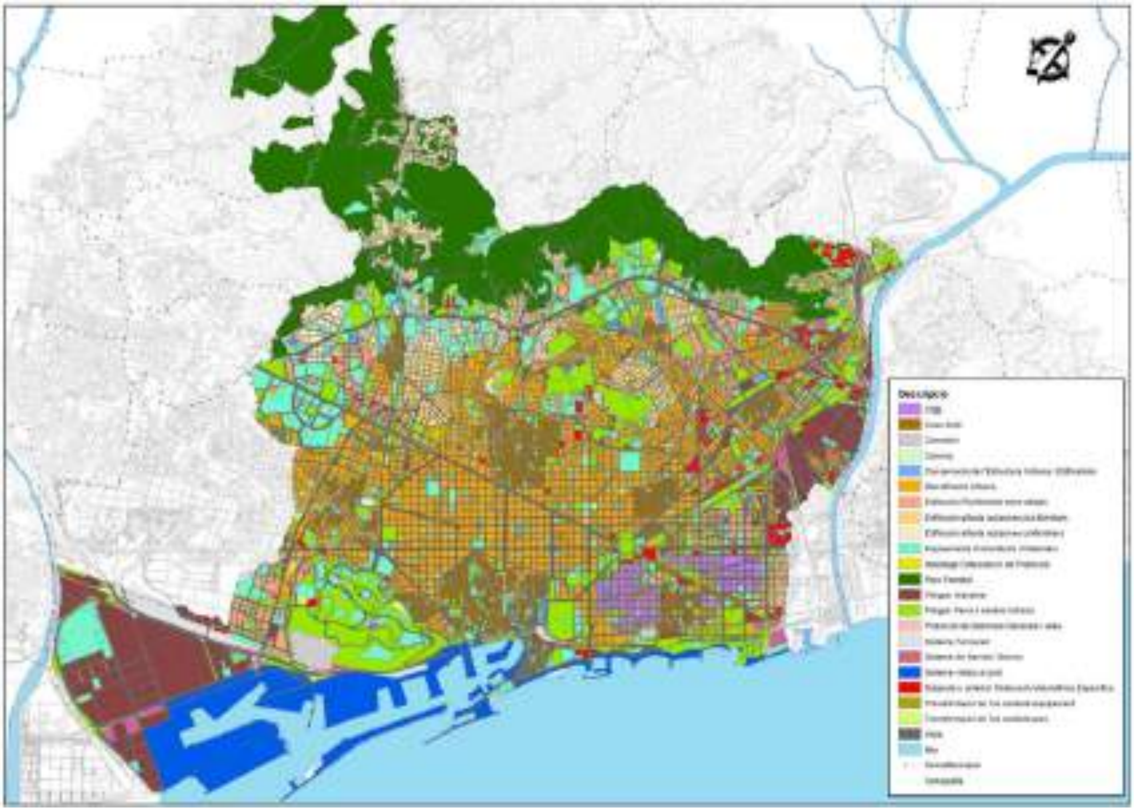


Figure 49: Distribution of the land use in Barcelona

The distribution of the land use is heterogeneous depending on each zone. The following table (Table 22) shows the classification of every land used identified, areas and impervious percentage related to everyone.

Table 22: Land use surfaces and percentages.

land use	Area (ha)	percentage %
roads	2.088,36	20,6%
buildings	1.845,30	18,2%
residential areas	454,24	4,5%
city equipments	1.032,95	10,2%
old town	363,93	3,6%
forest	1.647,52	16,3%
industrial park	609,08	6,0%
urban gardens	1.301,02	12,9%
cemeteries	49,40	0,5%
crops	4,69	0,1%
railways	125,50	1,2%
harbour	602,38	5,9%

4.1.3 Socio-Economics aspects

Some of the main outstanding indicators (social, economic, environmental, population) are collected in Figure 50.

Figure 50: Basic Barcelona city indicators

4.2 Organization of the city services management

Regarding **water cycle organization city services**, Barcelona City Council makes a great effort to protect and improve the Environment and Urban Habitat and believes that water is an essential factor in any decision for the city. That's why the Council has set up the Barcelona Cicle de l'Aigua**,** SA (BCASA) a company to manage the city's entire water cycle, carry out activities and provide services directly or indirectly involving the water cycle, beaches, coastline and environment. The company was approved at the Council's Plenary Session of 28 October 2013, reports to the Assistant Management of the Environment and Urban Services, part of the Urban Habitat Management Division, and carries out its functions under the leadership, supervision and control of the Directorate for Water Cycle Services (DSCA).

Responsibility for managing water in the city of Barcelona is divided among different organizations. In general terms, the autonomous community administration is responsible for supplying water at high pressure while its distribution to users is the responsibility of a group of municipalities or concession.

The City Council can take part in the better management of water on a general basis or, in the case of droughts, by reducing superfluous municipal consumption and carrying out awareness-raising campaigns. With the Catalan government, it also acts as the health authority to control mains water quality, through the Barcelona Public Health Agency (ASPB).

The Council also manages groundwater, as well as working to reduce leakages from the distribution network, in which it has the cooperation of the water distribution company responsible for the system's maintenance.

The strategic focuses of Barcelona Cicle de l'Aigua, SA (BCASA) are to further rational policies for water consumption, promote the use of alternative water resources and advance policies to improve urban drainage and the comprehensive management of the coastline and city fountains.

In the **area of transport or mobility**, authority in Barcelona is shared between different bodies and cooperation between them is therefore vital to achieve the strategic goals. There's a wide range of public transport networks, namely: Underground, Metropolitan Train (Ferrocarrils de la Generalitat de Catalunya or FGC), Railway (local, regional and state - Renfe), Tram, Bus (including district and tourist buses) and intercity bus.

Barcelona City Council shares responsibility for the low pressure water supply, for supervision and inspection and for actions when there is a risk of drought.

	Catalan government	Metropolitan Area	Barcelona City Council
Water planning	•		
High pressure supply	•		
Low pressure supply		•	•
Supervision and inspection	•	•	•
Approval of rates	•	•	
Action in drought risk situations	•	•	•

*Barcelona City Council delegates this responsibility to AMB.

Table 23: Barcelona city management responsibilities.

Regarding road infrastructures, the Spanish government is responsible for the basic state and European network, the Catalan government for the basic Catalan network and the government of Barcelona province for the local network. The County Council of Barcelonès is responsible for the complete maintenance of the ring roads in Barcelona and the City Council is responsible for managing the traffic and the safety of roads, pedestrians and bicycles, as well as goods distribution.

Barcelona's public transport networks are managed by 4 different administrations.

Table 24: Barcelonas's public transport administrations.

Administration responsible	Owner of the infrastructure	Owner of the service
Catalan government	Railway: Underground, FGC, Tram	FGC (including 7 Renfe local train lines*), intercity bus
Metropolitan Area of Barcelona (AMB)		Underground, Barcelona bus, AMB bus: Taxi
Spanish government	RENFE state railway network	RENFE (state, regional and 6 local lines)
Metropolitan Transport Authority (ATM)		Tram

Barcelona City Council is the responsible for street cleaning and waste collection, and hence it also manages the treatment of the different fractions of municipal solid waste. The Council can, nevertheless, manage all the process of collection, transport and treatment of each fraction on its own account, or contract the tasks totally or partially to private companies or even to social organisations.

Decree 1/2009, of 21 July, defines the powers and functions of local bodies as regards prevention and taking action intended to accomplish the aims defined in the Catalonia Municipal Waste Management Programme 2007-2012 (PROGREMIC). According to this Decree, the management of waste is the responsibility of the municipality. As regards planning for prevention, the Law on waste and contaminating soils, Act 22/2011, of 28 July, lays down that local bodies can, within the framework of their authority, draw up programmes for waste management in accordance with the National Framework Plan and the Autonomous Community waste plans.

European, state and Catalan regulations determine a hierarchy which establishes the order of priorities to be applied in waste management policies: prevention, preparation for reuse, recycling (even composting) other types of recovery (for example, energy recovery) and elimination (or disposal). On a European scale, this hierarchy is covered in Directive 2008/98/EC, of 19 November 2008. At a state level, Act 22/2011, of 28 July, on contaminating soils and waste, states that public administrations should pass programmes for waste prevention, setting the prevention targets and describing the existing prevention measures. Apart from this, there is also a National Integrated Waste Plan (PNIR) 2008-2015, Urban Waste of Household Origin, a text approved by an agreement of the Council of Ministers of December 2008. Finally, at the Autonomous Community level, there is also the Catalonia Municipal Waste Management Programme 2007-2012 (PROGREMIC) and the Metropolitan Plan for Management of Municipal Waste 2009-2016 (PMGRM).

At the municipal level, cleaning public space and managing waste is regulated by means of different ordinances passed by the City Council. This establishes the criteria for classifying waste within municipal competence, either special or not special, as well as any waste whose nature or origin means it must be handled by carriers and managers authorised by the Catalan Waste Agency.

For a better understanding of the Barcelona water cycle organization, it is necessary to identify the different stakeholders involved and the responsabilities they hold or develop within the water cycle at different levels. As mainly natural resources, jurisdiction over the water cycle belongs to public institutions, except the water distribution, which is operated by a private service company that manages the whole drinking water network within the city of Barcelona. The figure below (Figure 51) shows the Barcelona water cycle jurisdictional framework and responsabilities overlap among different stakeholders and jurisdiction levels:

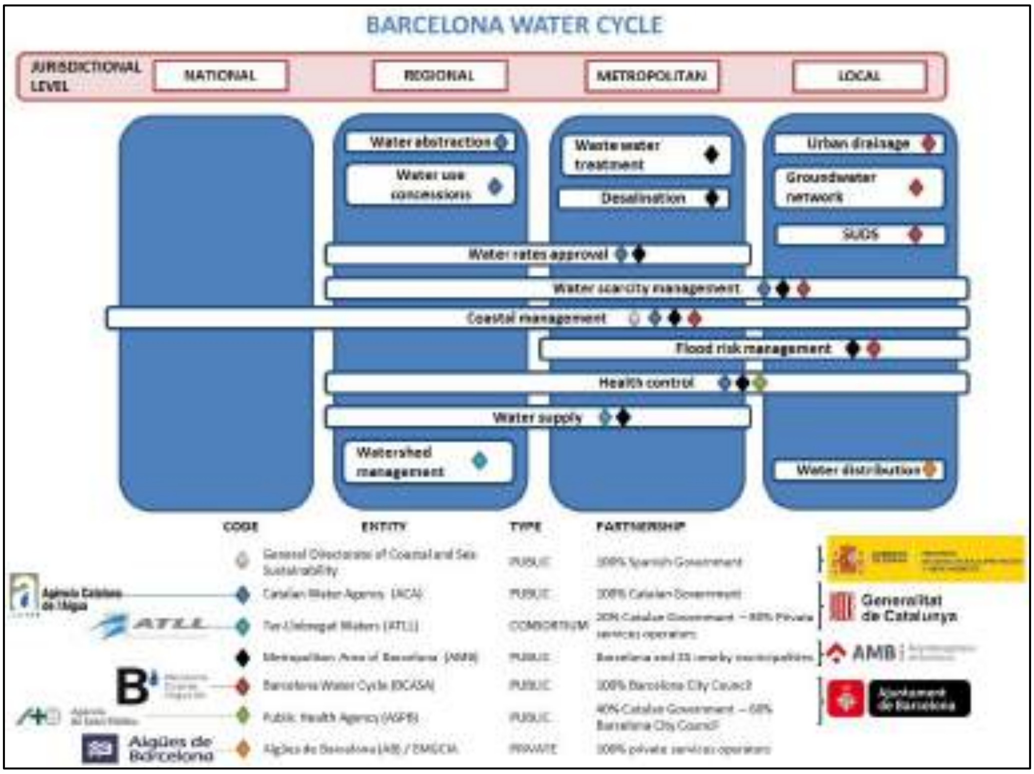


Figure 51: Barcelona water cycle jurisdictional framework and responsabilities overlap among different stakeholders.

Regarding the energy sector, it is remarkable the main role developed by the private services operators due to the national regulations that have lead to a liberalized sector. From the Barcelona City Council, local policies are developed by the Barcelona Energy Agency in the areas of urban planning and energetic management, and are adressed to foster the use of renewable energies within the city and the creation of a local energy operator. The energy sector framework of Barcelona is displayed in Figure 52.

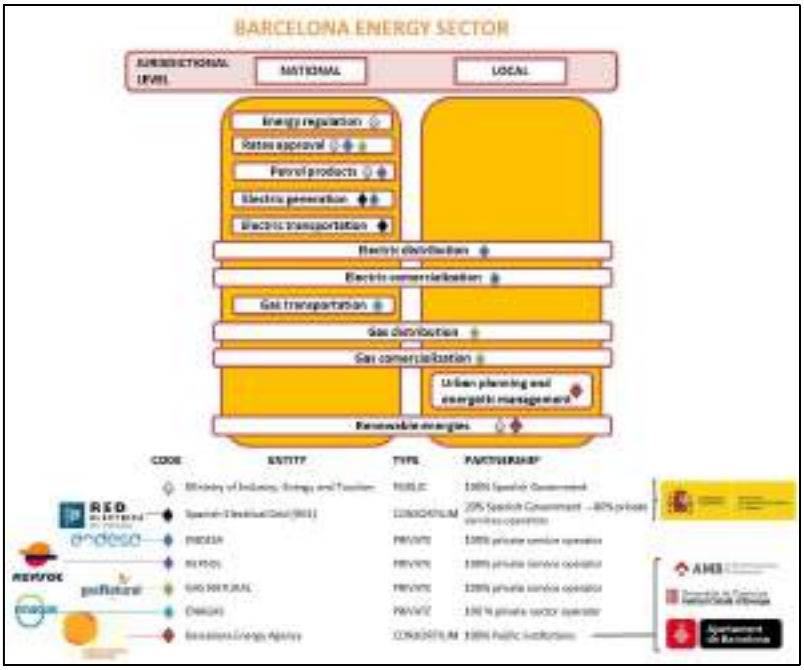


Figure 52: Barcelona energy sector jurisdictionial framework and responsabilities overlap among different stakeholders.

Barcelona transport sector is totally operated by public institutions. The cooperation between main actors at different scales is essential for the coordination of the mobility network within the city of Barcelona. Figure 53 shows how responsibilities are shared by stakeholders and their interactions through different jurisdictional levels.

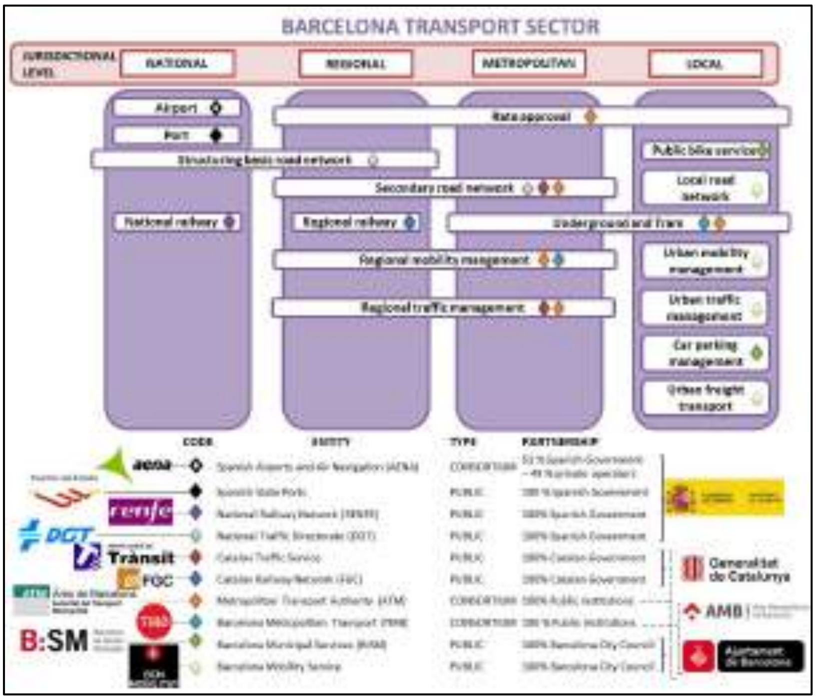


Figure 53: Barcelona transport sector jurisdictional framework and responsabilities overlap among different stakeholders.

In the area of solid urban waste, main administrative responsibilities are developed by the Barcelona City Council, while street cleaning, waste collection and transport is operated by private service companies hired by the City Council. Waste treatment plants are managed by public institutions as well as the waste management regulations or the development of recycling policies and social awareness campaigns. Figure 54 shows the jurisdictional framework of the Barcelona waste sector.

Figure 54: Barcelona waste sector jurisdictional framework and responsabilities overlap among different stakeholders.

Regarding the green infrastructure of Barcelona, the City Council is the main authority over green areas within the city boundaries. Where the ecosystem-based infrastructures increase their territorial influence and cross the city's limits, different public bodies assume their shared responsibilities in the resource management and natural protection areas. Figure 55 shows the interactions between the stakeholders involved and shared responsibilities.

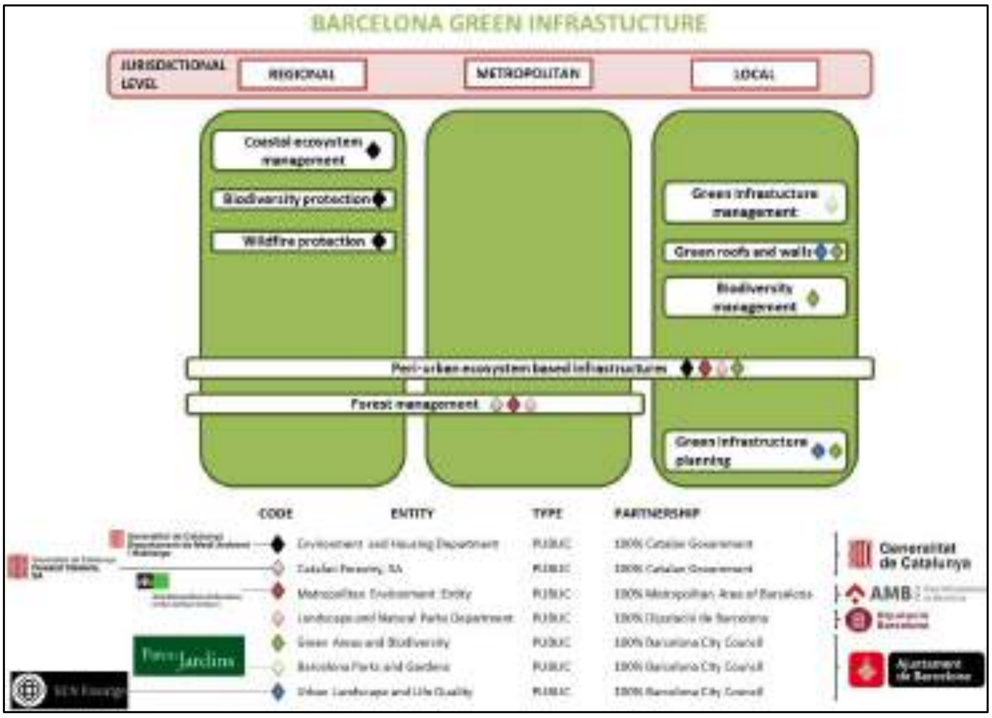


Figure 55: Barcelona green infrastructure jurisdictional framework and responsibilities overlap among different stakeholders.

4.3 Urban water cycle in Barcelona

Drinking water supply in Barcelona and its metropolitan area was satisfied until the early 1950's by local type groundwater sources. Within urban and industrial development, these groundwater sources were not able anymore to assume the water demand, situation that lead to the need of larger drinking water flows production. In addition groundwater resources were already intensively exploited, so it turned necessary to use surface water for drinking water production. Therefore, in 1955 the Sant Joan Despí (SJD) Distribtion Water Treatment Plant (DWTP) was built in order to satisfy the Metropolitan Area of Barcelona water demand. Almost a decade after it was launched, the SJD DWTP had to double its treatment capacity and in the 1970's a water system transfer from the Ter River was built in order to satisfy the growing water needs of the metropolitan area.

The Ter-Llobregat large system, which is the largest supply system in Catalonia (Figure 56), is supplying water to an area with roughly 5,5 million people and is currently running a deficit. Drinking water and industrial water supplies, irrigation supplies and maintenance flows have all historically shown insufficient guarantees. In 2009, which was the worst year, water deficit was around 176 hm^3/year (Catalan Water Agency, 2015).

Figure 56: Supply areas of the different large supply systems across Catalonia. (Generalitat de Catalunya, 2014)

In order to increase the available water resources, several actions were taken during last years, such as the Llobregat desalination plant launch in 2009, implementation of aquifer recovery systems, up-stream river pumping of regenerated water of the Baix Llobregat WWTP and infrastructure improvements, that have reduced that water deficit. More recently, drop of consumption owing to the socioeconomic conjunction, efficiency progresses at different stages and social concern as a result of the last drought episodes, has also contributed to the deficit reduction (Catalan Water Agency, 2015). It is estimated that the 70% of the reduction of consumption is due to a drop of drinking water demand, because of better water consumption habits and the resting 30% drop is because of a better water management, particularly in water leakage control in the distribution network. In fact, Barcelona is nowadays one of the cities (joint with Copenhagen and Brussels) with lower water consumption: roughly 104 litres per habitant and day that is slightly above the 100 litres per habitant and day. The WHO sets that from 100 litres per habitant and day there is an optimal access to water (World Health Organization, 2003).

In SJD DWTP, surface water of the Llobregat River and groundwater from the low valley Llobregat aquifer are treated for the drinking water production. The main differentiating feature of this large system is that water leaving the SJD DWTP can be mixed with drinking water from different sources and other large systems.

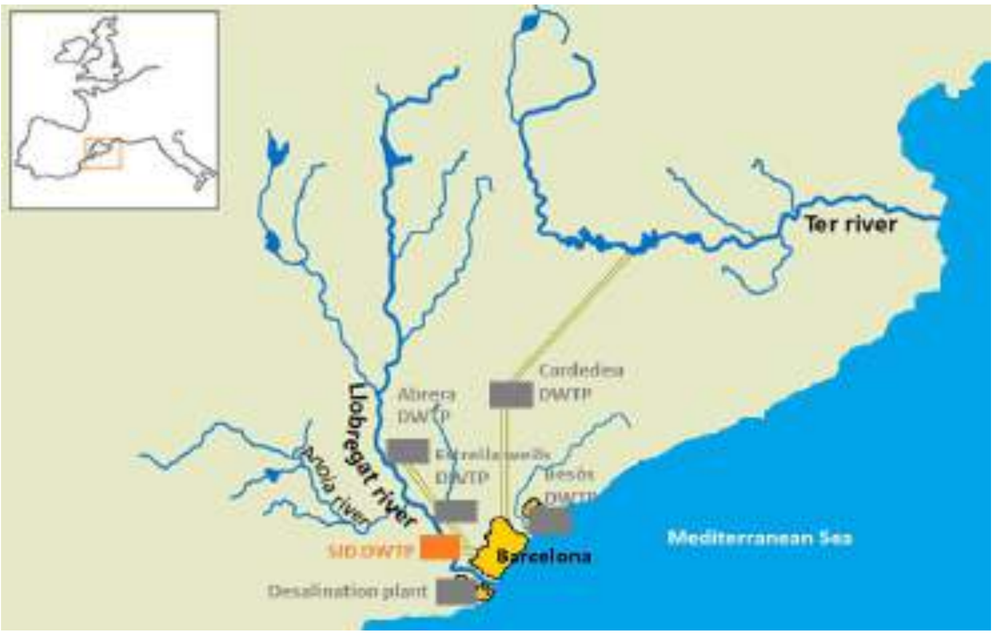


Figure 57: Ter- Llobregat system and its main drinking water contributions in Barcelona and its metropolitan area.

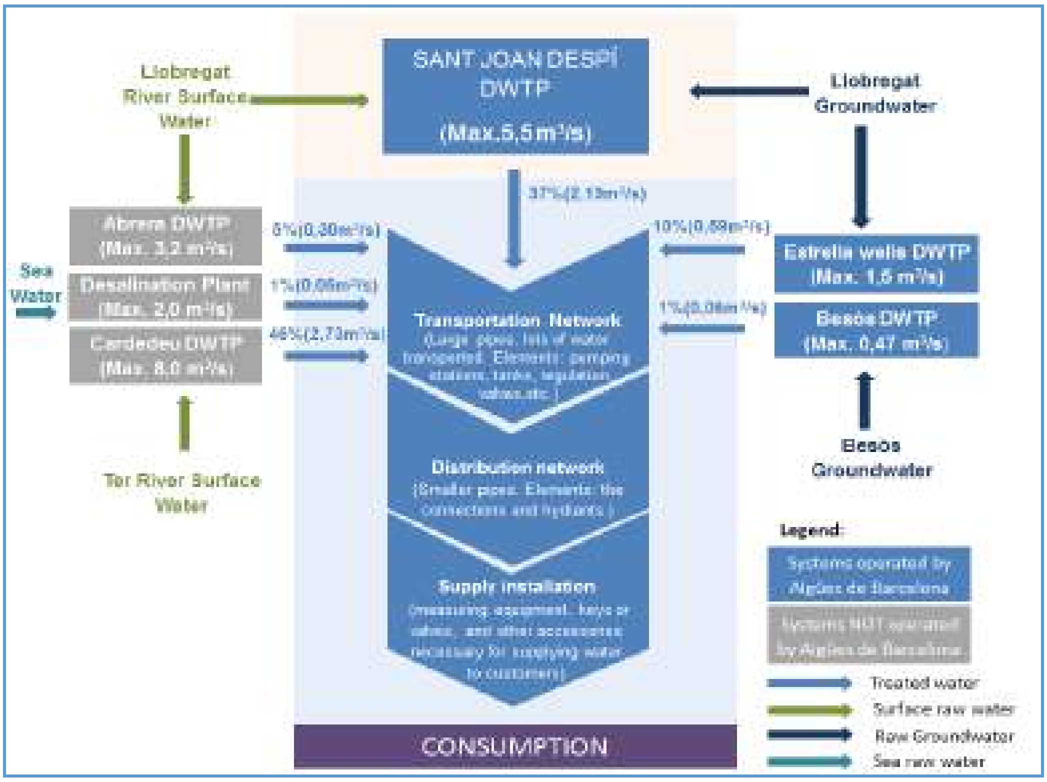


Figure 58: Flowsheet of the Llobregat-Ter supply system in Barcelona and its metropolitan area.

In Figure 58 and Figure 57, it can be observed the different water sources that can be mixed during transportation: output water from SJD DWTP (37%), Cardedeu DWTP (46%), Estrella wells (10%), Abrera DWTP (5%), the seawater desalination plant (1%), and Besòs DWTP (1%). Then, water stored in distribution tanks will be distributed along the whole distribution network until the final consumers' tap. The Table 25 summarizes the general information about the water supply.

Table 25 : Main indicators of Aigues de Barcelona

Name of the organization	**Suez**
Name of the water supply	Aigües de Barcelona
Catchment area of the water supply (km^2)	110 (Llobregat aquifer surface)
Drinking water supplied in 2015 (million m^3)	187,05
Length of pipes (km)	4.107
No. of people served by the water supply (actual data)	1.415.607 contracts (about 2,8 million people)
No. of employees	ca. 1000
Type of water safety plan implemented	ISO 22000 (2009)

4.3.1 Water Abstraction

Sant Joan Despí DTWP Abstraction

Surface water

The surface water is collected through grilles on the river bed, formed by a set of parallel bars made of reinforced concrete. Below the grille is a series of excavated galleries with different cross sections that take the water to the part of the plant where the sand is eliminated. The separations between the grille bars and the cross sections of the galleries are protected to prevent the sedimentation of particles less than 8 mm in size from passing through the grilles.

Table 26: Barcelona Water Abstraction Grille Characteristics.

Width of the Bars	159 mm
Separation between Bars	8 mm
Number of Grilles	4 (Plant 1) 2 (Plant 2)
Length of the Grille Zone	22.5 m
First Cross Section of the Gallery below the Grille	0.2 x 2 m (rectangular)
Last Cross Section of the Gallery below the Grille	1.2 x 2 m (rectangular)
Flow Rate per Gallery	3.3 m3/s

Groundwater

The groundwater from the aquifer of the Llobregat River is incorporated at the sand filtering output in an open tank that functions like a second elevation aspiration chamber. This groundwater resource makes it possible to cover demand in the event of not having other resources, or for optimising the quality of the treated water, by diluting the water coming from the previous treatment phase. Although the groundwater has saline levels equal to or higher than those of the surface water, it is of better quality.

At times when there is a surplus of drinking water originating from the surface, and with the aim of increasing water reserves in the subsoil and preventing saline water from entering the aquifer, artificial reloading takes place, by injecting drinking water into the aquifer through the equipment in the wells themselves. The total number of wells is 25 with 12 injection (recharge) wells.

Besòs DWTP Abstraction

The groundwater from Besòs River is extracted by means three pumps with a flow of 0,13 m^3/s and with a power of 6,4 bars. (Figure 59). This water is treated in two of the three lines.

The water from Rec Comtal groundwater source, enters into the collection chamber through the action of gravity, then this water is aspired by a pump of 1.5 bar. This water is treated just in one of the three line which includes a unity of ultrafiltration.

Figure 59: Abstraction pumping groups of Besòs DWTP.

Cardedeu-Ter DWTP Abstraction

The Ter River water is stored at a distance of 50 Km from DWTP in three in series reservoirs: Sau, Susqueda and the Pasteral. The water is used for energy production in Sau and Susqueda, while El Pasteral is used as a regulator of the water abstraction.

In each one of these reservoirs there are several gates at different levels that facilitate the water blend. A parameters (temperature, seaweed growth, etc.) control is needed to be carried out in account of thermal stratification phenomena which is produced in reservoirs. Thus the formation of anoxic zones is controlled and the most suitable abstraction high and the optimum stored volume needed of water are able to be identified.

The water is collected through grille bars when the flow is regulated and it is driven through a mesh sieve. It removes the suspended solids with more than 0.25 mm. Then the water is driven by the gravity action to the DWTP by means a pipe 56 km long with a diameter of 3 meters.

As a result of the last drought period in Catalonia (2006-2008), it was noticed the intense dam emptying caused changes in water pH, consequently thereafter a CO2 tank was built in order to fit pH water (Figure 60). However, in general, the adding of CO2 is not necessary because Ter River water arrives to the Plant approximately with pH 8.

Figure 60: Water reception in Cardedeu-Ter DWTP.

Abrera-Llobregat DWTP Abstraction

The collection is carried out directly from the Llobregat River by means a weir (small dam) of 100 wide meter (Figure 61). Firstly the water is driven through self-cleaning grille bars which retain the big materials suspended in water. Secondly the water is conducted to three channels for the elimination of sand (87.5 meter long), where is added potassium permanganate (KMnO4) to oxidize organic and inorganic compounds.

Figure 61: Abrera DWTP Abstraction

Estrella Wells Abstraction

The Estrella Wells are sited at Sant Feliu de Llobregat municipality and they abstract water from Llobregat Aquifer Figure 62. The growing industrialization around the course of the Llobregat River has caused a strong impact on the aquifer both in a qualitative and quantitative way. It should be pointed out the presence of certain volatile organic compounds organochlorines: trichloroethylene, tetrachloroethylene, trichloroethane and dicyclopentadiene.

Figure 62: Estrella Wells Site Map.

As a result of the hard drought suffered during 2007-2008 years and with the aim to recover the Estrella Wells as a hydric resources, some treatment stations were placed with stripping treatment. The water extracted by the six wells placed is treated in two stations, each one of them with 500 l/s of capacity. Just only one well (III well) was not available for a continuous extraction.

The underground water is collected through the Estrella Wells I, II, IV, V and VI. The stripping treatment is carried out in different facilities. The stripping treatment is an operation by means certain dissolved compounds are removed by air. The station that treats the IV, V and VI Estrella Wells Figure 63Figure 62 consists of four towers which allow to eliminate contaminants (from 300 to 5 ppm) by air stripping means (30.000 Nm^3/h).

Figure 63: S*tripping towers in* Estrella wells.

<u>Re-carbonate and chlorination:</u> After stripping phase, the water is stored in a tank of 1.000 m^3 where CO_2 (g) is added through diffusers to re-carbonate the water. Whit that, the pH is fixed after their increase as a consequence of stripping treatment. The tank also has a disinfestation system with sodic hypochlorite with a pumping station to incorporate water to the water supply network (Figure 64).

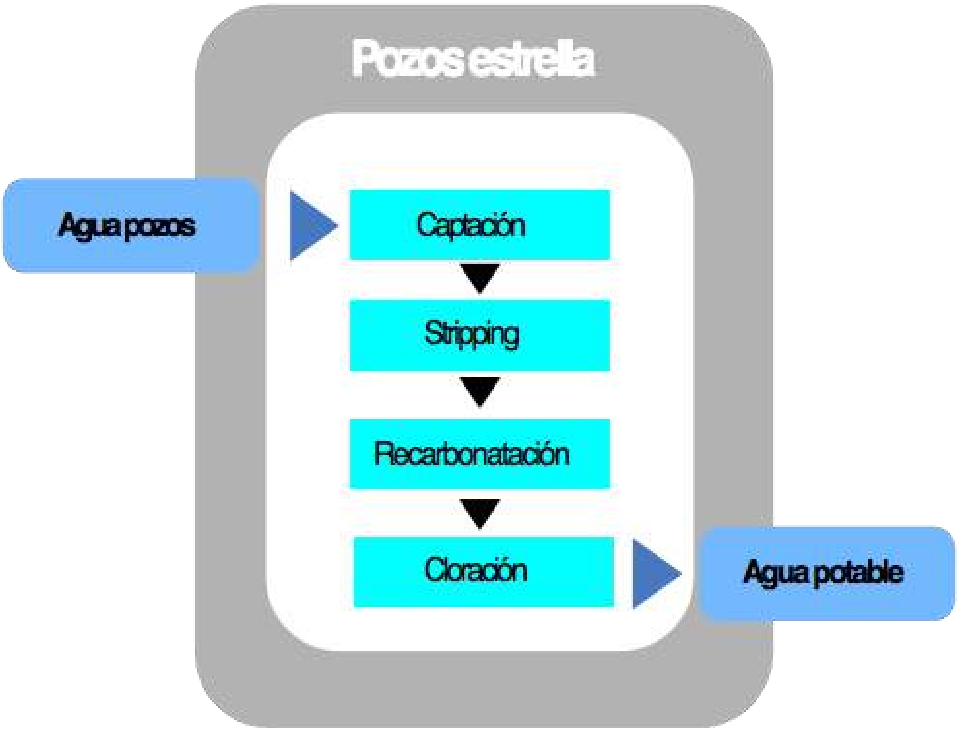


Figure 64: Scheme Well Estrella.

Main climatic effects or natural hazards affecting the service and critical infrastructures

Flash floods caused by the Mediterranean climate rainfall patterns, with intense precipitations mainly at the end of summer or in the autumn are also usual in the area of Barcelona. Apart from the economic losses these events cause, they also produce changes in the quality parameters of water courses (e.g. water with higher ammonia levels as a consequence of CSOs, higher levels of turbidity in river water) that affect the operation of DWTPs. If the DWTP is not able to cope with different water conditions, it may be necessary to stop the treatment process.

This phenomenon is especially significant in the abstraction area of Sant Joan Despí DWTP where turbidity, during intense rain episodes, involves serious problems to abstraction works. Moreover, the failure of hydraulic structures sited upstream of Llobregat River's final leg (as a consequence of these intense precipitations) increase the negative effect on turbidity.

In this situation, the water supplied comes from the aquifers after the required treatment seen before. However, using the water from the aquifer requires extra human resources, more frequent controls and, thus, higher costs. The first reason for that is that when groundwater is used, the amount of reagents needs to be adjusted, so that the treatment suits the quality of wells' water. Secondly, a stricter control of the aquifer condition needs to be carried out to ensure that the abstraction is not causing salinization of the aquifer and that it will be available to use in emergency situations in the future (short, medium and large term).

Groundwater is also used during drought periods, because due to the low river water flow, most of it comes mainly from Wastewater Treatment Plants' (WWTP) effluent and, thus, water quality is very poor (dilution factor is diminished). Furthermore, in order to maintain the ecologic flow of the Llobregat River, Sant Joan Despí DWTP cannot use its water totally.

There is a very significant energy supply dependency in abstraction facilities, especially in those of them which are equipped with pumps groups. The services are prepared to overcome an energy supply failure. The energy supply company or a specific provider provides power generators in crisis episodes for power cut, depending on the failure severity and importance. Some services have generators available.

4.3.2 Water Treatment

There are five distribution water treatment plants (DWTP) involved in the water treatment processes of Barcelona city (Figure 56 and Figure 57):

- DWTPs Llobregar River: Sant Joan Despí Plant (37% inflow), Abrera Plant (5% inflow),
- DWTP Ter River: Cardedeu Plant (46% inflow)
- DWTP Besòs River: Besòs Plant (1% inflow)
- Sea water: Desalinitation Plant (1% inflow)

All the DWTPs have generally a common previous treatments such as a collection system, a general pre-treatment processes in a Water Treatment Plant and others:

- Surface/Underground collection (see chapter Water Abstraction)

- Pre-Treatment (Elimination of sand, Sedimentation/Settling, Filtering through sand)
- Remineralisation (except DWTP Cardedeu)
- Granular activated Carbon filtering (except DWTP Besòs)

Regarding the impact and vulnerability of these installations by climate variables and other system failures (especially energy systems), the present subchapter reviews the most significant and differentiated processes of each one in order to identify the more sensitive/critical infrastructures of each DWTP.

The most vulnerable processes used in drinking water treatment plants of Barcelona will be exposed briefly in this section. They comprehend: membrane treatment, chemical treatment, disinfection and other types of treatments.

1. Membranes

A membrane is any material constituted by a thin layer (0.05 - 2 mm) with a selective resistance to transfer different components of a fluid, which permits separation of some elements (suspensions, solutes or solvents) which form this fluid. The main composition of a membrane can be cellulose acetate, organic polymers or inorganic materials (obtained by heating ceramic particles such as alumina, carbon, silica or zirconia).

Membrane technologies are similar to filtration, but require a previous pre-treatment to eliminate free fats, oils and other big molecules. Different membrane technologies available at the present time can be classified by the eliminated particle size: microfiltration, ultrafiltration, nanofiltration, Electro-Dialysis Reversal (EDR), ionic exchange and Reverse Osmosis (RO).

Ultrafiltration (UF) is used to eliminate colour, organic dissolved matter with high molecular weight, colloid particles, bacteria, some viruses and macromolecules (proteins), permeating all dissolved salts and small molecules. It is like a screening process where species separation modifies the chemical potential of the system.

Nanofiltration (NF) is used to eliminate mainly divalent cations and sulphates, apart from organic matter, total organic carbon, colour and some viruses, permeating also metals and monovalent salts (National Research Council, 2004). It is a diffusion and exclusion process, where monovalent ions are rejected in minor grade respect to the reverse osmosis (RO), that is why this technique requires less energy consumption and bigger permeate flows are obtained.

Electrodialysis reversal is based on the ionic charges separation through an application of continuous potential difference. In between of each electrode, a series of membranes are set. These are ion-selective and limit their migration, so that demineralized water is produced, with another flow of ion-concentrated water and a third flow of the electrode washing. Its main application is the production of drinking water from low-mineralised brackish water. It is also used in desalination processes from colloidal or organic solutions.

Reverse Osmosis (RO) is the best available filtration technique. It is used to eliminate all dissolved salts, inorganic molecules, organic molecules greater than 100 g/mol, permeating water molecules producing a purified flux (Dow Water Solutions, 2009). It is a diffusion and exclusion process which requires high energy consumption to overcome the feed flow osmotic pressure and therefore produce permeate without monovalent salts and other impurities.

2. Chemical treatment

Chemical treatment is needed to adjust certain amounts of elements in water. When a source of water is not in carbonic equilibrium and contains aggressive carbonic gases, its neutralization must be foreseen. This can be carried out by aeration, by alkaline reactants addition (lime, caustic soda, Na_2CO_3) or by filtration of alkaline-earth products (marble, Neutralite, Akdolite, Magno, etc.). If this mineralisation is insufficient to avoid water be corrosive against metallic piping, even if it is on carbonic equilibrium, a complimentary mineralization must be performed. Chemical treatments are thus classified in: oxidation processes, aeration, neutralization, acidification, remineralisation and softening.

Aeration or stripping is performed normally at the beginning of the water facility. It eliminates dissolved gases in water and enriches it in oxygen content. Other effects are: increase the dissolved oxygen content, reduce flavour and odours caused by some gases like H_2S, decrease CO_2 content, thus increasing its pH, precipitate Fe and Mn, and eliminate certain VOCs (volatile organic compounds).

3. Disinfection

In order to eliminate certain dissolved mineral matter which are undesirable (iron or manganese), to eliminate taste and odours, and to destroy pathogen agents, it is often based on chemical processes (oxidation with chlorine or its derivatives, ozone, electro-chlorination, potassium permanganate and even ionisation with Ag and Cu) or physical processes (UV radiation) .

Chlorine derivatives can be directly added or formed *in-situ*, and the most used are chlorine dioxide, calcium or sodium hypochlorite, and chloramine. Chlorine dioxide is used normally when there are odour and colour problems due to phenols presence. It does not produce THM, but the main inconvenient is the sub-products generation: ClO_3^- and ClO_2^-.

Ozonation oxides the majority of organic matter, eliminate the colour, organic substances which cause bad odours and flavours, iron (II), manganese (II), ammonia, etc. present in water. Ozone production takes place *in-situ*, by making an air or oxygen flow pass through an electric discharge.

4. Other treatments

Activated carbon adsorption is an advanced process which consists of an aquatic bed with activated carbon, aiming to eliminate organic matter, basically. The working principle of this process is to make better use of the big specific surface of the carbon to adsorb organic molecules which low polarity, to filter bigger particles and to allow partial deposition of colloidal matter in the external surface of the activated carbon. Nowadays two main types of activated carbon are used: granular activated carbon (GAC) and powder activated carbon (PAC).


Figure 65: Post treatment unity Abrera DWTP

Main climatic effects and natural hazards affecting critical services and infrastructures

The influence of several factors which may be modified due to climate change in water treatment processes are discussed in this section. Changes in temperature are the most significant causes on treatment processes. The different processes are affected in a different way a degree by temperature:

Chlorination (oxidation)

This process is quite independent of temperature, since this gas is highly soluble in water. Therefore, in general terms it seems that it will not be affected severely by temperature effects.

Settling

Maximum water density is approximately at 4ºC; at these values, flocks' settling may be more difficult and thus, this unitary process will not be as efficient as in summer. At higher temperatures (most likely scenario due to climate change), settling will be easier and thus, the process will be favoured.

Ozonisation

Ozone is at its limit in solubility so that temperature may affect the process. In particular, at lower temperatures it presents a higher solubility in water and thus, it will be more effective. Therefore, at greater temperatures (most likely scenario due to climate change), this unitary process performance is unfavoured.

Granular activated carbon

At lower temperatures, adsorption is enhanced, so that the process becomes more efficient. As a result, at higher temperatures (most likely scenario due to climate change), it will be unfavoured. In fact, at greater temperatures, desorption may take place, so that organics captured by the CAG filters may desorb and thus, may be a potential risk for the consumers.

Membrane-based processes (UF, RO)

The greater the temperature, the higher the permeate flow produced. Nonetheless, the rejection of contaminants tends to be lower. Therefore, different effects will be noticed in these kinds of processes. As stated before, UF and RO unitary processes are installed in Sant Joan Despí DWTP and Besòs DWTP

It is important to mention that membrane-based plants have been designed for operating temperatures ranging from 12 to 23ºC. Although it is possible to treat water at temperatures outside this range, the lifetime of the membranes may diminish significantly.

In the case of the seawater desalination plant from El Prat, since the Mediterranean is a closed sea, seawater temperature changes considerably. The desalination plant has already experienced periods in which warmer seawater (maximum of 27ºC) has been treated, due to changes in the thermocline position. Typically thermoclines' problems are faced in autumn.

Another problem encountered is *boron rejection efficiency*. The maximum concentration of boron in treated water is 1mg/L and in summer it can reach levels of 1,3 mg/L. Therefore, in summer pH adjustment is needed (with alkaline compounds) in order to transform boric acid (which diffuses through the membrane) from seawater to borate species, which are better retained by the RO membranes. This pH adjustment can diminish membranes' lifetime. A second RO stage may be needed in case boron rejection is not sufficient with pH adjustment.

In case seawater deep intakes are used for desalination plants, not significant changes in terms of water quality are encountered. Nonetheless, when intakes are closer to the seaside (except when using beach wells), algae problems can be found. Finally, regarding the intakes, it is worth mentioning that when water temperature increases, jellyfish population may also be higher, in which case, extra treatment would need to be introduced.

Reverse electrodyalisis (EDR)

In this case, the lower the temperature, the better the performance of the EDR process. This is mainly due to the fact that this process is based on the ions' mobility and not on the water passage through the membrane. High temperatures make the water pass though the membrane easier and this is not the process desired.

Therefore, at greater temperatures (most likely scenario due to climate change), this unitary process performance is unfavoured.

In fact, research on how to manage ecosystem services (riparian forest) to keep the temperature of the raw water low enough to fit the EDR requirements is being carried out and applied to the case study of Abrera DWTP.

Remineralisation

Remineralisation processes are linked to water temperature, since it is based on the dissolution of $CaCO_3$.For instance, low temperatures leads to a worse functioning of the remineralisation process. Therefore, at greater temperatures (most likely scenario due to climate change), this unitary process performance is favoured.

Biological processes

Natural processes that take place as water flows along the water, as well as intensive processes based on biological reactions (nitrifications) will severely be affected by temperature.

Power Supply Failure

Due the strong energy supply dependency in all treatment phases, every DWTP is prepared to overcome an energy supply failure. The energy supply company or a specific provider brings power generators in crisis episodes of power cut, depending on the failure severity and importance. Some plants have generators available.

There is not system duplicity except San Joan Despí DWTP which has three energy supply lines available. Each one of these lines provides all power needed for the plant normal operation, especially related to the pumping stations. These pumps require an extremely high power during the daily operation. Nowadays, there is not a power generator on the market with these characteristics.

In case of power cut affecting any of these lines, the energy supply could be provided for one of the others additional lines.

4.3.3 Water Distribution

The Barcelona whole water network is composed by 4574 km of pipes, 65 pumping stations and 72 water tanks with a water storage capacity of 250,542 m3.

This network is segmented into 117 pressure levels, and 214 DMAs (District Metered Area). Since 1976, the network has a centralized telecontrol system, organized in a two-level architecture. At the upper level a supervisory control system installed in the control center of Aigües de Barcelona (AB) is in charge of the strategic control of the whole network by taking into account operational constraints and consumer demands.

The remote control currently operates on 67 tanks, 121 actuators divided in 46 pumps (boreholes and booster pumps) and 75 valves, with 88 main sectors of demand.

The prevention of sanitary issues and the management of crisis are included in the Preventive Risk Management System of the company (Water Safety Plan), certified by ISO 22.000 (Production, Transport and Distribution). The prevention of malevolent acts and accidents/incidents is based on two pillars: Physical security and On-line sensors (analytical control). Specifically:

- 130 on-line sensors are deployed in the distribution network (tanks) measuring chlorine, pH, conductivity and temperature.
- 35 out of 72 tanks of the transport network are currently monitored with on-line sensors measuring Chlorine + pH, conductivity and temperature.

After drinking water leaves the DWTP it goes through several stages before it reaches the final consumer. Then, the supply system has the following stages (Figure 66):

- **Water storage**: water is stored in several tanks, the so called header tanks, which receive treated water from different inputs and the so called regulation tanks, which are used for the storage of water in its different pressure stages in which is distributed through the whole supply system.
- **Water transportation:** water is pressure-driven through a groundwater network and pumping centrals, which transport water until the diverse tanks and distribution

network. In some points of water transportation, might be direct inputs of treated water.

- **Water distribution:** at this stage, water is finally distributed to the end users through an underground network.

At different points in the supply network such as tanks, pumping centrals and points of the transportation and distribution network re-chlorination can took place. Re-chlorination aims to disinfect water and ensure that it is salubrious in microbiological pollution terms.

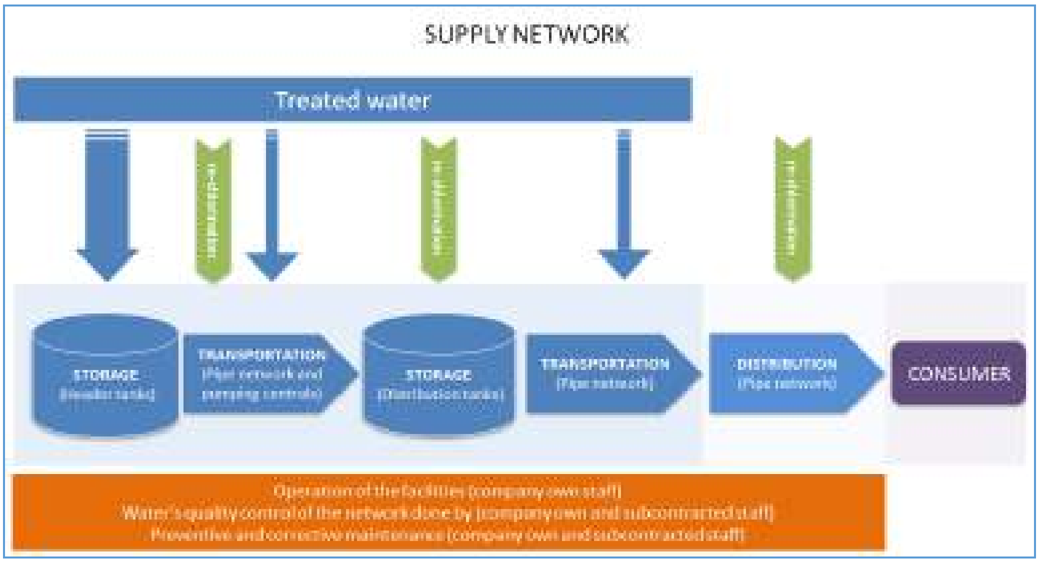


Figure 66: Storage, transportation and distribution flowsheet.

Furthermore, there are three main sub-processes that interact along the transportation and distribution processes: operation of the facilities, water's quality control of the network, preventive and corrective maintenance.

Water transport is pressure-driven in a pipe network (or gravity-driven if the tank is located in an upper height from the tank it feeds) through a pumping central. In the pumping central a motor pump catches water from a tank of the network and it elevates water normally to another tank.

a)

b)

Figure 67: a) Pumping central (Aigües de Barcelona, 2016) b) Transport pipe system (Barcelona City Council, 2016).

Water distribution aims to deliver water coming from the transportation network to the costumer through a pipe network, ensuring quality (Royal Decree 140/2003) and pressure (Royal Decree 314/2006, the Technical Code of the Edification in Spain) conditions. The distribution network is divided into sectors, which are from each other isolated and supplied by the transportation network in determined points, the so called control points where flow rate and pressure are controlled. Currently, the network has 230 isolated sectors with an average of 2 valves per sector and approximately 50% of the valves are automatic. These actions allow more flexible management of the network and ensure the correct identification of the sectors if water restrictions need to be applied.

Treated water input arrives to the header tanks with an adequate residual free chlorine concentration. However, under some circumstances such as high temperature, high organic matter content in water and an excessive residence time, residual free chlorine can be consumed reaching concentrations below the minimum mandatory concentration value. In order to comply with mandatory free chlorine contents, it is necessary to re-chlorinate in some points of the network.

To control the hypochlorite dosing, each re-chlorination point has an online free chlorine analyser, whose measure is monitored in the control center and used for flow rate regulation of the dosing pump. The centralised control center, called Operation Control Centre work (CCO, in Catalan), has as the primary objective the continuous supervision (24 hours per day, the 365 of the year) of water supply system in Barcelona and its metropolitan area.

Table 27: Distribution network general information (Aigües de Barcelona, 2016).

Service reservoir (tanks)	**69**
Storage capacity (m^3)	248.623
Supply network length (km)	4.624
Number of dead ends	1.626 (*)
Disinfection in the network	Yes (Sodium Hypochlorite)

(*) This number is considered taking into account one of the following situations: (i) there is a dead end and the distance to the closest service connection is longer than 15 m: (ii) there is a closed valve and the distance to the closest service connection is longer than 10 m.

Catalan Agency of Water. Simulation models

This section describes the Ter-Llobregat water management model used in the River Basin District Management Plan for Catalonia (PGDCFC) by Catalan Agency of Water (public company responsible for planning and managing the complete water cycle in Catalonia) to plan new investments by considering the following aspects of the Ter-Llobregat system:

- Availability of resources and reliability of the demands supply considering changes in demand, management rules and resources
- Preliminary study on the limitation of the infrastructures capacity for urban water supply (independently of resource availability)

- Preliminary study on the environmental sustainability for rivers (environmental demand)

This model considers water quantity aspects and it is used to calculate the monthly mass balance between resources and demands in the basin. It was developed using the SIMGES modelling tool (include a redrence) that allows the introduction of different model elements: demands, hydrological inflows, infrastructures (dams, main channels and pipes) and management rules (priority between uses and operational management).

Model development and Software used

The SIMGES module of the AQUATOOL suite is used to develop the water management model of the Llobregat river basin.

AQUATOOL was created the Technical University of Valencia (UPV), Valencia, Spain. This generic Decision Support System was designed for the planning stage of decision-making associated with complex river basins.

The SIMGES modelling tool can simulate the planning and operational management of a basin on a monthly basis. This module represents the distribution of water in the river basin (e.g. rivers, reservoirs, water uses and aquifers) subjected to management rules defined by the user.

The mathematical approach of the management model is based on optimization algorithms and the principle of mass conservation (conservative flow network optimization algorithm).

During the simulation, for each month of the simulation period, in a first step the flow network is solved with the hydrological inflow values, demands and management parameters. Then in a second step the aquifers are simulated, and iterations are made between these two values.

Finally, when the simulation period is finished, statistics and water supply reliability are calculated.

The algorithm will try to minimize an objective function, which represents the cost of different actions. As general rules and using the default configuration, the algorithm tries to:

- Limit the deficit in the demands
- Promote artificial recharge for the period without deficit in the demands (if the artificial recharge element is present on the scheme)
- Limit the pumping in aquifer except if there is deficit in the demands
- Release water from the reservoir only if there is a downstream demand

Table 28: **Table SIMGES elements and Ter-Llobregat model representation.**

	Model element	Description	Model representation
1	Consumptive demands	Amount of water needed to supply the different uses	Monthly values based on the PGDCFC for the years 2003 and 2007.
2	Non-consumptive demand	Hydroelectric stations and other industrial or leisure uses	Only Berga canal considered. Hydroelectric stations not considered.
3	Environmental demands	Minimum discharge that has to flow in the river	Monthly values based on the legislation for the period considered: - PHCIC (until July 2006): only Ter - PSCM (July 2006 – 2008): Ter and Llobregat
4	Hydrological inflows	Amount of water entering the system	Monthly values based on simulation results of two hydrological models: - HBV (period 1980-2008) - SSMA (period 1940-2008) for verification Also, flow measurements at the dams were used (period 2000 -2008).
5	Reservoirs	Surface storage capacity	Details on the reservoirs capacity, evaporation rates, and management rules based on PGDCFC.
6	Aquifers	Groundwater storage linked to the system	Based on current groundwater models and representation done in PGDCFC. Only the aquifer of Vall Baixa / Delta del Llobregat has been represented.
7	Alternative water resources	Amount of water coming from alternatives sources (reuse, desalination)	Not represented for the calibration since these alternative resources were almost inexistent before 2008
8	System connectivity	Connections between the different infrastructures and their capacity	Simplification of the previous models representations, so deficits in supply are only due to deficits in resources
9	Management rules	Priorities between demand in the Llobregat and Ter	Priorities between types of demands have been defined according to PGDCFC. No rules have been added to limit the reservoir release in drought period, so deficits in supply are only due to deficits in resources

Figure 68: Figure Scheme of the SIMGES model of the Ter-Llobregat.

Water Change

Figure 68 illustrates the scheme of SIMGES model of the Ter-LLobregat developed in the framework of the Water Change Project. The Water Change project, LIFE+ funding, (as it was seen in the Introduction of this deliverable, developed a methodology and a tool to assess the Global Change impacts on water resources, thus helping river basin agencies and water companies in their long term planning and in the definition of adaptation measures.

The main result of the project was the creation of a step by step methodology to assess Global Change impacts and define strategies of adaptation. This methodology was tested in the Llobregat river basin (Spain) with the objective of being applicable to any water system. It includes several steps such as setting-up the problem with a DPSIR framework, developing Global Change scenarios, running river basin models and performing a cost–benefit analysis to define optimal strategies of adaptation.

This methodology was supported by the creation of a flexible modelling system, which can link a wide range of models, such as hydrological, water quality, and water management models. Water management models of the Llobregat river basin were developed. Water quantity and water quality aspects are considered, using the modelling tools SIMGES and GESCAL respectively.

The development of the SIMGES model was based on the knowledge of specialists collaborating to the project, available data and previous models of the area, such as the model developed by the Catalan Water Agency in the framework of the River Basin District Management Plan for Catalonia (PGDCFC) (Agència Catalana de l'Aigua 2009a). The model developed is able to simulate the flow transfer within the basin. To perform this task it considers hydrological inflows, demands, management parameters and other system characteristics. Different model setups were elaborated for the calibration process and then model results were compared with observations for the historical period. Finally, the SIMGES model was considered satisfactory to represent the current water management in the basin. Nevertheless, as it is a simplification of the reality, some differences are observed with measurements, especially in situations of drought so results should be considered with the appropriate caution. In addition, a preliminary sensitivity analysis of the model was done, as well as a comparison with the outputs of the model used in the PGDCFC. Results show that the parameters and input values chosen for the SIMGES model are in an acceptable range.

Nowadays ACA do not use this model based on SIMGES as a tool for the water management of the Llobregat river basin. Instead of that, the Catalan Agency of water has developed a specific tool in order to regulate the final availability of water resource for the distributions units, according the water storage in water reservoirs. This tool is basically used to coordinate and regulate the amount of resource that could be supplied by the water supply operators.

Piccolo. Hydraulic network distribution simulator

Aigues de Barcelona employs Piccolo® as hydraulic simulator tool, for flow and water quality modelling in water distribution systems. Developed in partnership with Adélior France (GFI group) and combining a feature-rich user environment, high-precision modelling and a robust and powerful calculation engine, Piccolo® is used by Aigues de Barcelona and water companies to:

1. Network diagnostics: information about the current and future behavior of the network under any conditions, assess structural weaknesses in water distribution systems, to find the weak points and the elements overloaded and underloaded and optimization for short and medium-term repairing plan.
2. Optimization of network management: control flow, pressure distribution and retention times in order to minimize operating costs. Determining the correct interface devices installed on the network with the rest of its elements, reducing transit system water through the area balance of power and water consumption.
3. Control network performance and design improvements and extensions: for the planned expansion, or in conditions of increased demand.
4. Analyse the impact of different management strategies on residence times and the quality of tap water.
5. Analysis of the crisis: the scope and impact of the size limitations in water supply caused by eg. the source of pollution, blockage of the valve, except for emergency bus or reservoirs = increase reliability of supply areas by changing the way their power. Assess the risk of vinyl chloride monomer leaching, by means of a new module incorporated in 2013.

The computer model is equipped with a very efficient and easy to use graphical user interface, based on a system-down menu. It has the ability to visualize the various operating parameters of the network (eg. the distribution of pressure, flow velocity and many others). The data and results of calculations can be displayed in the form of colorful charts and graphs or in tabular form. The program is fully compatible with the environment of MS Windows and MS Office.

Integrated with a module to calculate the water quality allows eg. To determine retention times and allows the simulation of the spread and the concentration of water added to the chemical compounds, such as Chlorine compounds. Software package and can be extended with an analysis of the operating costs.

SAFEGE has developed several programming interfaces allowing the connection between GIS and Piccolo, based on database systems DDASE and Oracle.

Operation Control Center

As it was mentioned before in Sant Joan Despí Treatment Plant section, all the activity related to the distribution of drinking water is controlled and supervised by Aigues de Barcelona's Operational Control Center located in Collblanc (Barcelona). This center supervises, permanently and uninterruptedly (24 hours a days, 365 days a year) the key parameters of the water supply service of Barcelona metropolitan area to offer a continuous service at the necessary pressure. It manages the entire distribution of drinking water to Barcelona.

Through a daily water demand forecast for each supply zone, it plans the resources that the treatment plants need to provide. It moreover operates the supply facilities with the criteria of maximum technical and economic efficiency, maintaining the service's quality levels stable at all times. All this is achieved by regulating automatically and continuously the hydraulic installations, which allow to cover the water demand of the population.

The operation of the Control Center includes supervision of the appropriate volume of water resources, stabilization of the supply service pressures and control of the health guarantee offered by the flows supplied. It is thus the hub of activity for the supply of drinking water to almost three million people.

Main climatic effects and natural hazards affecting the services and critical infrastructures

Drought. Water scarcity

According to the records of the volume stored in the reservoirs that supply water to the Barcelona area (Figure 69), warning levels have been reached 13 times since 1940, and in 3 occasions these warning levels have evolved to emergency levels. It can also be seen that warning and emergency levels have become more frequent since 1997. In fact, the worst case of drought in the last 100 years is that of 2007-2008 (Serra et al., 2006 in (Bladé, I. et al. 2010)).

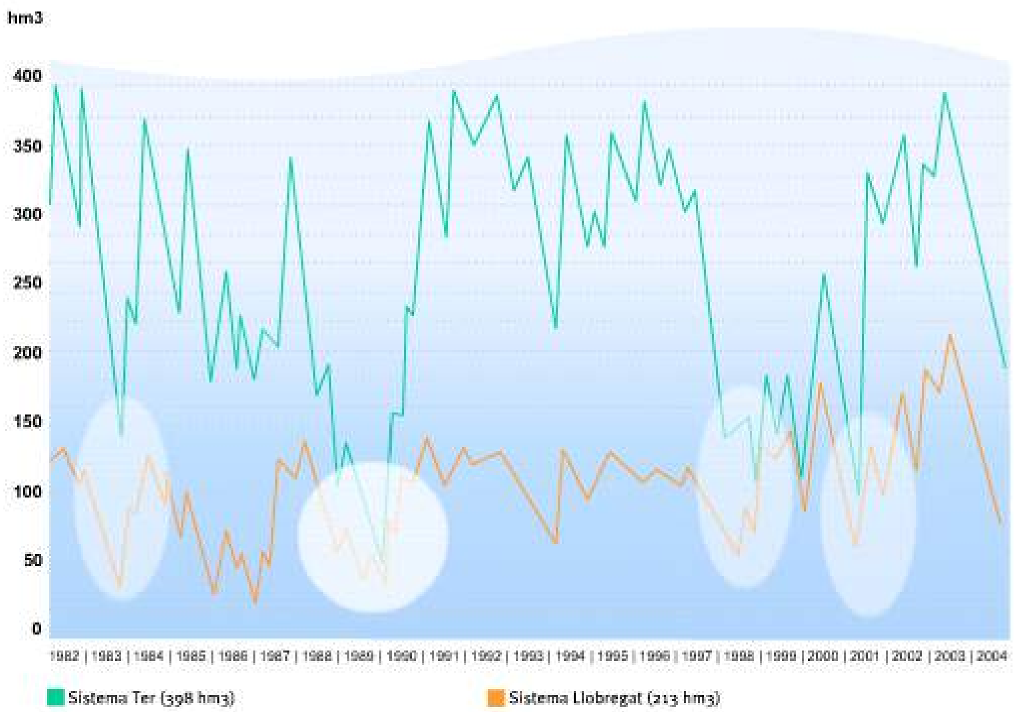


Figure 69: Evolution of Ter-Llobregat reservoirs annual supply contribution and demand (Agbar, 2009)**.**

As it can be seen in Figure 70, it is important to point out that balance between supply and demand are lower than in other similar cities indicating that safety margins do not meet desirable levels and that the area is at risk of a water deficit that is likely to become significant.

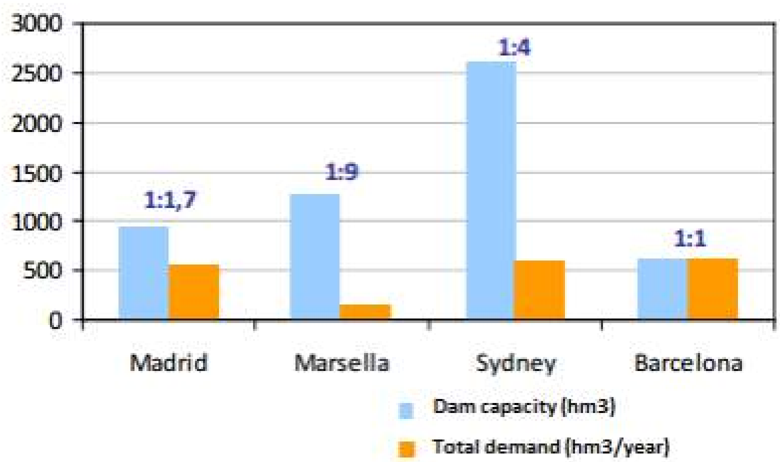


Figure 70: Reservoir capacity and total demand of similar water supply systems to Barcelona

The recent droughts have fostered significant investment to improve the resilience of the distribution network so that it can deal better with water stress situations. The actuations have focused on improving the zoning of the network, in order to create isolated sectors and automating the valves.

Rehabilitation of wells is another measure undertaken to increase water availability, since the Llobregat delta aquifer is a very valuable resource in emergency situations. However, the industrial development during the 60s and the 70s caused the contamination of several wells that were left unused. To overcome recent water stress situations and increase water availability, most of that wells have been rehabilitated using reverse osmosis or stripping techniques as it was detailed in Water Abstraction section.

Finally, changes in temperature in both directions also affect the distribution network. Higher temperature will probably increase the water demand, leading to higher electric consumption, as pumps will not be able to operate at their optimum efficiency. Conversely, water temperature should always be higher than 8ºC in order to avoid pipe bursts. To maintain temperature over this threshold, Agbar currently mixes raw water from the river with groundwater during cold spells.

Power supply system failure

Pumping stations and specific **chlorination points** have a depending on energy supply. In the more critical of those, (as it was commented in Water Treatment subchapter and due to the strong energy supply dependency) the energy supply company or a specific provider provides power generators in crisis episodes for power cut, depending on the failure severity and importance. AB has identified the most critical pipes, pumping stations and tanks (usually involving associated pumps) which energy supply would be provided in case of power cut.

The **Operational Control Center**, in case of emergency that it was disabled by the occurrence of a significant power cut (which could not be restored with generators or other external assistances), has a duplicated place available in the municipality of Cornellà, in which could be temporally reinstalled all of the functionalities and capabilities of Collblanc center.

4.3.4 Urban Drainage

Urban drainage in Barcelona has special relevance in the city infrastructures due to the climate and morphological characteristics of the territory, such as the high demographic density and land imperviousness. All these factors exposed previously increase urban flood risk and affect negatively on river and coastal water pollution during rain events.

The sewer system of Barcelona is a combined sewer network. Its main characteristic is that 55% of the sewer system allow access to maintenance personnel (height is over 1,50 m).

Figure 71: Example of the sewer network of Barcelona.

The main features of Barcelona sewer network managed by City Council are:

- 1.556 Km of combined sewer
- 44.089 manholes
- 15 storm tanks
- 44 gates (included the storm tanks regulation system)
- 15 pumping stations
- 60.000 wastewater inlets (from buildings)
- 73.171 rainwater inlets
- 41 combined sewer overflows:
  - 4 flow to beaches
  - 14 flow to harbour zone
  - 10 flow to Besòs River
  - 6 flow to Port Forum
  - 5 flow to forest zones (Collserola)
  - 2 flow to Llobregat River
- 31 rainwater sewer overflows:
  - 2 flow to beaches
  - 1 flows to Besòs River
  - 28 flow to forest zones (Collserola)

The sewer system of the city is configured in such a way that, during dry weather time, Barcelona is divided in three waste water catchments, as shown in the Figure 7. Waste water is carried, through four principal pipes, to three Waste Water Treatment Plants around Barcelona:

- Llobregat Treatment Plant, located in the municipality of El Prat de Llobregat
- Besòs Treatment Plant, located in the municipality of Sant Adrià del Besòs
- Vallvidrera Treatment Plant, located in Collserola.

Figure 72: Waste water catchments and Treatment Plants location in Barcelona.

Also, combined sewer network is divided in 31 rain catchments. Most of them flow from the mountain to the sea, and some other catchments flow to the Besòs River. During rainfall events, storm water flow exceeds the capacity of the sewer pipes connected to the treatment plants, and combined system overflows to receiving waters.

The next figure (Figure 73) shows the surface distribution of these rain catchments, and the Combined Sewer Overflow points.

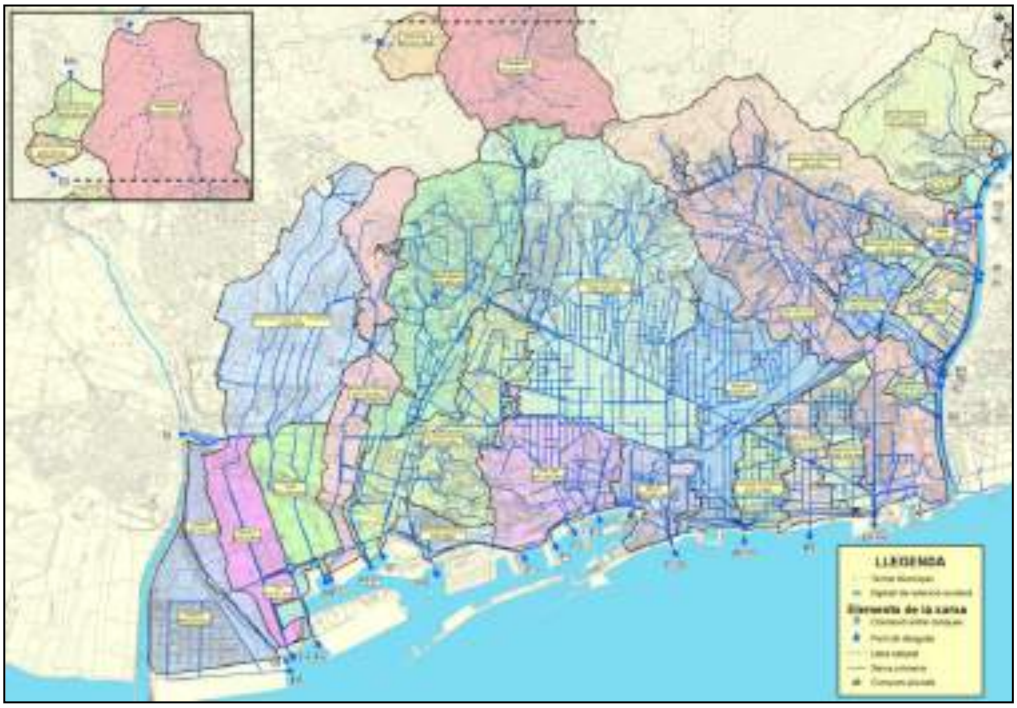


Figure 73: Rain water catchments and CSO's location.

During the last 25 years, the City Council of Barcelona carried out a great development of the sewer network of the city, making important public investments in new infrastructures on the way to improve the operation of the sewer system and management.

With the objective of define the necessary actions to improve the resolution capacity of the sewer network during intense rainfall events, such characteristics of the Mediterranean climate, the City Council developed the *Special Sewer Master Plan of Barcelona (PECLAB), in 1997*, in which introduced the concepts of hydraulic regulation and real time control applied to the case of Barcelona. The result was the planning of 13 new storm tanks, which function was to reduce the high flows generated on the sewer network during storms.

Nowadays, Barcelona has available 10 storm tanks operating, with a total storage capacity of 433.000 m^3, and 3 detention tanks operating, with a total capacity of 52.000 m^3. The next figure (Figure 74) shows the location of currently operating storm and detention tanks.

Figure 74: Operating storm and detention tanks location.

The benefits obtained in the sewer system with these infrastructures operating are the reduction of 3.700.000 m^3 and 940 Tn pollutants every year spilled in the receiving waters, and a significant reduction of flood risk in the storm tanks influence areas during storm events.

Figure 75: View of two operating detention tanks in Barcelona.

Barcelona Integral Sewer Plan (PICBA, 2006).

The current Drainage Master Plan (following DMP) of the city is the Barcelona Integral Sewer Plan (PICBA, 2006). The elaboration of the plan is based on a Geographic Information System (following GIS) and a Modelling System (in terms of water quality and quantity), including the sewer network, the WWTP and the receiving waters. The mathematical modelling system allows at any time to get results for:

- Levels, flows, and velocity at every point of the network
- Spills to the receiving waters during storm events

The modelling system of Barcelona sewer network uses the MOUSE Program, from DHI (Danish Hydraulic Institute). The next figure (Figure 76) shows an example of some area of Barcelona introduced in the model, and the results obtained with the simulation program.

The mathematical modelling of the sewer network is a very good tool to detect flood risk areas in the city and to plan the optimal actions and needed infrastructures in order to minimize negative effects in the city during storm events. The modelling system created during the development of the DMP of Barcelona is regularly updated and is currently used to design the new pipes and storm tanks planned at PICBA’06.

Presently, flood risk areas existing in Barcelona have been reduced to the zones presented on Figure 76. This figure shows these zones and the planned actions associated in order to reduce flood risk on them.

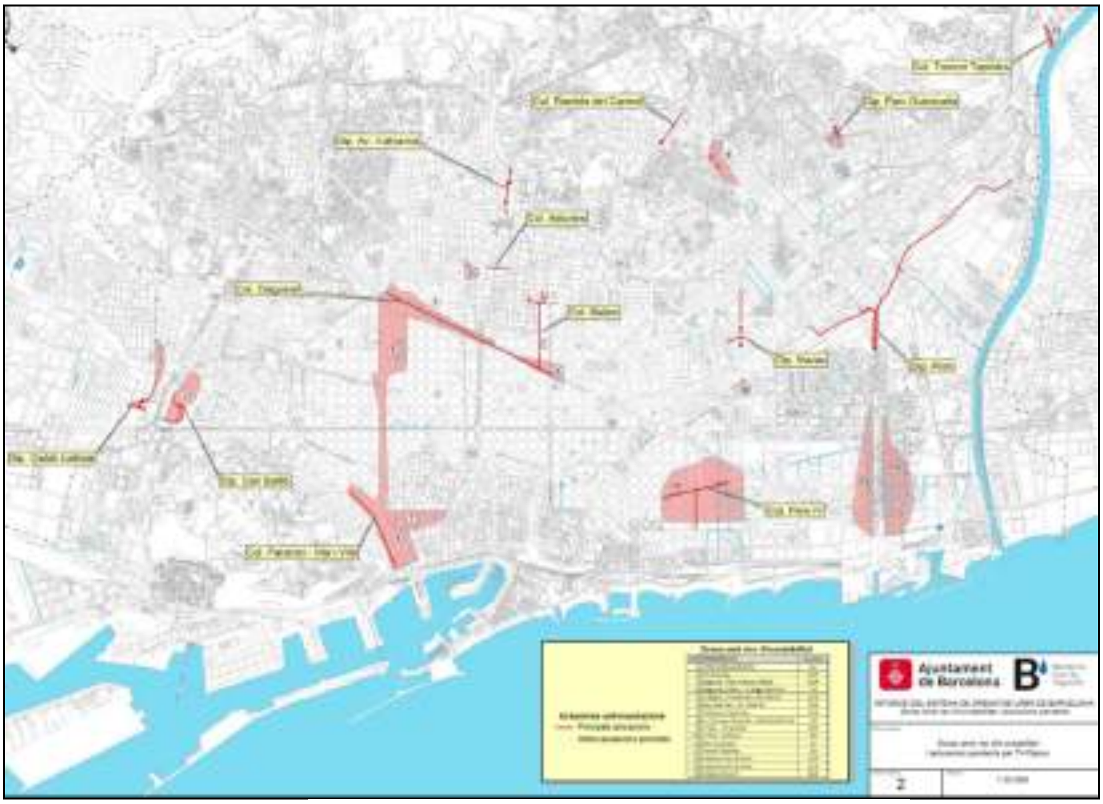


Figure 76: Flood risk areas and principal actions planned at 2016.

Real Time Centralized Operation

The implementation of the Real Time Control in the sewer system of Barcelona obeys to the application of the advanced management of urban drainage. The technological basis are:

- Real time information of the sewer system and the availability of sensors and devices
- Automatic local control programmed on RTUs (Remote Terminal Units)
- Weather forecast tools (based on radar forecast)

The sewer system of Barcelona has available 24 rain gauges, 195 level sensors, and 500 other sensors, which are monitored remotely from the *BCASA Control Centre* (Figure 77). The functions of BCASA Control Centre are the following:

- Supervision of the sewer system sensors: water levels, rain gauges, quality sensors, wind gauges.
- Remote Control of the sewer system actuators: pumping stations, gates, storm water retention tanks.
- Management of flooding warning system.

Figure 77: View of BCASA Control Center.

BCASA has available intensity rainfall data since 1994. The number of rain gauges installed in the city has increased during the last years due to the development of the advanced management of urban drainage in Barcelona. Moreover, Barcelona has available rainfall intensity data since 1927, from the rain gauge installed on the *Observatori Fabra (P25).* Rain gauges location currently operating are shown Figure 78.

Figure 78: Rain gauges operating location.

Also, presently BCASA has available a complete system of water level sensors, located on strategic points of the sewer network, in order to support the application and development of the real time control during rainfall events.

Flooding warning system

The procedure of activation of different flood warning levels in Barcelona rules according to the operating process approved in the BCASA Sewer System Operating Manual. This procedure uses a radar weather forecasting called *Flood Alert*, created by HYDS (Hydrometeorological Innovative Solutions), and is complemented with rain gauges monitoring. Real time data from rain gauges allows to decide different flood warning levels, as shown in Figure 80.

The rainfall emergency operation plan supposes 5 warning levels with different technical and coordinative procedures (Figure 80 a Figure 84). Moreover, according to the emergency levels, BCASA Control Center operates in real time on two critical vulnerable elements considering different mitigation measures (up to proposing the closing of the accesses):

- Ronda del Mig (an underground road in the center of the city)
- Besòs River (an urban park on the rivers floodplains).

A lot of Real Time Control strategies involving storm water retention tanks are currently employed, in order to minimize the effects of heavy storm events, in terms of flood protection and improvement of water quality in the receiving waters.

Figure 79: Flood emergency plan.

Also, there exists Emergency operation in rainy weather, controlled with a centralized operation system, which decides the warning level and starts a coordinated procedure, in order to protect citizens, minimize flooding and reduce environmental impacts like CSO's.

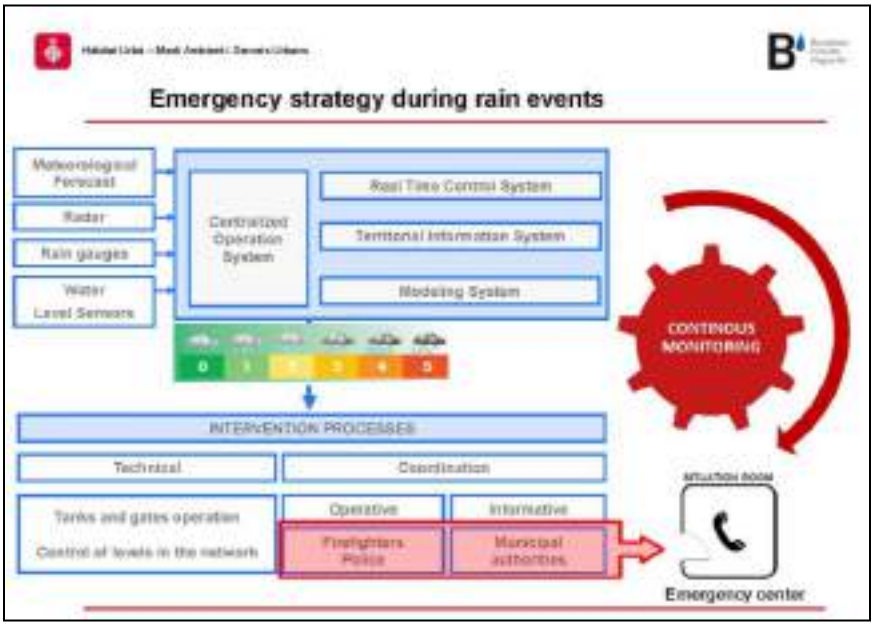


Figure 80: Rainfall emergency operation diagram.

Figure 81: Alert information area.

The operations of city council about flooding are based in the INUNCAT: Plan elaborated to operate in case of strong storms and intense precipitation episodes (flood episodes). It's the most important disaster response plan in Barcelona, since most dangerous and likely disasters that can occur in Barcelona are flood episodes, as it has been seen historically.

For drought episodes, there is no specific emergency plan for Barcelona city. ACA (Catalan Water Agency) has just finished the Drought Management Plan for Catalonia, including a list of measures to be implemented in order to prevent another emergency related to droughts like the one the whole area experienced two years ago.

Specifically INUNCAT, includes a list of towns, obligated or recommended to elaborate an additional plan, about flood, depending on their susceptibility of suffer a flood episode. There are 501 towns obligated or recommended to elaborate this additional plan, called PAM (Municipal Actuation Plan). Among them, it is included Barcelona, because of both its susceptibility and its importance, as it is the capital of Catalonia.

PAMs (in Catalan "Plans d'actuació d'emergència municipal" PAEM) develop to municipal level the special plans elaborated by the Autonomous Community and establish the systematic group of measures to be carried out in order to organize an efficient disaster response. These plans represent the result of an analysis regarding the risk mapping in Catalonia. This analysis was established and carried out by the Commission of Civil Protection of Catalonia through especial plans. In the specific case of flood risk, INUNCAT is the special plan existing in Catalonia.

As said, Barcelona presents several conditions that limit a quick discharge of runoff in case of storm events. Barcelona flood PAM includes the following cities:

- L'Hospitalet de Llobregat
- Sant Adrià del Besòs
- Montcada i Reixac

Moreover, Barcelona is limited by Llobregat and Besòs Rivers. Floodable areas related to an event with a return period of 500 years were estimated in the INUNCAT. As established by these studies, the impact of these floods concerning Barcelona should be very limited, so Barcelona PAEM about flood risk, only considers risks related to lack in terms of drainage system (in Catalan "Pla d'Actuació d'Emergència Municipal per a Risc d'Insuficiència Drenant"). The main aim of this plan is to establish a protocol of the municipal services to guarantee the coordination and efficiency of the necessary resources to minimize the flood effects. Specific objectives of the plan are the following:

- To minimize damages related to people, goods and urban activities;
- To forecast and prevent accidental damages;
- To rehabilitate areas, services and infrastructures affected by flood events;
- To provide useful information to affected people and to competent authorities.

According to the peculiarity of flood risk generated by lacks in the drainage system, some specific data are provided by the plan.

INUNCAT plan defined Barcelona as a Municipality with high flood risk and for this reason it needs a specific PAM regarding flooding. As previously said, in Drainage Master Plan of Barcelona only flood risk generated by runoff and sewer overflow is considered. Barcelona PAM adds some floodable areas for the river flood event with a return period of 500 years. These areas are occupied by industries and factories by due to the limitation of these areas, only flood risk due to poor drainage network capacity is considered.

PAM detected several critical areas in case of flooding in Barcelona. This classification is related to their significant importance in terms of vehicular circulation, or due to their depressed morphology (sag points of the city). The critical areas with high vulnerability in case of storm in Barcelona are:

- Gran Via (Plaça Cerdà)
- Ronda del Mig (Plaça Cerdà – Travessera de les Corts)
- Ronda del Mig (plaça Prat de la Riba - Via Augusta)
- Estació de Sants – plaça Espanya
- Ronda del Litoral (Barceloneta a Vila Olímpica)
- Ronda de Dalt (Vall d'Hebron – Nus de la Trinitat)
- Entorns plaça de les Glòries

Taking into account initial considerations about climate characteristics in Barcelona, PAM indicates different periods classifying each one of them, with a specific flood risk level, according to the frequency of the historic heavy storms events:

Low flood risk: from 16 November to 30 of April

Medium flood risk: from 1 of May to 14 of August

High flood risk: from 15 of August to 15 of November

Barcelona PAM involves three levels of activation: "pre-alert level", "alert level" and "emergency level".

- *Pre-Alert level* corresponds to the period of the operational preventive measures against the probability that an incident can be triggered. There correspond informative actions. Two types of events may produce this level:
  - Forecast of heavy rain
  - Afterwards an alert situation

- *Alert level* corresponds to the actions of operative prevention in front of an incident with overhead probabilities to unchain. It involves actions such as to provide information to operative groups. Two types of events may produce this level:
  - Imminent forecast of flooding produced by surcharged sewers
  - Afterwards an emergency situation
- *Emergency level* corresponds to the actions developed by all the operative groups to minimize the damages produced by flooding related to surcharged pipes and to restablish safety conditions. Two types of events may produce this level:
  - Flooding produced by surcharged sewers
  - Presences of flooded areas in the city

The CORFU project and the creation and calibration of a detailed 1D/2D coupled model

The EU 7th Framework Programme CORFU Project (Collaborative Research on Flood Resilience in Urban Areas, www.corfu7.eu) was an interdisciplinary project funded by the European Commission from 2010 until 2014, with the aim to improve the practice of urban flood risk management. In this context, eight case studies in Europe and Asia were developed with the main objective to analyze and improve resilience of cities to flood impacts. One of the case studies was Barcelona in Spain.

Specifically, the Raval neighborhood was selected as case study, considering, for the whole area, a flood risk assessment based on the hazard and vulnerability evaluation.

The Raval neighborhood, with almost 50,000 inhabitants in an area of 1.09 km^2 is one of the most densely populated areas in Europe (approx. 44,000 inh./km^2). This area is highly impervious with several vulnerable elements (such as schools, hospitals, major highways etc.) and it represents a critical point of the city where stormwater not conveyed into the sewer network and overflows from sewer manholes are stored. Moreover, the hydrological response time of Raval neighborhood catchment is very short (less than 30 minutes). (Figure 82).

Figure 82: Flooding in Sant Pau Street during the heavy rainfall event off 30 July 2011.

Traditional 1D sewer models were unable to adequately describe flooding situations in the Raval neighborhood and the causes producing these problems (great runoff volumes not conveyed into the sewers coming from upstream catchments). So a detailed 1D/2D coupled model, simulating surface and sewer flows was developed using Infoworks ICM version 3.0 by Innovyze (2013). ICM solves the complete 2D Saint Venant equations in a finite volume semi-implicit scheme (Godunov, 1959) with a Riemann solver (Alcrudo and Mulet-Martí, 2005).

The estimation of flood depth in a very accurate way is crucial for a micro scale hydraulic assessment as the one described here. Therefore, there was a need for a coupled 1D/2D approach in order to take into account surface flows coming from upstream catchments and the interactions between the two drainage layers (the sewer network and the streets, sidewalks, squares, etc.) through the surface drainage system.

Special attention was paid to the hydraulic characterization of the inlet systems (representing the interface between surface and underground flows) using experimental expressions developed by Gómez and Russo (2011). In order to consider surface and sewer flows coming into the Raval District from upstream catchments, an extended area was included in the study. Only main sewers were modelled for these catchments, while main and secondary networks were taken into account for Raval District and its proximity. The final model considered a total area of 44 km^2 with 3,874 nodes, 241 km of total pipe length and 6 major storage facilities with a total capacity of 170,000 m^3.

A 2D mesh covered the whole analyzed domain with 403,822 triangles. Parks and other green areas were represented in the same 2D mesh, through “2D infiltration zones” characterized by their specific hydrological, physical and geometric parameters, while buildings were represented as void areas (Figure 83). Runoff produced in the building areas was estimated considering an approximation of single non-linear reservoir and directly conveyed into the sewer network. This goes in accordance with local practice in Barcelona, where roofs and terraces (approximately corresponding to 50% of the whole analyzed domain) are directly connected to the underground sewers.

Figure 83: Flexible unstructured mesh with triangular cells representing the streets and pervious areas (shown with shadows) of the city.

Building areas (with roofs and courtyards) are excluded by 2D domain. On the bottom-right corner of the figure (Figure 83), it is possible to see the narrow streets of the Raval District involved in the 2D mesh.

The sewer model was calibrated and validated using data regarding 4 critical rainfall events occurred in 2011. These data concerned 11 rain gages, 29 limnimeters and several time series related to real time control devices. Moreover, other data collected in the post events emergency reports (elaborated by policemen and firemen), and amateur videos recorded during the selected storm events were used to calibrate surface flow. Detailed information about the features of the model can be found in Russo *et al.* (2015).

Marine model for CSOs detection and Real Time Management of Bathing Water Quality in Barcelona

In 2006 Barcelona's City Council and CLABSA (the mixed company that managed Barcelona sewer system from 1992 to 2013) developed an information system to respond to the requirements of the European Commission Directive 2006/7/CE concerning the management of bathing water quality directive (following BWD), both for internal coordination and for general public information:

- Internal coordination through a dedicated intranet with restricted access, where several information are supplied: bathing water quality prediction results, real time sensors information, rainfall and CSO events summaries, risk level status, etc.
- General public information through electronic panels at the beach (there are currently 3 panels installed in Barcelona) with static and dynamic synthetic information.
- General public web page with the same information provided at the beach panels and additional information (current and daily weather forecast, presence of jellyfish, etc.).

The information appearing on the panel and website con be updated remotely by a designated operator. All possible sources of information are received at a control center: meteorological data, beach lifeguards information (flag, jellyfish presence, sea state, etc.) or generated there (bathing water quality predictions). The system has been working since the summer of 2008 and was managed by CLABSA until 2013 and from 2014 by Barcelona Cicle de l'Aigua (BCASA), the new public company managing the drainage system in the city. The system won the IWA Award for the Project Innovation for the year 2010.

Figure 84: Real time of bathing water quality. Public information system.

In the last years European Policies have enforced the concept of integrated management of coastal with a multidisciplinary focus to promote sustainable management strategies. This integrated management requires the cooperation of all involved parties. An adequate implementation of the BWD implies collaboration between administration, local and regional, sewer managers, waste water treatment managers, etc. Due to the diversity of involved agents, Barcelona's City Council promoted the development of a coordination protocol: "Manual for taking actions in the case of sewer system outflows in the bathing waters of Barcelona beachfront" (from now on, "the Manual").

There was additional interest in writing the Manual to coordinate actions within the "Municipal actions plan for accidental contamination of marine waters" (PAM), which is the local development of the regional scale "Catalonia's emergency plan for accidental contamination of marine waters" (CAMCAT).

The CAMCAT is Catalonia's response to the "National Plan for contingent measures in case of marine accidental contamination" which enforces to develop these short of Plans in all national coastal waters. Additionally, there is a "General Protocol for Actions under contamination episodes in coastal waters and beaches" of the Catalonian Water Agency (ACA), with the objective to protect the health of bathers and preserve the quality of marina environment. The Manual accomplishes the requirements of the BWD regarding management actions related with short term contamination events. Overflows of the sewer system can be classified in two types: CSOs or combined sewer overflows (during rain events) or DWO or dry weather overflows due to malfunction of sewer system. The Manual establishes different procedures for each case, although with the same number and similar types of risk levels. The protocol is activated with the detention of an overflow, which can be triggered by telecontrolled sensors, camera images or direct observation at the beach. After that, a validation process is started, necessary to assure that the overflow is taking place and which is its origin. The protocol describes different entities responsibilities so that the responsible agent can diagnose the outflow and take correction measures for the immediate resolution of the problem.

Once confirmed, sanitary environmental management measures are launched. An evaluation of the affection of bathing water quality is performed and, if necessary, information is issued to avoid exposure of bathers to polluted waters. The procedure is characterized by the definition of risk levels, from 0 to 5, depending on the severity of the pollution event and the available information as the event develops. The risk levels allow the coordination between the Manual and the PAM. In this sense, once level 4 or 5 are reached, a warning is issued proposing the activation of the PAM due to a sewer overflow contamination event. Lower risk levels are resolved within the procedures described in the Manual.

Levels 0, 1 and 2 correspond to the phases of detention and validation of the overflow. Levels 3, 4 or 5 are related to the different effects that the overflow may impact on receiving waters quality. Both for CSO or DWO, level 3 implies probable affection of water quality, and therefore a yellow flag is issued at the beach (recommendation of not going in the water). Level 4 implies a certain affection of water quality with the issue of a red flag (bathing is prohibited). Level 5 is reserved for exceptional situations not contemplated in the Manual and are managed through the PAM.

Agile responses, coordination and collaboration between different affected agents are the key issues in the processes established in the Manual. The COWAMA technological tool becomes a key element in the evaluation in real time, and even prediction, of the affection to bathing water quality due to the sewer system overflows.

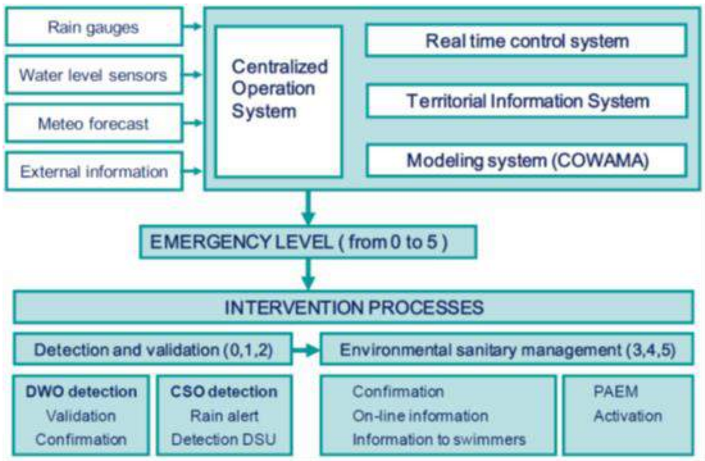


Figure 85: Workflow describing the management procedures for COWAMA.

The COWAMA project consists mainly of a computational application that links a sensors network with fluid flow simulations models in order to produce statistics on water quality to be supplied to local authorities and be published for public information.

The core of the application couples five different fluid flow and quality models, each of them simulating a subsystem: watershed, river basin, urban drainage network, WWTP and receiving waters (may be coastal or inland). Those models are fed either with real time or historical data obtained from sensors (rain gauges, water level sensors, etc.) and large scale forecasts (e.g. meteorological models).

The system is designed to work both online and offline:

- Offline mode: simulations based on historical data to reproduce past pollution events and retrieve long term statistics. These statistics allow the definition of beach profiles as required by the new BWD. Indeed, for beaches submitted to short duration pollution events, the directive imposes an evaluation of the estimated frequency and duration of contamination episodes. The same kind of long term simulations may be used to elaborate a cost-benefit analysis or measure the effectiveness of planned

modifications of the water collection system or of any relevant coastal infrastructure that may influence polluted masses transport.
- Online mode: Real time data on rain and sewer water levels are used for fast CSO detection and results from real time models are used for the alert systems and water quality forecasts.

The input data may be classified in static and dynamic. The static data are set for each simulation and do not change in the course of a simulation. It includes mostly the relevant physical data of the simulated domain (topography, bathymetry, pipes networks, catchments definition, etc.) and some fixed hydraulic (ocean bottom roughness, capacity curves, infiltration coefficients, etc.) and numerical parameters (advection scheme, turbulence parameterization).

The dynamic data may continuously change during one simulation. An example would be the opening of an operated gate at the inlet of an underground sewer storage tank. This information needs to be supplied all along the simulation. Dynamic data includes essentially data collected by sensors (in real time or differed in time) and results of other models needed for boundary conditions (sewer model outflows or wind forecasts for the marine model).

Different types of sensors may be used to feed the simulation models, detect pollution events but also to calibrate the models and validate their results: rain gauges, water level gauges, waste water automatic sampling stations, current meters (hydrodynamic coastal model calibration), HF radar data, tidal gauges, multi-parametric sensors for receiving waters quality, pyranometers, etc.

Each of the simulation models corresponds to one subsystem of the water cycle: catchments, river, collection system, WWTP and receiving waters. These models must be coupled in a single application that allows simulating the flow and the transport of contaminated matter carried by rainfalls, from surface runoff to pollution dispersion in receiving waters. This articulation of models initially thought to work independently constitutes a major difficulty and was one of the tasks accomplished in the framework of the COWAMA project.

- The watershed model for surface runoff calculation is based on semi-empirical methods. It gives flow rates at the different inlets of the drainage network and rivers of the studied area. This model is fed in real-time with data from rain gauges (MOUSE runoff module).
- The river and sewer network models (based on MOUSE tool developed by DHI, Danish Hydraulic Institute) are based on a very similar formulation. They solve numerically the Saint-Venant equations in one dimension and one equation for advection and dispersion of polluting substances. Additionally, bio-chemical degradation or production may be incorporated. Boundary conditions are normally provided by the watershed model, but may also be deduced real-time from water level gauges near the inlets of the system.
- The WWTP model is used for calculating flow rates and water quality parameters of the WWTP discharges to receiving waters. This model uses the sewers network model results as an input.
- The receiving waters model (MOHID developed by Maretec) is a three-dimensional coastal model, and may be used for costal zones as well as for estuaries and inland bathing areas. Model forcing (i.e. boundary conditions) includes wind, waves (wave forcing is obtained through SWAN, a dedicated model for wave generation,

propagation and breaking) and tides, data that may be historical or forecasted. This model solves numerically the free surface flow equations and the transport equations of relevant physical quantities (temperature, salinity, etc.). Ecological models for polluting substances degradation and production can also be included, in particular for simulating bacteriological mortality. Input data is given by the river, sewers network and WTTP models, in the form of hydrographs and contaminants concentrations curves. Water properties (thus pollution as well) can be modelled with an eulerian or a lagrangian approach, the earlier is indicated for large outflows (e.g. Barcelona) and the latter for smaller point source outflows or submarine outfalls, having the advantage of providing the ability to track pollution sources (lagrangian tracers). The final result is a three-dimensional map of bacteriological concentrations, with ability to obtain statistics at any location within the model domain.

To ensure results reliability of the different models they were calibrated on the basis of measurements obtained from sensors, treatment of satellite and aerial imagery, and also from field campaigns directly in bathing areas. In the framework of the COWAMA project, intense sampling campaigns were planned both with dry weather and during rainstorms. The principal analyzed parameters were the bacteriological pollution indicators: faecal coliforms, Escherichia coli and intestinal enterococcus.

Finally an internal reporting and alert system has been incorporated in the computational application. It is based on collected information and on the results of the models. The alert system emits warnings by email or through dedicated color coded icons in the application interface for easier interpretation. Automatic or on demand reporting capabilities have been developed. The system can generate Excel files, images with 2D model results, graphs with sensors or models data, animated gifs, etc. More information about COWAMA system can be found in Gutiérrez et al., (2010).

Main climate effects and natural hazards affecting urban drainage and groundwater systems and the related critical infrastructures

Sewer system

The sewer system is exposed to extreme rainfall events, because they may produce collapse of the sewer network and cause surface flooding. Specially exposed are the storm tanks and pumping stations, due to high flood may cause operating dysfunctions or structural damages on these infrastructures.

Also, river flood and coastal level elevation may cause dysfunctions around the discharge points of the sewer network into receiving waters, because the entrance of sea water or river flow may produce loss of capacity of the sewer network. In this case, specially exposed are:

- Gates existing on the discharge points of the sewer network to the Besòs River.
- Waste water pipes that lead waste water to the Treatment Plants, sitted near the coast line and Besòs riverbank.

On the other hand, Real Time Control elements (raingauges and water level sensors) are exposed to telecommunication failure, because these elements are remotely controlled and their correct operating depend of energy supply and telecommunication signal. Also, mobile elements of the sewer system (gates, pumping stations) are exposed on the same way.

Groundwater system

Nowadays, BCASA is the responsible of the management of groundwater network in Barcelona. In case of extreme drought, groundwater level decrease may affect directly urban services as streetcleaning and watering urban gardens.

Also, salt water intrusion during extreme drought may affect directly the quality of the groundwater and stop from using it.

4.3.5 Waste Water Treatment

Wastewater Treatment Plan of El Prat de Llobregat

El Prat de Llobregat WWTP has a treatment capacity of 420.000 m^3/day and includes a pretreatment section for retaining solids and grit removal, primary clarification for removal of suspended matter, a secondary treatment for simultaneous removal of organic matter, nitrogen and phosphorus and secondary sedimentation for the separation of generated sludge from treated water. The Barcelona Metropolitan Area (BMA) has a high concentration of industrial and agricultural activities, and a densely populated area (Figure 86).

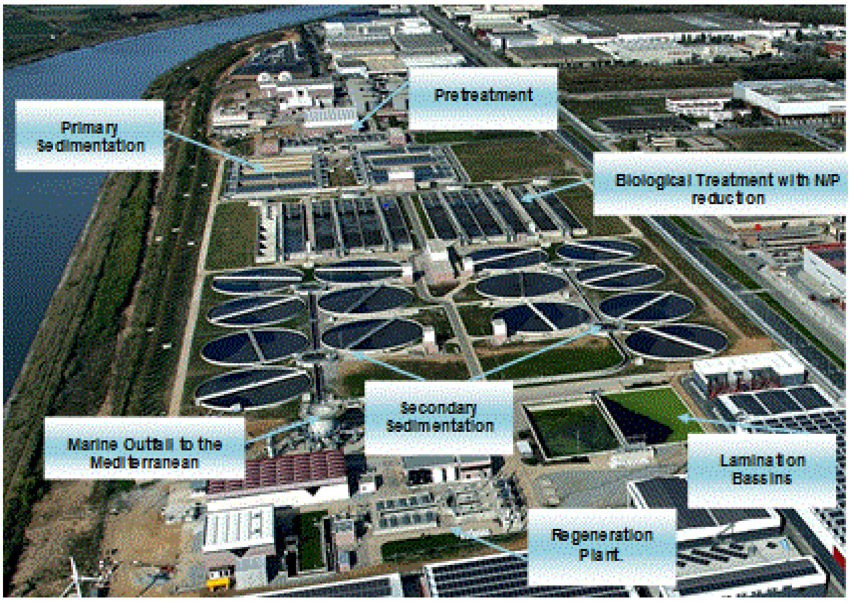


Figure 86: Current conventional treatment scheme of "El Prat" WWTP.

The pretreatment section has the following equipment:

- 4 raw-water wells with automatic cleaning bar screens divided in two groups of two.
- 9 submersible pumps with a capacity of 6.653 m3/h each one.
- 8 Coarse screens for retaining solids larger than 50 mm, installed in 2 m wide channels.
- 8 Fine screens for retaining solids larger than 3 mm installed in the same channels.

The screened wastewater flows through 12 aerated grit removal channels 35 meters long and 5 meters wide, distributed in 2 groups of 6. Pretreated wastewater is pumped into 12 rectangular primary clarifiers, 60 m long and 20 m wide, equipped with mechanically driven scrapers, distributed as well in two groups of 6. At the average treatment flow retention time in the primary clarifiers is 2, 67 hours and approximately 60% removal efficiency of suspended solids is obtained. The amount and volume of primary solids removed in the primary clarifiers is reduced in the anaerobic digesters together with solids coming from the wasted activated sludge from the biological process.

Following the primary clarifiers, the water flows through 12 four stage biological reactors (divided in two groups of 6) in each of them we can find three anaerobic chambers (800 m^3), three anoxic chambers (2200 m^3), a facultative chamber (800 m^3) and four aeration chambers (6600 m^3). This is an activated sludge treatment in which we can obtain a 97% efficiency of BOD5 removal and over 70 % removal of total nitrogen and phosphorus. The internal and external recirculation flow, the oxygen in the first and the last aeration chambers and the ammonium and nitrate in the last aeration chamber are continuously monitored. The aeration is done by four 4 7500 Nm^3/h turbochargers blowing through fine bubble diffusers.

Treated water is separated by the generated sludge in 14 circular secondary clarifiers distributed in two lines which provide an average retention time of 5 hours. Excess treated effluent which is not fed into the regeneration plant is discharged into the sea at a depth of 60 meters through a 3.200m long and 2,4m diameter submarine pipeline located in the same WWTP.

Water Reclamation Plant Description

El Prat de Llobregat reclamation plant, which has a design flow rate of 12.600 m^3/h and a peak treatment flow rate of 14,400 m^3/h, consists of the following processes:

1. Two lamination basins with a unit capacity of 7.807 m^3.
2. A total of 4+1 lift pumps with a unit flow of 3.150 m^3/h.
3. Three ACTIFLO® sedimentation units, each unit consisting of a 90 m^3 coagulation tank with PAC injection, a 90m^3 sand and anionic polyelectrolyte injection tank, a 198m3 maturation tank, and a clarification basin with a surface area of 42 m^2.
4. Ten ACTIDISK® rotary disc filters with 10-micrometre mesh.
5. Four ultraviolet light disinfection channels with a total of 216 lamps per channel arranged in two banks per channel.
6. A post-disinfection with sodium hypochlorite.

This basic water reclamation plant also supplies the advanced water reclamation facility for the Seawater Intrusion Barrier in the Llobregat Delta Aquifer. This facility allows the injection of reclaimed water by way of 15 wells, forming a barrier between the Mediterranean and the aquifer. Water flows are injected through the wells depending on their position in the aquifer, with a peak injection flow rate of 75 m^3/h. The reclaimed water injection capacity of the facility is 15,000 m^3/day. The facility is supplied with water from the basic reclamation plant, which passes through 10 μm rotary filters, an ultrafiltration stage and lastly the reverse osmosis process, after which it is disinfected with ultraviolet light. The water finally injected into the aquifer is a 50/50 mixture of water treated by reverse osmosis and water treated by the ultrafiltration stage (Figure 87).

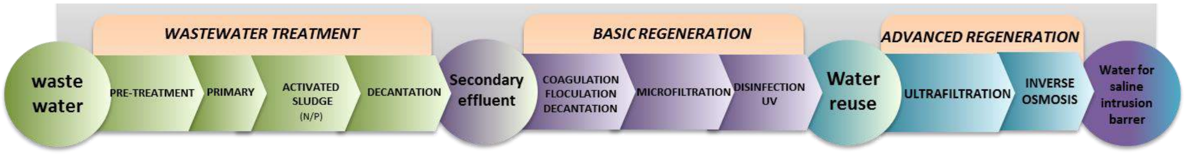


Figure 87: Diagram of El Prat de Llobregat WWTP.

Wastewater Treatment Plan Besòs

Besós wastewater treatment plant (WWTP) is the largest treatment plant in Barcelona area, with 2.5 million of PE, with a capacity of 525.000 m^3/day. It treats the wastewater generated in Barcelona (65%), Badalona, Montgat, Sant Adrià del Besós and Tiana. This WWTP is located in the middle of Barcelona city, as shown in the figure below. It is important to consider that the whole plant is constructed under the surface and all the air process flows are collected and treated separately (Figure 88).

Figure 88 Besós WWTP location in the middle of Barcelona city

The treatment processes are placed in separate buildings to favour the odour extraction and treatment, which are:

- Water line:

Pretreatment: screening and sand removal to separate the biggest solids found in wastewater. This processes are placed in a closed building with air extraction that is treated by scrubbers.

Primary treatment: coagulation-flocculation and primary settler (lamellar). The settlers are closed and the air under the cover is extracted and treated by scrubbers, this is the point where the extracted air is more polluted.

Biological treatment: activated sludge to remove organic matter followed by secondary settler (lamellar). The air of this building is treated by activated carbon filters.

- Sludge line:

Thickening of sludge: biological sludge is thickened by centrifuges up to 4-5%. The air extracted is treated by activated carbon filters.

Main climatic effects and natural hazards affecting the service and the related critical infrastructures

Temperature

Biological process

Seasonal changes can affect a plant's aeration tanks by shifting the dissolved oxygen capacity and efficiency of nitrification as temperature changes.

To sum up, the variation in temperature can adversely affect the biological processes: A sudden change in temperature from hot to cold can have an effect on this WWTP. Such decreases may lead to decreases in biological activity, causing the necessity to raise the number of reactors per each line of biological treatment.

However, **Besós WWTP** it is less affected by seasonal variations than other WWTPs because the ambient temperature is more constant underground. Along the years, they have observed that wastewater temperature has slightly increased, which in fact improves the efficiency of the biological treatment.

Coagulation

Temperature also affects the coagulation-flocculation processes. In particular, there is a temperature below which the coagulation process efficiency worsens. Therefore, a potential increase in temperature would favour the coagulation process.

Membrane based process (UF, RO)

Membrane based processes are affected by temperature. In particular, the higher the temperature, the higher the permeability, leading to a greater productivity. As a result, an increase in temperature may result in a positive effect from a production standpoint.

Flash floods

Pre-treatment process

Flash floods caused by the Mediterranean climate rainfall patterns, with intense precipitations mainly at the beginning of spring or in the autumn are usual in the area of Barcelona.

Changes in climate are expected to increase climate variability with likely more intense rainfall events. The frequency of occurrence flood events increases the demand of flow and consequently, it affects to the demand on drainage infrastructure, that which leads the clogging of the feed pumps and thus, failing to treat it. This untreated sewage is released into the environment.

Storm events will also give rise to increased erosion, soil loss, and landslides. Much of the pollution and eroded soil will end up in the coastal environment.

Sea level

If the sea level increases, sea water reaches the collectors by the overflows and can negatively affect the biological process by salinity. That could be a significant problem in Baix Llobregat WWTP but in general, the sea level is not a problem in Besós WWTP, on the contrary, waves and heavy seas are more frequent (2-3 times per year) and have the same effect (increasing the see level).

Energy suplly failure

As it was described for Distribution Water Treatment Plans, due the strong energy supply dependency in all treatment phases, in this case, every WWTP is prepared to overcome an energy supply failure. The energy supply company or a specific provider brings power generators in crisis episodes for power cut, depending on the failure severity and importance. Some generators are available in Plants.

4.4 Energy (Electrical sector)

Energy demand in cities is projected to grow by 57% between 2006 and 2030, about 2.7 times more than the growth forecast for areas outside cities (IEA 2008), and it is expected to account for 73% of the world's energy consumption by 2030. Total final consumption of energy per capita correlates with the share of urban population in the OECD countries. Various differences exist between cities such as Barcelona and areas outside cities with respect to the conditions that can affect energy demand (IEA 2008). These include, for example, diversity of functions (industrial, commercial or administrative), size and types of housing and buildings, density, land use and dominant transport mode.

Energy data at city level, including data on energy consumption and renewable energy production, are fundamental for understanding resilience challenges related to energy and for developing urban policies. In Barcelona total final energy consumption has been increasing until 2005, and fell after 2010, mainly as a result of the economic crisis. In 2012, the residential sector has become its largest consumer of energy, accounting for 29.3% of the city's total energy consumption. The city council, through its activities and mainly through its building stock, consumed approximately 472.250 MWh in 2008, of which 1.4% came from solar thermal sources. In 2008, renewable energies represented 0.6% of all energy consumed in the city as a whole (Barcelona City Council, Sugahara *et al.*, 2016). Local production of renewable energy has risen from 6.680 MWh in 1999 to 153.620 MWh in 2012. Such increase must be seen not only to account on the importance of decreasing carbon dioxide generation, but in this context on the provision for new resources when defining resilience strategies that nowadays consider standard electricity distribution system, while in the near future such paradigm is going to change with the introduction of the Smart Grid, that already considers higher component of distributed renewable energy sources (RES).

In Table 29 a comparison between Barcelona and Bristol in relation to the energy consumption as well as the local renewable energy production is shown, which is a fundamental element in urban resilience (Bristol City Council, 2014). Such data can help policy makers better assess the current situation finding potential solutions by knowing how to modify urban energy policies in accordance to indicators for city services and quality of life (ISO 37120:2014).

Table 29: Comparison between Barcelona and Bristol in terms of Energy consumption and RES.

City	Energy consumption	Local renewable energy production
Barcelona	60 415 TJ (2012) By sector (industry: 18.84%, transport: 22.84%, residential: 29.27%, comercial: 29.04%) (2012)	553 TJ (2012) By source (solar PV: 10%, solar thermal: 46%, small-scale hydro: 2%, biogas: 34%, biomass: 8%) (2012)
Bristol	216 TJ (2014) (electricity, by the city council) 84 000 TJ (2011) By sector (industry: 16%, transport: 27%, residential: 27%, business: 31% (2011) By source (electricity: 38%; city gas: 29%; oil: 33%) (2011)	553 TJ (2011) Potential quantity of RE (solar: 3.7 million TJ/year, wind: 935TJ/year, small scale hydro: 1 516TJ/year, biomass: 8 353TJ/year) (2011) Quantity of RE available (solar power: 5 400TJ/year, solar thermal: 15 000TJ/year, wind: 477TJ/year, small-scale hydro: 108TJ/year, waste power: 747TJ/year, waste heat: 2 695TJ/year) (2011)

Electrical utilities assets in different domains

Electrical utilities more and more recognize the effect of extreme weather events on power system operation and resilience. For example (Panteli et al., 2015):

- High temperatures and heat waves limit the transfer capability of transmission lines, increasing the energy losses (due to the temperature dependence of the impedances) and the line sagging. Also earthing impedance on substation will change in response to ground's moisture and temperature. Also, it is worth noting that high temperatures reduce the electric power generation of solar PV systems.
- High wind speeds during storms and hurricanes can lead to both faults and damages on the lines and even the towers. Also electric generation based on wind power may have to be shut down.
- Cold waves, heavy snow and ice accumulation can cause also failures of overhead lines and towers. Ice and snow may also gather on insulators, which bridge the insulators and provide a conducting path, resulting in flashover faults. Moreover, heavy snow and ice may increase fatigue and reduce efficiency of wind turbines and reduce solar PV generation.

- Lightning strikes on or near overhead conductors can also cause short circuit faults and transient voltage surge that may be transferred along the line and damage transformers wings
- Rain and floods may affect substation equipment such as switchgear and control elements. Also may impact hydropower generation and affect water availability for cooling purposes in thermal and nuclear power plants. The shortage of rain may cause wildfires which threaten transmission facilities.
- Finally the growth in the demand, population migration and change in load patterns, will affect energy delivery.

Those can cause the failure on key components of the system (Ward, 2013 and UK Cabinet Office, 2011), such effects can be even more severe by over-aged or degraded equipment. From these affections the utilities may propose some measures such as:

- Improve estimation for weather severity and location.
- Tree and vegetation trimming for clearing transmission lines.
- Buried of distribution and transmission lines or re-routing lines in areas less affected by extreme weather conditions.
- Elevating substation and relocating facilities to areas less prone to flooding.
- Increase and/or improve monitoring and visualization by improve set of sensors.

The utilities own many devices that are prone to some miss-functionality when severe conditions appear. That is a negative aspect since supervision and maintenance over many devices is required. But on the other hand, one can effectively manage the usage of such devices in order to prepare for a forthcoming weather event. Utilities may react by acting over:

- Reserve planning and demand side response
- Generation dispatch and energy storage
- Ensure black-start capabilities
- Coordination with neighbouring networks

For all these contingencies measures to be accomplished effectively, it is necessary to account on a proper telecommunication infrastructures, unless there is the possibility to act autonomously from the rest of the system, what may end up being islanding or autonomous operation.

For a proper asset assessment on the electrical sector component one option is to divide this sector in different domains: power generation, transmission, distribution and distributed energy resources, and each domain in different zones. Such division is proposed by the standardized Smart Grid Architecture Model (SGAM).

Power generation domain

- **Hydroelectric electricity generation sub-domain**: A typical hydroelectric power plant is automated by means of a so-called Hydroelectric electricity generation automation system. The system controls the process of electricity generation and related safety requirements using controllers and sensors.
  In the component layer one can list several components from this system:

1. *Process:* Pump, motor, switch gears, circuit breakers, VSD, Motor soft-starter, control valves, transformer, generator
2. *Field:* PLC, Flow Meter, Temperature Sensor, Frequency converters, AC Drive, Protection Relay, Power Meter.
3. *Station:* SCADA (Supervisory control and data acquisition), HMI and Engineering Workstation

- **Wind Electricity generation sub-domain**: The Wind Electricity Generation sub-domain refers to the conversion of wind energy into electricity. In the component layer here is a list of components in the same zones:
    1. *Process*: Switches, Switch breakers, Instrument Transformers (power transformers, current transformers and voltage transformers), Grounding systems, Feeders, Generators, Loads, Wind turbines, Static converters, Motors, Electric cables, Terminal blocks, Filters, Capacitor banks, Voltage line attenuators, Current limiters, Lightning protection, surge protection, wind sensors, temperature sensors, PLC couplers
    2. *Field zone:* IEDs such as reclosers, Power Factor Compensation, Static Converter, PLC protection, Surge Static switch, Feeder, Protection relays, Wind speed sensor, Temperature sensors, Signal repeaters, Remote terminal unit (RTU), Network Hub, Network switch.
    3. *Station zone:* Data concentrator, SCADA, Human-Machine Interface, Controllers (Voltage and frequency stabilizers, Flicker and noise compensators), Wind forecast system, Router, Network hub and switch
    4. *Operation zone:* Data server, Power station management system, Fault Location, isolation and restoration system (FLIRS), Process data interface, to exchange information with the transmission system operator (HMI), Router, Firewall.

- **Solar Electricity Generation Sub-Domain**: This sub-domain only covers grid-connected photovoltaic (PV), where arrays of solar panels, are connected to the power grid by means of power inverters, injected the power generated by the photo-conversion process. For the component layer the zones include:
1. *Process:* Switch breakers, Grounding systems, Current transformers, Voltage transformers, PV panels, Static converters, Electric motors, solar trackers, Terminal blocks, Lightning protection, Surge protection, Wind, Temperature and, Irradiance sensors, Image recorders.
2. *Filed and Station zone*: ED such as reclosers, Static converter, PLC Protection relays, Wind speed, Temperature and, Irradiance sensors, Digitalizers and transducers, Protocol converters, Signal repeaters, Remote terminal unit (RTU) (for data aggregation or to interface equipment with a SCADA), Network Hub and switch.
3. *Operation zone*: Data server, Power station management system, Process data interface, to exchange information with the transmission system operator (HMI), Router, Firewall.

Transmission domain

The electricity transmission domain covers high-voltage lines and transformers. An electricity transmission utility (TSO) is responsible for transporting power over long distances, from the power stations (generators) to the distribution substations (distribution feeders). It is a large, critical infrastructure, commonly referred to as the ”power grid".

One very important aspect of the transmission grid is that there is no auto-pilot: it needs constant, centralized, human operated monitoring and control. This is because there is a delicate balance between generation and load that has to be kept at all times, otherwise some critical operating parameters such as frequency and voltages would stay out of limits and automatic protections would quickly disconnect lines and transformers. In such scenario, as it is known from recent blackouts, the grid is prone to cascading failures, which may end up in a large-scale outage. Recovering from a large blackout is a delicate procedure that may take anywhere from about 4 hours to several days.

Following the previous example, one can distinct between devices located at different zones:

1. *Process zone*: Bus, Transmission line, Transformer, Capacitor (shunt or series), Reactor (shunt or series), Switches and breakers, High-voltage direct current links (HVDC), Flexible Alternating Current Transmission System (FACTS).
2. *Field zone:* Digital measurement sensors (on/o_ status of switches & breakers), Sensors (VT/CT) , RTU and IEDs such as fault detectors, Protection Relay such as bay controller, station controller, capacitor-bank controllers, PLCs (such as ULTCs, shunt automation, SVCs, FACTS controls, HVDC controls, etc.), Voltage regulators, Phasor Measurement Unit (PMU).
3. *Station zone:* Network Interface Controller (NIC), Router, Phasor Data Concentrator (PDC).
4. *Operation zone:* SCADA, Energy Management System (EMS), Wide Area Monitoring System (WAMS), Model Exchange Platform.

Distribution domain

The distribution grid is the final stage of energy conversion before the electricity is supplied to end users. It transforms the high voltage received from the transmission grid to levels appropriate for customer usage. Distribution grid responsibilities include detecting faults and other abnormal situations, taking action to protect people and components and restoring service after interruptions occur (MIT, 2011). Commonly, metering for billing purposes is also responsibility of distribution operators.

Distribution networks generally have a radial, or tree-like, topology. There is a single path, and therefore, a single point of failure, from a substation to a given load (e.g., a household). To improve resilience some distribution networks are organized in a ring, or loop, topology. In some rare cases, they are organized as a mesh network. In either case, there is still a single active path between a substation and a load. When necessary (e.g., after a failure), the active path can be changed by means of circuit breakers. Management and automation systems are becoming increasingly important to meet the demands of the energy distribution infrastructure. This task is performed by Distribution Management Systems (DMS). These are geographically distributed systems that communicate using the network to perform control functions.

For this domain the zones containing the assets would correspond to the following:

1. *Process zone*: formed by primary equipment of the MV/LV of the electrical network, including switching elements (circuit breakers and switches), power transformers, metering devices and voltage regulators.
2. *Field zone*: Mainly for protection and monitoring such as: protection relay, operation, revenue and grid meter, fault detector, recloser, bay controller, and switch controller. PLCs such as field controllers.
3. *Station zone*: RTU, HMI, Historian, PLCs such as: station controller, feeder controller, capacitor bank controller, load tap changer controller.
4. *Operation zone*: includes the various IT servers used in the DMS SCADA and Outage Management Systems (OMS).

Der domain

In order to reduce greenhouse gas emissions and increase resilience to extreme weather conditions, it is of advantage the use of renewable but unstable power generation such as, photovoltaic cells and wind turbines. Those will be accommodated in smart grid, in addition to controlled and predictable storage systems. Such systems can be added into the power grid by using micrograds, that can act as isolated energy islands (matching demand with local generation-storage) or grid connected.

In addition to specific type of controllers (Microgrid central controller – MCC, distributed controllers, etc..), and bidirectional power flow sensors and data acquisition systems, this domain would include similar components as the ones described in previous section.

Extreme weather effects and Girona use case

Extreme events, including natural disasters and accidents, have major effects on urban energy supply and the occurrence and the damage caused by the disasters both seem to have increased recently (Figure 89). So it is clear that critical power infrastructure must be resilient to high impact low-probability (HILP) events.

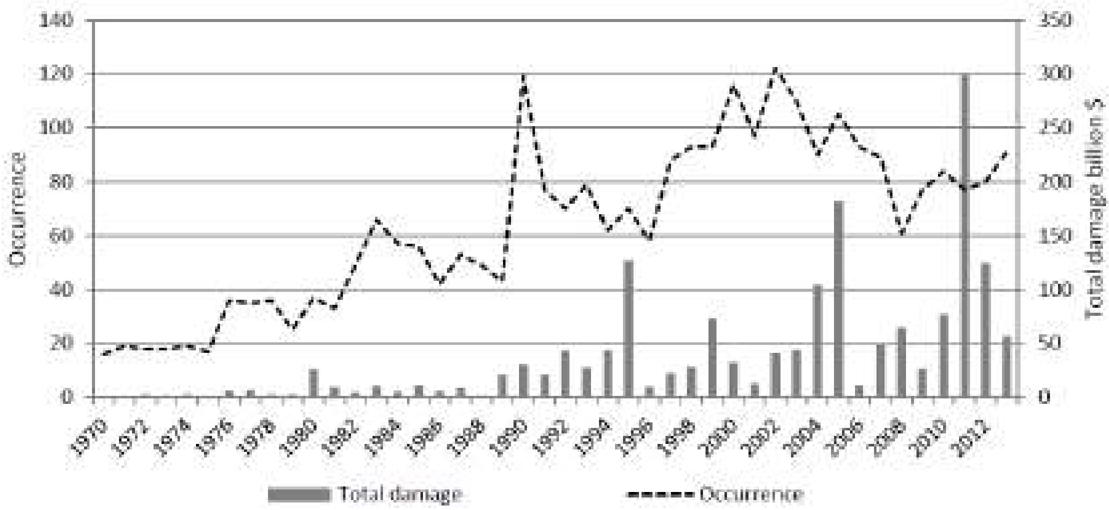


Figure 89: Number of annual disasters and economic damage due to natural disasters in OECD countries.

One example showing the huge influence of natural disasters over civil services occurred in the province of Girona, next to Barcelona province, where a heavy precipitation event swept on 8 March 2010, with a total amount that exceeded 100 mm locally and snowfall of more than 60 cm near the coast. This snowfall event affected mainly the coastal region and was accompanied by thunderstorms and strong wind gusts (exceeding 90 km/h) in some areas. Most of the damage was due to “wet snow”, a kind of snow that favors accretion on power lines and causes more than 3.400 tower and post electrical line-breaking and subsequent interruption of the electricity supply. As a consequence, hundreds of trees were destroyed and, in some areas, the electricity networks collapsed.

The Meteorological Service of Catalonia issued the first meteorological warning three days before the event, as well as two special press releases to inform the public (Vilaclara et al., 2011). The government activated “NEUCAT”, the emergency plan for snow. The event had high societal impact, a total of 36 high-voltage power-transmission towers were damaged by snow and wind. As a consequence, more than 450 000 customers were affected by power outages over the following days and the electricity company spent EUR 60 million on repairs. The damage to forests was substantial, affecting 150 000 ha, while fallen branches and trees affected infrastructure such as roads and made access to residential areas more difficult (El Periodico, 2010 and Llasat et al., 2014) .

Figure 90: Extreme weather effects and measures.

Distribution power grid modeling

There exist different distribution electric networks models that can be used to reproduce and to predict vulnerabilities of the electrical power system and networks when an extreme climate situation occurs.

Focusing on the electrical models for Barcelona city, it must be remarked that the existing model and certain level of detailed data is protected under ethics issues, since this relies on personal information of consumers. It is worth noting that, in case finally the real model would not be available, a benchmark grid for distribution electric power networks will be adapted trying to make it as similar as possible to certain behavior of Barcelona city.

At any case, the impacts on the grid of any extreme weather conditions will be simulated with such models (in specialized software for electrical systems as Digsilent Power Factory) through the modification on generation and consumption levels at certain nodes, or lines and cable tripping.

Benchmark model

The benchmark model to be modified to behave as a Barcelona case (in case the real model is not available) will be the well-known **CIGRE Low Voltage distribution network** (Amaris et al., 2015). The base model represents a real-world LV network. This benchmark is flexible enough to allow modifications including renewable energy penetration and different fault modification.

A schematic representation of the model is shown in the following Figure 91.

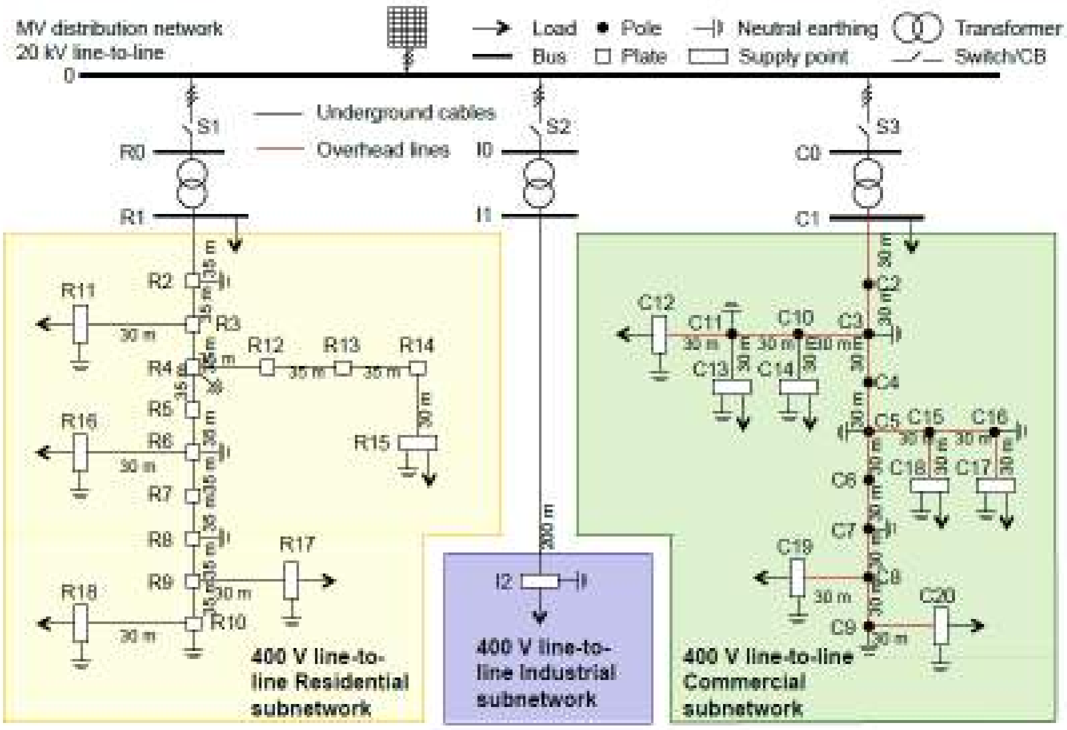


Figure 91: schematic representation of the CIGRE model.

It is worth noting that different loads as industrial, residential and commercial networks are included and represented. Also it is worth noting that this model may be easily expanded for including renewable energy sources, storage, and electric mobility, among others.

Barcelona distribution model

If finally a real model (or data) for the electric distribution network of Barcelona is available, it will be used to analyse the impact of the weather extreme conditions on the electrical service of Barcelona. In the case there is such model, it will be used directly. On the other hand, if there is only data, it will be used to develop the full model. For that reason, it is expected to develop a distribution network of Barcelona which will include critical loads of the city and certain detail on MV and LV distribution grid including electrical substations. It is worth noting that it is foreseen that in case of need of more detailed study of a certain part of the city, such part of the city may be modeled in detail. Potentially such detailed area may include a generation, electrical mobility substations (tram, metro and train), and critical loads as hospitals, schools, etc. nearby.

Type of Study	- **Electrical power flows**. In other words, it allows the computation of the certain electrical variables according to some inputs and restrictions (if required), in a static mode. For that reason, that models are applied for planning with a short period of time update to validate the status of each point on the electrical network.
Input variables	- Active power generated of PQ and PV buses - Reactive power generated of PQ buses - Active power consumed of PQ and PV buses - Reactive power consumed of PQ buses - Magnitude voltages of PV buses - Voltage magnitude of Slack bus - Phase voltage of Slack bus. where Slack bus refers to reference electrical node (bus), PQ bus indicates an electrical node where the active and reactive power is considered as input, and PV are the buses where the electrical active power and voltage magnitude are fixed as input.
Output variables	- Voltage magnitude of PQ buses - Phase voltage of PQ buses - Reactive power of PV buses - Phase voltage of PV buses - Active power of slack bus - Reactive power of slack bus - Currents of all branches - Loading of all branches, transformers and power converters - Frequency - Max. Short-circuit currents - Switches status - Losses in the cables It is worth noting that certain output variables are obtained as combination of other outputs.

	Benchmark model	**Barcelona Model**
Model owner	OpenAccess (IREC has it)	Endesa
Model status	Model improvement: Modification to adapt it to Barcelona Case (IREC ownership)	In use (for electrical network status analysis)
Input/output data owner	Benchmark: OpenAccess/IREC Barcelona Case: - Inputs: Endesa - Outputs: OpenAccess/IREC	Endesa

4.5 Transport

Modes of transport

A total of 7.896.903 stages of journeys are made in Barcelona every day, of which 64.08% correspond to internal journeys and 35.92% to connecting journeys (between Barcelona and the exterior).

Mobility has increased over the last two years, both for internal journeys, and also for connecting journeys, after some years of decreasing, probably related to the economic recovery.

For internal journeys, the predominant modes are cycling and walking with 49.29%, while public transport predominates for connecting journeys with 50.75%. Regarding private vehicles, these are used much more in connecting journeys, accounting for 41.64%, than internal journeys, where they represent 17.38%.

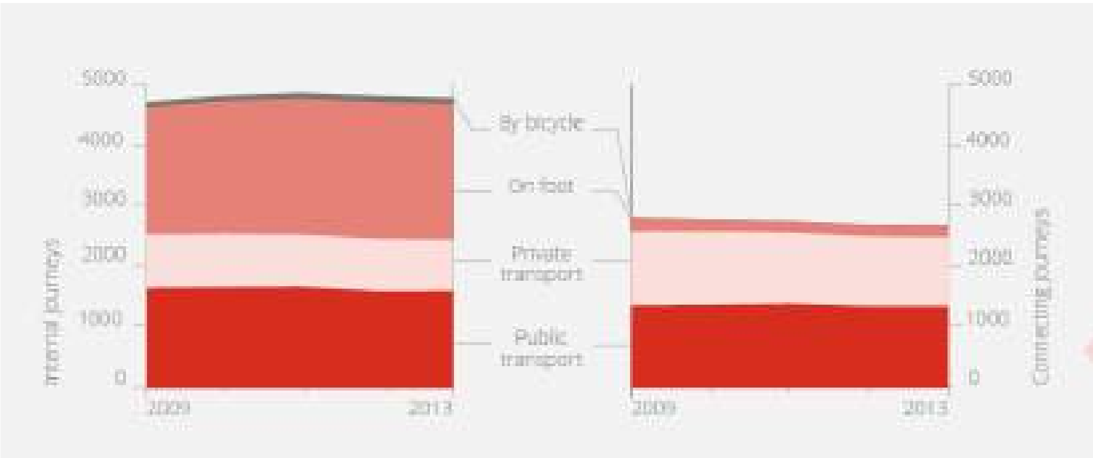


Figure 92: Barcerlona's transport. Internal and connecting journeys.

Mobility on foot is increasing. New zones have been created with priority for pedestrians, with journeys on foot reaching 32.48% at present for internal and connecting journeys as a whole.

Journeys by bicycle are increasing. The number of stages increased by 6.29% last year, with a total of 145.022, of which 134.772 were internal. In 2015, 4 km of cycle lanes were built, the current figure now totaling 120 km, representing 0.06m/per capita. Regarding the use of bicycles as public transport or "Bicing", in 2015 the number of bicycles in service remained stable and the number of users has decreased to 12.5 million travelers per year.

Mobility via public transport remains quite stable. Compared with 2012, the number of public transport ticket validations has increased 3.84%. This growth is linked to the mobility rise along with the improvement of the public transport network.

98.9% of the population lives 300 meters from some form of public transport (Table 30)

Services	1999	2004	2008	2012
Natural areas at 300 metres	99.4	99.5	99.4	99.3
Urban transport at 300 metres	98.7	98.7	99.9	98.9
Recycling points at 300 metres	99.9	99.2	99.2	58.4
Educational centres at 300 metres	62.7	68.5	67.3	89.3
Educational centres at 300 metres	28.8	28.1	34.2	32.5

In general terms, Barcelona is a city where different services are close to people

Mobility via private vehicle is quite stable. The number of journeys by private vehicle went from 2,088,348 in 2011 to 2,060,640 in 2015. But it is important to highlight the growth of the last year after a period of decline in private traffic. The number of vehicles shows a similar behavior, showing a growth in 2014 and 2015 after years of decline. The car occupation rate continues to be very low (1.27 people/ car).

In 2015 there were 442 km of "30 zones" in the city, where the speed limit is 30 km/h, calming the traffic and reducing accidents.

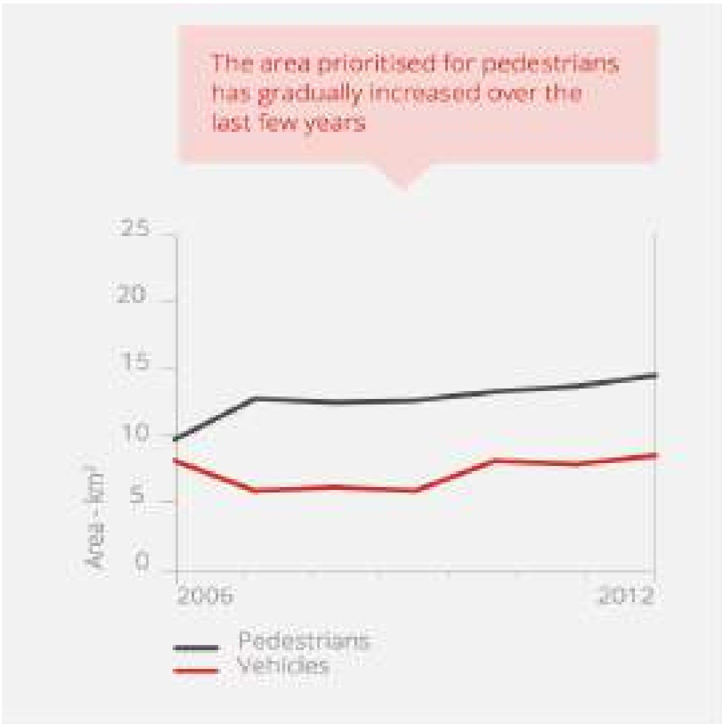


Figure 93: Area prioritized for pedestrians and vehicles in Barcelona.

City vision for the future

Barcelona wants to become a city where mobility is more sustainable and where the quality of life is improved in the districts, democratizing the use of public space and promoting more sustainable forms of movement. It also aims to internalize the environmental costs of its mobility, tackling the impacts generated.

Challenges and opportunities

Barcelona's mobility is partly affected by the city's geographical location as this has considerable physical limits as well as a distinctly central position, making it a hub and driving force for Catalonia, attracting a large amount of activity and consequently a lot of journeys to and from the city.

It is surrounded by hills, rivers and the sea. For this reason there are only four access corridors (along the Llobregat and Besòs rivers and towards the north and south). These corridors are full of infrastructures and their narrowness makes it difficult to construct new ones.

It's the central point for a large metropolitan area. It's the center of a complex territorial structure that is highly dense and made up of a series of medium-sized towns. Over the years, activity (especially industrial) has moved to these towns, leading to fast growth in mobility requirements between Barcelona and its surrounding area.

A lot of journeys pass through the city. Barcelona's strategic location in the middle of the Mediterranean corridor and with one of the Mediterranean's most important ports, as well as it being an important economic centre for Catalonia, means that a large amount of traffic pass through the city.

Large thoroughfares divide the city. The presence of large capacity road infrastructures in the city centre such as the Meridiana and Gran Via does not only have direct environmental impact (pollution, noise) but also physically splits the city.

Barcelona is a dense, compact, complex city. These features mean that there are relatively short distances between locations which, together with the city's mixture of uses and services, encourages walking.

It's one of the world's most popular tourist cities. Most tourists travel by public transport and their needs must therefore be included in the city's mobility planning.

The bus network is very complex. Inherited from the 1950s, its aim was to connect the historical center with the city's different districts. As a result, the current network is not isotropic, making it difficult to fit with the city's transformation in urban planning terms. . In the last years there is a transformation, modifying the bus line's path to an orthogonal network, covering same areas with less busses, increasing the commercial velocity.

Barcelona's hilly terrain affects mobility. A large part of the city is on a slope, making walking and cycling more difficult, as well as access by public transport (that's why district buses have been introduced in many areas of Barcelona).

Enhancing the use of bicycle. Since the "Bicing" bicycle sharing service was introduced and the cycle lanes were widened, cycling has become more popular. Expanding the use of bicycles and including them in the electric mobility plan has become a core policy in the city's mobility plan.

Mobility simulation model

The model consists of a graph representing the road network (which includes basic fields of each road section for the simulation: traffic direction, number of lanes, speed, etc.) and a traffic matrix (representing vehicle journeys between different points of origin and destination within the area of influence of the city).

The graph is maintained by collecting any changes on the road network information from planning committees and inventories. The travel matrix traffic is obtained by exploiting the EMEF (working day mobility surveys) and by calibrating it with available information on traffic gauging. The process of load assignment allows to obtain intensities of movement in each section of the road. Calibration is the process of adjustment of the matrix origin-destination obtained though the surveys with respect to the intensity of traffic scenario of reference; it is based on an iterative process of allocation and readjustment of the matrix by applying algorithms to adjust travels between each zone of origin and destination, until we obtain an adequate degree of correlation between the results of the traffic allocation and gauging incorporated into the simulation model.

Currently, the model is used to obtain different data regarding mobility in private vehicles, both at a very local level (average daily traffic -IMD-, l speed and level of saturation by section) as well as at a district or city level (veh·km, veh·h, % de veh·km circulating in congestion).

These data are also necessary for the calculation of noise maps or emissions of pollutants. At the same time, it is also used for traffic simulation to validate urban transformation processes affecting the city's basic mobility network.

The Directorate of Mobility Services is working to integrate other modes of transport (public transport and cycling) in this graph, as well as other information related to mobility, such as accidents, in order to have a more complete vision of the journeys made in Barcelona.

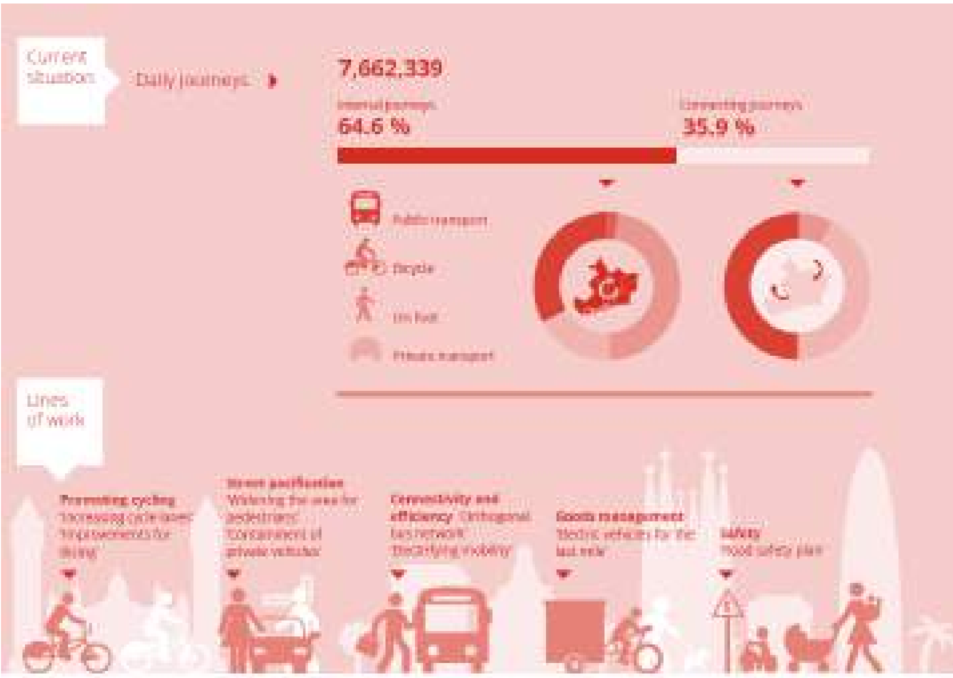


Figure 94: Main transport indicators of Barcelona.

Main climatic effects and natural hazards affecting the service and the critical infrastructures

The main climate variables that can affect the infrastructures and continuity of service of the city mobility system are rainfall, sea water level, tides and wind. Depending on the type of component and climate event, the failures can result in interruption of public and private transportation systems. Rises in temperature can also be a determinant factor regarding mobility patterns and have an impact in the modal distribution, for instance in heat season, resulting in a major use of acclimatized modes of transport, whereas milder temperatures in winter could have the opposite effect.

Exposure and vulnerability of the elements integrating the mobility system varies depending on their location and other factors. Regarding interdependencies and cascading failures, some elements of the transport system are highly dependent on energy supply. Flooding, affections in the sewage and water supply systems, as well as physical collapse of other underground infrastructures can also potentially affect mobility infrastructures located in the underground, and thus result in the interruption or loss of quality loss in the related services.

4.6 Telecommunication

Since its inception, Telefónica has needed buildings to locate its own equipment for the development of the telecommunications services it provides. These buildings were named "Central Stations" and they are commonly referred to as "Central Stations".

Where the Telephone Service was installed, it was necessary to open a new "Central", which connected all the Clients within a radius of coverage of approximately 5 kilometers. This distance limitation was determined by the physical characteristics of the copper used as carrier of the communications.

With the new century, other elements such as muxfines, EARs, etc. appeared in the network. These new elements were housed in outdoor enclosures, RITIs and underground enclosures. They helped to extend the distance between the Clients and the "Central" in a few kilometers.

As a consequence of this access network, Telefónica currently supports some 6,500 buildings and 10,800 other locations, including fuse boxs, premises, underground enclosures, etc. By means of that, Telefonica provides its "Fixed" network services.

The technological evolution of the access networks and the networks of Nucleus, Platforms and Systems will change these requirements of points of presence. In the coming years there will be a concentration of Customers and Services, which will cause some of the 6,500 existing buildings to be abandoned and others to have a greater importance than they currently have.

In the case of the city of Barcelona, Telefonica has attended all PBXs (30 in total) under the generic criteria for protection against power failure in buildings, which house telecom equipment based on their criticality.

The “Centrals”, in order to guarantee the corresponding Availability, have uninterrupted power, thanks to:

- Main Power Supply with two independent power companies.
- Secondary Electric Power Supply or Emergency. Designed to provide electric power to one or more systems, equipment or facilities of a building, before the failure of the power supply common.

  Whatever the power supply is, it must be able to operate the systems, equipment or facilities it serves with a minimum autonomy as required by the most demanding of systems, equipment or facilities that feeds them.

  This secondary electric power supply must fulfil the following conditions:

  - Power Supplies. They must be independent of the usual supply and come from one or several sources:
    - Another company than the usual supply company or the same company if the lines, being independent, come from different substation or processing center;
    - A generator set, with redundant fuel replacement.
    - A battery system of accumulators.
  - Switchboards and protections. They must be independent of those of habitual supply, constituting a fire risk area with respect to these for a time of at least sixty minutes.
  - Distribution lines. They must be protected against the action of the fire during the time that, in each case, is specified in the current regulation.

Fire protection facilities, explosive atmospheres and other catastrophic risks comply with international directives and national, regional and municipal legislation. Likewise, it complies with the areas not included in said legislation, and contributes the experience of Telefónica in this matter.

Telefonica internal standard is more restrictive than national legislation.

The IP Network of Telefonica is structured in 3 levels: Access (Residential and large customers), Transit and Interconnection, as shown below:

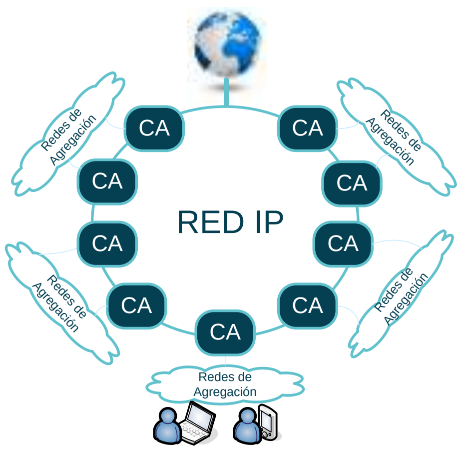


Figure 95: Access centers of Telefónica.

The IP network offers an availability of 99.99%. That is only on general because it depends on each level of the network (Large Customers or Residential Access, Interconnection and Transit) and on every telecommunications service.

Also, all network backbones consist of rings, with the corresponding mechanisms for cuts.

In summary:

The capacity and security of these infrastructures are, therefore, of the maximum criticality for Telefónica and they have been projected with the availability as fundamental criterion of design. They have the maximum measures of protection, diversification and redundancy applied to both the equipment, the links and the buildings that house them.

Backbone Network of FO and Transport of Catalonia

Telefónica has the network of optical carriers with the greatest extension and capillarity of all of Catalonia. The overlapping of the infrastructure of the network (inter centrals) carriers and optical loops of customers allow it to cover, with own means, practically all the municipalities of the territory.

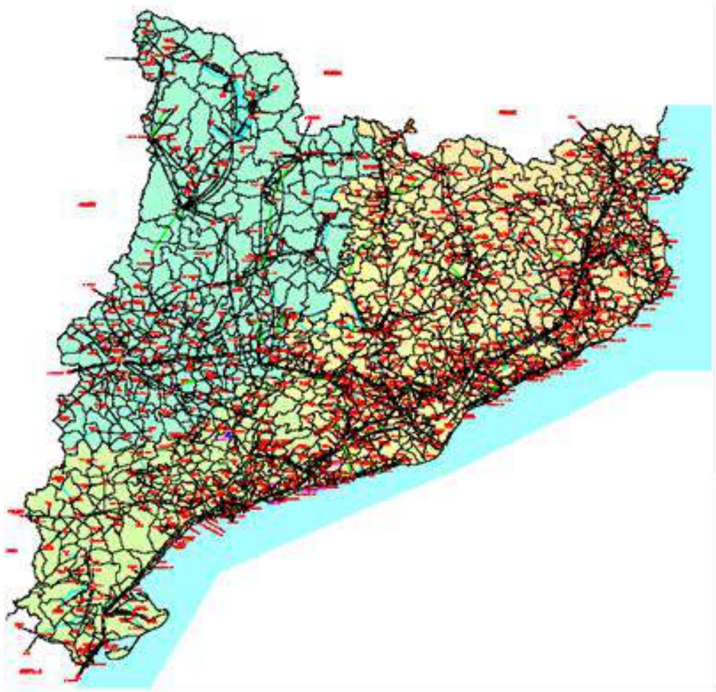


Figure 96: Teléfonica Network FO de Catalunya

Mathematical models implemented

Currently, there are no specific mathematical models to simulate the Resilience of telecommunications infrastructures, this does not imply that they may exist in the future.

On the web http://www.telefonica.es/calidad you can be found all Quality Certificates Telefónica Group, namely:

Certificates of the Quality Management System:
Https://www.telefonica.es/es/acerca_de_telefonica/calidad/certificados

About Quality of Service:
Https://www.telefonica.es/es/acerca_de_telefonica/calidad/niveles-de-calidad-de service / sobre-la-calidad-del-servicio

Main climatic effects and natural hazards affecting the service and the critical infrastructures

In Barcelona, infrastructures can be affected by extreme weather events such as heavy rains and heat waves.

In the first case, heavy rains, there are two types of possible conditions. The first one is of a physical type due to infiltration problems, i.e. direct damage to posts, fuses boxes and cabinets which support the networks. In addition, the phenomenon of high intensity rainfall affects telecommunications because it acts as a curtain between the transmitter and the receiver. When a signal travels through a rain zone, an attenuation effect will occur. This occurs because the energy absorption of the electromagnetic waves by the water droplets. According to experiments, the communication begins to be impacted by intense rains from 10 GHz onwards.

With regard to the effects of heat waves, water and oxygen no condensate vapors have absorption lines in the microwave and millimetric waveband. In the case of water vapor, strong absorption lines are produced for wavelengths of 1.35 cm, 1.67 mm and below, and for oxygen the wavelengths of the absorption peaks are 0.5 and 0.25 cm. This attenuation, additive, as a joint effect of the water and oxygen vapors, is additive. Communications are affected when attenuation levels exceed 10 dB / km.

4.7 Waste

In the last five years the waste collected in the city has dropped by 16% to 730,285 tonnes in 2013. At the same time the rate of waste generation per person has also fallen, reaching 1.23 kg/person/day.

The actions carried out since November 2012 reveal the potential of waste reduction provided by the measures contained in the Waste Prevention Plan for Barcelona 2012-2020. The generation of waste in the second half of 2013 indicated a change in trend and incipient stabilisation to some degree.

In 2013 the amount of waste avoided thanks to the implementation of the measures described in the Waste Prevention Plan was 1,846,209 kg. These data provide some initial measurements regarding the viability of the different measures and the sectorial and global potential in the medium and long term.

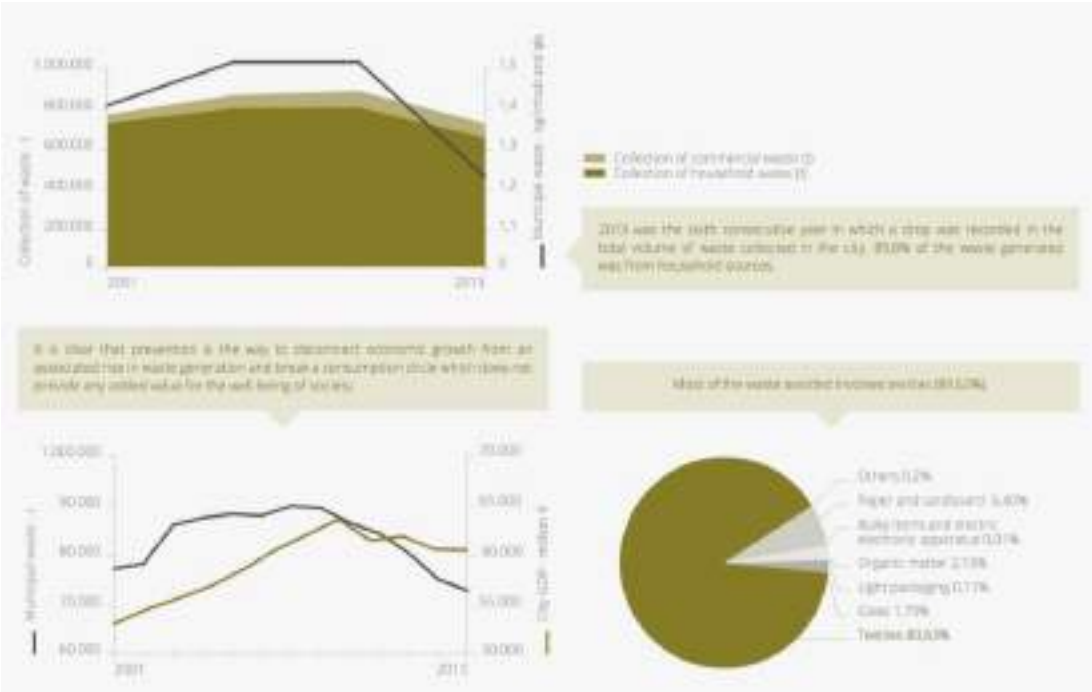


Figure 97: Barcelona Collection waste indicators

Different types of waste collection for greater effectiveness and efficiency

In view of Barcelona's diverse uses and urban structure, different types of collection are implemented with the aim of ensuring an effective and efficient collection of municipal waste, promoting selective collection and furthering reintroduction into the production and consumer cycle for all those resources whose useful life is not yet over.

Household. This is the waste originating from the city's housing and from shops and services that don't have any specific commercial collection. This is mainly done by means of community bins, where citizens can separate waste by fraction (organic material, glass, packaging, paper-cardboard and residual waste). Apart from promoting the selective collection of recoverable waste, this system also reduces the volume and diversity of waste coming into the processing installations. The collection is handled by several companies contracted by the City Council, each of which is responsible for one of the zones into which the city is divided, in line with technical and efficient management criteria.

Commercial. This is the waste generated by shops with a specific collection system, such as big stores, economic activity centres and industries with waste that can be assimilated in this category. The system involves the separate collection of fractions of organic material, packaging, glass, paper-cardboard and residual waste. The owners of businesses generating waste can opt for the municipal waste system which is assigned to them by quantity and/or zone or manage this by means of a carrier authorised by Catalan Waste Agency, with documents to certify the management system.

Markets. This is the waste generated by the 40 municipal food markets and the different markets and street markets, except for Mercabarna, Barcelona's wholesale market. Organic material, paper-cardboard and residual waste are separated for collection.

Collection of bulky items (furniture and junk). There is a free collection system in which each street has a set day assigned to it and another system where residents can pay for items to be collected from their home within 36 hours.

Other collections. Collection of organic material, apart from residual waste, in the parks and gardens of Barcelona City Council. At Mercabarna, the collection of residual waste, organic material and paper-cardboard; also dead animals, which is mainly done by social organisations.

Apart from these types of refuse collection, the Council provides different services for citizens which enable all the waste that should not be included in the residual waste fraction to be separated:

Green points. These facilitate the collection and provisional storage of waste that will not t in the selective containers to be taken later to the processing plants. The city has 7 zone green points, 23 district green points, 96 stops for the mobile green point and 2 mobile green points which can be requested by schools and institutions, as well as by civic bodies or associations.

Collection of clothing. The City Council and the Training and Work Foundation have signed an agreement to implement a new service for the door- to-door collection of used clothing in 2012. This service allows citizens to ask to have used clothing collected from their homes – minimum 2 bags, free of charge, by calling one of the citizen service phone lines.

Over the last few years Barcelona has introduced improvements into municipal processes and services for collection and management as regards changing habits and patterns of behaviour of citizens and of different social and economic agents with regard to the selective collection and recovery of resources which have not ended their life cycle. Particularly of note is the introduction of the selective collection of organic material. The active involvement of citizens in selective collection is largely the result of the communication campaigns carried out, creating a favourable social context, and the cooperation with hundreds of organisations, organisations, companies and institutions connected with waste generation in the city.

Consolidation of waste collection habits

The people of Barcelona have consolidated their recycling habits. In absolute terms, 264,044 tonnes were collected in 2013, 5.6% less than in 2012. This reduction is explained by the decrease in the total generation of waste in the city. In 2013 selective collection also dropped 3.3 per cent as compared with the total amount of waste in comparison with 2010, the year in which it reached its peak (39.5%) coinciding with the time when organic material started to be collected from the city as a whole and the number of green points was extended.

In spite of this the percentage for 2013 was still almost 4 points higher than in 2009. The reduction in the percentage of selective collection for 2013 can be largely explained by the decrease in the amount of paper and cardboard collected, partly caused by thefts from bins and partly by the economic crisis.

The relative increase of glass and packaging fractions and the increase in the use of green points also indicate that the people of Barcelona have consolidated their waste separation habits.

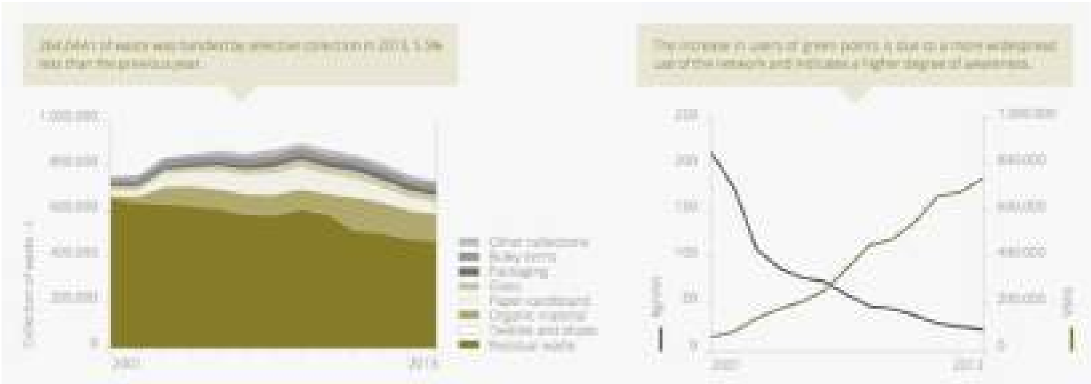


Figure 98: Barcelona waste collection. Collection of packaging waste and users of green points

The collection of packaging waste remained stable in 2013. The relative increase in the collection of glass indicates that citizens are increasingly aware of this.

In 2010 there was a considerable increase in the tonnes of organic material collected compared with previous years. Since then the collection of this fraction has remained stable in relative terms. Inappropriate waste – refuse thrown out by mistake amongst the organic part as well as nappies, which should go into general waste, has remained at around 20% since 2010.

The number of citizen visits to Barcelona's network of green points increases year by year and this has become consolidated as a reference facility. In 2013 these green points were visited by 741,086 users, the highest figure of the last few years. The rise in green point visits indicates the increasing awareness of citizens.

Treatments for each kind of waste

The generation of waste entails a number of environmental impacts at differing scales (local, regional or global) related to its collection, transport and processing such as energy consumption, emissions into the atmosphere and the contamination of water and soil. Other impacts such as noise, smell, occupation of public space or the landscape or visual impact may also affect the quality of life. Reducing this is therefore the main way to prevent such an impact, as well as optimising the transport routes for its collection and ensuring this is given the best treatment in line with the hierarchy laid down by current legislation:

Organic material, both coming from speci c generators (e.g. Mercabarna) and from selective collection, can be treated by either composting or anaerobic digestion.

Packaging is separated at sorting plants and, as part of the Comprehensive System for Waste Management of light packaging, the sorted material is taken to authorised recovery organisations.

Paper-cardboard from shops is collected separately via a special system and assigned to authorised recovery organisations. In 2008 Barcelona City Council was given "Tu Papel 21" certification from ASPAPEL (Spanish Association of Manufacturers of Pulp, Paper and Cardboard) for its good management of the selective collection of paper and cardboard.

Glass is taken to authorised recovery organisations.

Bulky items from municipal collection or dumps (small amounts) are taken to the bulk waste sorting plant in Gavà-Viladecans.

Residual waste: in accordance with the PMGRM, which aims to process such waste before using it for energy recovery or disposing of it, this is sent to mechanical-biological processing plants (Ecoparks) where an attempt is made to reclaim and recover the maximum possible amount of materials before carrying out its final processing.

The residue from this processing cannot be recovered any further and can only be used to produce energy or disposed of via controlled methods.

The different treatments given to waste are therefore:

Material recovery: this includes the recycling of glass, paper and cardboard, light packaging items, bulky items, waste from green points and other specific collection systems; the composting of organic waste from parks and gardens and the organic fractions selectively collected. It also includes organic waste sent for mechanical-biological treatment.

Mechanical-biological treatment: treatment of the residual waste fraction, where recyclable materials are separated (the resulting residue is later used to produce energy).

Energy recovery: waste sent directly to produce energy.

Controlled dumping: waste that is sent directly to a controlled dump.

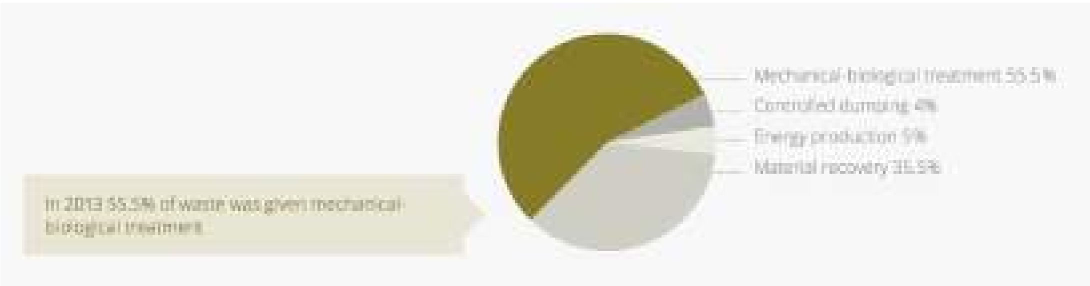


Figure 99: Barcelona waste collection. Waste Treatments

City vision for the future

Barcelona wants to become a city that takes advantage of 100% of the waste generated. Beyond preventing waste generation, Barcelona wants to build a model of consumption and development with the lowest possible ecological footprint and to move towards a circular economy. The milestone is to prevent waste as far as possible and for any refuse generated to be turned into quality raw material. This can only be done by ensuring the co-responsibility of citizens and social and economic agents as a whole. We therefore need to continue explaining the global and local benefits of good waste management.

Challenges and opportunities

Prevention of waste is a necessity, an opportunity and a priority: a necessity because we cannot keep up waste management with such high long-term costs and an opportunity because consumption habits have changed over the last few years and the selective collection of waste has become more fully established; also a priority because prevention is the way to disconnect growth in the economy from rising waste generation.

The main challenges and opportunities that have to be tackled are:

The compact urban structure makes it easier to manage waste by reducing distances between people and collection points, making it unnecessary to take waste very far. The diversity of urban areas nevertheless requires an adaptation of collection systems to offer a service available to everyone and consistent with the setting in which this is found.

The number of inhabitants and their diversity is an aspect directly affecting the quantity of waste generated and the quality of the waste collected. The city now has over 1.6 million inhabitants as well as a considerable number of tourists. Their seasonal presence and lack of knowledge as to how the city works makes waste management harder. The city's foreign residents also have lower levels of environmental awareness.

There are general limitations which make it hard to influence citizens' consumption habits such as market limitations in options for sorting products or the fact that certain products have a limited lifetime. Over-packaging and the disappearance of products sold in a loose format are also significant factors.

There are limitations connected with management instruments, such as regulatory development and planning which favour local and super-municipal endeavours that are still in their early stages or the lack of prevention consolidation in certain areas of management.

Ensuring optimised selective waste collection that functions correctly enables its impact on city people to be minimised and reduces noise pollution and the emission of local contaminants.

Obtaining quality materials in waste recovery processes, such as urban mining, is of key importance in finding a market for them, thus contributing to the circular economy. In spite of this the present economic situation encourages the breaking of material circuits (theft of copper, metal, etc.), making it necessary to create parallel circuits in order to integrate them.

The incorporation of smart and innovative technologies helps to improve the operation of the waste management model, making this more efficient and sustainable.

Figure 100: Main waste indicators of Barcelona.

Main climatic effects and natural hazards affecting the service and the critical infrastructures

The main climate variables that can affect the infrastructures and continuity of service of the waste management system are rainfall, sea water level, tides and wind. Depending on the type of component and climate event, the failures can result in interruption of waste management collection and treatment. Strong wind episodes can result in an increase of demand of the service too.

Exposure and vulnerability of the elements integrating the solid waste system varies depending on their location and other factors. Regarding interdependencies and cascading failures, some of its elements are highly dependent on energy supply. Flooding and affections in the drainage system, can also potentially result in the interruption or quality loss in the services related to waste management.

4.8 Green Infrastructures

Current situation and general context

Nature is present throughout the city but often in isolated areas, without continuity. Urban green spaces provide ecological values that are essential for the city such as nature, biodiversity, complexity and connectivity and socio-cultural values, such as health, well-being, beauty, countryside, culture and helping social relations.

One of the city's priorities is and has been to develop these environmental and social services for green spaces, protect existing free spaces and extend and connect them whenever possible.

Barcelona has been working to protect free areas and biodiversity for many years now. Some of the key milestones are as follows:

Barcelona's Agenda 21. In 2001 the Citizen Commitment to Sustainability was passed, renewed in 2012, dedicating 10 lines of action to protect and improve green spaces and biodiversity.

New OMA (2011). Approval of the new OMA (General Ordinance of the Urban Green of Barcelona), whose Title 7, on green spaces and biodiversity, governs the implementation, maintenance, use and enjoyment of green spaces and biodiversity, as well as their different components.

Participation in the Local Action for Biodiversity project. This project by cities involves: assessment of urban biodiversity, institutional commitment, preparation of a 10-year biodiversity plan and implementation of 5 actions in the city. As part of this project, Barcelona signed the Durban Commitment. One of Barcelona's good practices to encourage biodiversity on a global scale is to apply criteria of sustainability to its purchases of wood.

Approval of the Green Infrastructure and Biodiversity Plan. This plan, approved in January 2013, is the strategic instrument that defines the municipal government's challenges, goals and commitments regarding the conservation of nature and biological diversity, encouraging the population to get to know its natural assets, enjoy them and look after them.

The Green Infrastructure and Biodiversity Plan contains 68 actions grouped into 10 strategic lines to achieve the following goals:

- Conserve and improve the city's natural assets, preventing the loss of species and habitats.
- Achieve the largest area possible of green spaces and their maximum interconnection.
- Obtain as many environmental and social services as possible related to nature and biodiversity.
- Increase society's appreciation of nature and biodiversity.
- Make the city more resilient to emerging challenges, such as climate change.

The amount of green area is increasing

Barcelona has remarkable natural assets thanks to the size of the Collserola range of hills, covering more than 8,000 hectares in total. Collserola Park is a wooded park that forms part of 9 municipalities; 22.5% of its area is within the municipality of Barcelona. It's the largest and most diverse wooded area in the city and the only one benefitting from specific protective measures. The park has a mosaic of habitats providing a considerable range of species. It should be noted that the EU's 1992 Habitats Directive designates three of these (Quercus ilex forests, pine forests and dry grasslands) as habitats to be conserved.

From Barcelona's ecological map (in an analysis of trends since 1977), it can be concluded that forests and urban green zones have increased and that crops now have a nominal presence.

Rivers and the sea complete what can be considered as Barcelona's natural environment, most of which has been modified in some way.

Also of note are the 4.5 km of Barcelona's beaches, a result of the process to recover the coastal environment started in 1980, from the most westerly beach of Sant Sebastià to the beach of Llevant, created in 2006.

Regarding the extent of these areas, Barcelona has 3,615 hectares of green accounting for 35.3% of the municipality's area (2013 data). Of these hectares, 1,102 are strictly urban green (made up of parks and gardens), 1,698 correspond to the municipality within the Collserola Nature Park and it's estimated that 740 are private green spaces, located mostly in the higher part of the city. Looking only at public green spaces, this area is equivalent to 18.05 m2 green space/inhabitant (6.84 m2 in the urban section, without counting Collserola). The overall amount of green space is therefore quite good but only 30% is strictly public and urban. 20% of the remaining hectares correspond to private green spaces (acting as a lung for the city and providing environmental benefits but without the public being able to use them) and the remaining 50% is the wooded green area of the municipality of Barcelona that lies within Collserola.

The area per inhabitant is tending to stabilise although it increased slightly in 2013. Nevertheless, the distribution of public green zones in the city's different districts is quite uneven. Public green is concentrated mainly in the districts of Sants-Montjuïc, Sant Martí and Horta- Guinardó. If we include Collserola, then Sarrià-Sant Gervasi is the district with the largest public green area.

Apart from Collserola, Montjuïc is the city's other wooded park. With 450 hectares it's the space in the city with the greatest biodiversity. It includes 16 parks with a considerable presence of flora and fauna and Montjuïc cliff has been included in the Catalan government's Inventory of geological spaces. There are more than 60 species of vertebrates as well as a considerable assortment of ornamental plants from different bio-geographical regions. The parks of Tres Turons and Ciutadella are also particularly important thanks to their size, with very different characteristics.

In spite of the size of the two large wooded parks, the city's predominant urban green space is modest in size (between 1 and 5 hectares) and tends to be located in the middle of the urban development, within reach of citizens. 57% of the green spaces measure less than 1,500 m2 and, in general, are not very interconnected.

The trees lining the streets are also important, totalling around 161,000 units with 150 different species and cultivars. There are still 54 areas of natural interest within the city that have been inventoried but do not benefit from any protection, although there are some conservation measures.

Within the urban part of the city there are other types of urban green in addition to parks and gardens that provide a range of biodiversity: squares, allotments, flower beds, ornamental pools and ponds, walls and roofs, etc. These form a network of spaces of varying sizes. 115 green or living roofs have been counted in the city, totalling 4.3 hectares.

Figure 101: Barcelona Green Infrastructures

City vision for the future

Barcelona sees the city of the future as a city where nature and urban life interact and develop; its goals are therefore:

- Establish an ecological infrastructure that provides environmental and social services and that reconnects the city and the territory.
- Appreciate, preserve and strengthen the city's biodiversity and prevent the loss of species and habitats as a natural asset of the Earth and as a benefit for present and future generations.
- Take advantage of all opportunities to provide a place for nature and encourage people's contact with natural elements.

Challenges and opportunities

The compact nature and complexity of the city of Barcelona impose some limitations on urban green and biodiversity but also provide diversity. The main conditioning factors that should be considered are:

- Barcelona is a compact city, geographically limited between the sea, hills and rivers and also densely populated. One of the most densely populated cities in Europe, Barcelona has little land available to develop new green spaces.
- It comprises a wide range of environments and ecosystems. The two estuaries, with their deltas; the coastline with sandy beaches, the hill of Montjuïc; the Collserola range of hills inland and the plain, which is the area most occupied by the urban fabric mean that the city has a particularly varied range of habitats.
- It's a hot city with little, irregular rainfall. The months of June and July are critical, with minimum rain and maximum temperature. In general the lack of rain and its irregular distribution throughout the year limit the vegetation's ability to retain water, being further amplified in the urban green by the land's inability to absorb water. This situation is likely to get worse due to climate change.
- Some fauna and flora could be invasive. This has created problems for public and natural spaces on the outskirts of the city and could lead to indigenous species being displaced.
- Green planning is relatively recent. Until 1976 the city of Barcelona did not have an urban development plan including provisions for green spaces. On the other hand, the Collserola Special Plan dates from 1987.
- Barcelona, sensitive towards urban green and biodiversity. Barcelona has been working to protect urban green areas. Biodiversity has been included in municipal policy commitments and both human and financial resources are allocated to it, working in coordination with other institutions and bodies, both local and international.

Figure 102: Barcelona Green Infrastructures overview

Main climatic effects and natural hazards affecting the green infrastructures
Green infrastructure and the environmental services it provides are very directly affected by meteorological, climatological and hydrological hazards. It is highly exposed to extreme hot weather and heat waves, drought, forest fire, flooding (flash/surface, river, coastal and storm surges) and salt water intrusion. At a lower degree it is also exposed to severe wind.

4.9 Barcelona matrix of exposure and direct impacts among extreme climate variables and failure in urban services

The information collected in the section of this deliverable is used to create specific tables for each research site to relate climate variables and direct and indirect impacts of main urban services analysed in RESCCUE according to their level of exposure. These tables could be used in the WP4 for the elaboration of the interdependency matrix of each research site

In previous sections, urban services have been described according to the potential interdependencies among urban services failures, regarding cascade effects and the consequences involved in each failure. Summarising these descriptions, the Table 31 presents a synthesis of the main correlations among climate variables (temperature, rain and wind) likely hazard (heat wave, sea level rise, flooding, drought, CSO's, windstorm) and urban services.

The urban services are broken out in subsystems and critical elements. For each one of this critical element, it has been signed when the element is exposed or not to each hazard or even when the hazard has not been considered. Moreover, a qualitative assessment of the severity of the hazard (high or low) has been added.

URBAN SERVICES	URBAN SERVICE CYCLE	SUBSYSTEMS	CRITICAL ELEMENTS	Precipitation	Wind	Extreme temperature Hot	Extreme temperature Hot	Water scarcity	Wild fire	Flood	Flood	Flood	Wave action	Chemical change	COMMENTS ABOUT POTENCIAL DERIVED RISCS / CASCADE FAILURES
			HAZARD	Rain Storm	Severe wind	Heat wave	Extreme hot weather	Drought	Forest fire	Flash Surface flood	River flood	Coastal flood	Storm surge	Salt water intrusion	
			SEVERITY (HAZARD)	High	Low	High	Low	High	High	High	High	High	High	High	
Energy	Electricity	Power generation	Large power plants	✓	✓	✓	✓	✓	✗	✓	✗	✗	✗	✓	Energy system is highly exposed to rain storm, flooding (flash/surface, river, coastal and storm surges) and wildfire. At a lower degree it is also exposed to severe wind. Enery is the most critical service because of the dependencies it generates on the rest of the urban services. A disruption in energy supply can potentially affect telecommunication, urban water cycle, waste collection and treatment and transportation systems.
			Distributed power plants	✓	✓	✓	✓	✓	✗	✓	✗	✗	✗	✓	
		Power Transmission	High-Voltage overhead lines	✗	✗	✓	✓	✓	✗	✓	✗	✗	✗	✓	
			High-Voltage burried cables	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
			Conventional Electric Substations	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	
			Underground Power substations	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
			Compact substations	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	
			Gas Isulated substations	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	
		Power Distribution	Substations	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	
			Medium Voltage overhead grid	✗	✗	✓	✓	✓	✗	✓	✗	✗	✗	✓	
			Medium Voltage buried grid	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
			Transformation Centers	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	
Telecommunic		Network	Antennas	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	Telecommunication system is highly exposed to rain storm, flooding (flash/surface, river, coastal and storm surges) and wildfire. At a lower degree it is also exposed to severe wind. There's a dependency in teleccomunication systems in the opertation of most services, however, critical operations, such as those direclty related with security and emmergency planning and management have a secured communication system through RESCAT network)
			Telecommunication network fibre	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
			Telecommunication network aerial copper	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	
			Telecommunication network underground copper	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
		Nodes	Operation centres	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	
			Collserola tower	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	
Urban Water C	Water Supply	Water abstraction	Catchment wells	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓	✗	Urban water cycle system is highly exposed to rain storm, droughts, flooding (flash/surface, river, coastal and storm surges), salt water intrusion and forest fire. At a lower degree it is also exposed to severe wind. Potentially affected to misfunctioning of the drainage system are those elements exposed to rain storm flooding, that is energy, telecommunications, solid waste (collection, treatment and cleaning), and transport systems. There is a very direct relation of the green infrastructure services with the water system cycle, since it is highly vulnerable to water scarcity, it and can potentially be affected by flooding as well.
		Water treatment and storage	Drinking water treatment plants	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓	✓	
			desalination plant	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓	✗	
			Drinking water network	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
			ATLL water storage tanks	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	
			ATLL secondary water storage tanks	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	
		Water Distribution	Drinking water network	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
			Goundwater network	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
	Urban Drainage	On source	SUDS	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
		Sewers system	Sewer network	✗	✗	✓	✓	✓	✓	✗	✗	✗	✓	✓	
			Pumping stations	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	
			Interceptors	✗	✗	✓	✓	✓	✓	✗	✗	✗	✓	✓	
			Storage tanks	✗	✗	✓	✓	✓	✓	✗	✗	✗	✓	✓	
			Gates	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	
			Weirs	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	
	Waste Water Treatment		WWTP	✗	✗	✓	✓	✓	✗	✗	✗	✗	✓	✓	
			Saline intrusion barrier (network)	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✗	
			Saline intrusion barrier (wells)	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓	✗	
			EDAR El Prat reclaimed water network	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
			Submarine emissaries	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Waste	Solid waste	Solid Urban Waste Collection (SUW)		✗	✗	✓	✓	✓	✗	✗	✗	✗	✓	✓	Solid waste collection, treatment and cleaning system is highly exposed to rain storm, flooding (flash/surface, river, coastal and storm surges) and wildfire. At a lower degree it is also exposed to severe wind. Misfunctioning or disruption of the service directly affects public space and can have grave implications regarding the image of the city, that could have negative consequences in its economic activity, and potentially result in public health issues. Surface elements of the mobility and water drainage infrastructures could be altered by the obstruction of solid waste.
		SUW Treatment	Treatment plants	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	
			Cleaning centers/vehicle storage	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	
			pneumàtic waste collection plants	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	
		Cleaning		✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	
Mobility	Roadways	Roadways	Structuring basic network	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	Mobility system is highly exposed to rain storm, flooding (flash/surface, river, coastal and storm surges) and wildfire. At a lower degree it is also exposed to severe wind. Alterations in the transportation networks affecting mobility flows have a critical inffluence in the city functionality at a global scale. Regarding the systems described in the chart however, waste collection and cleaning services would be the most affected. Most elements in the energy system are either underground or aerial, however, energy supply depending on fuel, requiring trasportation by road, could potentially be affected by misfunctioning or disruptions in the mobility system.
			Secondary network	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	
			Local basic network	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	
	Rail, metro, infraestucture for river and sea transportation	Rail, metro, infraestucture for river and sea transportation	Surface railway network	✗	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	
			Surface railway stations	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓	✓	
			Underground railway network	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
			Underground railway stations	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	
			Underground railway stations (exits)	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	
Green infraestructures				✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	Green infrastructure and the environmental services it provides are very directly affected by meteorological, climatological and hydrological hazards. It is highly exposed to extreme hot weather and heat waves, drought, forest fire, flooding (flash/surface, river, coastal and storm surges) and salt water intrusion. At a lower degree it is also exposed to severe wind. It is a critical service regarding adaptation to the impacts of climate change related withtemperature rise and to fight urban

✗	Exposed
✓	Not Exposed or Not Considered

Table 31: Barcelona matrix of exposure and direct/indirect impacts from climate variables and failure urban services.

5 Research site characterization: Bristol Site

5.1 Main features of the research site

This section is composed by information from the Met Office, British Geological Society, Bristol Water, Wessex Water and UK Governmental Bodies.

Bristol City Council (BCC) is the 10th largest local authority in England. BCC operates as a unitary authority for the region and the city boundary also marks the county boundary. This Local Authority system of governance means that it is managed under a one tier structure and there are no further divided parishes or separate areas of governance. The city council area is divided in to 34 wards represented by 70 councillors.The county borders North Somerset to the South, divided by the River Avon New Cut and Avon Gorge. BCC shares a boundary at the North and North East with South Gloucestershire. BCC is bound by Bath and North East Somerset to the south east. Altogether these councils make up the West of England Partnership. See Figure 103 below indicating the west of England counties.

Figure 103 - Showing the West of England councils and Local Authorities and their boundaries with BCC.

5.1.1 Population and climate

The estimated population of Bristol in 2016 is 449,300 making it the eighth most populous city in the UK. It is one of the most densely populated parts of the UK and after London the second largest city in the southern region. The growth rate of the population is one of the highest in the country. This rapid expansion is noticed in particular around the central area where growth is at its highest. A large student population is usually situated in the central area, including an influx of students from overseas, which contributes towards the growth of the central region. Figure 104 below shows the relative rates of population growth throughout the city over the last decade. The difference in geographical areas, defined by the BCC ward boundaries, is shown in this map projection. This demonstrates the tendency of people concentrating towards the city centre.

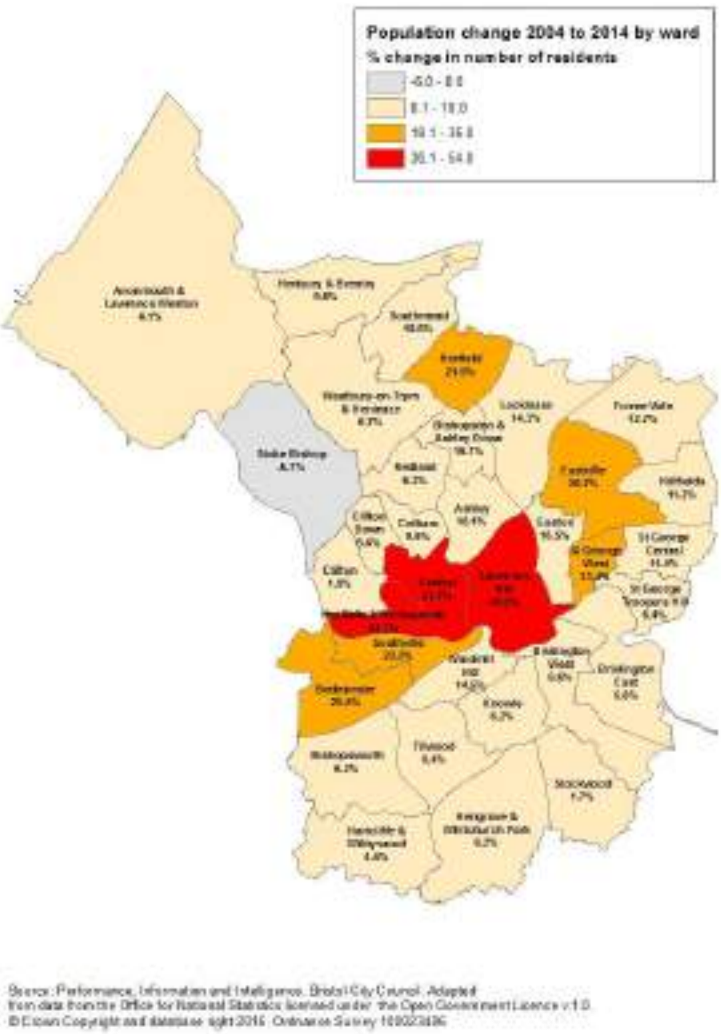


Figure 104 - Showing the high population increase in the Bristol central area over recent years.

The high population expansion in Bristol overall is attributed to net migration and a higher birth than death rate. Despite the unprecedented population growth in recent years from migration the prediction is that migration will decrease over time. It is the significant increase in births and decrease in the number of deaths which will be the main contributing factor to the expanding population. The birth rate becomes enhanced by rising fertility levels, increases in the number of women of child-bearing age and an increase in the number of non-UK born mothers. The decrease in deaths is partly a result of falling mortality rates. With all of this considered Bristol's population by 2027 is expected to reach half a million people.

The population by age in Bristol shows a relatively young age profile with more children under sixteen than people of pensionable age (those over 65 years old). The median age of people living in Bristol in 2015 was 33.1 years old.

Ethnic background is quite diverse in Bristol. The non-'White British' population make up 22% of the total population in Bristol. The Black or Minority Ethnic group (BME) populations (all groups with the exception of all the White groups) make up 16% of the total population in Bristol. Figure 105 shows where the Black and minority ethnic population tend to be located.

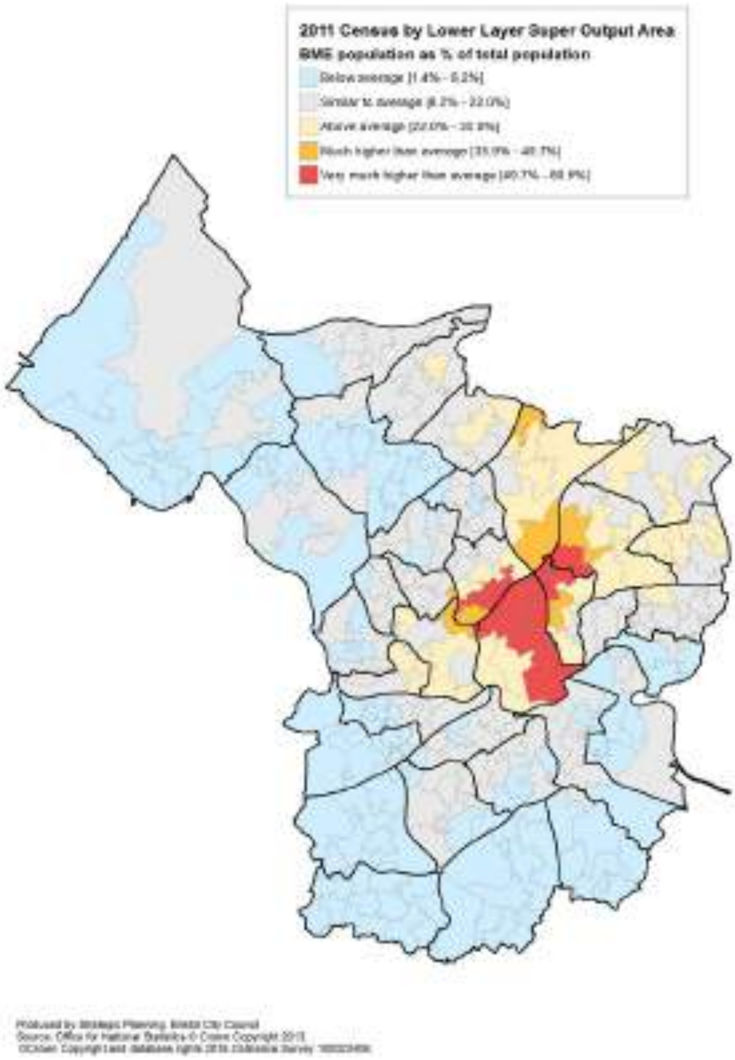


Figure 105 Showing the Black or Minority Ethnic group (BME) populations in Bristol.

There are at least 45 practicing religions registered within the Bristol region. 187 countries of birth are represented and at least 91 main languages are spoken by people living in Bristol. This richness in diversity is also shown to be increasing over time.

As an island nation with temperate maritime climate, the UK is prone to variable weather conditions. These are influenced by weather systems from the North Atlantic Ocean and from mainland Europe. Conditions at sea are particularly influential on the weather experienced in the southwest of England, where Bristol is located (see Figure 106 below). In comparative terms the impacts are not felt as much in Bristol compared to rest of the south-west region, but their effects are still quite apparent. The influence from the Atlantic Ocean generally keeps the average temperature in Bristol maintained above freezing point throughout the year. With this, it also brings rainfall and prevailing south-westerly winds. In the summer seasons the region will sometime benefits from the far extents of the Azores high pressure system, bringing warmer and drier conditions. Hot weather warming the surrounding waters however inevitably brings with it accompanying rainfall at some stage. This is when summertime thunderstorms then arise. This high weather variability within the temperate maritime climatic environment that Bristol is situated means a certain lack of seasonal consistencies. It also produces fluctuations and variation in the weather patterns day to day.

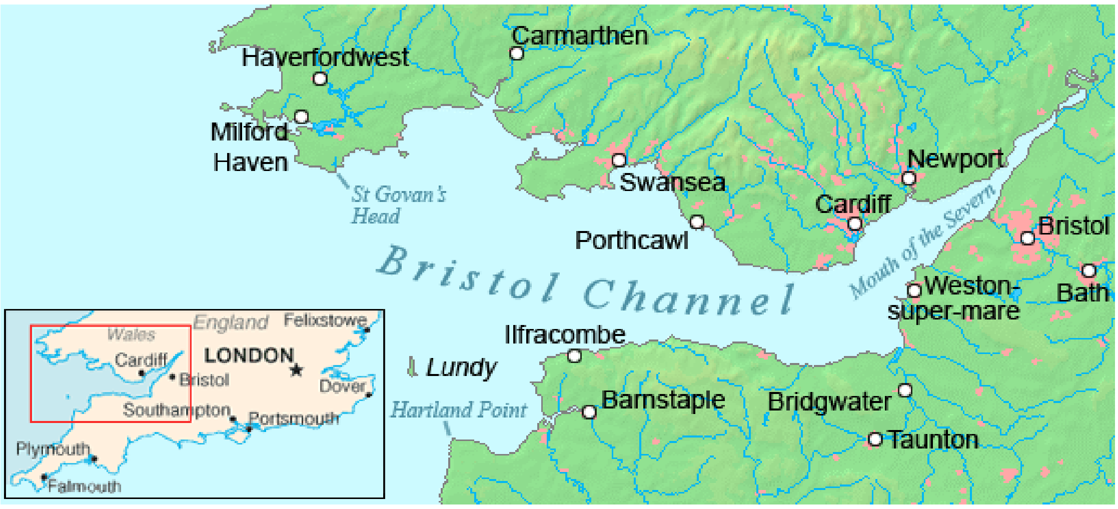


Figure 106 - Showing the location of Bristol in South-west England

(Chris O, (2016), Bristol Channel [ONLINE]. Available at: https://en.wikipedia.org/wiki/Bristol_Channel#/media/File:Bristol_channel_detailed_map.png [Accessed 16 September 2016].)

Mean annual temperatures for Bristol are around 10.5°C, making it one of the warmest cities in the UK. The mean daily maximum temperatures for the Bristol area are between 13.5-15°C, whilst mean daily minimum temperatures are between 6.5-8°C.

According to historic records and trends in climatic data, January is typically the coldest month in Bristol. The mean minimum temperatures reach only 1-2°C. In contrast the warmest months for the region are typically July and August. The daily maximum temperatures during these months reach between 21-22.5°C.

Weather extremes producing conditions beyond the average temperature ranges previously described above are quite rare. Meaning extreme heat waves and extreme cold spells do not occur regularly. High temperatures, if they do occur, will be associated with hot air travelling across from mainland Europe. This is brought in on south easterly winds and often accompanied by strong sunshine. Although this is rare, mini heatwaves do occur every so often.

Bristol is one of the sunniest cities in the UK with on average between 1500-1600 hours of sunlight per year. June is the sunniest month with the longest days and span of sunlight. December in comparison is the darkest month experiencing the least hours of sunlight. The hilly environment in Bristol means convective cloud can often form and result in a reduction in the amount of sunshine exposure. Winter frosts are frequent in Bristol, but snowfall is relatively uncommon. There is however snowfall on occasion during the colder winters encountered (in 2008 and 2009 for example). Annually there is on average less than 10 days of snowfall or sleet falling. If snow does fall it will usually not remain for any substantial time before melting. Statistically it typically lasts less than six days on average before it clears. If there is snow falling it will tend to fall between the periods of early November to late April.

In Bristol Atlantic depressions and convection systems are the causing factors for the rainfall formation. Around autumn and winter is when the Atlantic depressions exude their most significant impacts and most rainfall is attributed to this source. The convection systems are more typical in summertime, during the hotter months, and formed by solar surface heating. The thunderstorm clouds this produces are more sporadic and isolated in nature yet typically more intense and unpredictable. June and September 2016 saw this type of weather system in Bristol and with it the associated severe heavy downpours. Sea temperature largely dictates this and this is at its maximum in the late summer (cooler in winter and spring). Air humidity also contributes this as well. The annual average humidity factor of 78-80% being a factor, as is the vapour pressure which averages at >10.5 hPa.

Rainfall in Bristol is fairly persistent and consistent throughout the year, with 170-180 days of rain over 0.2 mm, 120-130 days of rain over 1.0 mm and 25-30 days of rain over 10.0 mm. The average annual rainfall in Bristol lies between 800-900 mm and autumn and winter are slightly wetter seasons. There is variation with this though with a notable increase from the north to the south of the city. In north Bristol the average annual rainfall range tends to be lower, at 600–900 mm, whereas in comparison to south Bristol where it is higher at 900–1,200 mm. Altitude could be attributed to this. The hillier areas in the south force moist air to ascend the higher topographic land causing the cooling effects and producing condensation and rain formation.

December and January see the most rainfall in Bristol while April to July is the driest. The main change in influential weather systems being from the Atlantic depressions when the sea is warmer to when it is cooler and the Azores high pressure system takes over. 2012 was observed as the wettest year on record in the UK. In recent years there have been wetter, milder winters with hotter, drier summers. So the effects of climate change may therefore already be apparent and noticeable in Bristol and the UK.

Exposure to the elements and the Atlantic front South-west England encounters some of the highest average wind speeds in the country. This lessens when it reaches the Bristol area but the impacts are still felt. Mean wind speed for the Bristol region, controlled by this factor, is between 8-10 knots and typically comes in a south-westerly direction. The exception is at Avonmouth in West Bristol. Due to its position on the Bristol Channel, winds tend North-easterly. A passage of deep depressions close to or across the British Isles enhances the wind strength. This is more prevalent in winter when wind speeds and gusts are strongest. November to March have the highest mean speeds in comparison to lighter winds between June and August. The mean sea level pressure of approximately 1014 – 1016 hPa also affects Bristol due to close proximity of the coastal region.

5.1.2 Morphology and land characteristics

Bristol is located in the south-west of England near to the Severn Estuary and the Bristol Channel. There are two major rivers flowing through Bristol, the River Avon and the River Frome. Due to the proximity to the sea (Severn Estuary), the River Avon is influenced by the tide throughout Bristol.

The flow of water through Bristol is heavily influenced by the topography. The northern and southern extents of the city are located on high ground that both slope down towards the city centre. Therefore the rivers in the north and south follow this topography and flow down to the River Avon, which defines the lowest lying areas of the city. The most northerly extent of Bristol, in the vicinity of Avonmouth, is also low lying as it is located on a coastal plain of the Severn Estuary. The significant drainage network and location of major rivers and culverts in the BCC area is displayed in Figure 107 below.

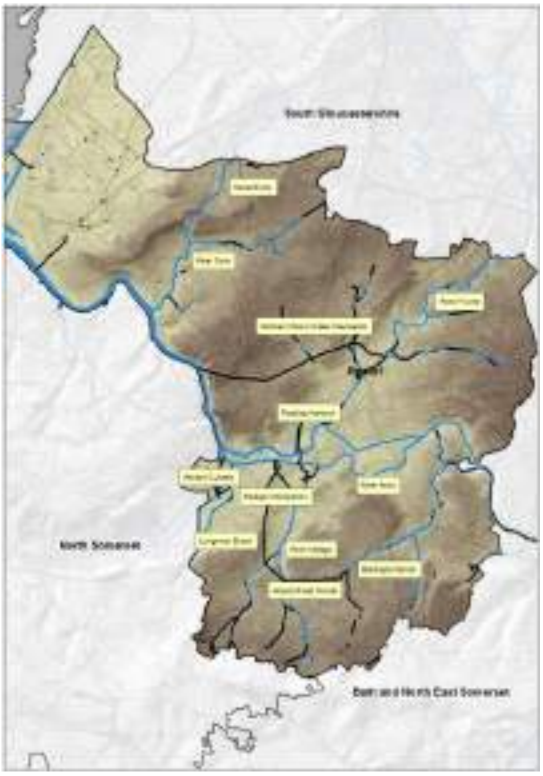


Figure 107 - Identifying the Significant drainage network and location of the major rivers (blue) and culverts (black) in the BCC area (excluding Avonmouth).

At Avonmouth, in West Bristol, the River Avon flows into the Severn Estuary from which tidal waters encroach from the Bristol Channel. A rhine network of drainage ditches drains this area. Those of significance are indicated in Figure 108. The Severn Estuary is reported to have the second highest tidal range in the world of 14 m. This leads to extreme high and low tides.

Figure 108 - Showing the significant drainage network of the Avonmouth rhine network (in red) and where it discharges into the River Avon (in green).

A lot of the urban extent of Bristol is based around these rivers and watercourses and this urban sprawl is displayed in Figure 109 below.

Figure 109 - Indicating the urban extent of Bristol and the greater Bristol area (parts are outside of the BCC jurisdiction and administrative area). The darker grey coloured shading indicates more heavily urbanised areas.

Limestone, mudstone and sandstone comprise the typical geology characterization of the Bristol area. This is mostly overlain with clay soil. A map indicating the main geological bedrock composition in the Bristol area is shown in Figure 110 below. The areas of limestone and sandstone are much freer draining and allow greater permeability in contrast to the relatively impermeable mudstones. Where the River Avon flows from Bath in the east, it flows through flood plains and areas which were marshes in the past.

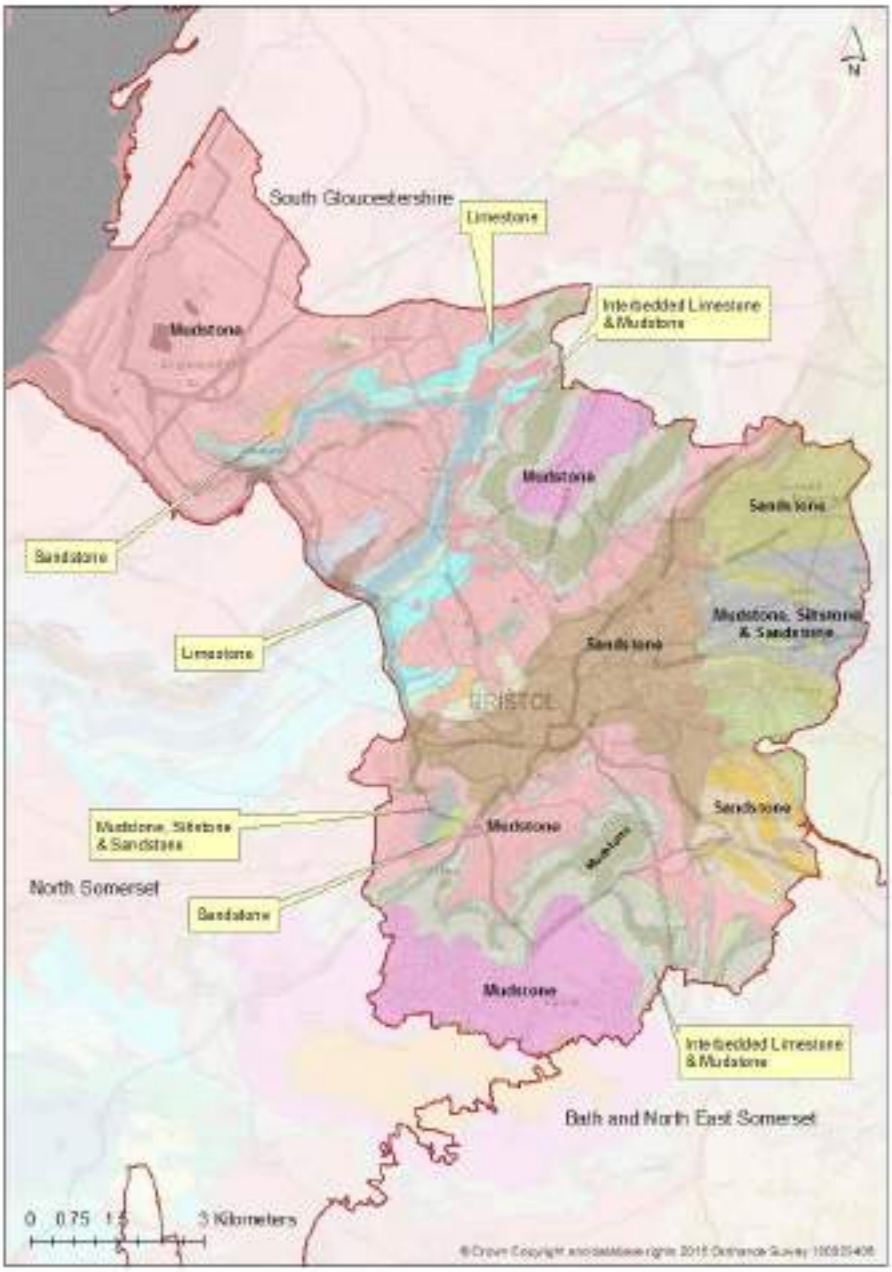


Figure 110 - Showing the main geological composition of the Bristol region.

Other geological indicators are superficial deposits, mass movement and artificial land also apparent in the Bristol region. Figure 111 shows where this tends to occur. Mass movement suggests the area at the base of Dundry Hills more susceptible to landslip constraints. Here and at Avonmouth these factors are more evident of higher potential for geohazards.

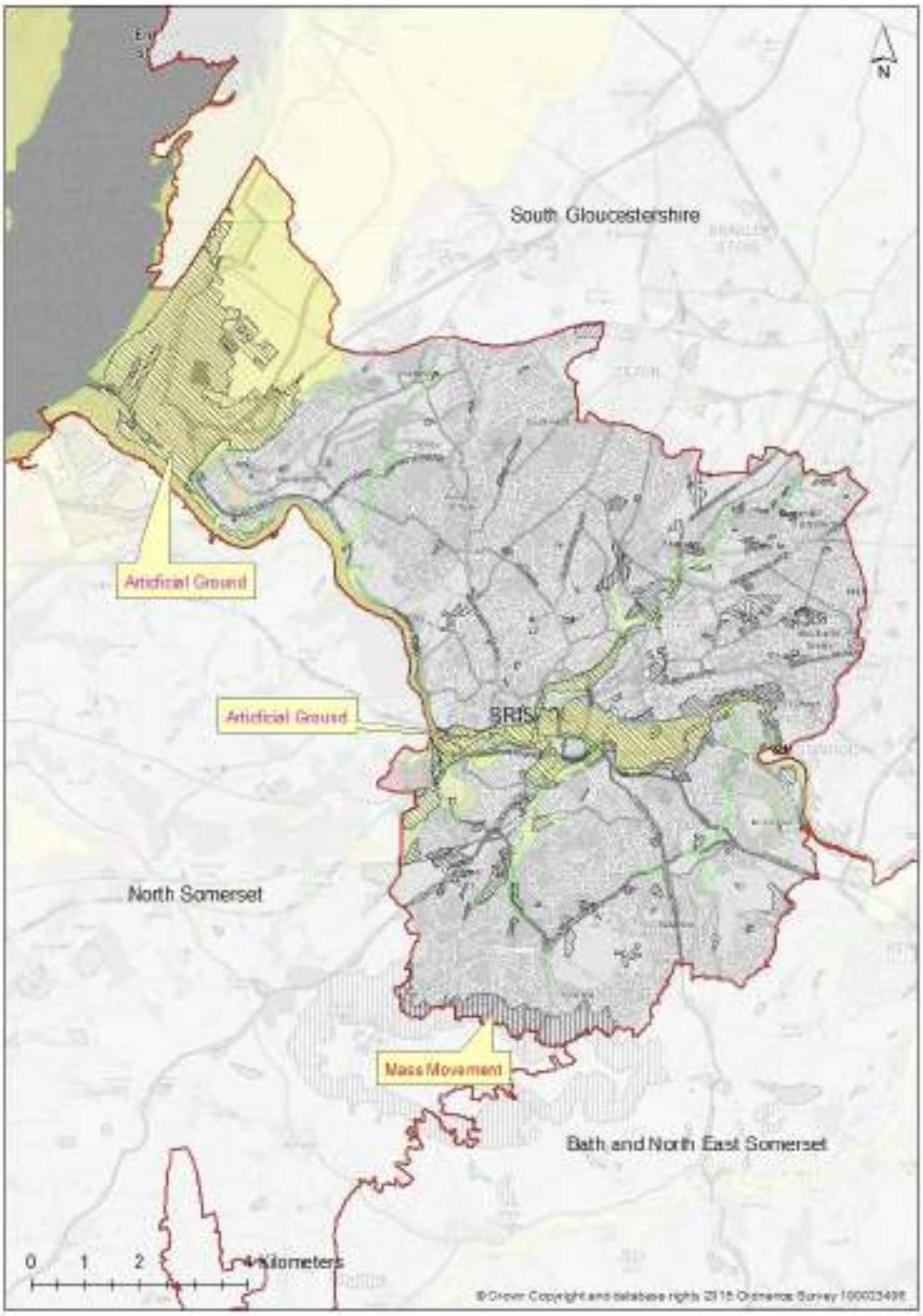


Figure 111 - Showing key geological indicators of historical geological activity in the Bristol area. Yellow shading indicates areas of tidal flat deposits of clay and silt.

The Bristol landscape is very hilly. The topography of the Bristol region is displayed in Figure 112 below. This indicates the variation in topographic levels throughout the city demonstrating how hilly the Bristol landscape is.

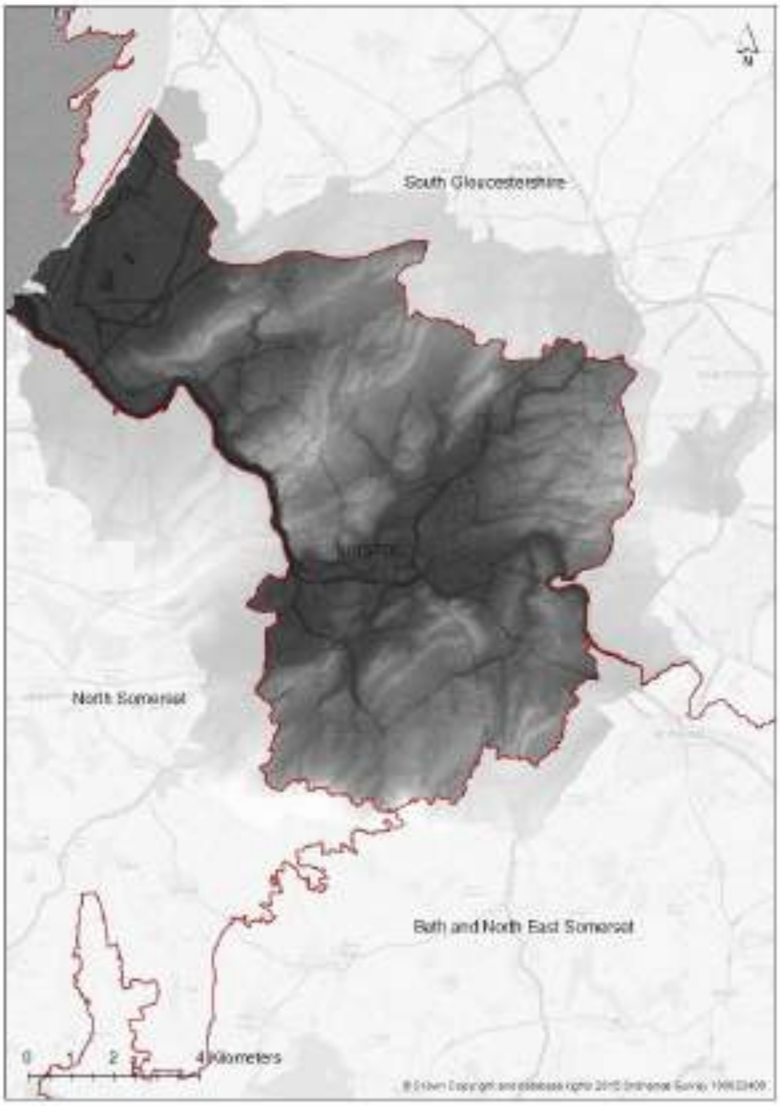


Figure 112 - Illustrating the topography of Bristol. Darker areas indicate the topographic low points and the lighter shading the higher elevations.

The clay soils typically encountered throughout the city provide a degree of imperviousness and lack of uptake for the rainfall landing on it. Certain areas do provide the opposite effects to this though. The highly fractured limestone formations can provide excellent infiltration potential, as can some of the sandstone formations.

Bristol is heavily urbanised and as such much of the surface cover is predominantly impermeable. This brownfield land can result in more rapid runoff of surface water during heavy rainfall events.

5.1.3 Socio-economic aspects

Bristol is classified as one of the Great Britain's 10 Core Cities. The Core Cities are defined as the councils representing England's eight largest city economies outside of London, combined with Cardiff and Glasgow. The Core Cities drive economic growth locally and nationally, contributing more than a quarter of the combined wealth of England, Wales and Scotland. They have importance in business generation and job creation. In Bristol the main economic hub and business district is located in the central area. Inclusive of this is the newly developing Temple Quarter Enterprise Zone.

Bristol has areas defined as amongst some of the most deprived in England. Yet these are adjacent to some of the least deprived in the country. Based on the following aspects; Income Deprivation, Employment Deprivation, Education, Skills and Training Deprivation, Health Deprivation and Disability, Crime, Barriers to Housing and Services and Living Environment Deprivation. This reflects the versatility of social backgrounds and inequality in the city.

In Bristol 16% of residents - 69,000 people - lives in the most deprived areas in England (ie within the most deprived 10%). The greatest levels of deprivation are found in South Bristol. Figure 113 below shows the areas of greatest deprivation in the BCC area in 2015.

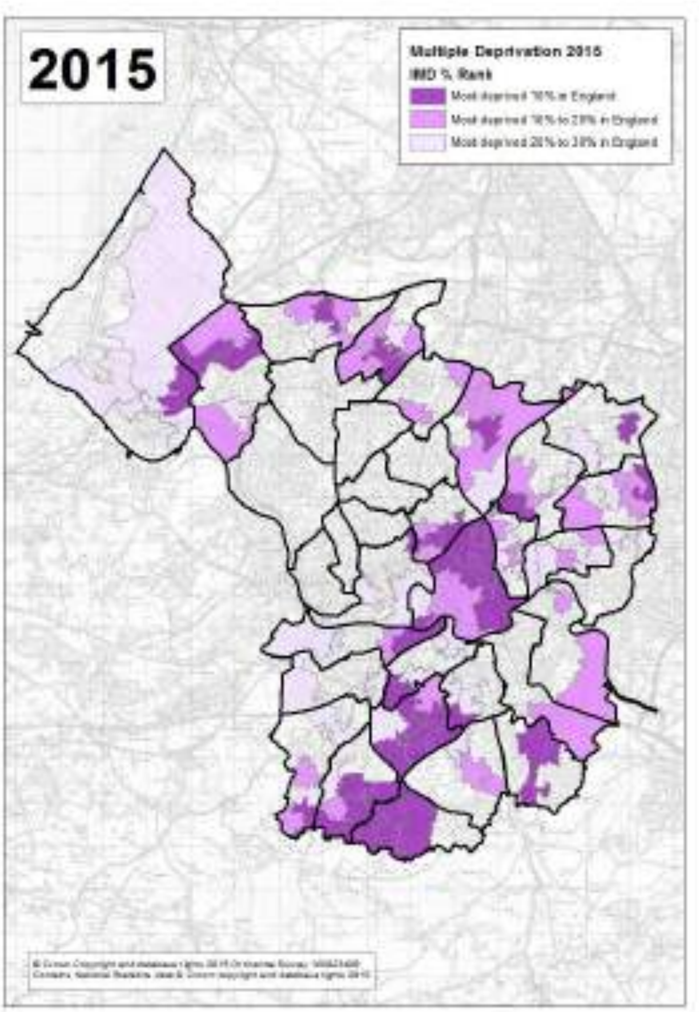


Figure 113 - Showing the areas of greatest deprivation in the BCC area in 2015. The darker purple shading indicates greater levels of deprivation.

5.2 Organization of the city services management. Bristol and the resilience

Water-Urban Drainage

With respect to water management in Bristol, this is regulated by four key Risk Management Authorities (RMA's) who operate within the region. There are particular sources of water or specific areas covered by each of these RMA's. The following provides a description of their individual roles and responsibilities. This is displayed in Figure 114 and Figure 115 which also demonstrates the overlap, interconnectivity and relationships between these organisations.

Figure 114- Risk Management Authorities in Bristol and the flooding sources they are responsible for managing.

The Environment Agency is the central Government agency with the responsibility for a strategic overview of all sources of flooding and coastal erosion in the UK, in particular flooding from Main Rivers and the sea. It is also the enforcement authority for reservoirs.

Environment Agency

The Environment Agency has the following flood risk management functions:

- A **duty** to develop, publish, maintain, apply and monitor a national strategy for flood risk management

- A **duty** to co-operate with other risk management authorities in the exercise of their flood risk management functions
- A **power** to arrange for functions to be exercised on its behalf by another risk management authority
- A **power** to designate structures or features that affects flood risk so that a person may not alter, remove or replace that structure or feature without prior consent
- A **power** to consent or refuse works carried out in, or adjacent to main rivers and sea defences
- A **power** to carry out flood risk management works that are considered desirable, having regard to the national flood risk management strategy
- A **power** to enforce land owners to undertake necessary maintenance works on main rivers
- A **duty** to act as a statutory consultee on planning applications with regards to flood risk
- A **duty** to act as the enforcement authority for reservoirs with a storage capacity of 10,000 m^3 or greater
- A **duty** to identify flood risk areas, publish hazard and risk maps and prepare flood risk management plans in co-operation with Lead Local Flood Risk Authorities

Wessex Water is responsible for managing the flood risk from all public sewers in Bristol and work closely with Bristol City Council and the Environment Agency to ensure a co-ordinated approach.

The Lower Severn Internal Drainage Board is responsible for managing water levels in the low-lying areas around the Severn estuary, which in Bristol applies to the Avonmouth area.

Internal Drainage Board

The Lower Severn Internal Drainage Board has the following flood risk management functions:

- A **duty** to co-operate with other risk management authorities in the exercise of their flood risk management functions
- A **power** to undertake land drainage work in its area
- A **power** to enforce land owners to undertake necessary maintenance works on ordinary watercourses within its area
- A **power** to manage water levels within its area
- A **power** to consent or refuse works carried out in, or within 8 metres of an ordinary watercourse within its area
- A **power** to designate structures or features that affects flood risk so that a person may not alter, remove or replace that structure or feature without prior consent

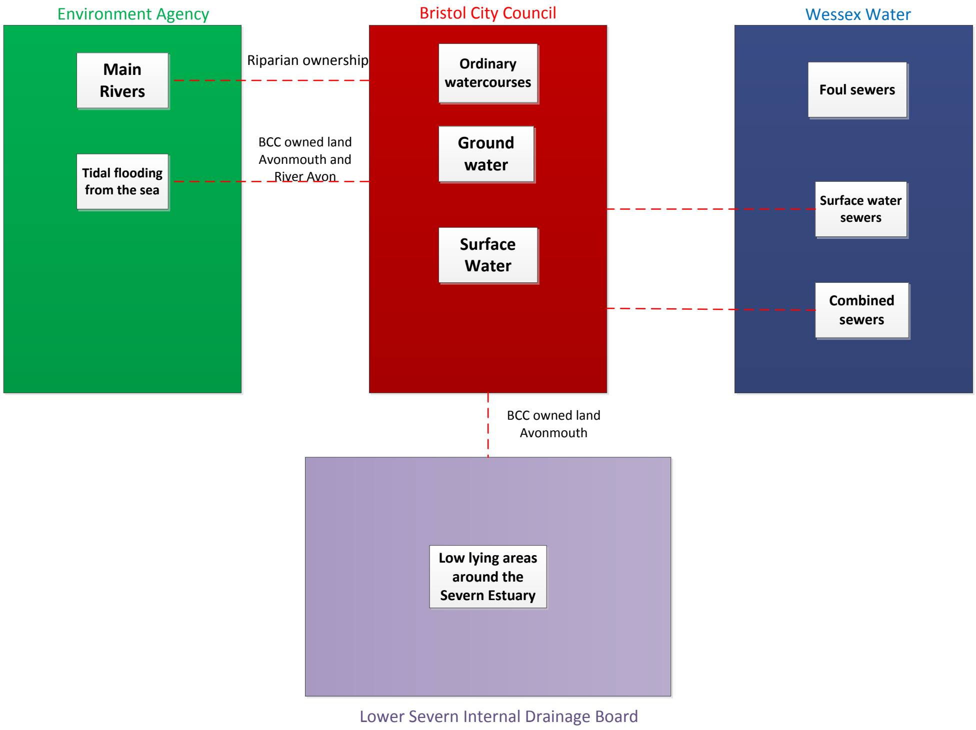


Figure 115 - Showing the overlapping responsibilities of the Risk Management Authorities operating in Bristol.

Lead Local flood Authority

In response to the major events of 2000 and 2007, the UK government established the formation of Lead Local Flood Authorities (LLFA) via the Flood and Water Management Act of 2010. LLFAs take a lead role in co-ordinating the approach to managing flood risk in their administrative areas. In 2010, Bristol City Council was identified as an LLFA.

Bristol City Council is the Lead Local Flood Authority in Bristol, and as such leads on co-ordinating local flood risk activities within its administrative boundary. It is also responsible for flood risk management activities related to ordinary watercourses, surface water and groundwater.

Bristol City Council is also the highway authority in its area, and as such has the responsibility for providing and managing highway drainage and roadside ditches.

As the lead local flood authority, BCC has the following functions:

- A **duty** to develop, maintain, apply and monitor a strategy (this Local Flood Risk Management Strategy) for local flood risk management in its area
- A **duty** to co-operate with other risk management authorities in the exercise of their flood risk management functions
- A **power** to arrange for functions to be exercised on its behalf by another risk management authority
- A **power** to request a person to provide information in connection with its flood risk management functions
- A **duty** to investigate flooding in its area and publish the results of the investigation

- A **duty** to establish and maintain a register of structures that have a significant effect on flood risk in its area and a record of information about each of those structures, including ownership and state of repair
- A **duty** to make a contribution towards the achievement of sustainable development
- A **power** to designate structures or features that affects flood risk so that a person may not alter, remove or replace that structure or feature without prior consent
- A **power** to carry out work that may cause flooding if the benefits of the work will outweigh the harmful consequences
- A **power** to carry out flood risk management works that are considered desirable, having regard to the local flood risk management strategy
- A **power** to enforce land owners to undertake necessary maintenance works on ordinary watercourses
- A **power** to consent or refuse works affecting the flow of ordinary watercourses

Highways Authority (BCC)
As the highways authority, BCC has the following flood risk management functions:

- A **duty** to co-operate with other risk management authorities in the exercise of their flood risk management functions
- A **duty** and **power** to drain the highway

Internal Partners
As well as our risk management authority partners (explained in the next section), there are several service areas within BCC that have an important role to play in managing the causes and consequences of flooding. They are called as *internal partners*, who have the following roles and responsibilities in relation to flood risk management.

Civil Protection Unit

- Prepare and test emergency flood plans to ensure the city is prepared to respond to a major flood event.
- Ensure the council can care for the welfare and support of those affected during a flood.
- Provide expert advice to the emergency services during a flood.
- Assist the council in recovery of communities affected by a flood

Marine Services

- Operate and maintain the city docks flood defences
- Work in partnership with the LLFA to increase understanding and improve future flood defences to manage the risk of climate change

Highways

- Maintain the highway drainage network and respond to blocked gullies that pose a flood risk to property
- Maintain highway culverts, bridges and other structures
- Work in partnership with the LLFA when delivering highway schemes to identify opportunities to reduce the risk of flooding

Strategic Planning and Development Management

- Consider flood risk in local plans
- Ensure development proposals are appropriate and do not increase flood risk to third parties

Parks and Estates

- Maintain park areas and assist with clearing blockages from watercourses in public open space.

Sustainable City and Climate Change

- Achieve more effective flood risk management within the delivery of a wider climate change strategy
- Provide specialist environmental advice to Council and partners

Residents and businesses of Bristol also have an important role to play in flood risk management. Those who live and work in Bristol are encouraged to:

- Report flooding incidents
- Take steps to protect their property and make it resilient to flooding
- Prepare their own emergency plans
- Volunteer to become flood wardens

As the LLFA, BCC are responsible for managing *local* flood risks. However, the wider role of the LLFA requires BCC to lead the co-ordination of flood risk management. In addition, BCC holds the position as the Harbour Authority, Highways Authority, Coast Protection Authority. All flood risk management activities are done so in coordination and partnership with the relevant Risk Management Authorities, stakeholders and community groups.

The role of the BCC Strategic Resilience Officer includes understanding the city's resilience needs and systems. In order to develop a strategy to withstand, respond, and adapt more readily to shocks and stresses. Carried out by coordinating procedures with other key organisations and municipal bodies involved.

Energy

The electric grid is managed by **National Grid** electricity and gas utility company. The infrastructure and network assets such as pipes, towers, underground cables and overhead lines that deliver gas and electricity comes from the Distribution network operators (DNO), which for the region is **Western Power Distribution** and **Wales and West Utilities** who also provide the gas emergency service.

The energy suppliers consist of various different companies to pay for network costs and charges which are separate to those managing the infrastructure.

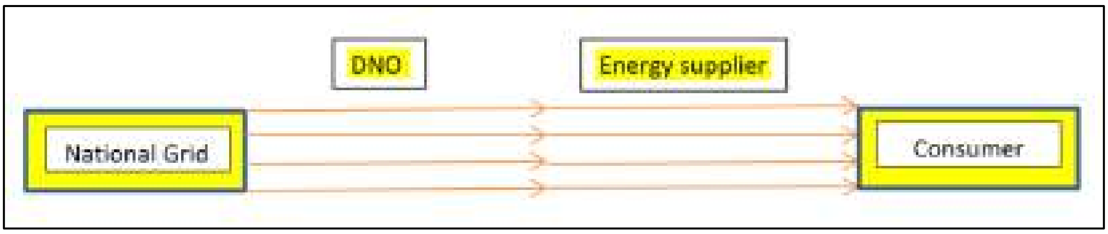


Figure 116: Schematic of energy provision

Water- Water Distribution

Bristol Water – provide fresh drinking water throughout Bristol and to a proportion of the surrounding south west region. The water is sourced partially from the Mendip Hills, located south of the city from Chew Valley Lake, Blagdon Lake, Cheddar Reservoir and Barrow Gurney Reservoirs. The remainder is piped from the River Severn via the Gloucester and Sharpness Canal. 6,772 km of local water mains serve 1.2 million customers in a 2,600 km area, Bristol is included within this. The reservoirs are regulated by the **Environment Agency**.

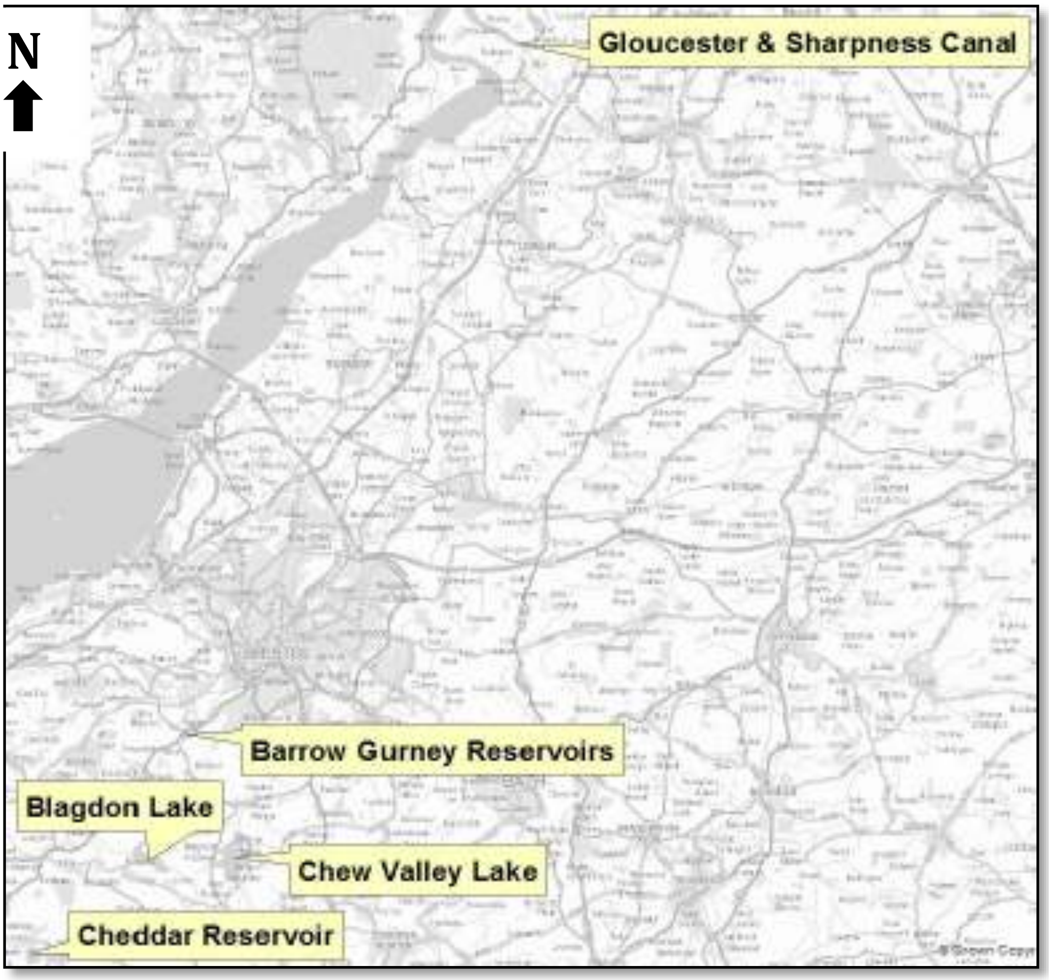


Figure 117: Bristol drinking water provision from surrounding reservoir resources

Transport

The highway road network is managed and maintained by **BCC Highways Department** who perform the following roles in relation to water management on the highway:

- Maintain the highway drainage network and respond to blocked gullies that pose a flood risk to property
- Maintain highway culverts, bridges and other structures

- Work in partnership with the Lead Local Flood Authority when delivering highway schemes to identify opportunities to reduce the risk of flooding

Motorways, of which there are the M4, M5, M32 and M49, are managed by **Highways England, a** government-owned company who carry out maintenance and operation of the Strategic Road Network (motorways and trunk roads).

Public bus services are principally covered by **First Group** but other service providers include **Wessex Bus.** More rapid bus services exist in the **MetroBus** service and **Park and Ride** that have fewer bus stops.

Network Rail owns and manages the train stations, tracks and railway infrastructure it is a public sector body of the Department of Transport. Various train operating companies provide the trains themselves though for passenger transport, including: **Virgin** and **Great Western Railway.** The main train station is **Bristol Temple Meads**, located centrally. **Bristol Parkway** is located in the north and many smaller connecting stations in between.

Several passenger ferry services operate on the Bristol Floating Harbour and at times along the River Avon. Including the **Bristol Packet**, **Number Seven** and **Bristol Ferry**. The majority of these services are used for recreational purposes but some journeys for commuting for work and business purposes are also made.

Bristol Port Company, located in the west of the city adjacent to the Severn Estuary is a major shipping port receiving and transporting cargo as well as providing a holiday Cruise Terminal.

Bristol Airport is located south of the city with connecting flights throughout Europe, parts of North America, North Africa and Caribbean.

The airport, motorways, A roads, train stations and waterway related modes of transport are indicated in the figure below (Figure 118).

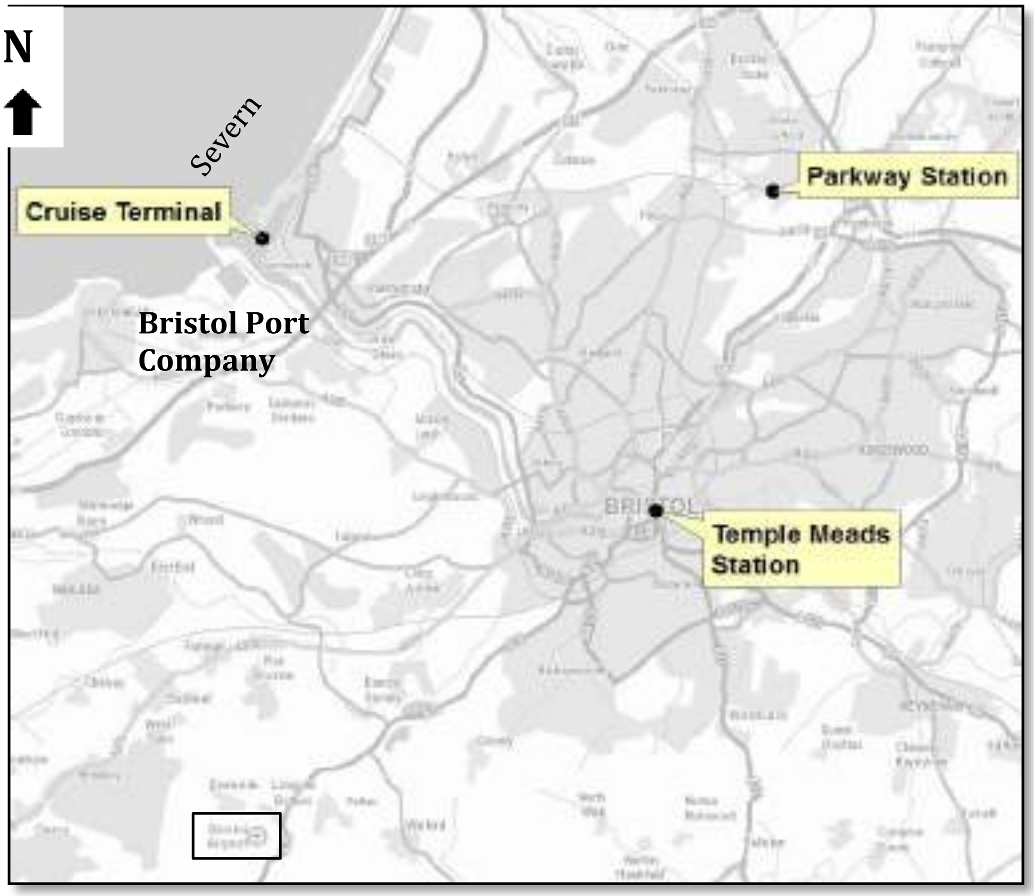


Figure 118: Key transport points in Bristol

Waste

Bristol Waste Company is responsible for recycling, waste collection (including fly tipping), weed spraying, street cleansing (including graffiti, leaf clearance, debris clearance and refuse clearance), winter maintenance (gritting) and emergency call outs for example oil leaks and flooding. This is linked to BCC. They make 17 million scheduled collections every year, operate 180 vehicles and collect 140,000 tonnes of waste and recycling per annum. 53,000 tonnes of this are for composting or recycling. 800 miles of streets and footpaths are cleaned throughout the city. The waste collection and management is for public areas including households, businesses (note these can use private suppliers) and public highways. It excludes waste clearance from parks and open spaces as the responsibility lies with the landowner. Their resources include 21 crews (gang sweepers), 12 Mechanical sweepers (sweepers and drivers), three pump vans (graffiti removal, vans and drivers), four fly tipping crews (crew consists of two people) and one Hiab operator. For the city centre there are 32 operatives/drivers with a mix of the above disciplines.

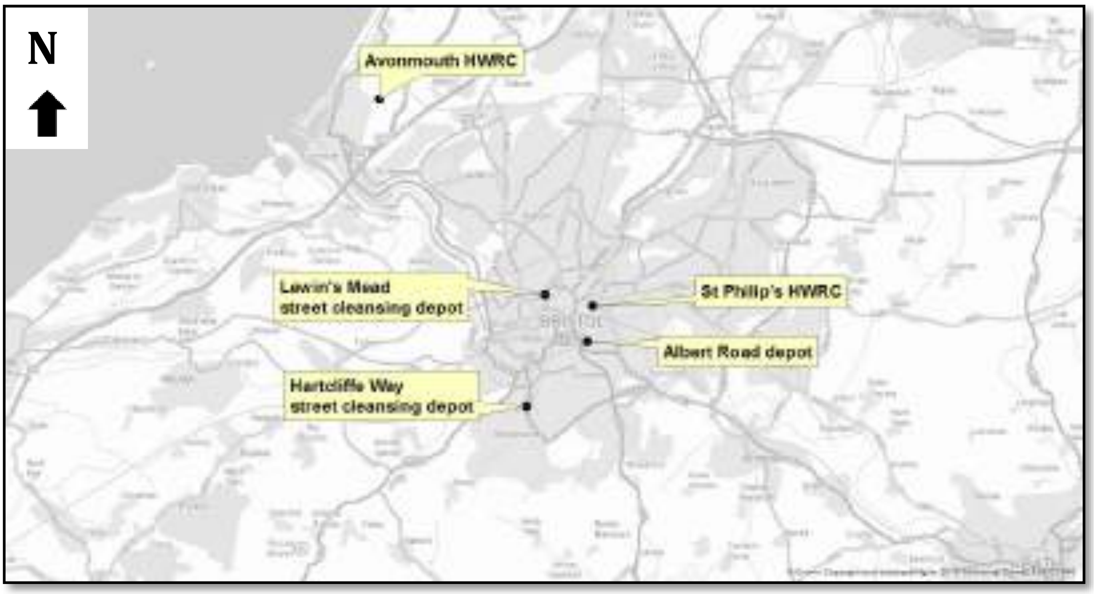


Figure 119: Bristol Waste Household Waste Recycling Centres (HWRC) and Depots locations

Telecom

The main telecommunications providers consist of the **Open Reach** division of **British Telecom** for the landline phone services. They have ownership of and maintain the telephone wires, ducts, cabinets and exchanges that connect homes and businesses to the national broadband and telephone network.

For the mobile network and digital communications there are many providers including 3, EE, O2 that are operational.

Green Infrastructure

This is predominantly managed by **BCC Parks and Estates Team**. Who maintain park areas and assist with clearing blockages from watercourses in public open space in respect of water management.

5.3 Urban Water Cycle in Bristol

Bristol has a close relationship with its rivers and waterways and owes much of its prosperity to living and trading within the tidal extent of the River Avon, which flows from east to west through the centre of the city. Managing the interaction with these rivers and the tide has often been at the forefront of the city's developers and engineers throughout the history of the city. The most significant evidence of this is the Floating Harbour, a unique inland harbour constructed in the early 19th century to provide a constant water level for mooring purposes and encourage the growth and prosperity of the city.

The Floating Harbour is regulated by BCC City Docks Marine Services. At low tide lock gates and sluices are opened to lower the Floating Harbour level and enable river flows from the River Avon to pass out to the Severn Estuary. During high tide these gates are closed and encroaching tidal waters prevented from entering the Floating Harbour. The River Frome flowing from north to south through Bristol also diverts into the Floating Harbour around the central area. Figure 120 displays this hydrological and hydraulic system. The Floating Harbour level is maintained at 6.2 m AOD (Above Ordnance Datum. This is a reference point in the UK from which other topographic height levels elsewhere can be compared) but can be adjusted to plus or minus 300 mm which represents a significant volume of water over its entire expanse. Failures of the key infrastructure including the Underfall Sluices that drain the Floating Harbour are included in the Central Area Flood risk Assessment (CAFRA) flood modelling available from BCC.

Following the great surface water and fluvial flood event of 1968 major works were undertaken in Bristol to alleviate flood risk in the city. This saw the introduction of major infrastructural improvements in order to reduce the risk of surface water and fluvial flooding. In south Bristol the Malago interceptor tunnels divert flows from the River Malago up to the River Avon New Cut. The River Avon New Cut is a man-made dug channel, the original course of the River Avon runs through the route of the Floating Harbour.

In the north of the city, the Northern Storm Water Interceptor (NSWI) takes flows from the River Frome, diverting it further downstream of the River Avon. When opened, the NSWI can save additional flows entering the Floating Harbour. This would otherwise raise the existing level. The opening of these sluice gates is conducted by the Environment Agency and often carried out when heavy flows are passing through the Frome catchment. They may also be opened when a high Spring tide is expected as outfalls may become tide-locked during this time and water builds up in the Floating Harbour. A pre-lowering of the Floating Harbour is also sometimes conducted before a high Spring tide to give additional capacity for flows entering it, while unable to pass on to the River Avon and Severn Estuary.

Figure 120 - Showing the open channel watercourses (in blue) and where they have been diverted by man-made, culverted, piped systems (in black) in Bristol.

Models of the system include the CAFRA conducting by BCC. CAFRA analysed combination events of tidal floods and fluvial flood flows (i.e. the joint probability of the two flooding sources occurring simultaneously) of varying magnitudes. This was to establish the predominant risk and threat to the city centre now and into the future, including the predicted impacts of climate change. The conclusion was the high tidal element causes the greatest risk, far outweighing the fluvial component. The CAFRA study included a large-scale hydraulic model of the tidal and fluvial systems in central Bristol. The model itself was completed using a combined 1D and 2D model built using ISIS-TuFLOW software packages. The majority of the river networks in central Bristol were simulated using the 1D ISIS software, with the topography and ground surface represented using 2D TuFLOW. The model is currently being updated as part of the ongoing River Avon Tidal Flood Risk Management Strategy. Key datasets available, in addition to the model files themselves, are in GIS (ASCII) format and predominantly include results from the model runs, including flood depth, hazard, level and velocity. The model is owned by BCC and is therefore relatively available for use under licence, however, some restrictions exist on the dissemination of results. More information provided via: https://www.bristol.gov.uk/documents/20182/33916/CAFRA_Summary_final.pdf/d0243d87-3f61-448b-bcda-33403bd1e41b.

Figure 121. Flood extent of an extreme tidal flood event in the current day in central Bristol. Source: CAFRA study.

BCC also own a 1D/2D coastal and fluvial flood simulation model that predicts the risk to the Avonmouth and Severnside area. As with the CAFRA study, the Avonmouth model was built using ISIS 1D software to represent the river network and coastal boundary, with TuFLOW software representing the 2D topography and ground surface. This model also predicted the likely impacts of climate change, and is being updated by the Avonmouth and Severnside Ecology Mitigation and Flood Defence project, which is proposing to construct flood defences to increase the protection to the Avonmouth area. Similar outputs to the CAFRA study are available from the Avonmouth Severnside model. More information on the Avonmouth Severnside model can be found via https://www.bristol.gov.uk/planning-and-building-regulations/planning-policy/planning-evidence.

The above studies and assessments have been used by BCC and partners to identify a number of high risk areas across the city. Two of these have particular relevance to the RESCCUE project, Ashton and St Phillips Marsh. The Ashton area is located in the west of the city, immediately south of the River Avon and is predominantly characterised by residential properties, with some industrial areas and a sports stadium. The mechanisms by which flooding affects this area are complex, the various watercourses that drain the area (such as Longmoor and Colliters Brooks) discharge via culverts to the tidal River Avon. As a result, the area has the potential to be affected by direct fluvial and tidal but also tidelocking. Like much of central Bristol the area is served by combined sewers (sewers that convey both foul and surface water) and as such sewer and surface water flooding has the potential to cause significant impacts. In order to help manage the risk, Wessex Water own and operate a large pumping station called Ashton Avenue Pumping Station. This not only helps to move foul water to Avonmouth Sewage Treatment Works to the north of the city but also helps the local watercourses and sewer systems manage tidelocking by discharging such flows during high tides.

St Phillips Marsh is located to the east of the city, between the River Avon and Floating Harbour (notably the Feeder Canal). It lies adjacent to Temple Meads railway station. It is characterised predominantly by industrial units and operations and some residential properties. The flood risk posed to this area is more straightforward than Ashton, in that the predominant risk is from direct tidal flooding. Tidal flooding could occur to the area if a storm surge coincides with a high spring tide in the Avon. If a severe (in the region of 1 in 50 annual chance or greater) event were to occur, the area would experience widespread flooding due to its low lying and flat nature. Indeed, much of the ground is at a lower topographical level than the banks of the Avon.

General vulnerabilities of urban water cycle in Bristol

The vulnerabilities to the urban water cycle when considering the impacts of climate change include capacity restraints of piped culverted systems, due to increased rainfall durations and intensities and consequential increased fluvial flows. Higher sea levels raising tide levels will also contribute to tide locking outfalls, resulting in surcharging and breaching of defences.

As the flood modelling is carried out externally via consultants; as part of the research within RESCCUE, BCC will be looking to work closely with the UNEXE to utilise their in house software to carry out further flood modelling within the city. The software that will be used is the Urban Inundation Model (UIM) which is a 2D finite difference based model that uses non-inertia flow equations that has been modified to facilitate flow at coarse resolutions whilst still allowing for the effects/influence of fine scale features to be included (Chen, Djordjević, Leandro, & Savić, 2007) (Chen, Evans, Djordjević, & Savić, 2012). This approach allows for reduced computational runtimes whilst still maintaining accuracy. It is envisioned that the multi-layered approach outlined by Chen *et al*. (2012) can be further modified to allow for the representation of surface flow through culverts, under bridges and through buildings (if certain depths are exceeded). This would be ongoing research where data from these models would be referenced against historical data and data from previous models to examine the differences. Further to the use of the UIM BCC will also be looking to use the CADDIES (Cellular Automata Dual-DraInagE Simulation) software that uses a more simplistic rule based way of representing surface flow and as such produces results in an order of magnitude quicker than that of the standard hydraulic models such as UIM and Infoworks. Figure 122 shows the flood depth outputs taken from the CADDIES approach (b-c) at various time steps in comparison to flood depths derived via Inforworks (a). For the Infoworks case the computational runtime was 19 m 47 s whereas for CADDIES cases b-c where the time steps were 0.01s, 0.03s, and 1s respectively the run times were 3 min 33 s, 1 m 46 s, and 15 s.

The high performance allows the CADDIES to be utilised for carrying out large numbers of events within relative short time frames. One example would be to examine pipe bursts at 100 m intervals along the water distribution network, which could easily lead to thousands of simulations required to cover the entire city. If these pipe burst scenarios are carried out in such a manner with flood maps produced for each, by analysing all of the outputs, it could be possible to spatially visualise the locations within the network that pose the greatest risks to infrastructures and/or services in the event of a pipe burst.

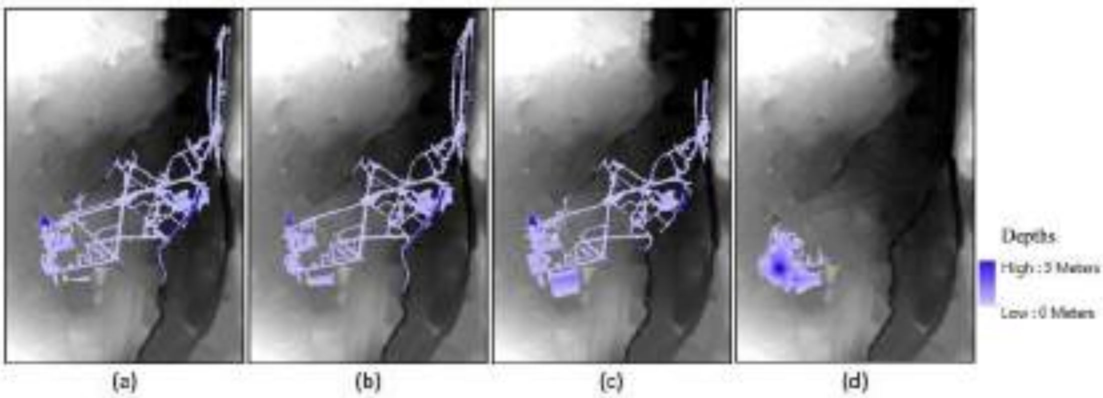


Figure 122 - Comparison of CADDIES approach at varying time steps [b-d] against Infoworks approach [a] (Gibson, et al., 2016)**.**

5.3.1 Water Abstraction

Bristol Water area of supply covers 1000 sq miles and serves a population of about 1.1 million people, including Bristol city and nearby villages (approx. 20 mile radius). The supply of such an extensive area happens in such a way that no zone is solely dependent of one water source. The way the water supply is setup allow the system to be robust and also mitigates the effects of large peaks during the dry season.

In addition to the system, in 2009 it was introduced additional capacity enabling the water supply to cope with larger operational emergencies, namely by the use of the following schemes:

- Increased the raw water transfer capacity from Cheddar Reservoir
- Increased system transfer of treated water across the north of Bristol
- Increased capacity of the South Bristol Ring Main

The improvements made above did not contributed to an extended capacity, but to a more flexible water supply.

There are two main water source categories for Bristol Water:

- 50% imported from Welsh Reservoirs via Severn River
- 40% from Reservoirs (Mendip Reservoirs – Chew, Blagdon and Cheddar)
- Minor water supply from a number of small groundwater sources

River Water

Abstraction is made from the River Severn and conveyed via Gloucester and Sharpness canal to supply the biggest northern treatment works and is able to provide about 50% of current water available. During dry periods the amount of water extracted is increased in order to allow a maximum conservation of water available in the reservoirs.

Groundwater

The amounts of water available have been assessed by Bristol Water by using the UKWIR methodology [4]as a stand-alone source. This source amounts of about 10-15 % of all available water. As such the water output is optimized to an optimum level to meet the base load demand.

Bristol Water supplies drinking water and serves a population of 1.1 million people along with all the associated businesses in an area of 2,400 square kilometres (1,000 square miles) centred on Bristol. They own three major reservoirs (Chew, Blagdon and Cheddar) and a number of boreholes as sources of raw water. But nearly half the water used in the area comes from rivers outside of their area of supply including the River Severn.

Bristol Water have a range of treatment works from the simple to the highly complex. These feed water into a network of pumping stations, storage reservoirs and mains so as to deliver high quality of water to customers' properties as they want to use it.

Surface Water

The surface water reservoirs allow the system to cope with demand peaks that exceeds the river and groundwater sources. Bristol Water has modelled the yield from these reservoirs based on the hydrological rainfall run-off model for the Mendip catchments based on long series climate records dated back from 1829 to the present. These records complement the previous model by providing data of droughts that happened in late 1890s. The additional data allows to evaluate the frequency of droughts that may trigger restriction on water use and also the water levels of the reservoirs when these events occur.

There is a significant level of resilience and connectivity in both raw water mains network and the treated water bulk transfer systems. The system is flexible in terms of resource sharing and allows optimum seasonable availability. In addition there is also a substantial connectivity of the surface water reservoirs allowing a more flexible operation.

The current management of the interconnectivity of the Mendip reservoirs and its critical constraints, such as pumping and transfer capacity is done by two different but complementary models. A simple mass balance spreadsheet and a more robust model oriented to optimisation of the resources. Both models compute wins and losses of the system and set the yield of the system to meet demand if a 24 month dry occurs.

[4] UKWIR methodology is for the determination of surface water and groundwater source outputs. It was developed in order to provide a standard, relatively simple and auditable means of assessing outputs from the wide range of surface water and groundwater source types and aquifers in the UK for a variety of water level and demand conditions.

Main climatic effects and natural hazards affecting the service and the critical infrastructures (CCH Planning Scenarios)

The increasing warming climate will probably trigger a higher demand for water. This additional demand will be mostly felt in the required baseline of water supply. At this stage that increase in the baseline demand has not been estimated in the demand forecast. Instead figures from a research study published in 2003 "Climate Change and the Demand for Water" were used to estimate the higher consumption with the increasing temperature in the UK for both households and non-households consumption.

In 2030 there is an estimation that a loss of resource yield should be about 3% of the current deployable output. Climate change induced consumption will induce an additional 1% in the increase of demand overall. Solely climate change impacts are not sufficiently to drive specific investment requirements, but they will be part of the drivers for a higher demand in a near future, but still have a small contribution when compared to the impacts caused by growth in demand for water due to increasing population. But still there is risk that the predictions for climate change to be more severe than initially previewed and the cascading events can assume relevant importance.

In a growing city it should be expected an increasing water demand, but for Bristol there has been a decrease in demand, mostly due to the decrease in the supply of non-household clients and leakage improvements.

The Environment Agency (EA) is responsible for managing water resources in England. In order to ensure there is enough water for people (public water supply, industry and agriculture) and a healthy environment, the EA controls how much water is taken with a permitting system. Existing licences and new ones are granted by the EA and they use the catchment abstraction management strategy (CAMS) process and abstraction licencing strategies to do this. In order to ensure the various water courses are not affected ecologically, the EA has run The Restoring Sustainable Abstraction programme for a number of years. It is used to investigate into sites where abstraction may be affecting the ecological wellbeing. This programme has been responsible for the reviews of a large number of licences.

Reservoir storage is critical to the resource system. In total approximately 35% of the deployable output is derived from the yield of the three Mendip reservoirs, south of Bristol. During the summer months, water from the reservoirs is used to meet the peaks in water consumption. One reservoir whereby abstraction of water occurs for drinking water is the Chew Valley Lake reservoir, located south of Bristol. This is a pumped storage scheme, pumping water from Winford Brook that is stored in Chew Magna compensation reservoir to Chew Valley Lake (see Figure 123 location map). The modelled inflows have been used against an abstraction rule to derive the quantity that can be pumped to Chew Valley Lake, while maintaining adequate stored water for compensation requirements.

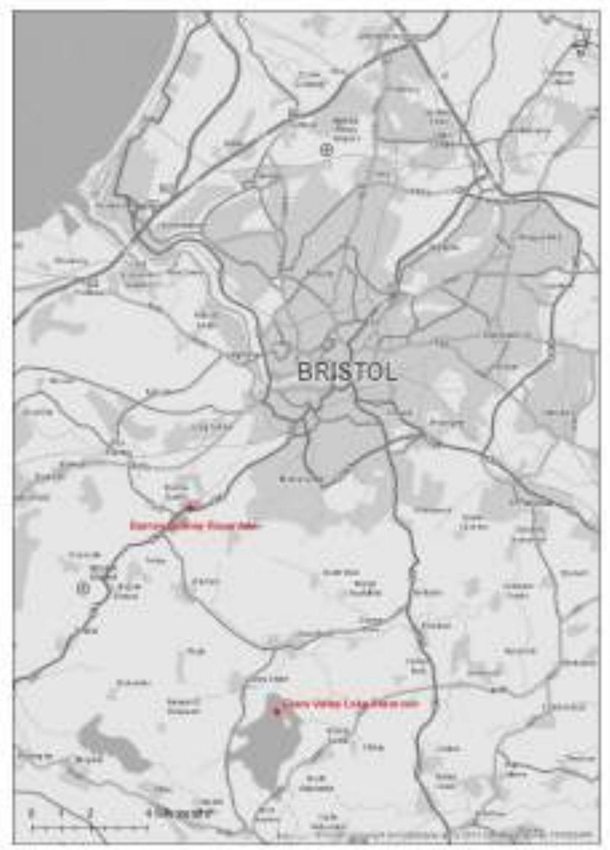


Figure 123 - Chew Valley Lake and Barrow Gurney Reservoir locations

Not all of the water is available to the company for use by its own customers as the actual available water is reduced by impacts such as:

- Sustainability: long-term reductions in abstraction required for environmental reasons
- Quality: Sources likely to be at risk of failing Drinking Water Standards
- Outage: Pollution, treatment works maintenance or other plant failure
- Process loss: water treatment or raw water use or losses (e.g. aqueduct loss, filter washing)
- Bulk supplies: Water contracts to supply industry or other water companies (on a secure basis).

River Avon water from above the tidal limit supplying the Floating Harbour (Bristol City Docks) is usually discharged to join large flows in the tidal Avon at a rate between 50 and 500 Ml/d. This option is to capture the water before it is discharged, and transfer it to existing reservoirs at Barrow, approximately 8 Km to the west of Bristol city centre. Water from this source will be used to offset demand on Mendip resources allowing more to be taken from these reservoirs to supply growth in the south of the company area, and maintaining security of supply overall. The water is of poor quality containing pesticides and herbicides, and has an occasional chloride load with a high silt load. A completely new treatment process to remove organic compounds and nitrates from the water has been included. Although the reservoirs referred to fall outside of the Bristol City and Council limits there are groundwater protection requirements in Bristol due to the locality of the Bristol aquifer. Figure 124 gives a summary of constraints for groundwater in the Bristol area.

Figure 124 - Groundwater constraints summary for Bristol.

The potential for the interconnectivity between the Floating Harbour and Barrow Reservoir is illustrated by Figure 125.

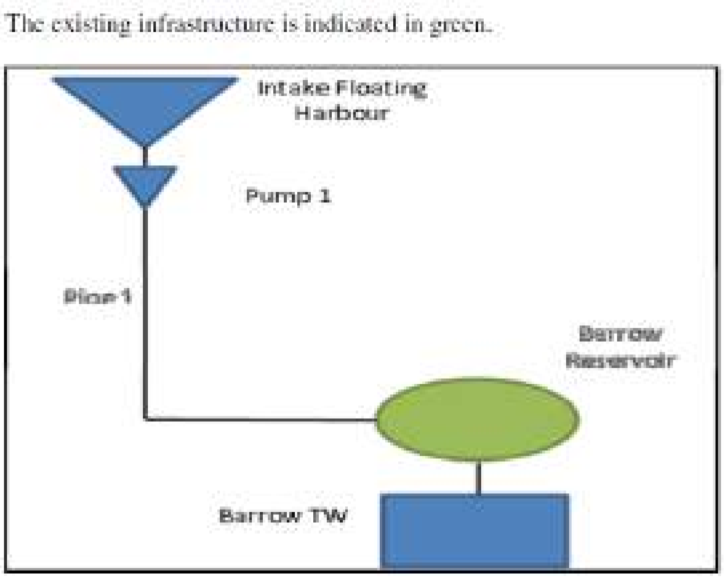


Figure 125 - Bristol Floating Harbour and Barrow Reservoir connection

Below also it is provided an indication of the groundwater table depths throughout the city.

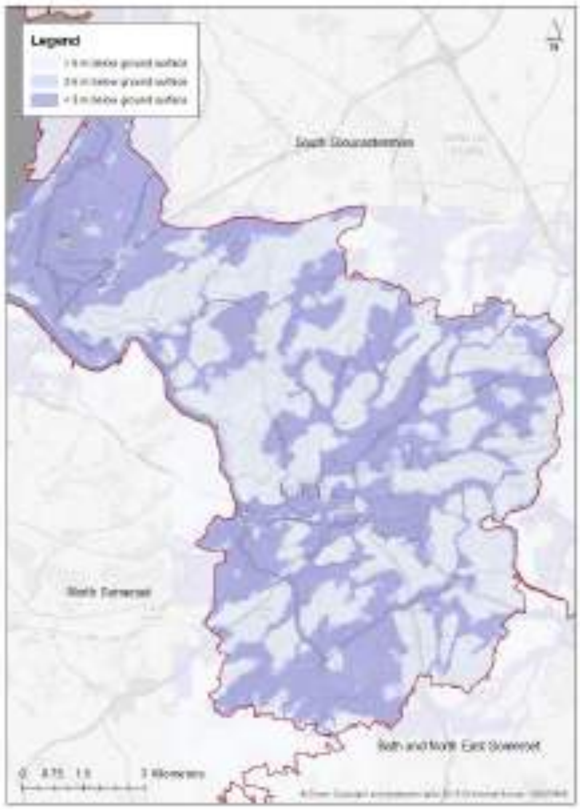


Figure 126 - Showing depth to the water table around Bristol.

Due to the reservoirs being located on higher ground outside of the city, their failure is predicted to have catastrophic effects on Bristol. With a large majority of it, especially the city centre, inundated if the storage unit were to collapse.

The increasing population and associated water demand and consumption in Bristol may be difficult to maintain in the future. This will be noticeable if water availability is reduced due to the effects of climate change.

5.3.2 Water Treatment

The type of water treatment depends on the quality of raw (untreated) water. Raw water is split into three categories: DW1 (Very Good), DW2 (Good Quality) and DW3 (Poorer Quality). The minimum treatment needed for the water is determined by which category it falls into.

In total, Bristol Water has 24 treatment works with output ranging from 0.5 million litres a day at Priddy to 165 million litres from Purton. Barrow treatment works is the nearest to Bristol city, it treats water that was categorised at DW2 and was Bristol Water's first treatment works.

The Avon has a number of potential pollution sources upstream. Discharges from the sewage treatment works at Saltford and Keynsham (east of Bristol) plus combined sewer overflows in east Bristol itself and towns such as Bath and Chippenham.

The water quality in the Bristol harbour has improved significantly in the last thirty years, however, sudden heavy rainfall still causes changes in the water quality from time to time. The River Avon flows directly into the Feeder Canal at Netham Lock and has a major influence on background water quality in the Floating Harbour. It is the main source of water to the Harbour.

After very heavy rainfall, when the River Avon is in spate, the gates at Netham Lock are often closed to prevent excess water coming into the harbour. This reduces the amount of background contamination from the River Avon entering the Harbour during this period. During heavy rainfall when flows in the River Frome are very high, much of the excess river water is diverted into the Northern Storm Water Interceptor at Eastville to reduce the flood risk to the city centre. This water is piped underneath the city and directly out into the Avon Gorge at Black Rocks, just downstream of the Suspension Bridge through the Northern Storm Water Interceptor.

Water quality analysis conducted by BCC Environmental team is conducted to show conformity to Water Framework Directive requirements. This data is available online on the Bristol.gov.uk website. On analysis the River Trym in north Bristol has a water quality rating defined as poor. Misconnections such as washing machines leading into watercourses contribute towards this. Polluting agents from illegal activities like fly tipping of waste products is another cause. There can be associated health hazards to human life and wellbeing with water borne diseases and poor water quality. An increasing population has potential to worsen these effects further for the human impacts described above. As does the continued detrimental impacts on the environment, hydrological cycle and atmosphere from climate change.

Main climatic effects and natural hazards affecting the service and the critical infrastructures

A consistent and plentiful supply of water is something that most of contemporary society is used to and most of times take it for granted. Climate change is bringing one more layer of complexity for the provision of this essential service.

Bristol shares the same typical problems that can be seen across the UK, where both weather and rainfall patterns are changing. Curiously the change of these patterns bring two contrary effects: water shortage and flooding.

The water shortage results mainly from drier and hotter summers, which can even be more exacerbated by the increase in demand for water during these periods. An additional problem occurs when the water levels in aquifers and river decreases, the concentration of pollutants also increases further limiting the usable water resources. The increased level of pollutants can make the water treatment works inefficient with a consequential decrease of water quality to be supplied.

Drought events can cause the coastal water resources to become increasingly more saline, as supplies from rivers decrease and saltwater moves further upstream. In coastal cities, sewer and treatment facilities face risks from rising sea levels as well as storm surges.

Flooding is also one of the consequences that is exacerbated by climate change. Most recently record levels of rainfall have been recorded with a consequential disruption of water supply, power, roads, generating damages to property and insurance claims. In case of heavy downpours the runoff flows into rivers and lakes, washing sediment, nutrients, pollutants, trash, animal waste, and other materials into water supplies. Bristol still rely on old Victorian drainage infrastructure that was not designed to deal with more frequent storm like events that overcharge stormwater drainage systems. In cities like Bristol most damages arise from surface water runoff overloading the drainage system. Extreme rainfall events can saturate and clog the drainage system, mixing both grey water with sewage water. The first barrier to these events are the storm water retention basins. Those can become obsolete when such events occur, leading to a dilution of raw water with rain water, altering water parameters and consequently the water treatment processes.

5.3.3 Water Distribution

Chew Valley Reservoir

The construction of the Chew Valley Lake began in 1950 and took five years to build. Its purpose was to create a drinking water reservoir for Bristol via the Barrow treatment works. The lake is owned and operated by Bristol Water and is now used for recreational purposes also including sailing, fishing and birdwatching. It was created by the damming of the River Chew as well as flooding from nearby farmland in the Chew Valley and the Mendip Hills. The lakes capacity is 20000 million litres and it is the largest artificial freshwater lake in the South West and the fifth largest in the UK. It has an area of 1200 acres. It is located outside of the Bristol city limits as shown in Figure 123. Consequences of its failure would be catastrophic for Bristol as flood waters would encapsulate a large proportion of the city causing mass devastation.

Supply Demand Balance

An accurate supply and demand balance allows to predict a baseline for water demand in present and set future needs. At present times the supply demand is still balanced and no driver can be identified as a dominant component for deficit, but at this stage the population growth is one of most influence followed by climate change impacts. Previous and ongoing efforts to address leakage issues may result in a positive increase in the available water output. Further interventions for leakage reductions are predicted to maintain a proper supply/demand balance. Bristol Water has made predictions for future supply/demand. They have concluded that until 2018 the balance can be achieved with current assets. From 2018 onwards various drivers will take their share on the deficit of water supply and this will tend to increase significantly by 2040. Additional measures will need to be taken to ensure a positive balance between the supply and demand is maintained.

Bristol Water will prioritise solutions where leakage and energy efficiency schemes can be employed as they consider those to be the most cost effective to be carried out in short-term and can deliver better environmental benefits. If those schemes are not enough to guarantee a proper balance between supply/demand additional resources will need to be put into place to enable a proper security supply.

On average each person uses over a tonne (1,000 litres) of water each week. Some other values about water distribution system of Bristol are:

- **Number of supplies** 518,000
- **Length of mains** 6,700 kilometres
- **Population served** 1,151,000
- **Average daily supply** 264 million litres
- **Sources** 68 (including reservoirs, rivers, springs, wells and boreholes)
- **Raw water reservoirs** 14 (the largest, Chew Lake, can hold 20,460 million litres)
- **Treatment works** 16 (output ranges from 2 million litres/day at Tetbury to 165 million litres/day at Purton)
- **Pumping stations** 164
- **Covered storage reservoirs** 139 (the largest, Pucklechurch, can hold 115 million litres)

Main climatic effects and natural hazards affecting the service and the critical infrastructures

Extreme cold warm cycles can also lead to pipe bursts which can subsequently disrupt water supply and indirectly temporary closure of roads and other services whilst repairs are carried out. Under these extreme snowfall and cold weather circumstances the city of Bristol can come to a temporary standstill. The colder, snowier winters of 2008 and 2009 brought with them this associated disruption.

The piped water distribution network is provided by Bristol Water. Vulnerabilities in the system include the occasional pipe burst. The chances of this occurring may increase over time as this deteriorates**.** Also with greater future demand there may be more of a strain on the system. An example of the vulnerabilities of the system was noted in in September 2014. A water main burst in the Kingswood area in the neighbouring South Gloucestershire Council region. Adjacent to Bristol and situated at lower ground this left thousands of Bristolian residents without a fresh water supply for up to 48 hours. Eight homes in the immediate vicinity of the incident were flooded up to 1.2 m in depth and residents had to evacuate their homes. These residents only returned to their homes after an eight month recovery process. In total over 50,000 homes in and around Bristol were left without a fresh water supply for up to two days following the incident.

Vulnerability to scarcity of water and Climate Change: Drought Plan for Bristol

Water companies in UK and Wales are required by statute to have contingency plans for coping with periods of drought. This shall describe how the water supply is maintained at a reliable level.

In Bristol 85% of the water supply is provided by either river or reservoir sources supplies. In the event of severe drought these sources can decline in quantity and/or quality dependant of the severity of the drought. These extreme events capable to cause water management some issues are not common and historically only happened 5 to 7 times over a course of 100 years. Drought events that come with some restrictions for users are more common with an average of 15 years interval.

Historically the last of these events happened in 1830, and if that event would replicate now a water supply failure could occur. Even this might seem worrying an event such as this would only occur 1 in every 100 years and guaranteeing a level of service in any conditions would not be cost effective as it would increase the water bills for a contingency that might not be even used. **Bristol Water is mostly vulnerable if droughts last longer than 1 single year and if the winter is particularly dry.** This is an event that occurs every 50 years on average. The reservoirs are managed by the level of water contained and the water resources usage over the year. The raw water system is all interconnect allowing a more efficient water management by managing 6 different reservoirs and if was only one. The Figure 127 outlines the reservoir control curves that trigger key actions dependant of drought severity.

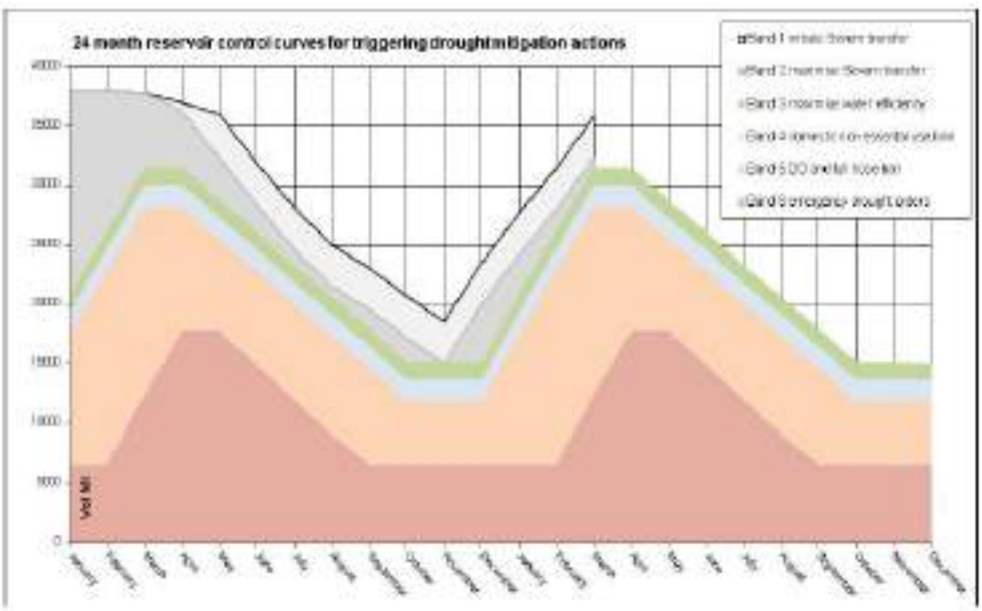


Figure 127: Bristol. 24 months reservoir control curves.

5.3.4 Urban Drainage

Wessex Water is responsible for managing the flood risk from all public sewers in Bristol. This comprises separate storm and foul sewers and also combined sewers which contain the both. Many of the older parts of Bristol have these combined systems which were originally built back in Victorian times. Where combined sewer systems occur in greatest abundance in the city is displayed in Figure 128.

Figure 128 - Showing areas of Bristol with the highest proportion of combined sewers.

The urban sewer network can be beneficial for dealing with prolonged rainfall events over time. As water is released quickly through the system whereas on greenfield land the groundwater table gradually rises. The urban drainage network does not deal so well with short, intense rainfall events however. This is due to a limited amount of capacity in the network. The resultant effects can then be surcharging and flooding.

Combined Sewer Overflows (CSOs) are also found in the Bristol area. Again Victorian made these systems can have severe health implications. They operate by spilling excess sewer flows into watercourse during exceptionally high flows. This can then contaminate the receiving watercourse. There are associated human health hazards associated with this.

Wessex Water has the following responsibilities for managing the sewer network.

- A **duty** to co-operate with other risk management authorities in the exercise of their flood risk management functions
- A **duty** to provide, improve and extend a system of public sewers and to cleanse and maintain those sewers
- A **power** to construct lateral drains following the provision of a public sewer

- A **power** to adopt a sewer within its area that is constructed to suitable standards
- A **power** to alter the drainage system of premises in its area that connects with a public sewer
- A **power** to investigate defective sewers
- A **power** to discontinue and prohibit the use of any public sewer in its area

BCC Highway drainage also exists which is managed monitored and regulated by BCC Highways team. These are for managing surface water flows on the highway in conjunction with the predominant Wessex Water system.

The Bristol Surface Water Management Plan (SWMP) has analyzed the existing drainage network in pluvial flood conditions. The SWMP primarily involved a hydraulic modelling assessment predicting at the impacts of heavy rainfall events over the Bristol region, making considering to the sewer network. This was achieved by linking a 2D ground surface with a 1D sewer network within the Microdrainage Windes software, using the Floodflow package. The SWMP also used a multi-criteria analysis approach to identify the areas of the city at highest risk of surface water issues (known as High Risk Areas), which themselves have been used by BCC as a basis for our development management approaches. In addition to the model files, datasets available primarily include results files in GIS (ASCII) format.

Datasets include flood depth, hazard and velocity, which in turn also help identify critical flow routes through the city. This can all be utilised to highlight critical infrastructure at substantial risk. BCC own the SWMP model under a data sharing agreement with Wessex Water. Given the naturer of Wessex Water being a private company, relatively tight restrictions exist on the sharing of the SWMP model. Such restrictions generally concern public availability of the model, rather than licenced use on projects led by BCC or Wessex Water. More information is available:
https://www.bristol.gov.uk/documents/20182/33916/2012.08.08%20SWMP_Final%20Phase%201%20Report-No%20Appendices_0.pdf/6d93f555-0558-4d0c-b94b-532620d3914c

Main climatic effects and natural hazards affecting the service and the critical infrastructures

One of the more pressing concerns within Bristol is that of flooding as the expanding population in the central area also combines with an area subjected to heightened tidal flood risk over time. The Central Area Flood Risk Assessment conducted by BCC established this risk will increase in the future and worsen still with sea level rise and increased stormy conditions. Whilst at the same time the population and amount of people living in this area is predicted to increase further still as well. This densely populated area will expose even more people to the risk of flooding from a large tidal event.

The areas of deprivation in south Bristol that were highlighted correlate with an area subjected to a high risk of surface water flooding. Areas located furthest south in the city border on the North Somerset Council boundary. These lie at the base of Dundry Hills. These steep sloping clay hills generate much surface water runoff during heavy rainfall events. Their steep topographic position and soil composition, which does not allow much percolation and infiltration to ground, directs large quantities of runoff towards residents below. The resultant flash flooding this area is susceptible to makes them particularly vulnerable during heavy storm events. The problem could be exacerbated due to the higher levels of deprivation associated with the area. A lack of access and availability of services, resources and broken communication links can add to this vulnerability. Knowing who to approach in the event of an emergency and having the means to do this could be a hindrance. Affordability of resilience measures to manage the risk themselves could also be a potential barrier restricting resilience. There are also areas of high depravation indicated in north Bristol in the Southmead area which is prone to surface water flooding.

The locality of the high BME population in Bristol also coincides with an area identified as at high risk to flooding. Problems associated with this can be language barriers and communicating flood risk to people. Those new to an area may also be unaware of the risk posed.

The main Bristol business hub that provides much of the city's employment and keeps it thriving is located centrally. Again the high tidal flood risk posed to this area and the impacts of climate change that will exacerbate this are a major threat to Bristol's economy and functioning properly.

Geographically the hilly topography of the Bristol region can lead to faster surface water velocities. This can prove to be an instant flood hazard and danger in instances of sudden, heavy downpours and flash flooding.

There are Health and safety concerns from contaminated watercourses due to Combined Sewer Overflow (CSO) spills. Which is an urban drainage related problem.

5.3.5 Waste Water Treatment

Avonmouth Sewage Treatment Centre

Geneco's largest treatment centre is at Avonmouth processing around 300 million litres of sewage a day. The centre provides an easy to access, cost effective and environmentally friendly responsible liquid waste treatment for customers such as waste management companies, council waste teams and commercial organisation. Through this innovative processes is produced environmentally friendly biogas and nutrient rich bio-fertilisers. Also, more than 3000 homes in Bristol are being powered by gas produced from their own waste.

Bristol Avonmouth Waste Water Treatment Works is Wessex Water's largest plant. It's location is shown on the Figure 129.

Figure 129. Avonmouth sewage treatment works. Location

It is situated on 46.5 hectares of marshland reclaimed from the Severn Estuary at Avonmouth. This serves the Bristol area and beyond, treating the bodily waste of up to a million people in South West England.

This sewage sludge AD (anaerobic digestion) plant is fed by Bristol's four major sewer systems and treats on average 210 megalitres per day (210 million litres of sewage). The sewage treatment process involves screening plastic, paper and sanitary material from non-flushable items such as wet wipes and nappies and grit. Biomethane is a product of the AD process and used as a natural gas substitute. This is produced by micro-organisms breaking down biodegradable material in the absence of oxygen.

Main climatic effects and natural hazards affecting the service and the critical infrastructures

Flooding is one of the consequences that is exacerbated by climate change. Bristol still rely on old Victorian drainage infrastructure that was not designed to deal with more frequent storm like events that overcharge stormwater drainage systems and Wastewater Treatment Plans. In cities like Bristol most damages arise from surface water runoff overloading the drainage system. Extreme rainfall events can saturate and clog the drainage system, mixing both grey water with sewage water. The first barrier to these events are the storm water retention basins. Those can become obsolete when such events occur, leading to a dilution of raw water with rain water, altering water parameters and consequently the **water treatment processes of** wastewater treatment plant

5.4 Energy

The Energy Service at Bristol City Council ensures the city has a secure energy supply, is resilient to future changes, and actively reducing carbon emissions for the city.

Bristol has committed a budget of up to 300m for energy efficiency and renewable energy by 2020. Since 2005, the carbon emissions have constantly reduced in the city, despite a growing economy. Bristol's aim is to become a European hub for low-carbon industry and it has demonstrated 4.7% growth in the green economy in 2012. One scheme that helps to reduce carbon emissions is Bristol City Council's Warm Up Bristol scheme is an initiative designed to make the private housing stock in Bristol more energy efficient to create cosier and healthier homes.

Bristol was one of the first local authorities to buy electricity generated from renewable sources, when contracts were negotiated for the Create Centre and the Records Office (B Bond) in 1998. Since then, more properties have been using 100% renewable electricity. This contributed to the target set out in our Energy Policy of buying 15% of the council's electricity from renewable sources by 2010. We are now working to the '20-20-20' targets:

- A reduction in EU greenhouse gas emissions of at least 20% below 1990 levels
- 20% of EU energy consumption to come from renewable resources and a
- 20% cut in primary energy use compared with projected levels, to be achieved by improving energy efficiency

Below are descriptions of projects and schemes that have been set up by Bristol City Council in order to increase the cities usage of renewable energy.

Wind Energy

By the end of Autumn 2013 the Energy Management Unit will have seen through the whole Avonmouth Wind Turbine project, which has taken over ten years, leading to Bristol City Council having the first Local Authority owned wind turbines. Following a review of renewable energy potential in different parts of the city in 2002, EMU landed on the idea of a wind turbines development. After addressing any potential concerns, EMU submitted a planning application with supporting Environmental Impact Assessment, Environmental Statement and Statement of Community Involvement in August 2008. Planning permission was granted in January 2009. The works on site commenced in April 2013 with construction completion in the autumn and full wind turbine development takeover in December. The combined power of both turbines will generate an estimated 14,000 MWh per year and will be in use until the end of 2037.

Solar Energy

To date the Energy Management Unit has installed Solar PV in 36 schools in Bristol. Not only has the project generated renewable green energy for the schools, it has also increased awareness of energy issues amongst the staff and pupils and also significantly reduced carbon emissions. In the forthcoming months the Energy Management Unit has plans to install solar PV on another 32 domestic sites, ten schools and a corporate office building as part of the Western Power Distribution SOLA project.

Biomass

Since 2005, the Energy Management Unit has been involved in the installation of 15 biomass boilers at various sites around Bristol, including the Mshed in the harbourside. In recent weeks EMU have also just finished the redevelopment of Blaise Nursery wood fuel station, where the council's tree surgery waste is recycled into biomass fuel. It is the UK's first local authority owned wood fuel station and ensures there is sufficient wood fuel supply for both Bristol City Council's biomass boilers and others installed in the West of England.

As much of the energy provision is by private companies the key Energy infrastructure data and installations will need to be provided by them. A main electricity provider for the south west region England region is Western Power Distribution. There are 186 electrical substations distributed throughout the Bristol region.

With regards to natural gas much of this is provided nationally through British Gas. However as with the electricity there are many different companies and providers of this service.

Main climatic effects and natural hazards affecting the service and the critical infrastructures

Pipe and cable breakage are threats for disrupting energy supply. Demand of limited natural resources in the future could also be a concern. Flooding of critical infrastructure systems could be more likely in the future due to the increased effects of climate change. This would also potentially disable key communications networks, heating and cooking supplies.

5.5 Transport

Bristol is known as the gateway to the south west. This is due to its many connections and transport routes in and out of the city. The motorways in the city, managed by the Highways Authority, include the M32 linking to the central area from the M4. The M4 traverses east to west across the country, connecting to London eastwards and Cardiff to the west. This then connects to the north and south via the M5, another major motorway passing through Bristol. As well as this there are 18 major A roads in Bristol and 6114 streets in the BCC limits. These areas of adopted highway are managed by BCC. Including in this is the Portway. A key A road route linking to the motorways and central areas. Figure 130 shows the key road network in Bristol. Data for BCC adopted highways that have particular traffic sensitivities is available. Approximately 250 have been identified.

Figure 130 - Showing some of the main transport roads in Bristol

The rail network in Bristol also connects to all major cities via the Temple Meads station in the central area and Bristol Parkway just north of Bristol. Bristol Temple Meads Station is located adjacent to Flood Zone 3, a high risk area. See Figure 131 below.

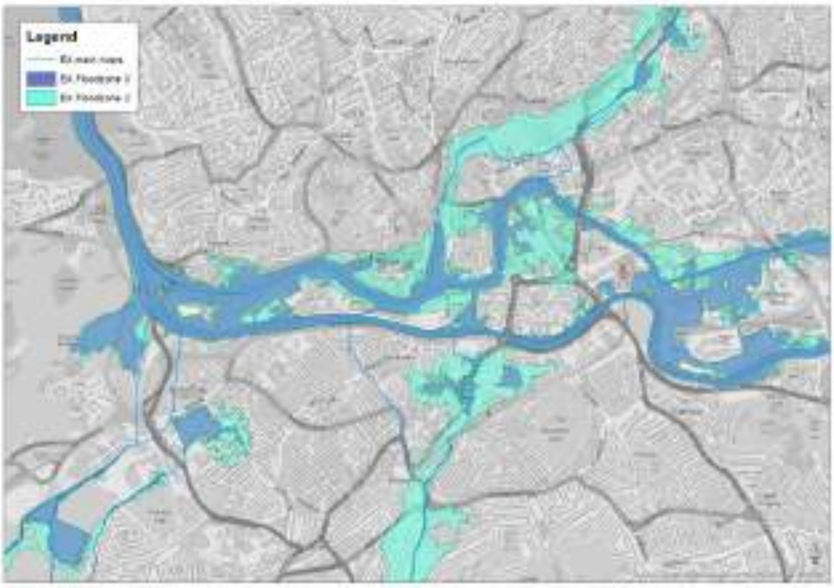


Figure 131 - Temple Meads Train Station (indicated by the red star) EA Flood Zones.

At Avonmouth Docks there are links from the sea to elsewhere in the world. This is used heavily for industry and more recently tourism cruises.

Bristol airport lies south of the city with direct flights to Europe and other parts of the world.

There are many bridges and retaining walls also throughout Bristol which are BCC assets and critical parts of infrastructure to keep the city moving at all times.

The network and traffic controls in Bristol operate on a system designed to optimise traffic flow. B-Net fibre cable and SCOOT and ASTRID are the systems used. The traffic light actions are determined by detectors which function more or less frequently, dependant on the traffic present. This is to enable a more constant flow of traffic. The operating systems alternate dependant on the time of day. During busier times SCOOT will try and maximise the traffic flow. While during quieter periods B-Net will operate, run by local conditions. ASTRID will use historical data and probability estimates. A drawback of this system is irregularities during times like bank holidays for instance. The BCC Control Room Team will work in conjunction with these systems by monitoring CCTV camera images. Other systems that are having been experimented with include the WAZE system, INRIX, Paramics, Highway Agency feeds (for motorways) and occasionally TomTom. These are less frequently applied though. Greater gain is apparently to know extreme traffic events rather than the usual congestion and the algorithm sometimes lose this (for example picking up cyclists in counts in the TomTom system).

Traffic trends observed in Bristol are busier times Monday morning and Friday night, whereas Wednesday is quieter. Annual variation shows - mid October to December traffic worse because of Christmas shoppers and more exiting of car parks. Issues with the models are that they cannot reflect human error and chaotic behaviour, such as parking on the street and bus dwell time on bus stops too accurately. Flood events or other hazards occurring during these particular times worsen their effects.

Within the mathematical modelling side the University of Exeter (UNEXE) will be investigating the use of an Open Source vehicle modelling software package known as SUMO [5](Simulation of Urban MObility). This software allows for the simulation of multiple transportation modes including public transport and pedestrians and additionally allows for the inclusion of time schedules for traffics lights. One of the aims of the research at UNEXE will be to simulate flood impacts on the road network in Bristol to look at the effects on traffic flow disruption and see what means can be put into place to minimise such impacts. The proposal by Exeter for assessing impacts of hazards for the traffic modelling side is to therefore build upon the work outlined by Pyatkova *et al*. (2015) by looking at the impact of flood events on traffic/journey times. Figure 132 shows the methodology previously used for linking the traffic model with the flood model whereby the flood extent maps serve as a bridge/interaction point between the two. The numerical modelling results under extreme scenarios provide the information of extent, depth and propagation of flood events. These will in turn affect the accessibility of road networks during the events, which are used as additional restrictions in SUMO model

[5] http://www.dlr.de/ts/en/desktopdefault.aspx/tabid-9883/16931_read-41000/

configurations. The traffic conditions for both scenarios, with and without flooding, will be simulated and compared to evaluate the disruptions caused by flooding.

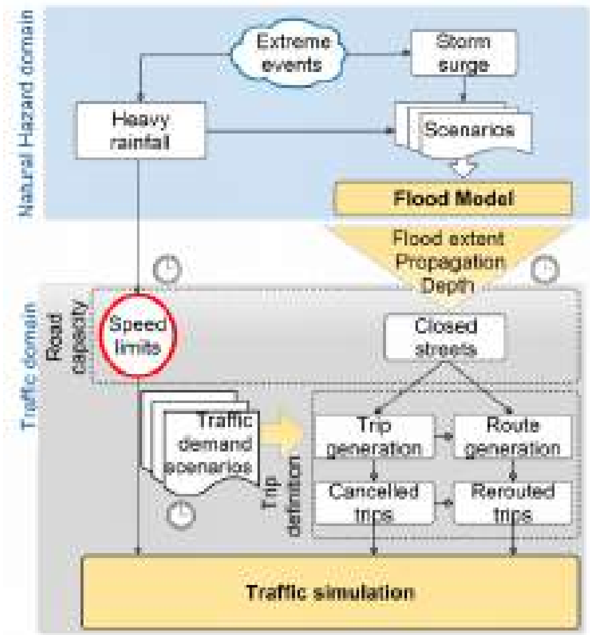


Figure 132 - Methodology of linking traffic simulations with Flood Models proposed in PEARL project (Pyatkova et al. 2015).

Main climatic effects and natural hazards affecting the service and the critical infrastructures

Like many other roads in Bristol, this **experiences flooding problems,** but with more significant impacts. Due to its importance it is a vital route that when inaccessible causes much disruption and congestion. Its location adjacent to the tidal River Avon means it is exposed to tidal flooding during certain high Spring tides. The road will remain flooded through at least the duration of the high tide so may be beyond 45 minutes to an hour but the disruption can last longer. Other roads in the central area that suffer tidal flooding are Commercial Road and Cumberland Road that have minor impacts on the network. Clarence Road has a bigger impact on the traffic network. Cattlemarket Road underpass is positioned at low depth and so becomes inundated and inaccessible during very high tides. This also causes risk to human life from drowning unless cordoned off by BCC Network Management Team. Bond Street sees the biggest queues of traffic in Bristol, with those entering the city via the M32.

Rainfall causes even more disruption on Bristol's highways. Flooded roads become impassable, leading to congestion on alternative routes as well. Examples of this with regard to vital, key routes include the M32 between J3 and Newfoundland Circus. The Bath Bridges and Whiteladies Road routes also are all critical routes into the centre. Scotland Rd in east Bristol is the main route into Brislington Park and Ride, an express bus route and car park service. This regularly floods during heavy rainfall events, blocking this important route. Drainage capacity restrictions, due to extreme pluvial flows are the major disruptor here.

In November 2016 a problem occurred in Bristol involving the B-Net switch not working. This communication break caused traffic signal failure during the 17:00 rush hour traffic and then associated major congestion in central Bristol. Problems with the network switching, B-Net, SCOOT Saturation and Server maintenance were identified as the causes for the disruption.

There is a disadvantage observed with existing systems of communication with the local police. Their road closures and notifications of this do not always link up well with the Control Room Team's traffic management plans. Road works are determined as another major disrupting factor in slowing up traffic conditions.

With regards to **snowfall** even though this does not happen regularly each winter when it does it brings much disruption. Due to its rarity UK services are not so well equipped to deal with the extreme cold and snow and ice conditions. **Snowfall often leads to disruption of transportation services both private and public sectors** and results in increased pressures on local authorities to maintain routes to enable restoration or continuation of traffic flow. In Bristol only critical routes are gritted during snowfall events which leave 60% of the network down and unaccounted for. Road closure at the Three Lamps junction and then the resultant congestion on St Johns Lane is example of a previous snow event causing hold ups.

Failure of the **rail network** from Avonmouth Docks can disrupt the distribution of goods delivered and transported from the region. Likewise the vulnerability of flooding of the rail network disables people travelling elsewhere around the country or into the region. If this is not functioning stations like Temple Meads are critical for business and to the local workforce and economy.

5.6 Waste

Bristol leads in the UK on waste reduction and management. It has clear targets and is achieving reductions in waste to landfill and has targeted recycling and energy recovery from residual waste. Bristol Waste Company cover 17 million scheduled collections every year, operate 180 vehicles, collect 140,000 tonnes of waste and recycling per annum – of which 53,000 tonnes is sent for composting or recycling. They clean 800 miles of streets and footpaths and deal with 180,000 ad hoc job requests and service queries annually.

The long term mission is to achieve a 'zero waste' Bristol, where we make the most of efficient use of resources by minimising the city's demand on natural resources, preventing or minimising waste generation and maximising the repair, re-use, recycling and recovery of resources instead of treating them as waste. Vision for a city where there is a clean, green, safe and sustainable street-scene for residents and for visitors to Bristol.

Bristol has the lowest waste per capita of any major English city and substantially (23%) lower than the UK average. In 2011, the household waste per capita was 378kg in Bristol compared to the national average of 449kg.

The potential of recovering energy from waste has grown considerably since the opening of a Mechanical Biological Treatment (MBT) plant in Avonmouth in 2011. The Avonmouth facility produces a fuel from the waste which is then used to power a co-located energy facility that applies methods such as 'gasification' and 'pyrolysis' technologies. Around 25% of Bristol's waste is now converted through these methods.

Another potential opportunity for increasing energy recovery from waste has been presented by the establishment of Bristol City Council's Energy Company in 2015: Bristol Energy & Technology Services (Supply) Limited (BETS). The Council is the ultimate owner of BETS. It provides an alternative supplier of energy distribution for the citizens of Bristol but is not associated with the treatment and processing of waste to energy recovery.

The progress made as a result of Bristol City Council policies and services are summarised in the graph below, which shows the percentage of household waste by treatment method. The amount of household waste is clearly decreasing at a significant rate.

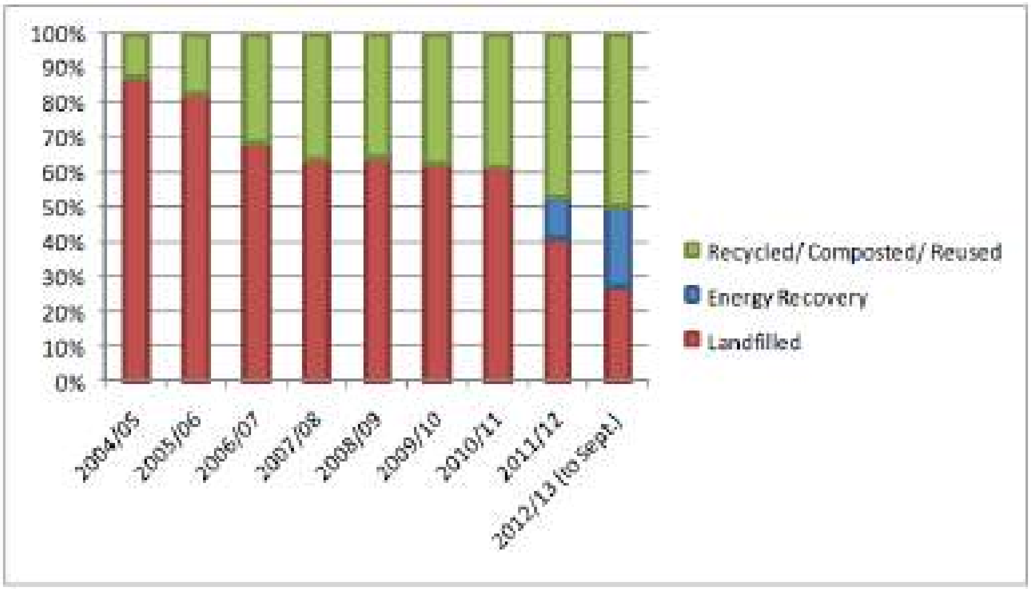


Figure 133 – Waste management processing in Bristol.

In 2011, the recycling rate in Bristol was 50%, since new waste collection and waste treatment services and facilities were introduced. Ideally we must stop the problem at its source (see Figure 134, below). This means significant changes from manufacturers, packaging methods and most of all, from the consumer. Also, it means that Bristol City Council has an important role in encouraging everyone to behave in a more sustainable way, through promotion and education, the provision of services, and ultimately, through enforcement action.

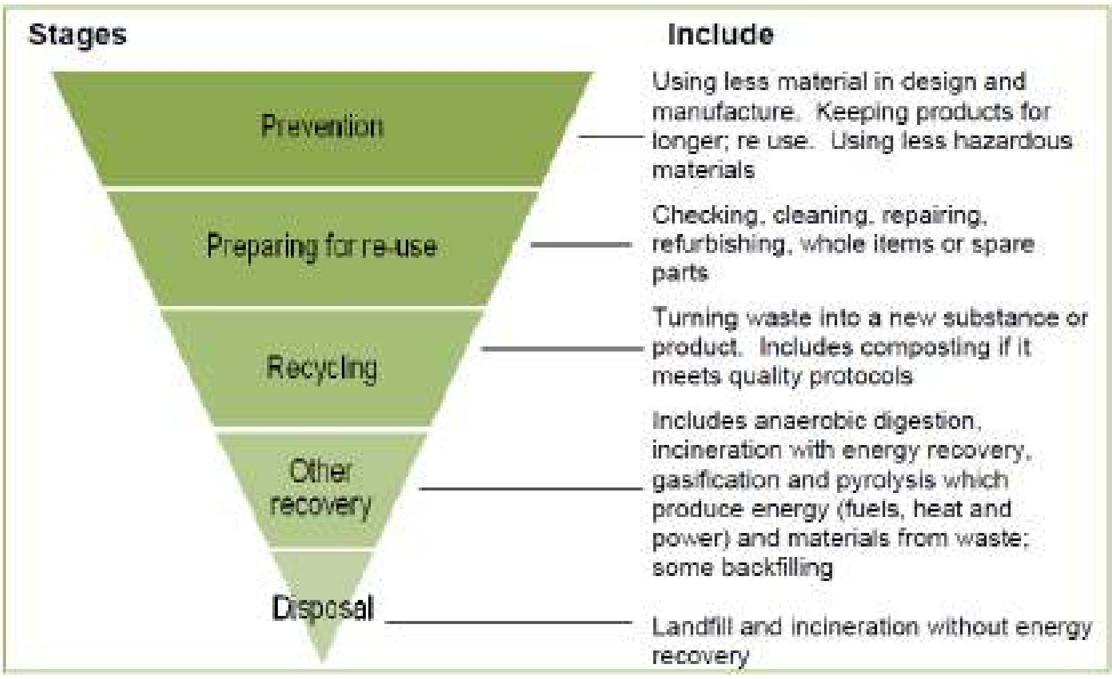


Figure 134 – Waste management strategy.

Bristol is fortunate in having a wide range of local community organisations and structures that are already involved in waste and resource management activities which can provide a firm basis for future partnership working going forward. Bristol Re-Use, set up in 2015 by the Bristol Green Capital Partnership's Waste Action Group, has brought together a network of Bristol-based Re-Use organisations, such as The Bristol Wood Recycling Project, Children's Scrapstore, SOFA Project and Bristol Textiles Recycling Ltd.

Main climatic effects and natural hazards affecting the service and the critical infrastructures

Bristol Waste is a part of Bristol City Council and operates the refuse collection and recycling service. Vulnerabilities to its functioning properly include snowfall. When encountered in abundance this has in the past disrupted collection routes and prevented waste being removed. Certain main routes will be gritted and snow removed when covered in a snow storm. This leaves less busy or inaccessible areas more vulnerable to human health hazards and poor hygiene. Due to encountering putrefying effects of rot and decay, whilst attracting germ and disease ridden insects such as flies. The key gritting routes are available on the Bristol Pinpoint website.

RESCCUE
RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

5.7 Green Infrastructures

Current situation and general context

Bristol is often regarded as the greenest city in England and within the UK. This is due to a vast amount of green space and parkland present. Much of this is available for recreational use, including hosting many festivals and provides excellent amenity value making the city a healthier and happier place to live in. The green areas and associated sustainability principles are core features of the city. Addressing the impacts of climate change aspects such as low carbon living are fundamental to the future of the city and its people. This is evidential in Bristol becoming crowned Green Capital in 2015.

Some of the main aims in Bristol are to conserve green infrastructure, raise awareness of the benefits and adapt to climate change. The large quantities of green areas enhance biodiversity, ecology and nature whilst giving amenity value to residents and the general public. Further benefits derived from this however can also include temporary flood water storage provision. The flooding of less vulnerable land use areas during a flood being far more preferential to land functions deemed of higher vulnerability, such as residential units for instance. Green spaces also provide an important cooling effect in cities.

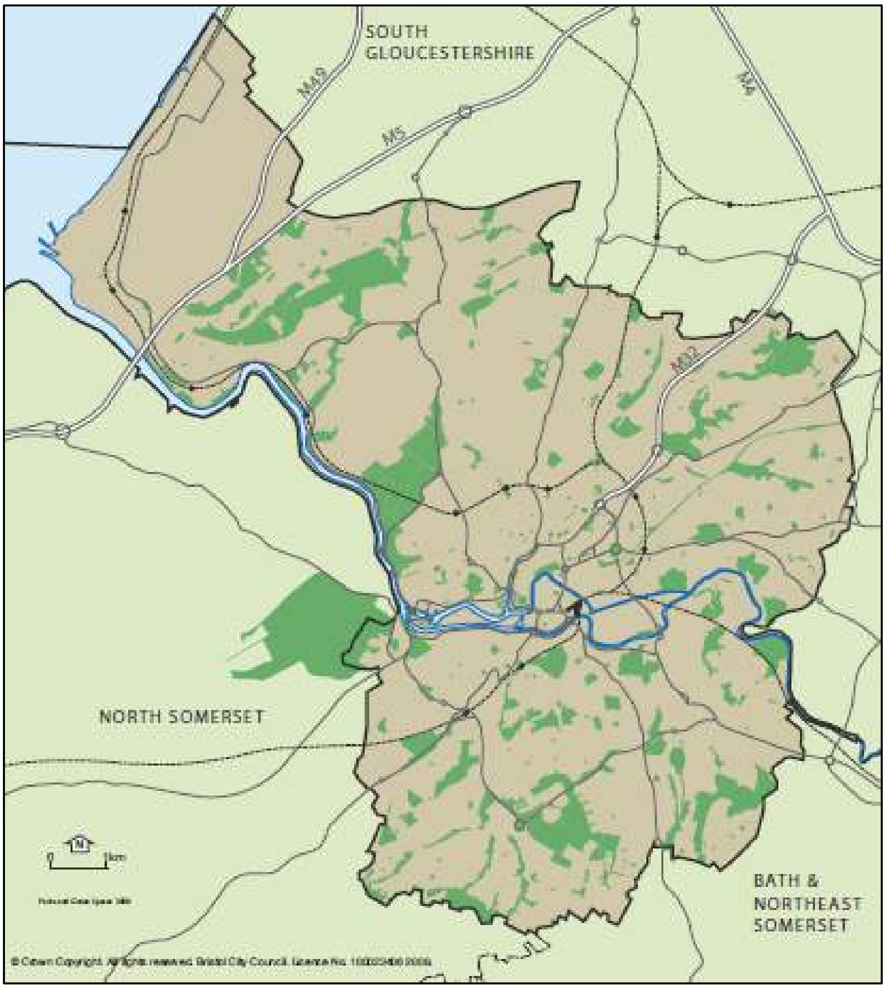


Figure 135: Bristol map of green space

Sustainable Development

City planning objectives aim to focus and prioritise development on existing brownfield areas and avoidance of infringing on regions of current Greenfield land. This helps to preserve more freely draining permeable cover such as grasses and vegetated areas. Whilst also limiting the increase of impermeable surface cover, in the form of concrete or hard surfaces for example, that produces a greater amount of surface water runoff off and potential for pluvial flooding. This approach aligns with the national non-statutory technical Sustainable Drainage Systems (SuDS) standards and aims to avoid increased flood risk from developments threatening third parties. Maintaining Greenfield run off rates is a key motivation for new developments planned.

Planning Policy

Steering development away from high risk areas and green space is part of the National Planning Policy Framework guidance and the associated Technical Guidance. That and avoiding an increased flood risk to third parties following development are paramount. Effects felt by building over Greenfield land. These objectives are imbedded in national Planning Practice Guidance and local planning policy such as the Bristol Local Plan, Site Allocations and Core Strategy. Key policies include;

- **Policy BCS6 Green Belt,** Countryside and other open land around the existing built-up areas of the city will be safeguarded by maintaining the current extent of the Green Belt. Land within the Green Belt will be protected from inappropriate development as set out in national planning policy.
- **Policy BCS9 Green Infrastructure**, aims to protect, provide, enhance and expand the green infrastructure assets which contribute to the quality of life within and around

Bristol.

- **Policy BCS13 Climate Change**, The use of green infrastructure to minimise and mitigate the heating of the urban environment.
- **Policy BCS14 Sustainable Energy**, impacts on biodiversity, landscape character, the historic environment
- **Policy BCS15 Sustainable Design and Construction,** Scope out opportunities to incorporate measures which enhance the biodiversity value of development, such as green roofs.
- **Policy BCS16 Flood Risk and Water Management**, All development will also be expected to incorporate water management measures to reduce surface water run-off and ensure that it does not increase flood risks elsewhere. This should include the use of sustainable drainage systems (SUDS).

The main policy linked to green infrastructure is the Bristol parks and green space strategy for maintaining and prioritising critical parks and green spaces in the city. The Bristol Biodiversity Plan likewise promotes the conservation of the natural environment. Creating pocket parks and greenway channels are further motivations to enhance city living, expanding green coverage and deriving their multiple benefits cumulatively.

Sustainable Drainage Systems

The West of England Sustainable Drainage Developers Guides encourages and promotes the use of greener more sustainable drainage systems for new development. Aiming to mimic the natural environment and avoid the use of traditional hard engineered piped solutions for drainage provision. Options such as ponds, swales, detention basins, green roofs, bioretention pods, wetland areas rather than attenuation tanks or oversized sewers are preferred. The benefits gained from this include managing flood risk, water resources, water quality and biodiversity as well as providing recreational and educational areas for the community.

Much of the green space in Bristol is centred on some of the key waterways, as indicated in Figure 136 and Figure 137. Making it critical these areas are preserved to save encroaching on areas exposed to a higher risk of flooding that will worsen further still into the future with the effects of climate change.

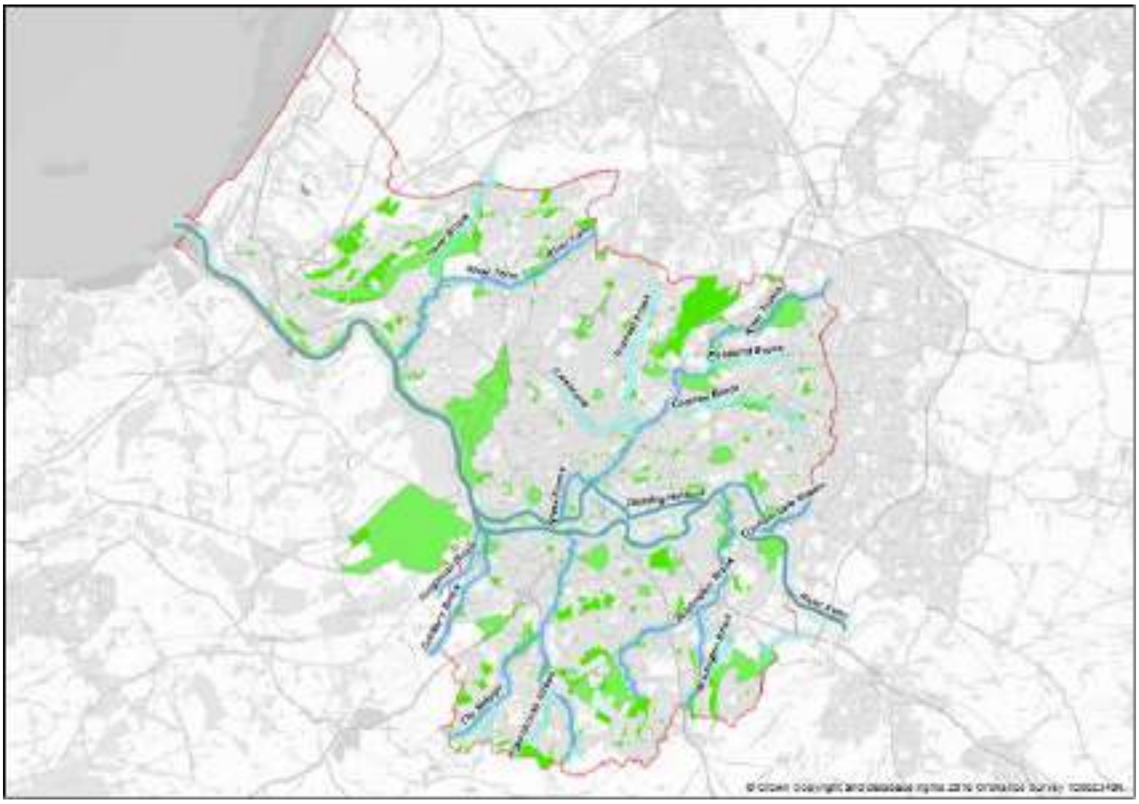


Figure 136: Blue corridors and green space

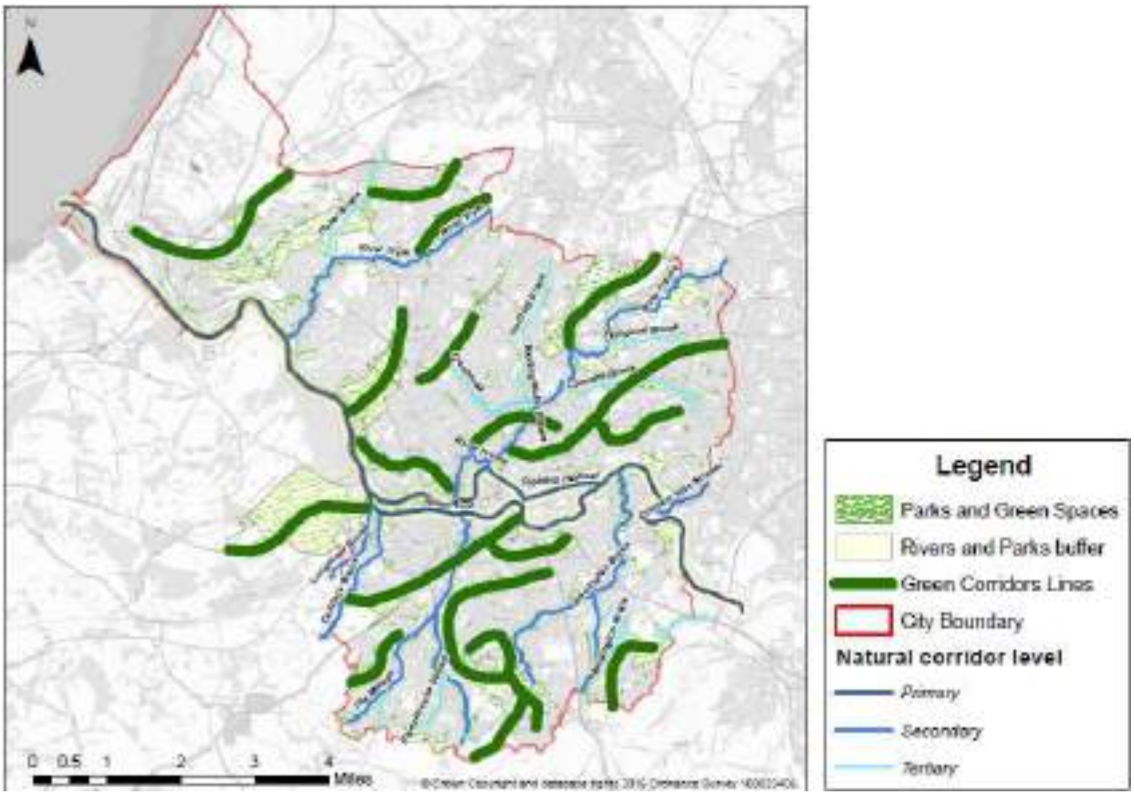


Figure 137: Bristol green corridors map

Green infrastructure statistics and figures

In Bristol there are 427 parks and green spaces across the city (as defined in the Parks and green space strategy where primary function is recreation) covering 1871.76 hectares. This includes the part of Ashton Court Estate which technically lies in North Somerset Council. 52,284 trees are mapped across the city, including 10,591 trees on the adopted highway, 869 highways trees not in the adopted highway, 21,565 parks trees, and 7,915 Housing Department trees. Additionally there are 511.59 hectares of council managed woodlands where trees have not been mapped individually.

There are 6,184 allotment plots covering 105.5 hectares over 104 council run sites plus a number of association run sites. There are 897 hectares of parks service managed grassed areas including parks, highway verges and housing sites.

The trees lining the streets provide important environmental benefits but could also cause detrimental effects relating to weather related damage, particular if infringing on the traffic network.

Outside of the main park areas and larger stretches and expanses of green space there are many other smaller pockets and areas of green space within Bristol. Including gardens, allotments, flower beds, green or living roofs, public rights of way, city farms, school playing field, wildlife centres, community gardens, adventure playgrounds, cemeteries, church yards, council grazing land, street trees, highway landscapes including verges, traffic islands and central reservations.

Challenges and opportunities

- City aims are to promote development to ensure a prosperous thriving economy, which on restricted land space available resultantly means encroaching on green space.
- Limited council funding is available to preserve and maintain all of the green space. Especially due to austerity measures and recent cut backs.
- Vandalism and antisocial behaviour can make park areas less appealing for the community to utilise. Regular maintenance and monitoring can deter this though.
- Certain smaller sections of green space will be sold off in order to generate income and enable future development.
- Overland surface water flows from Dundry hills to the south of the city as well as all other rivers and tributaries end up flowing into Bristol from the surrounding areas. These lie adjacent to some densely populated areas, particularly around the central area. Preservation of and management of these key blue and green networks is therefore critical.
- The Severn Estuary and various woodland regions around Bristol comprise a wide range of environments and ecosystems. Beneficial on many fronts to the population of Bristol, from air and water quality benefits to recreational activities and diverse species of flora and fauna.
- The predominantly clay soil throughout Bristol is regularly interspersed with sandstones and fractured limestone bedrock. This makes for mixed infiltration and consequentially drainage potential throughout the region. Greater natural exposure of land over a larger area therefore increases chances of the uptake of water to ground. In turn this can reduces the potential of flooding incidents.
- High water table levels and flooding from Greenfield land following prolonged rainfall can occur near areas of green space. As was witnessed in 2012 when the UK observed the highest annual rainfall on record. In these instances traditional piped sewer systems can work more effectively by efficiently removing water away from the catchment. They do not cope so well for the high intensity rapid downpours typical of thunderstorms which will become more prevalent according to climate change forecasts and predictions.

Main climatic effects and natural hazards affecting the green infrastructures

Green space adjacent to tidal watercourses will become more frequently washed out, destabilising river banks. High water table levels and flooding from Greenfield land following prolonged rainfall can occur near areas of green space. Dry ground can lead to hindering infiltration potential and increase the chance of overland flow following heavy downpours. Strong winds mobilise more vegetation and debris which can subsequently become stuck on trash screen grills and cause blockages and flooding problems. The winds can also blow over trees also resulting in damages. Rapid snow melt following a quick thaw of snowfall positioned on hillsides facing towards properties could result in pluvial flooding.

5.8 Bristol matrix of exposure and direct impacts among extreme climate variables and failure in urban services

The information collected in the section of this deliverable is used to create specific tables for each research site to relate climate variables and direct and indirect impacts of main urban services analysed in RESCCUE according to their level of exposure. These tables could be used in the WP4 for the elaboration of the interdependency matrix of each research site.

In previous sections, urban services have been described according to the potential interdependencies among urban services failures, regarding cascade effects and the consequences involved in each failure. Summarising these descriptions the Table 31 presents a synthesis of the main correlations among climate variables (temperature, rain and wind) likely hazard (heat wave, sea level rise, flooding, drought, CSO's, windstorm) and critical urban services.

The urban services are broken out in subsystems and critical elements. For each one of this critical element, it has been signed when the element is exposed or not to each hazard or even when the hazard has not been considered.

URBAN SERVICES	URBAN SERVICE CYCLE	SUBSYSTEMS	CRITICAL ELEMENTS	CLIMATIC VARIBLE: Temperature HAZARD: Heat Wave	Temperature Sea level rise	Rain Urban flooding	Rain Drought	Rain CSOs	Wind Windstorm	Rain Snow	COMMENTS ABOUT POTENCIAL DERIVED RISKS / CASCADE FAILURES
Energy	Electricity	Power generation	Large Power plant	✓	✓	✓	✓	✓	✓	✓	
			Distributed power plant	✓	✓	✓	✓	✓	✓	✓	
		Power Transmission	Substation	✓	✓	✓	✓	✓	✗	✗	Damages, collapse, interruption of energy supply. Water supply cascading effects: failures regarding electromechanical and control systems. Urban drainage: failures iregarding pumping and control systems. WWTP: failures regarding electromechanical elements and control systems. Street light and automated traffic control system goes down: failures regarding function and control systems. Telecommunication: cellulars towers, central offices and other critical communications used in monitoring and controlling the delivery of electricity.
			Overhead lines	✓	✓	✓	✓	✓	✗	✗	
			Underground cables	✓	✓	✓	✓	✓	✗	✗	
		Power Distribution	Substation	✓	✓	✓	✓	✓	✗	✗	Damages, collapse, interruption of energy supply. Water supply cascading effects: failures regarding electromechanical and control systems. Urban drainage: failures iregarding pumping and control systems. WWTP: failures regarding electromechanical elements and control systems. Street light and automated traffic control system goes down: failures regarding function and control systems. Telecommunication: cellulars towers, central offices and other critical communications used in monitoring and controlling the delivery of electricity.
			Overhead lines	✓	✓	✓	✓	✓	✗	✗	
			Underground cables	✓	✓	✓	✓	✓	✗	✗	
Urban water (	Water Supply	Water Distribution	Distribution network	✗	✓	✗	✗	✓	✓	✓	Increase Water Demand. Insufficient availability, limitation in supply Pipe burst - Low temparatures - Cascading effects on several urban services affecting control and communication systems.
		Water Abstraction	Pumping stations	✗	✓	✗	✓	✓	✓	✓	Insufficient availability, limitation in supply Energy supply failure, mechanical failuire, Telecontrol failure
			Resources	✓	✗	✗	✗	✓	✓	✓	Insufficient availability, limitation in supply. Superficial and groundwater water quality deterioration
		Water Treatment	WTPlants	✗	✓	✗	✓	✓	✓	✓	Treatments performance reduction / Energy supply failure/Mechanical failure/ Telecontrol failure. Cascading effects on several urban services affecting control
	Urban Drainage	Sewers system	Sewer network	✓	✓	✗	✗	✗	✓	✓	Limited conveyance capacity, high street runoff (level and velocity), CSOs. Contamination fo land from CSOs. Transport cascading effects: road and rail traffic disturbance and interruptions, flooding of underground infraestructures (metro, train, parkins). Solid waste: overturn, dragging and damage on wastes. Energy: Damage to equipment and lines. Control of river level at dock cia sluice gates Other urban services: pedestrian ways, parking lotsplaygrounds, among others, untreated discharges, pollution of receiving water bodies. Long drought of drought followed by rainfall can lead to severe toxic contamination at outflow
			Pump stations	✓	✓	✗	✓	✗	✓	✓	Electrical or mechanical failures due to flooding with consequences in terms of pumping lower capacity and CSOs. High salinity degrading mechanical equipment. Excesive inflows. Transport: Road traffic disturbances and interruptions.
	Waste Water Treatment	Waste Water Treatment Plant (WWTP)	WWTP	✓	✓	✗	✓	✗	✓	✓	Excessive inflow anfd dilution generating lower treatment efficiency and CSOs. High rainfall could increase pressure on system.
Waste	Solid waste	Solid Urban Waste Collection (SUW)	Pneumatic collecting plants	✓	✓	✓	✓	✓	✓	✓	
			Pneumatic collecting network	✓	✓	✓	✓	✓	✓	✓	
			Waste vehicles	✓	✓	✗	✓	✓	✓	✓	Damage, road closures. Cascading effects considered on urban drainage: obstruction of components and surface flows
		Cleaning	Solid waste containers	✓	✓	✓	✓	✓	✓	✓	
		SUW Treatment	Waste treatment plant	✓	✓	✓	✓	✓	✓	✓	
			Cleaning stations	✓	✓	✓	✓	✓	✓	✓	
Transport	Roadways	Roadways	Main roadways	✓	✗	✗	✓	✓	✗	✗	Flooding , stormwind and snowfall can cause interruption of public and private transportation including underground infrastructures. Several urban services could be affected by cascading effects if maintenance or repair tasks are required during failures.
			Secondary roadways	✓	✗	✗	✓	✓	✗	✗	
			Local roads	✓	✗	✗	✓	✓	✗	✗	
			Traffic signals	✓	✗	✗	✓	✓	✗	✓	Wind can generate failures of traffic control systems. Several urban services could be affected by cascading effects if maintenance or repair tasks are required during failures.
	Rail	Rail	Surface rail network	✓	✗	✗	✓	✓	✗	✗	Flooding, stormwind and snowfall can cause interruption of public and private transportation but Flooding and stormwind can include underground infrastructures. Several urban services could be affected by cascading effects if maintenance or repair tasks are required during failures.
			Surface rail stations	✓	✗	✗	✓	✓	✗	✗	
			Traffic signals	✓	✗	✗	✓	✓	✗	✓	Flooding and wind can generate failures of traffic control systems. Several urban services could be affected by cascading effects if maintenance or repair tasks are required during failures.
Green infrastructures				✗	✓	✓	✓	✗	✓	✓	Green space adjacent to tidal watercourses will become more frequently washed out, destabilising river banks. High water table levels and flooding from Greenfield land following prolonged rainfall can occur near areas of green space. Dry ground can lead to hindering infiltration potential and increase the chance of overland flow following heavy downpours. Strong winds mobilise more vegetation and debris which can subsequently become stuck on trash screen grills and cause blockages and flooding problems. The winds can also blow over trees also resulting in damages. Rapid snow melt following a quick thaw of snowfall positioned on hillsides facing towards properties could result in pluvial flooding.
	✓	Not Exposed or not considered									
	✗	Exposed									

Table 32: Bristol matrix of exposure and direct/indirect impacts from climate variables and failure urban services

6 Conclusions

This deliverable provides the characterizations of the RESCCUE research sites with a full description of the organization of the city services management, and the functioning / operation of the main urban services and the related infrastructures with special focus on the green infrastructures.

The main climate effects and natural hazards affecting strategic services and critical infrastructures are also underlined and specific matrices linking weather variables and critical services / infrastructures have been elaborated. These matrices have been used in the WP4 for the resilience holistic assessment and the interdependency analysis among strategic urban services and critical infrastructures.

Specifically, several natural hazards related to climate variables have been identified for each urban service (Water Cycle including Water treatment, Water supply, Urban drainage and Waste water treatment, Energy, Transport, Telecommunication and Solid waste).

The interdependency among urban services involves all of the services that have been analyzed, although only some of them will be analyzed in detail, in the framework of RESCCUE, through sectorial models in order to reproduce their behavior for the current and future scenarios under extreme climate conditions.

In some cases the dependency with the system failure leads to complex correlations that produces cascading effects. For each site the matrix provides detailed information correlating climate variables, hazards and exposure with the failure consequences on each urban services and the likely cascade effects involving other infrastructures. From the analysis of these matrices, it is clear that energy is one of the most critical links on the cascading effect chain. The functioning and operation of Water Cycle features (processes in treatment plants, pumping stations and centralized controls) Transport (traffic signals, underground or superficial electric transport, centralized controls) and other critical infrastructures and services are totally based on energy supply.

Regarding sectorial models used by operators, the models currently used have been detected and their state has been analyzed for all three RESCCUE sites (Barcelona, Lisbon and Bristol). These models will be updated in RESCCUE (Task 2.2), while other ones will be developed. In each case, sectorial models performed in the RESCCUE framework will be used in the Task 2.2 (WP2) developing simulations concerning the behavior of strategic urban services for current scenario and in the Task 2.3 (WP2) developing simulations concerning the behavior of the same services for future climate change scenarios. This information will be essential to achieve hazard assessment for current and a wide range of future scenarios. Moreover, some of these models will be integrated in order to provide multi-hazard assessment (i.e integration of flooding-transport model, bursting pipe-flooding model, urban drainage-marine for CSOs analysis on bathing waters, etc.). Finally the detailed hazard and multi-hazard assessment will be used in WP3 for the detailed assessment of direct and indirect impacts produced by natural hazards related to climate change.

The Table 33 just summarizes the state of the main sectorial models nowadays and the improvement expected to be developed by RESSCUE project. According to the structure of the project, these developments would be carried out during task 2.2 of WP2.

Table 33: Sectorial models and improvements expected by RESCCUE.

	Status	**Responsible**	**RESCCUE improvements**	**Notes and task developers**
Barcelona sectorial models				
Urban Drainage Model	1D/2D calibrated flooding model (considering 1D sewer model and 2D overland flow) covering the half of Barcelona administrative land is available (Infoworks ICM)	AQUATEC	Improvement of the model in flood prone areas with presence of critical infrastructures through the introduction of secondary network and the refinement of Digital Terrain Model and the cell size Simulation of the multiple climate change scenarios	Secondary networks and sewers features will be provided by BCASA and included in the model by AQUATEC for the whole administrative limits pf Barcelona city AQUATEC will develop all the simulations considering current and future scenarios
Marine model for water quality prediction	Marine model for water quality prediction (Cowama) to be updated	AQUATEC	Improvement of the marine water quality model for pollution prediction. Simulation of the multiple climate change scenarios.	Further calibration with field data provided by BCASA New bathymetry provided by BCASA will be introduced in the marine model Integration with Urban Drainage Model for CSO analysis

				AQUATEC will develop all the simulations considering current and future scenarios
Bursting pipes model	To be developed	AQUATEC	Identification of critical assets (pipes, pumping station, etc.) according to the consequence of its failure. On the basis of Water Supply Master Plan Information of Aigües de Barcelona, critical failures due to bursting pipes will be analyzed taking into account cascade effects produced by local flooding	AQUATEC will carry out the simulation of this kind of failures using the 2D overland flow model developed for the urban drainage service
Water resource model	Correlation between reservoir water levels and availability of resources for distribution units (from Catalan Water Agency)	CETAQUA	Development of hydrological numerical model to make a correlation between rainfall and reservoir inflows tool managed by Catalan Water Agency (ACA)	CETAQUA will develop the hydrological model and carry out all the simulations considering current and future scenarios
Water quality model	To be developed	CETAQUA	Quality simulation of Llobregat River's final leg in order to manage the pollutants and flows increase due to rainfall affecting to abstraction works	CETAQUA will develop the hydrological model and carry out all the simulations considering current and future scenarios

Electrical model	Distribution power grid model of Barcelona city. Model currently in use for grid status determination and planning. The model will be developed / prepared in Digsilent Power Factory software.	IREC	Introduction of model modifications to include the impact of flood, sea level rise, etc. on electrical network. Introduction of climate change impact on future grid scenarios (i.e. with high penetration of renewable) Improvement of the model to consider microgrid resiliency enhancement.	IREC with the support of ENDESA will develop the model at city scale with special focus on flood prone araes (nearness of Besós and Llobregat rivers) and carry out all the simulations considering current and future scenarios. Determine relation of climate change with both power generation and consumption. Availability of consumers' data, and grid status.
Integrated flooding traffic model	To be implemented Availability of macro dynamic model provided by BCN CC	BCN CC	Implementation and validation of an integrated flooding-traffic model and simulation of climate change scenarios.	UNIEXE will led this implementation with the support of BCN CC AQUATEC will provide and dynamic flood maps for calibrated events, and also for current and future scenarios current and future scenarios

Lisboa sectorial models	Status	Responsible	RESCCUE improvements	Notes and task developers
Urban drainage model	1D and 2D stormwater models. For a significant part of Lisboa, a 1D Model based on Storm Water Management Model (SWWM), is available. A calibrated 1D/2D key model based on an integration of SWWM with Modelação Hidrodinâmica (Hydrodynamic Modelling) (MOHID land) is available for critical parts of the city, namely downtown	Hidra and CML	Improvement of the dynamic simulation model in critical, including calibration and validation Simulation of the multiple climate change scenarios taken into account the existing and future infrastructures	Hidra will carry out the simulations according to the agreed scenarios for the case of Lisbon (current and future).
Energy distribution model	Simulation model of the electrical distribution network, with the identification of dependencies in case of failure (DPlan software, geographic	EDP D	Improvement in the combine possibilities of simulation procedures, adding risk areas due to climate/weather extreme events and urban service interdependencies at city scale, to predict vulnerabilities in the electrical	EDP will carry out simulations according to the agreed scenarios for the case of Lisbon (current and future).

	based integrated analysis and optimization system for distribution network)		power systems and networks, enabling the increase of network resilience in Lisbon.	
Traffic model	Lisbon's Smart Control of Traffic System monitors traffic in the downtown area (traffic lights, TV cameras, speed meters, radars and traffic, speed controllers and message panels). It has a Central Operational Control that concentrates the flow of information needed for real-time operation that integrates the traffic management	CML	Implementation of an operational system to forecast the Meteorological Risk in Lisboa to be linked to all urban systems considered.	In the design stage. Objective: to implement urban sharing platform and network communication.
Waste model	Optimization system for urban waste collection paths	CML	Implementation of an operational system to forecast the Meteorological Risk in Lisbon to be linked to all urban systems considered.	In the design stage. Objective: to implement urban sharing platform and network communication
Bristol sectorial models	**Status**	**Responsible**	**RESCCUE improvements**	**Notes and task developers**

Urban drainage	1D/2D Integrated Urban Drainage Model – 1D sewer network and 2D ground surface (Infoworks). Model completed using Microdrainage WinDes software, FloodFlow package	BCC	Improvement of the model in flood prone areas with presence of Cis. Facilitated through change in model software to a more powerful engine/package (Infoworks ICM) Simulation and assessment of the hydraulic and environmental benefits of separating surface water flows from combined sewers in the Ashton and St Phillips Marsh flood prone areas Simulation of the multiple climate change scenarios Working with UNEXE to help validate their flood models (CADDIES and/or UIM) which are being developed as part of the RESCCUE project	UNEXE, BRISTOL CC and Wessex Water will develop all the simulations considering current and future scenarios

Tidal and Fluvial Flooding	1D/2D model of the tidal and fluvial systems in central Bristol, including assessment of joint probabilities. Hydrology calculations include an allowance for climate change. Model developed in ISIS (1D river network) and TuFLOW (2D ground surface) software, developed as part of the CAFRA project	BCC	Model is currently being updated by a separate project and will be available to the RESCCUE project. RESCCUE project will look to improve estimates of climate change through alternative future scenarios	UNEXE and BRISTOL CC will develop all the simulations considering current and future scenarios
Integrated flooding - traffic model	To be implemented	UNEXE	Implementation and validation of the traffic model and simulation of climate change scenarios	UNEXE will build up traffic model representation of Bristol and look at effects of flooding (CADDIES and/or UIM)on the traffic network

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