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RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

D4.4

Report from HAZUR® implementation in Barcelona, Lisbon and Bristol - summary version

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1. Changes with respect to the DoA
   D4.4 was added in Amendment AMD-700174-17
2. Dissemination and uptake
   Public
3. Short Summary of results (<250 words)
   The objective of this D4.4 is to report concisely, friendly and excluding personal or confidential data on the results of the resilience assessments in Barcelona, Lisbon and Bristol and to discuss the process of HAZUR® implementation of urban resilience in the three cities performed in Task 4.1. In Task 4.1, every HAZUR® local expert (Aquatec, Hidra, Urban DNA), with the support of some experts from specific sectors, had to apply the current HAZUR® methodology using the HAZUR® tool (Assessment mode) to generate a final resilience assessment report of the three cities. The report justifies seven conclusions:
   a) HAZUR® can be adapted to provide different forms of value to each city;
   b) Task 4.1 has included very diverse approaches and implementation teams necessary to widely validate the HAZUR® methodology and tool;
   c) HAZUR® Assessment should select a limited number of priority infrastructures and services;
   d) HAZUR® must include a strategic analysis as a framework for the project;
   e) constructive feedback of the HAZUR® tool that has been made by local experts, operators and the research teams should be integrated in upcoming versions;

f) the importance of guaranteeing the confidentiality of data and key information; and
g) the importance of standardization initiatives in development that would have facilitated the work carried out.

4. Evidence of accomplishment
   This document

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RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

Summary Figures

1. Introduction

1.1 Overview

This document D4.4 summarizes the implementation of HAZUR® in Barcelona, Lisbon and Bristol as part of the RESCCUE project (RESilience to cope with Climate Change in Urban areas): a H2020 research project that aims to help cities around the world to become more resilient to physical, social and economic challenges, using the water sector as the central point of the approach.

RESCCUE will generate models and tools to bring this objective to practice, while delivering a framework enabling city resilience assessment, planning and management. This will be achieved by integrating software tools, methods and new knowledge related to the detailed urban services performance into novel and promising loosely coupled models (integrated models), multi-risk assessment method and a comprehensive resilience platform. These tools will allow the urban resilience assessment from a multisectorial approach, for current and future climate change scenarios, including multiple hazards and cascading effects. The RESCCUE approach will be implemented in three EU cities (Barcelona, Bristol and Lisbon) and, with the support of UN-Habitat, disseminate their results among other cities belonging to major international networks (Velasco et al., 2018). The RESCCUE Work Package 4 (WP4) aims at performing a holistic resilience assessment and to test and improve the capabilities of HAZUR®.

HAZUR® is a methodology and a web-based tool that currently provides an assessment of the urban services and critical infrastructures status under certain shocks and stresses. It also analyzes the cascade effects that have collateral impacts on several strategic urban services due to the failures of critical infrastructures. It is therefore the perfect **starting point to develop a further sophisticated and complete set of models and tools** that will allow a better analysis, management and planning of the city with a holistic approach. Through the RESCCUE project, HAZUR® will be updated to become a crisis management and planning tool.

1.2 Integration of D4.4 within the RESCCUE project

RESCCUE Work Package 2 and Work Package 3 analyze climate change impacts in several strategic urban sectors of Barcelona, Lisbon and Bristol, three cities that are different, but all concerned about the interdependencies between different urban services and the cascade effects, which is one of the main objectives of this WP4. As a part of WP4, **the deliverable D4.1 reports on the HAZUR® implementation in each city** informing exhaustively about how the HAZUR® methodology and tool have been used in Barcelona, Lisbon and Bristol to assess Urban Resilience (Task 4.1). The three cities included as pilot sites will be the validation platforms of the improved HAZUR®, for which a Resilience Action Plan will be presented at the end of the project. **This deliverable D4.4 aims at summarizing the D4.1** to facilitate dissemination of the results of Task 4.1.

1.3 Objectives of the present report D4.4

During the development of RESCCUE, a greater need to widely disseminate the results of the Task 4.1 has become evident since it is an element of the project that can have public repercussion when carried out in three large cities and promote the replicability of the project. **The objective of this D4.4 is precisely to report concisely, friendly and excluding any personal or confidential data on the results of the resilience**

assessments in Barcelona, Lisbon and Bristol and to discuss the process of HAZUR® implementation of urban resilience in the three cities.

According to the project, every HAZUR® local expert (Aquatec, Hidra, Urban DNA), with the support of some experts from specific sectors, had to apply the current HAZUR® methodology using the HAZUR® tool (Assessment mode) to generate a final resilience assessment report of the three cities. A specific online training course was developed to train these HAZUR® local experts and to engage different stakeholders.

The report D4.4 is structured in four sections: 1) **Introduction**, 2) **HAZUR® approach**, 3) **Evaluation of the HAZUR® implementation in the three pilot cities** and 4) **Conclusions and lessons learnt**.

2. HAZUR® approach

This section starts with a positioning and description of the HAZUR® Assessment methodology to analyze and diagnose urban resilience and how the tool supports it.

2.1 State of the art and positioning of HAZUR®

Urban networks and infrastructures, which cities depend on to function, are highly vulnerable to hazards and their interdependencies complicates its functioning singularly (Rinaldi et al, 2001; Lhomme et al., 2013). Studies regarding the interactions between urban subsystems have concluded that most of the disturbances and failures occur through or are spread (cascading effect) by utilities and transport networks or critical infrastructures (Boin et al., 2007; Gonzva et al., 2015).

Several types of interdependencies existing in urban networks and infrastructures depending on their functional (and logical) or geographical nature have been studied (Toubin, 2014). This line of analysis introduces to the notion of urban cascading effects, defined as the transmission of the impacts of a given trigger event from a system to other related systems. Specifically, it considers how the interdependencies lead to the propagation of impacts between systems. This is precisely very important when the combined impacts of propagated events have greater consequences than the first impacts and when multiple stakeholders are involved (Ekman & Lange, 2014).

In recent years, several methods and tools have been developed to identify and model the system interdependencies and simulate cascading effects.

In recent years, several methods and tools have been developed to identify and model the system interdependencies and simulate cascading effects. They differ in the ease of implementation and the level of granularity and mathematization. A wide range of methods can be found, from the practical approach developed by Toubin, to the complexity of the DIESI project. Toubin was inspired by the work of the Ecole Polytechnique de Montréal (Robert et al., 2013), conceptualized to help overcome a climate change event, as a great deluge, and has been operational since 2013. This study has been contrasted with a different scope in Paris, Orleans and Mantes-la-Jolie and it requires a strong mobilization of managers and other stakeholders, particularly through participation in collaborative workshops, but requires a reasonable amount of time and input data as all the infrastructures are modelled in a simplified and functional way. In a broader sense, the DIESI project "Design of an interoperable European federated simulation Network for Critical Infrastructure" (Rome et al., 2009; Setola et al., 2016) combines three technical network sector simulators (electricity, rail,

telecommunications) and a flood simulator, requiring a long period of implementation, a large amount of sensitive data and a deep knowledge of the networks as well as the complete control of the sector simulators.

With a more systemic and collaborative approach, the HAZUR® Assessment methodology, developed by Opticits and used in the RESCCUE project, started with the collaboration between IQS (Universitat Ramon Llull) and the city of Barcelona (Fontanals et al., 2012) and is inspired by several international research works, especially the publications from the École des Ingénieurs de la Ville de Paris and in the industrial safety assessment systems, as the HAZOP methodology. HAZUR® can be considered as a realistic approach as it considers all types of services, infrastructures, networks, actors, dependencies, hazards and impacts. The HAZUR® operational understanding of urban resilience (Ehret et al, 2016; Francis et al, 2014) relies on ensuring continuity of critical services. This is a key driver included in the Rockefeller Framework for Resilience (Opticits, 2014), considering that urban metabolism and service supply cannot be managed but in an integrated way.

Inspired by several international research works and in the industrial safety assessment systems, HAZUR® can be considered as a realistic approach as it considers all types of services, infrastructures, networks, actors, dependencies, hazards and impacts.

This methodology is the one that has been used in this first phase of RESCCUE. This approach integrates the results of collaborative workshops, specific studies, data management tools, simulations, predictive models and other tools in an innovative way. Additionally, RESCCUE project aims also at further developing the initial version of the HAZUR® web-based tool and other tools to develop a system to manage urban areas coping with climate change.

2.2 General description of the HAZUR® Assessment

For the successful application of HAZUR® in the RESCCUE project case studies, the methodology conceptually described (Fontanals, 2014) has been adapted for the urban resilience assessments of Barcelona, Lisbon and Bristol. It is important to note that HAZUR® is both a methodology and a web-based tool (Software as a Service, SaaS) with a systemic and collaborative approach. The HAZUR® tool is the first city-resilience-oriented online tool that provides a holistic city cross-management methodology, strategic service monitoring and systemic simulation. It has been designed to go through the whole process of integrating urban resilience concepts into operations protocols of basic municipal services, and design and operation of critical infrastructures.

In general, HAZUR® implementation begins by collecting and ordering the necessary information to develop the process (pre-assessment). It then organizes three inter-functional working groups called Strategic, Steering and Action Group. Then, a second batch of analyzed and selected information that includes the identification of the KPIR and the areas of improvement (assessment) is obtained. In parallel, the obtained information is included, organized and analyzed in the HAZUR® support tool (Assessment mode), which is used to manage the city resilience (plan, do, check, act) thanks to the simulation capabilities (Manager mode).

HAZUR® uses a methodology of strategic analysis from the Business Management and a methodology of general analysis from the industrial safety auditing systems based on the HAZOP methods

HAZUR® Assessment uses a methodology of strategic analysis coming from the Business Management (Harrison, 2012) transporting the frame of the well-known and regulated area of industrial safety auditing services with the method HAZOP (Redmill et al, 1999). The HAZUR® Assessment was designed including several exercises or workshops to collect or manage the information in a specific way. Workshops have a pyramid structure. The defined groups work structurally to frame the project and to produce data according to the proposed HAZUR®

methodology. The Strategic Group validate the conclusions of the workshops of the Leader (or Steering) Group, and this Group validates the workshops of the Action Group.

The HAZUR® web-based tool supports the intelligent management of the resilience of an urban system, allowing the municipal managers to visualize the different interdependencies between the services and the critical infrastructures of the city and the consequences of possible impacts that may affect the environment.

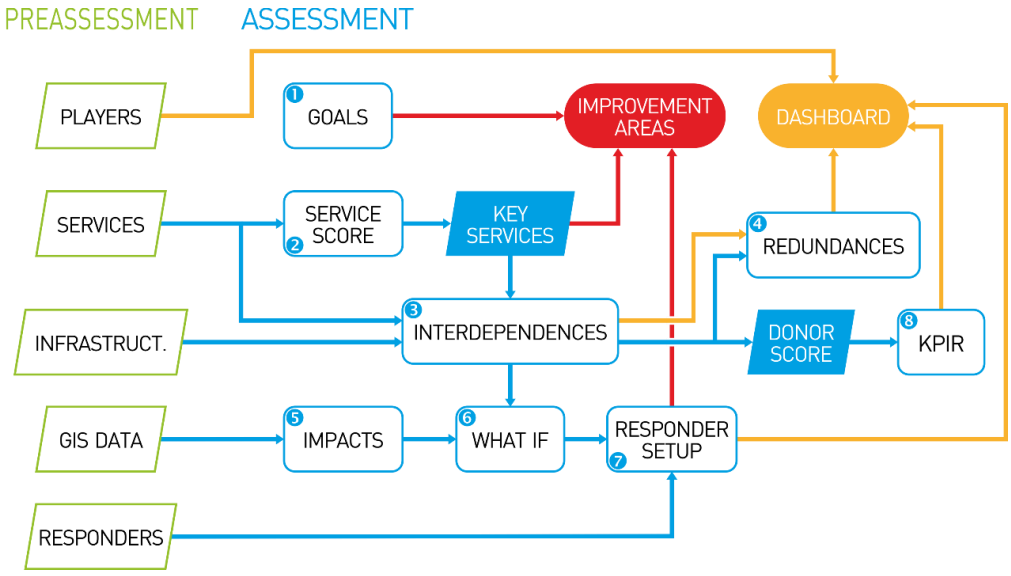


Figure 1: HAZUR® Assessment workflow

2.3 From the take-off of the project across the assessment...

Once the stakeholders and the Groups have been created, the pre-assessment starts with the identification of key factors to define different concepts affecting the urban resilience in order to agree on the resilience objectives (**Goals** and **Service Score**) and the **Impacts** to consider. The assessment follows with several exercises, such as an **Interdependences**[1] matrix exercise and a **What If** matrix exercise (analyzing direct impacts in the region or city if natural or industrial risks are triggered). The assessment continues by building up in the **Dashboard** an understanding scheme of urban processes and their interconnections (Interdependency Map). Once the scenario has been clearly defined, analysis of the efficacy of Responders (prepared human intervention teams and the technical equipment) ready to neutralize undesired effects is performed. After this process, management indicators (**Key Performance Indicators for Resilience**) are identified and weak points of the urban system considered (**Improvement Areas**) appear in a natural way allowing to identify the resilience improvement projects for the city.

HAZUR® Assessment, including both the methodology and the web-based tool, is already a replicable solution that can be implemented in every city.

[1] HAZUR® uses the term interdependences, but interdependencies is more commonly used.

The HAZUR® Assessment, including both the methodology and the web-based tool, is already a replicable solution that can be implemented in every city. Therefore, the assessment does not aim at using a huge quantity of data, even if in further stages of the resilience management they will be necessary for simulation purposes. The data must be able to be verified and handled by the consultant teams.

Figure 2: HAZUR® methodology & tool

2.4 Until the HAZUR® (Manager mode) for climate change

Urban Resilience Management is out of the scope of Task 4.1 and it corresponds to the Task 4.3, but it is deeply related to the HAZUR® Assessment. While HAZUR® Assessment allows stakeholders to know the state of resilience of the system and identify the starting point from which to begin to manage to improve urban resilience, Urban Resilience Management includes the planning of measures and projects to improve the urban resilience as well as the day-to-day management of the services and infrastructures of the system from a resilience point of view. It is important to highlight that urban resilience is a process of continuous improvement over time and that the proper management of Urban Resilience will enable increased efficiency and resilience of the urban system, built as a system of systems. The longer a city works on Resilience, the more prepared the city will be to respond and recover to impacts of any kind.

Normally a City Resilience Office that, among other things, organizes Urban Resilience Boards should be created and/or a Chief Resilience Officer should be appointed. The Manager mode in HAZUR® tool is intended to be used by them containing the best essential information related to the resilience of the city under study. This key information should be kept updated to allow correctly modelling and simulation the interdependencies, cascading effects and their spatial and temporal evolution. HAZUR® for climate change will support the Urban Resilience Office, allowing the municipal managers to visualize the different effects and alternatives to their decisions to cope with the climate change impacts.

HAZUR® (Manager mode) for climate change will support the Urban Resilience Office, allowing the municipal managers to visualize the different effects and alternatives to their decisions to cope with the climate change impacts.

3. Evaluation of the HAZUR® implementation in the three pilot cities

This section explains how the first implementation of HAZUR® in Barcelona, Lisbon and Bristol was performed, including the training of local experts, the approach of the three cities assessments, and how the HAZUR® Assessment methodology has been adapted to perform the assessment of urban resilience in the three cities. Then, it includes the description and discussion of the evaluation of urban resilience that has been carried out. These assessments should have followed the first steps of the HAZUR® implementation process:

1) Strategic Analysis that determines the scope and focus of the implementation of HAZUR®,
2) Analysis of the relevant elements, and
3) Diagnosis of the resilience of the city.

However, as it will be explained in Section 3.2, the implementation approach used in each city has led to some changes in the implementation process. The elements to analyze in each city are the characteristics of the city and its vulnerabilities, the players, the urban services and the infrastructures (including the score of the services), as well as their interdependencies and redundancies, the impacts on the cities and the cascading effects of the impacts. The key performance indicators for resilience (KPIR) and improvement measures should have been inferred from these assessments.

3.1 Training of consultants

Since the assessment of the urban resilience of the three cities had to be performed according to the HAZUR® methodology, the eighteen RESCCUE members responsible for the HAZUR® local implementation (Aquatec in Barcelona, Hidra in Lisbon and UrbanDNA in Bristol) and some other contributors of this WP4 (EIVP, LNEC, UniExeter and UNHabitat) have been trained on the HAZUR® methodology and tool, and a User's Guide has been developed.

The training has been done through a specific online course designed to achieve the project goals and facilitate a common vision on urban resilience among the different stakeholders and partners (Researchers, City Managers, Operators, Consultants, Multilateral representatives…) participating in the RESCCUE project. The online course was designed for a 30-hour training partially self-paced. It explains what urban resilience is and how to implement it using HAZUR® methodology as well as a general approach to assess and manage Urban Resilience in the context of a H2020 project as RESCCUE, and includes additional material (papers, videos, links, additional literature) as well as 5 tests and 5 exercises. The course has been tutorized by OptiCits team.

Figure 3: Support material for the consultants training.

Additionally, to facilitate the use of the tool, three documents, "Opticity Walkthrough. A Guide to implement HAZUR® for the RESCCUE partners", "Opticity Demo Guide. Quick guide to follow the HAZUR® demo smoothly" and "HAZUR® User Manual", have been developed in the framework of the project.

3.2 Different approach, different tasks, different results

RESCCUE is built around three research sites (Barcelona, Bristol and Lisbon) that represent different challenges in terms of building urban resilience. These research sites have been selected due to their strong involvement with urban resilience as demonstrated by their selection and participation in the 100 Resilient Cities Program funded by the Rockefeller Foundation, which promotes the creation of specific resilience offices. However, the three cities are at different levels of maturity.

The three research sites had already identified quite different water-related risks as crucial in their hazard analysis. Water related risks are a common feature that the three of them share. They are managed in different ways depending on the city and local stakeholders' characteristics.

RESCCUE is built around three research sites (Barcelona, Bristol and Lisbon) that represent different challenges in terms of building urban resilience.

The political leadership has not been committed in the HAZUR® Assessment and the involvement of municipal stakeholders in the project has been different in each city:

- The **Barcelona** Resilience Department is focused in implementing its own resilience solution within the framework of the Climate Plan, while continuing the urban resilience management through Resilience Boards, the Infrastructures and Urban Services Resilience evaluation update and its engagement in the social resilience. The strategic lines of the Climate Plan, whose scope is strongly linked to RESCCUE, include: mitigation, adaptation and resilience, climate justice and promoting citizen action. Additionally, Barcelona participates in other international initiatives, like the City Resilience Profiling Program (CRPP) promoted by UN-Habitat or the C40 cities network. Therefore, the HAZUR® implementation has been performed with a low commitment of the municipality in the HAZUR® Assessment.
- In **Lisbon**, the Lisbon Municipal Council (CML) is intensively working to promote climate resilience and to address sustainability in its several dimensions. CML has supported the implementation of HAZUR® through an intersectoral working group coordinated by the Municipal Civil Protection Service in articulation with Urban Planning Department and other municipal departments/divisions in the context of the Lisbon Drainage Masterplan and the Flood Charter of the Municipal Masterplan.
- The **Bristol** implementation team has analyzed how the Bristol Resilience Strategy drafted within the framework of the 100 Resilient Cities complements the RESCCUE project objectives with the aim of involving infrastructure and service leadership across the city. Therefore, the approach was to choose meaningful engaging scenarios in collaboration with the Bristol Flood Risk and Asset Management Team to gain the support to expand the application to the whole city, and most importantly, to grow and support the sustainment of a resilient approach.

These similarities and differences between cities have led to implement HAZUR® in a specific way for each city, combining the general tasks proposed by the assessment HAZUR. It highlights the flexibility of the HAZUR approach and tool to serve cities with different needs and priorities.

	Task description	Barcelona	Lisbon	Bristol
PREASSESSMENT	Scope definition			
	Assigning a Project Manager in the city			
	Identifying Players and preparing Strategic, Steering and Action Group			
	Goals workshop			
	Service Score Workshop			
	Identifying main Services			
	Identifying main infrastructures			
	Identifying areas (GIS Data)			
	Identifying responders			
	Project presentation to Strategic Group			
	Project presentation to Steering Group			
ASSESSMENT	Analysis of the Services			
	Analysis of the Infrastructures			
	Interdependence matrix			
	Identifying impacts			
	Analysing responders			
	Identifying redundancies			
	Identifying KPIRs			
	Identifying time variables			
	Identifying improvement projects			
	Interdependences Matrix Workshop			
	Impacts Workshop			
	What If Workshop			
	Responders Set Up Workshop			
	Improvement projects identification			
OUPTUTS	Resilience Report and city model in HAZUR® tool			
	Presentation of the results (Strategic and Steering Groups)			

Figure 4: Activities performed in the HAZUR® Assessment in Barcelona, Lisbon and Bristol: green, yellow and red show if HAZUR® Assessment exercises/functionalities have been performed, partially performed or not performed.

The results of the first implementation of HAZUR® in each of the three cities are summarized in the following sections.

3.3 Barcelona HAZUR® Assessment

Barcelona has been formally studying its resilience since 2011, when the "Security of Services Supply" (3Ss) project was performed. Since then Barcelona has its **own model of resilient city** that is **now focused in climate adaptation** (which has led to the Climate Plan, presented in 2018), the **infrastructures and urban services resilience evaluation** and **a care model for people in vulnerable situations** or victims of trauma. In parallel, Barcelona is elaborating indicators to measure resilience within the framework of the CRPP initiative with the UNHabitat office support, collaborating with UNSDR as members of the "Making cities Resilient" campaign and with the C40 cities network working to reduce the effects of Climate change, and participating in the "100 Resilient Cities" initiative of the Rockefeller Foundation.[2]

This international commitment is the result of a long history of the Barcelona resilience that has evolved into a strong operational approach including long-term objectives of resilience and climate change adaptation. The maturity of Barcelona involvement in urban resilience (a concept that was not used then) during the last 30 years has become evident in the planning and development of major improvements in the city regarding urban drainage (huge stormwater retention tanks and regulations systems to manage Mediterranean rainfall), the electric power distribution grid, both medium-voltage and high-voltage, securing energy supply, as well as in public transport and alternative transportation allowing a drastic reduction of private cars circulating in the city. Finally, the organization and investment on the response teams has been reviewed based on the system used to meet the 1992 Olympic Game requirements, the most important impact on the city in the last decades.

Barcelona international commitment in Urban Resilience is the result of a long history of the Barcelona resilience that has evolved into a strong operational approach including long-term objectives of resilience and climate change adaptation.

In any HAZUR® Assessment, it is important to previously establish the strategic framework, the scope and the project goals after the strategic analysis that should be led by City Council and have political support. It is true that in Barcelona is not really essential to have a large political collaboration in the project to have valid results because the Barcelona City Council has its own resilience strategy and Urban Resilience Department that coordinate resilience boards, involving 72 professionals and 20 organizations. Two RESCCUE members, Suez Group, to which Aquatec belongs, as concessionary company of the water cycle and the electrical distribution network owner (Endesa, ENEL Group) have participated in the resilience boards, which allow them to have large information and intersectoral knowledge of the city. In this **HAZUR® implementation**, the strategic framework and the different exercises (Service Score, What If, Interdependencies, Redundancies and Responders Setup) have been **performed by the consultants according to their expert knowledge**. In the end, the assessment was performed by a team from Aquatec (Suez Group) with the support of five companies, a research center and municipal services have also participated. Note that in Barcelona there are tenths of public, para-public and private companies managing urban infrastructures and services. During the HAZUR® Assessment performed in RESCCUE, 786 infrastructures and 56 services have been identified in the whole city excluding the so-called Social Sector.

[2] *Barcelona Building a Resilient City*, 2017.

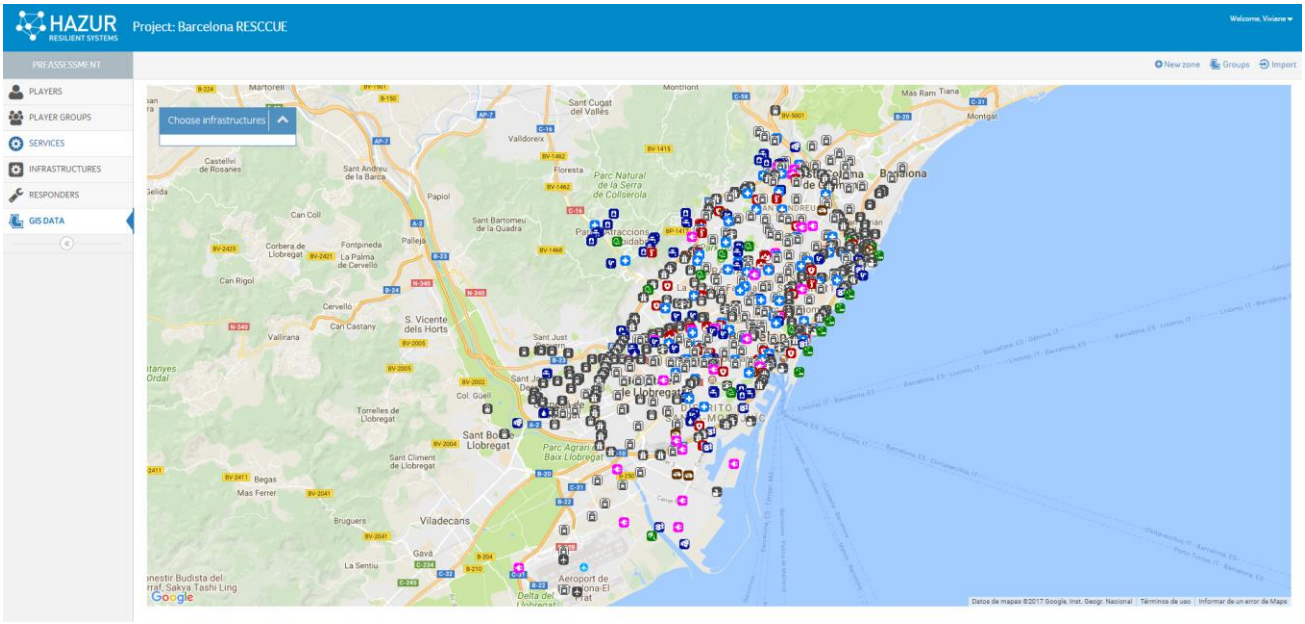
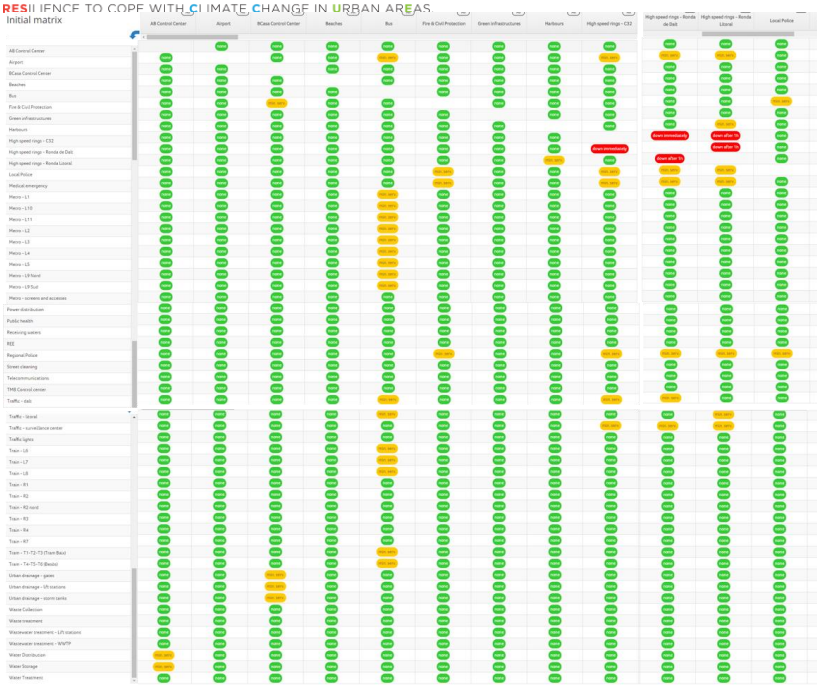


Figure 5: Infrastructures for Barcelona city case (Source: GIS Data - HAZUR® project Barcelona RESCCUE).

The large amount of services exists because they are not always very different (for instance, each metro line is a different service). As previously noted, the scope of HAZUR® implementation for Barcelona is citywide. In addition, some infrastructures located outside the administrative boundaries of the city have also been considered due to their relevance (such as the airport, commuter train stops, waste collection parks and pump stations). This scope has resulted in **a very complex system with a high number of services and infrastructures** introduced in the tool.

The analysis of interdependencies, key in the HAZUR® Assessment, has been performed mainly at service level, but due to the large amount of services the number of analyzed interdependencies is very important. This is because the Barcelona experts wished to analyze interdependencies within the same HAZUR® service (for instance, within the metro service, there are interdependencies where the closure of a metro line affects another one) even if the available version of HAZUR® was not able to consider interdependencies within the same service. Therefore, it has been decided to set up a service for each metro line. This allowed a very precise mapping of the city infrastructures as seen in the Resilience Map here below, that show the interdependencies between the different services in Barcelona according the data in the interdependencies matrix:

The analysis of interdependencies, key in the HAZUR® Assessment, has been performed mainly at service level, but due to the large amount of services the number of analyzed interdependencies is very important.



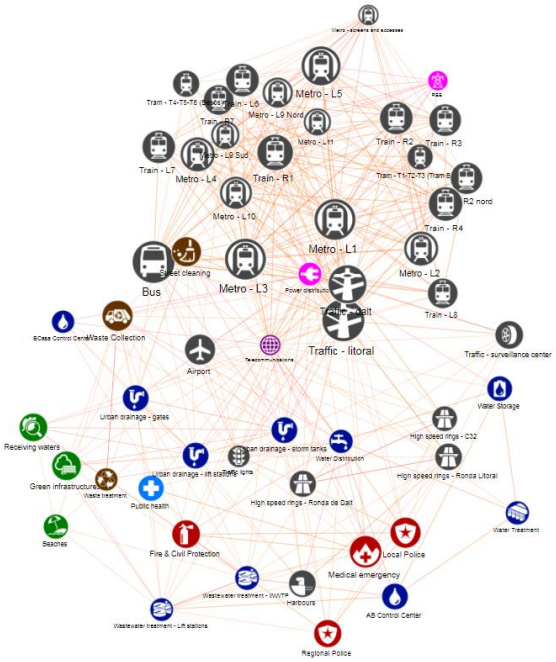


Figure 6: Interdependencies matrix and Resilience Map for Barcelona (Source: Interdependences and Resilience Map - HAZUR® project Barcelona RESCCUE).

Additionally, power distribution and some mobility related services also have been analyzed at detailed infrastructure level. In the end, due to this functional choice, 56 services and 786 infrastructures have been introduced in HAZUR® tool.

Interdependencies analysis has been performed by Aquatec and **partially validated** in a workshop with several players and using collaborative matrixes both individually and in a dedicated workshop, but it is easy to understand that it is very difficult to validate efficiently 708,122 interdependencies. The main donor services are Power Distribution, Telecommunications, Water Distribution and Mobility.

Cascading effects have not been analyzed in detail by the consultants, given that it is difficult to handle a detailed analysis including 708,122 interconnections. **Its validation in a pilot test**, where errors may occur in the tool, in the evaluation of an infrastructure or in the consideration of a concrete service which is not really a service, **overwhelms the RESCCUE resources and should therefore be simplified**.

Power distribution -> Tram - T4-T5-T6 (Besòs)

CONFIDENTIAL

(T4) AUDITORITE...	none	down immediately
(T4) CA L'ARANY...	none	down immediately
(T4) CAN LLIMA S...	none	down immediately
(T4) CIUTADELLA...	none	down immediately
(T4) DIAGONAL ...	none	down immediately
(T4) FLUVIA STAT...	none	down immediately
(T4) FORUM STA...	none	down immediately
(T4) MARINA STA...	none	down immediately
(T4) PERE IV STA...	none	down immediately
(T4) SELVA DE M...	none	down immediately
(T4) WELLINGTO...	none	down immediately
(T4, T5, T6) CIUTADELLA...	none	down immediately
(T4, T5, T6) DIAGONAL ...	none	down immediately
(T4, T5, T6) GLOR...	none	down immediately
(T4, T5, T6) GLÒR...	none	down immediately
(T4, T5, T6) TALL...	none	none
(T4, T5, T6) TALL...	none	none
(T4, T5, T6) TORR...	none	none

Figure 7: Example of interdependencies at infrastructure level (Source: Interdependences and Resilience Map - HAZUR® project Barcelona RESCCUE).

Since **the scope of the RESCCUE project is climate change**, the assessment has been consequently limited to climate related impacts: flood due to severe rain storms, heat waves, sea level rise, severe droughts, severe winds and combined sewer overflows caused by intense recurrent rainfall. Based on these general events, seven specific impacts were chosen to be analyzed in detail with HAZUR® in WP4:

- Sea level rise + storm surge of 24h duration and up to 50cm height
- Flooding caused by extreme rainfall (historical flood zones). Event duration of 4h
- Severe droughts (12 months)
- Heat waves Tmax > 35ºC for 3 or more days
- Severe winds V > 90 km/h. Event duration of 6h
- CSO caused by recurrent rainfall (T1 or less). Event duration of 1h.
- Snowfall > 10 cm in 12h

KPIRs and improvement projects presented in the assessment are not the result of the analysis of cascading effects nor of the stakeholders' consensus but have been proposed by the consultants. In this sense, it is evident that it would have been necessary to stick to a limited number of services and infrastructures (100 in total, representing 9,900 combination would be already the maximum advisable) previously agreed or it would have been possible to work in limited spatial areas, as done in Lisbon and Bristol. Once the HAZUR® framework has been established, the tool allows to further increase the number of infrastructures and services selected.

Figure 8: Example of effects of severe winds of 90 km/h or more in different services. (Source: What If - HAZUR® project Barcelona RESCCUE).

The main objective of Aquatec in the HAZUR® implementation in Barcelona was to **show the potentialities of a multisectorial approach of the urban resilience assessment focusing on water and with specific interest in the interdependencies**. However, it would be useful to use it to appropriately complement the urban resilience model in place and to position this project as a non-redundant and complementary way within initiatives in the process of being set up or already in place with the support of the Barcelona City Council, the Rockefeller foundation, UNHabitat, and UNISDR. It was not possible for the Barcelona team to find the best way to access the information about the implementation of other assessments and to evaluate the potential use of HAZUR® for the Urban Resilience Boards led by the Barcelona City Council. To share know-how with RESCCUE, IP concerns were mentioned by UNHabitat office and municipal departments, but on the other side within the RESCCUE project the HAZUR® methodology and tool has been shared with municipal departments and UN Habitat office, improving their resilience approaches. Therefore, **exploring potential synergies among different resilience approaches would be not only important, but also possible in a city like Barcelona**.

It would be useful to use HAZUR® in Barcelona to appropriately complement the urban resilience model in place and to position this project as a non-redundant and complementary way within other initiatives

3.4 Lisbon HAZUR® Assessment

Lisbon is tackling resilience from different approaches and within several programs and initiatives. The resilience assessment performed using the HAZUR® methodology has been performed by Hidra (a private international engineering company specialized in urban infrastructure, water services and related fields) supported by a working group coordinated by the Municipal Civil Protection Service in articulation with several municipal departments/divisions and in collaboration with LNEC, the Portuguese Laboratory for Civil Engineering). Therefore, the initial strategic analysis of the city has not been performed within the RESCCUE project nor using HAZUR®. The **HAZUR® implementation approach in this city case has been rather technical**, aiming at having a holistic understanding of the interdependencies, with special focus on water-related services and power, in several cases at infrastructure level.

Regarding the study area, the HAZUR® Assessment has been **focused on a crucial and critical area** corresponding to the drainage catchment basins J and L of Lisbon Drainage Masterplan since the Lisbon Urban Planning Department intends to improve and update the Flood Charter of the Municipal Masterplan, taking advantage of the efforts carried out and the useful information acquired under RESCCUE project and HAZUR® implementation. The analysis of the study area is considered as a priority and its results aim at being a starting point for the assessment of the whole city. The chosen area, with a 6.295 km^2 extension and 76,400 inh., represents 7.3% of the Lisbon area and 13.9% of its inhabitants. It is the center of Lisbon economic and touristic activities, has a high density, and overlaps with the historical center of Lisbon, making it vulnerable to climate related risks. Even if the study is focused on this area, services and infrastructures beyond this area are considered as long as they provide services to it, as seen here below:

The study area — the high population density historical heart of Lisbon, but also economic and touristic center— is of special interest in the framework of the updating of the Flood Charter of the

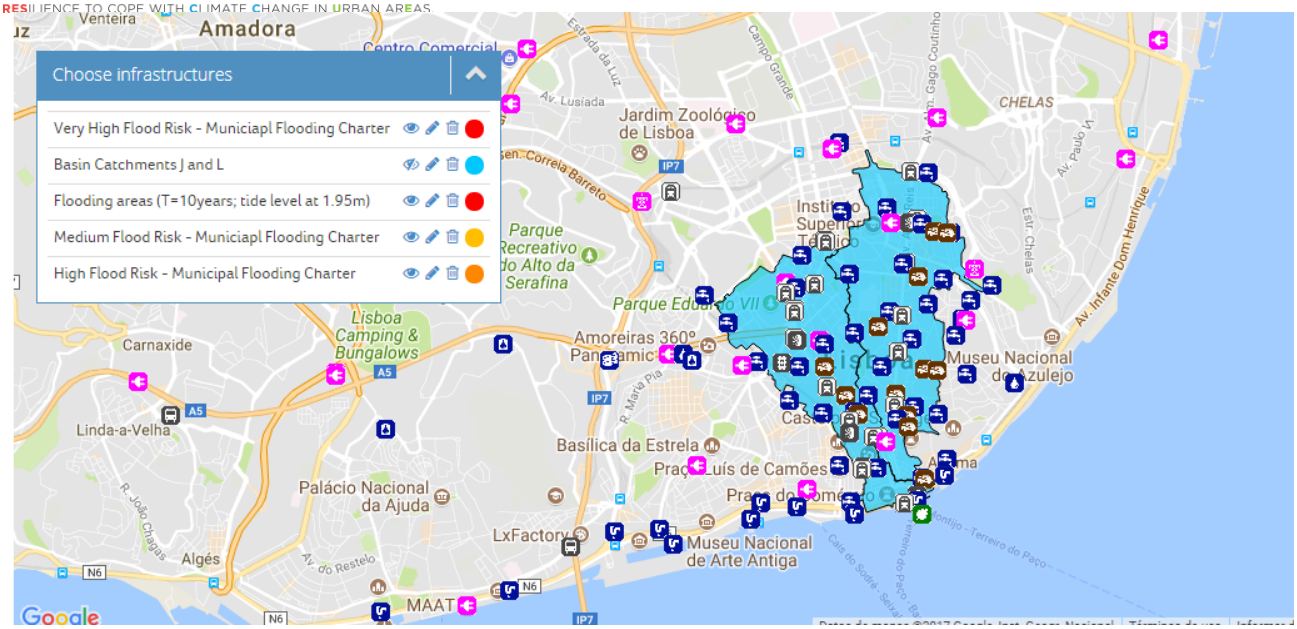


Figure 9: Infrastructures taken into account in the study and J and L drainage catchment basins (Source: GIS Data - HAZUR® project Lisbon RESCCUE).

In Lisbon, **26 players from 4 city council departments and 5 companies, both private and public, have participated in the main steps of the HAZUR® implementation**. First, as explained, Lisbon RESCCUE partners (LNEC, Lisbon Municipality – Civil Protection, EDP - Distribuição, AdTA) and stakeholders from the Mobility Sector, Water Sector and Waste Sector (Lisbon Municipality) were involved in the strategic analysis of the Lisbon Assessment. The contribution and involvement of the players in other main issues (service and infrastructure definition, redundancies, responders, interdependencies, impact, What If matrix, etc.) has been important. Since the HAZUR® implementation in Lisbon did not intend to perform a complete urban resilience assessment, the entire HAZUR® methodology has not been followed in this case. For example, player groups have not been created as such. However, even if the workshops foreseen in the HAZUR® methodology were not held as such, some workshops or presentations were held mainly at steering and strategic levels, involving department directors and managers, both from private and public companies. This has allowed to achieve the goals of the HAZUR® implementation in Lisbon with a slightly different approach.

Players have been actively participating in the assessment even if workshops were not organized according to the HAZUR® methodology

Lisbon team has created a city model that shows the **main city services, excluding services related to citizens' welfare** (Health, Emergencies and Social sectors in HAZUR), **and infrastructures that serve the critical study**. They include the services from the Water Supply system (Water Sourcing and Transportation, Water Treatment, Water Storage, Water Pumping, Water Distribution), the Wastewater Drainage system (Urban Drainage, Wastewater Treatment), the Power Sector (Primary and Secondary Power Distribution), the Mobility Sector (Subway, Bus, Public Transport Hubs, Traffic Management), the Waste Sector (Unselective Municipal Waste Collection, Waste Vehicles Operation and Maintenance, Waste Treatment), the Mobile Telecommunications and the Receiving Waters. Summarizing, **18 services and 146 infrastructures** were introduced in HAZUR® tool, which show a realistic mapping of the services and infrastructures of the area of study.

HAZUR® implementation in Lisbon focuses on the study of the basic services supply

The detailed analysis of the services studied, including **many interactions with the involved players**, is of tremendous interest to understand the concrete interdependencies. In many cases, interdependencies were analyzed at infrastructure level and validated by the involved players. For example, the analysis of the secondary power distribution as donor service details the effects on the following receiver services: Water Pumping, Water Sourcing and Transportation, Water Treatment, Urban Drainage, Wastewater Treatment, Bus, Subway, Traffic Management, Waste Vehicles Operation and Maintenance, Waste Treatment and Mobile Telecom. The Lisbon assessment includes **a detailed analysis of the analyzed services within HAZUR®** and a summary of the **citywide interdependencies**, even if they are not all included in the HAZUR® tool, as it refers also to emergency services, health, energy (fuel) and to the socioeconomic sector. This detailed analysis has allowed, for instance, to highlight the importance of the internal communication system to guarantee communication with field operators in case of failure of mobile telecommunication system. Dependences on external contractual services that they activate for "business as usual" operation and for non-programmable events are also mentioned. For example, one of the services has a pool of companies (country wide) from whom they rent some supplies, in case there is need to reinforce their own resources or the dependence on the maintenance company of a key service.

Holistic understanding of the interdependencies within the chosen city services has been done in a detailed way

It is important to highlight the high donor score (i.e. number of services depending on) of power supply, water supply and wastewater drainage and treatment services. As an example, see here below the analysis at both infrastructure level and citywide of the interdependencies for Urban Drainage:

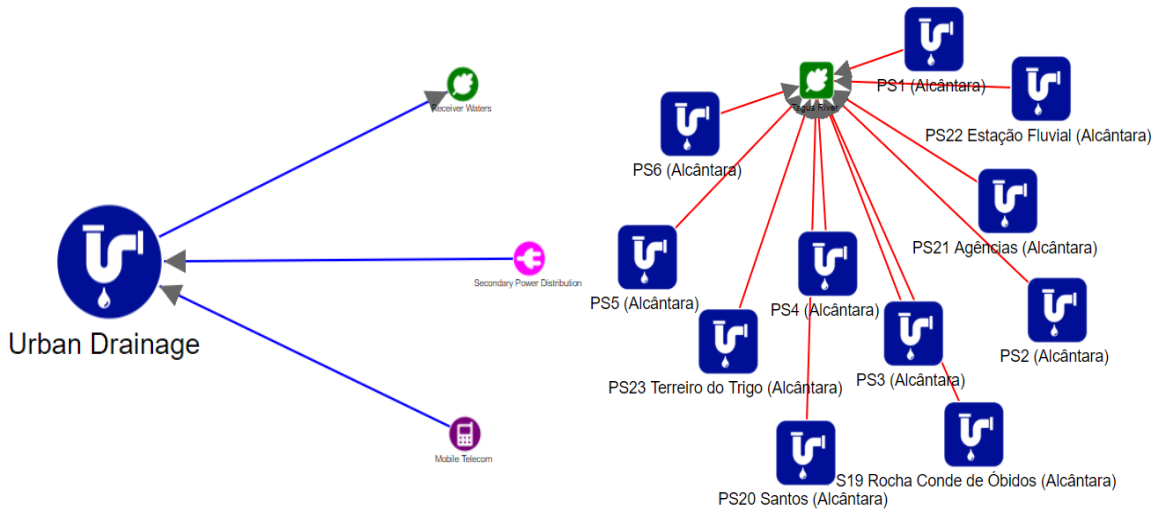


Figure 10: Interdependencies for the Urban Drainage service and respective infrastructures as donors, in Lisbon (Source: Resilience Map - HAZUR®, project Lisbon RESCCUE).

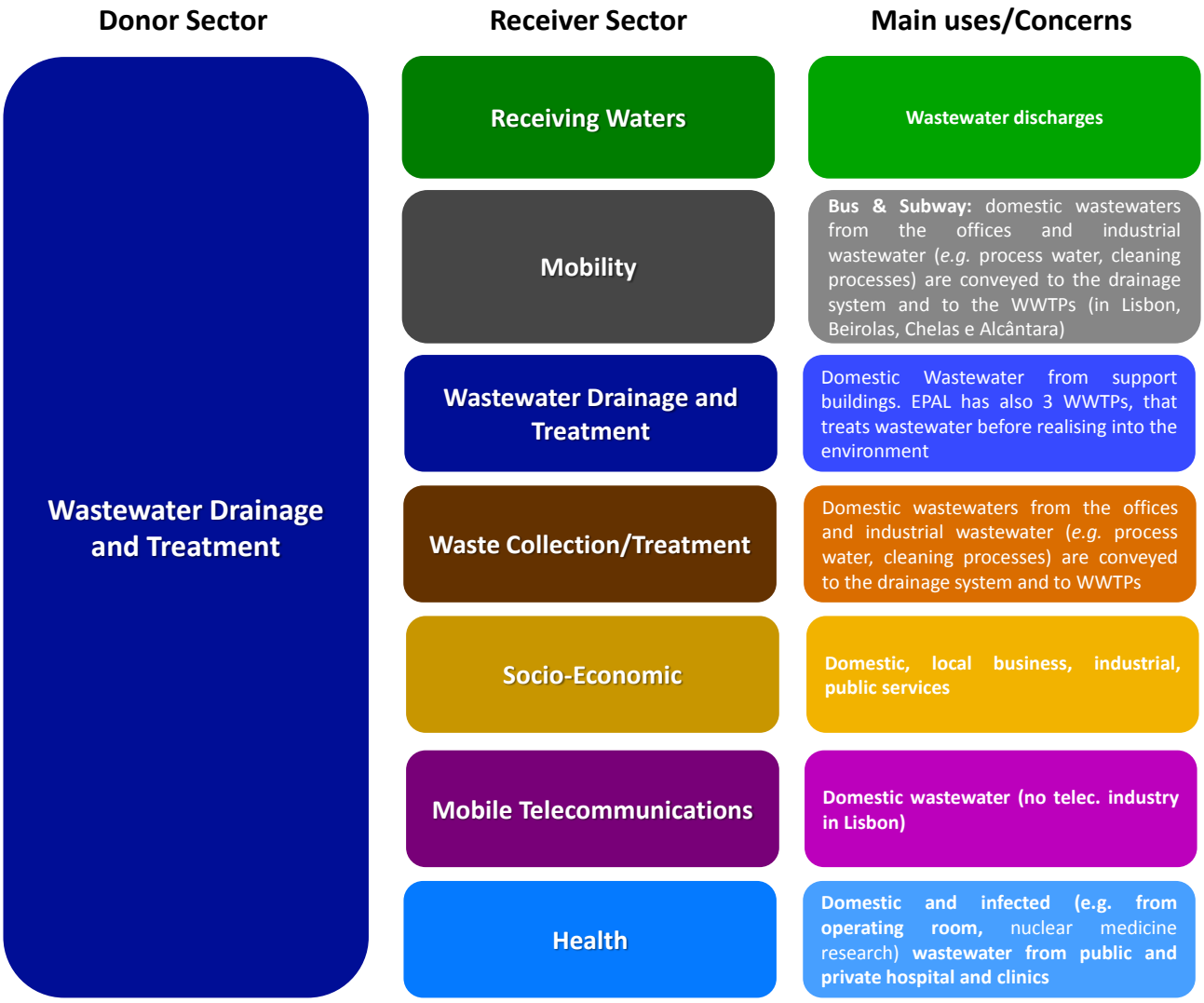


Figure 11: Interdependencies summary between Urban drainage and treatment (as donor) and other services (as receivers).

The **impacts** considered in the Lisbon case, based on the RESCCUE project scope, are**: intense rainfall, sea level rise causing urban flooding, heat waves due to extreme temperatures** (only qualitative analysis at service level) and **wind gusts** (only qualitative analysis at service level). Specifically, the following impacts have been studied: very high risk of city flooding, flooding - rainfall of T=10 years - sea level at 1.95m, and urban flooding on 4 power distribution infrastructures. Additionally, the Lisbon local team has also collected information on other impacts non-related to climate change, but that have a periodic impact on the management of urban services and infrastructures, such as strikes.

After the analysis of the above data, the HAZUR® Assessment allows the **analysis of cascading effects**, which is detonated when, due to the falling of a service or infrastructure, a chain of events starts that affects many services or infrastructures, often non-related with the first one. For instance, the HAZUR® implementation in Lisbon analyzes in detail the cascading effects of the failure of a specific power substation.

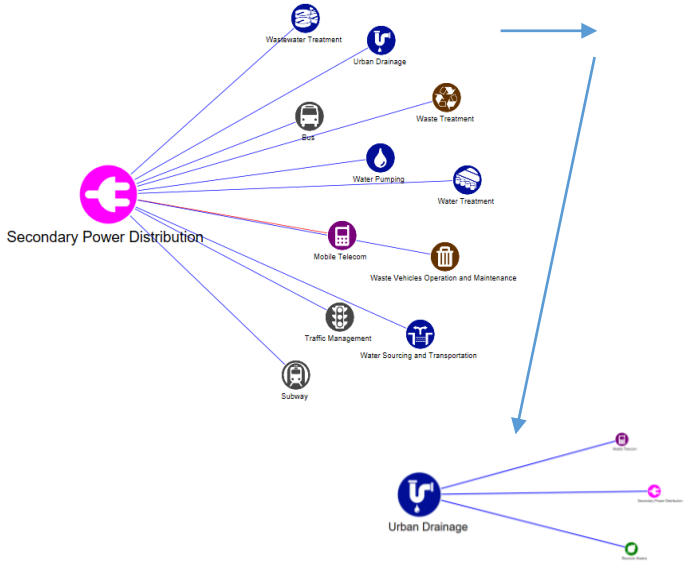


Figure 12: Cascading effects due to a Substation Failure. (Source: GIS Data - HAZUR®, project Lisbon RESCCUE).

In this specific case, if the power substation fails due to a flood, and its failure is not solved within a certain period, some pumping stations fail (the failure is not immediate due to the fact that the pumping stations have fuel emergency generators). If these pumping stations fail, the wastewater is not pumped to the wastewater treatment plant, producing a discharge of untreated into the river. The discharge may also affect the river quality and some uses may be temporarily interrupted (not likely, due to the discharge flow of the pumping stations, duration of the failure and hydrodynamic characteristics of the river). Note that if there is also a failure in fuel supply to the generators, the pumping stations fail as well. This substation does not provide service to the infrastructures considered critical for the water and waste sector, otherwise the impact of the failure and its cascading effects should be relatively more significant.

The HAZUR® implementation in Lisbon analyzes in detail the expected cascading effects of the failure of a specific power substation due to a hypothetical flooding

During this assessment, a total of **27 Key Performance Indicators of Resilience** (KPIR) have been proposed and mostly validated by the different sector representatives. Considering the project scope, they are mostly service indicators and with special focus on Water Sector. Proposed KPIRs are divided in three categories:

- **Quality service indicators**: they are defined by the regulatory body or determined by the services themselves. These indicators are useful on the long run, to perform analysis and study future trends. Example: Service interruptions [*No./(1000 service connections . year) in water distribution (retail)*]

0	Secondary Power Distribution	General	Quality of the service	hours	
0	Urban Drainage	General	Structural collapses in collectors	/100 km.Year	
0	Wastewater Treatment	General	Discharge compliance	-	

Figure 13: Example of the table of Quality Service KPIR as shown in HAZUR® (KPIR - HAZUR®, project Lisbon RESCCUE).

- **Alarm/notification indicators** (proposed for two strategic sectors): two notifications for power services and one for water. Since alarm/notification indicators are useful directly on the crisis or directly before the crisis, it would be interesting to have a few more of these in order to manage urban resilience. However, these three could already be a good test in case indicators are to be integrated with the tool in a later phase of the project. Example: number of customers without power supply.

In a complete HAZUR® implementation, a further validation of the proposed KPIR would be necessary as they are the starting point of the Urban Resilience Management

- **Overall system performance to flooding**: they have been developed during the implementation of the project in Lisbon. These ones are useful and synergic to the HAZUR® process in order to better develop impact simulations. Example: percentage of Buildings affected (%) in case of flooding.

Improvement projects have been proposed based on the services investment plans, as this part of the HAZUR® implementation was not performed. These improvement projects, included in 6 improvement areas, will help increase the service/infrastructures resilience and reduce the cascading effects, if not directly at least indirectly, due to the increase of the flexibility and robustness of the service/infrastructure and creating redundancies. Additionally, programs that reduce the effect of the impact on the services, in particular those related with flooding and the "Plan of Action to a Sustainable Urban Mobility" (2014 – 2020), have also been considered. Improvement area tables include strategic analysis (mission, vision, related goals and values), budget, responsible stakeholder and several improvement projects within in each area, resulting in a total of **27 specific improvement projects**. Some examples are: minimizing flooding in critical areas in Lisbon, projects to improve sewage systems and CSO and stormwater control, 3 improvement projects to provide urban public passenger transport service contributing to a development that meets the needs of the present without compromising the future generations' needs, projects to ensure the continuity of the service in Lisbon in case of unavailability/outage in relevant substations. These improvement projects will be defined and developed in WP5.

Even if the Lisbon assessment is the diagnose of the urban resilience at a very specific level by being focused on the city services interdependencies, the **HAZUR® implementation in Lisbon was developed at two different levels of detail**. A holistic analysis of the city, by considering the city as a system of systems, was made at service level, and a detailed analysis was made around a critical area corresponding to two major catchment basins facing multiple hazards. Thus, despite this geographic limitation, this work will help expand the results citywide and will embody a starting point to assess interdependencies and cascading effects between urban services and infrastructures.

Lisbon assessment has focused on services interdependencies and will complement the other urban resilience initiatives in place

In conclusion, Lisbon has been addressing urban resilience by means of several projects and initiatives during the last decade and the results of the present project will be useful to complement them. Specifically, the Lisbon Municipality is available to participate and collaborate in the a multi-sectorial resilience approach based on the HAZUR® methodology and tool during the RESCCUE project, integrating its functionalities with the 100 Resilient Cities program results, the CRO role and the planned Centre of Integrated Operations (COI – Centro de Operações Integrado).

3.5 Bristol HAZUR® Assessment

The Bristol local team has created clear links between the city's resilience strategy, published within the framework of 100 Resilient Cities program, and the implementation of HAZUR®, i.e. **aiming to involve the leadership of the city**. The assessment builds on an analysis of the Bristol resilience strategy and how this strategy supports the RESCCUE project objectives. Two strategic RESCCUE project goals were developed for the Bristol HAZUR® implementation:

- Firstly, and most importantly, to ensure that **tools** are delivered for resilience that are **of value to the city**, and that the **city will sustain through continued use**
- Secondly, to **fulfil the project requirements** of our commitment to the European Commission.

The **main vulnerabilities** of Bristol are: tidal flooding, rainfall and river flooding, combined storms, sea level rise (longer-term), aging Infrastructure (e.g. sewers) and aging Population. Specific resilience-related characteristics include coastal and fluvial flood; drought; sea-level rise; chronic energy crisis; food shortage; failure of infrastructure; poor health infrastructure; social cohesion; gentrification and lack of affordable housing.

Choosing meaningful engaging scenarios helped to gain the support (for instance, overcoming reticence on sharing data or attending meetings) and will allow to expand the application to the whole city

One of the risks detected by the experts for the HAZUR® implementation was that the use of a technology-enable tool and/or a research project could make it difficult to engage city leadership (the "*black box*" syndrome). This is the reason why the approach was to ensure choice of meaningful and engaging scenarios that would intrigue and gain support (for instance, overcoming reticence to share data or attend meetings) in order to expand the application to the whole city. These priority scenarios were chosen so that stakeholders could easily relate to and engage in them as they were relevant and plausible scenarios, like pluvial flooding in city 'hot spots', tidal surge in the harbor and city center or water pipe bursts affecting specific critical infrastructures. **This more focused approach ensures that we do not overlap with other service and infrastructure analysis systems in use, which could generate resistance and lead to inefficiencies** (e.g. through holding information in yet another place). Thus, understanding the methods, tools and systems in place across the city and understanding where RESCCUE / HAZUR can *complement* these is a core focus.

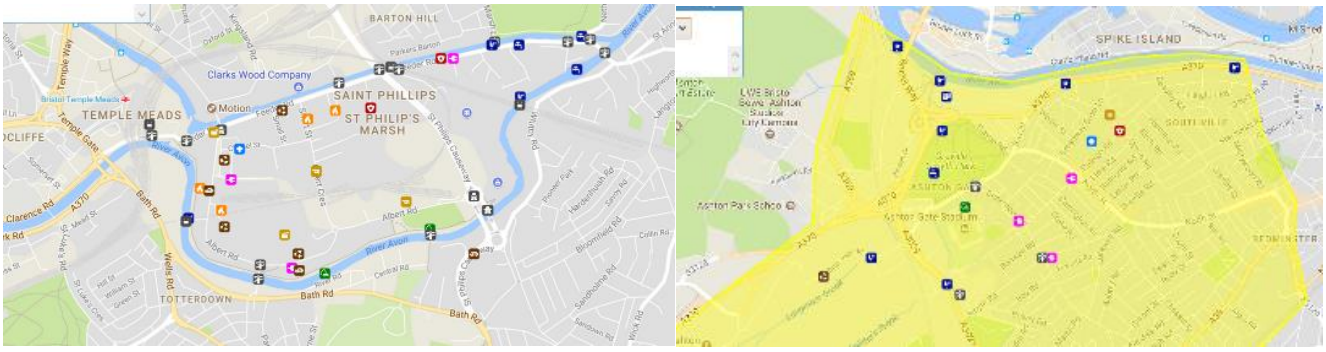


Figure 14: Bristol "hot spots", chosen study areas

The **two areas have different characteristics**: one being principally residential; the other primarily light industrial / commercial with a central location and involving a more diverse spread of infrastructure and service providers. Both areas capture the vast majority of services that are relevant city-wide. Obviously, they have location-specific infrastructures (an advantage to keep things practical), however also tend to include infrastructure categories that are similar on a pan-city basis**. Expanding to a pan-city perspective is being**

achieved by focusing on themes and areas that are of particular (leadership) concern due to their higher risk / impact of failure, or provider complexity: termed "Hot Spots".

In Bristol, **37 players from 16 organizations** were involved in the HAZUR® implementation. The three player groups were not formed as such as the Bristol 'City Office' is in its formative stages. There was an important involvement of the stakeholders in the four workshops that were held, resulting in a real collaborative approach where a multidisciplinary group of stakeholders worked together. The first workshop helped to engage stakeholders in the project and to identify and discuss specific resilience concerns (purpose, challenges, approach, synergies with ongoing activities, data sharing, …). In the second workshop, the work focused on three scenarios, exposing and discussing issues and concerns that lead to the final definition of areas and impacts to elaborate in the two following workshops, where the HAZUR® model of each area was developed and validated. Additionally, ad hoc meetings and discussions have taken place with stakeholders to engage, clarify and seek information.

Stakeholders have been involved in the four workshops, resulting in a real collaborative approach where a multidisciplinary group of stakeholders worked together

23 services (from 10 different sectors) and 77 infrastructures have been included. The services cover not only the main utilities (services related to Water system, Energy, Mobility…), but also a large variety of the concerns of the stakeholders that have participated in HAZUR® (schools, food supply, hospitals, community…). **The choice of infrastructures has been done according to the priorities of the two chosen scenarios** and includes a major sport infrastructure that is periodically extremely busy, electricity substations within areas exposed to a high risk of surface water flooding and a pumping station that may be influenced by the effects on the urban drainage sewer network.

Analyzed services include not only the main utilities, but also a large variety of the concerns of the stakeholders (schools, food supply…).

In Bristol, specific interdependence relationships for the principal 'life-line' services in the two scenarios have been mapped in HAZUR®. **Specific interest was given to energy, power, telecommunications, transport and water sectors during the workshops**.

Initial matrix

	Education	Emergencies services	Energy	Environment	Food Supply	Health	Junctions	Power Distribution	Power Transportation
Education		none	min. serv.	none	min. serv.	none	min. serv.		none
Emergencies services	none		min. serv.	none	none	none	min. serv.	min. serv.	none
Energy	none	none		none	none	none	none	down after 8h	min. serv.
Environment	none	none	min. serv.		none	none	none	min. serv.	none
Food Supply	none	none	min. serv.			none	none	min. serv.	none
Health	none		min. serv.	none	min. serv.		none	down after 24h	none
Junctions	none	none	min. serv.	none	none	none		min. serv.	none
Power Distribution	none	none	min. serv.	none	none	none	none		down immediately
Power Transportation	none	none	min. serv.	none	none	none	none	none	
Rail services	none	none	min. serv.	none	min. serv.	none	none	min. serv.	none
SP Key industrial supplies	none	none	min. serv.	none	none	none	none	down after 2h	min. serv.
Streets	none	min. serv.	min. serv.	none	none	none	min. serv.	min. serv.	none
Telecommunications	none	none	min. serv.	none	none	none	none	down after 12h	none
Transport	none	none	min. serv.	min. serv.	none	none	down immediately	min. serv.	none
Urban Drainage	none	none	min. serv.	min. serv.	none	none	none	min. serv.	none
Waste Collection	none	none	min. serv.		min. serv.	none	down after 5h	none	none
Waste Treatment	none	none	min. serv.	none	min. serv.	none	none		none
Wastewater Treatment	none	none	min. serv.		none	none	none	min. serv.	none
Water Distribution	none	none	min. serv.		none	none	none	min. serv.	none
Water Sourcing and Transportation	none	none	min. serv.	none	none	none	min. serv.	min. serv.	none
Water Storage	none	none	none	none	none	none	none	none	none
Water supply	none	none	min. serv.		none	none	none	min. serv.	none
Water Treatment	none	none	min. serv.		none	none	none	min. serv.	none

Figure 15: Initial Interdependence Matrix for Bristol (Source: Interdependences HAZUR®, project Bristol RESCCUE).

A more detailed analysis is given for the water supply service, as it is a main donor service that has implications (of different importance) on transport, power distribution, energy, telecommunications, water treatment, emergency services, waste collection, waste treatment, rail services, industrial supplies, environment, education, health and food supply.

Figure 16 Intedependences in water supply service (Source: Interdependences HAZUR®, project Bristol RESCCUE).

The goal of this analysis was to prove the approach within the city in order to expand it city-wide later once the approach is sufficiently understood, supported and aligned with other methods used by city infrastructure and service owners/operators. To keep the approach manageable (mitigate the *'black box'* risk) the idea of identifying a (growing) number of priority 'hot spots' around the city has been applied. By conducting resilience assessments using HAZUR® in these initial two areas of Bristol, the poignancy of the tool in demonstrating urban interdependencies can be effectively demonstrated for appropriate further application to the Greater Bristol area.

At an overall level, the figure below provides an overview of all interdependencies within the current combined model. This indicates complexity (i.e. city reality), however **the 'moving connected balls' visualization provides a very engaging and intuitive interface of the situation** – far more intuitive and useful than the underpinning analysis in the various supporting tables and matrices. And thus, very useful for stakeholder engagement purposes.

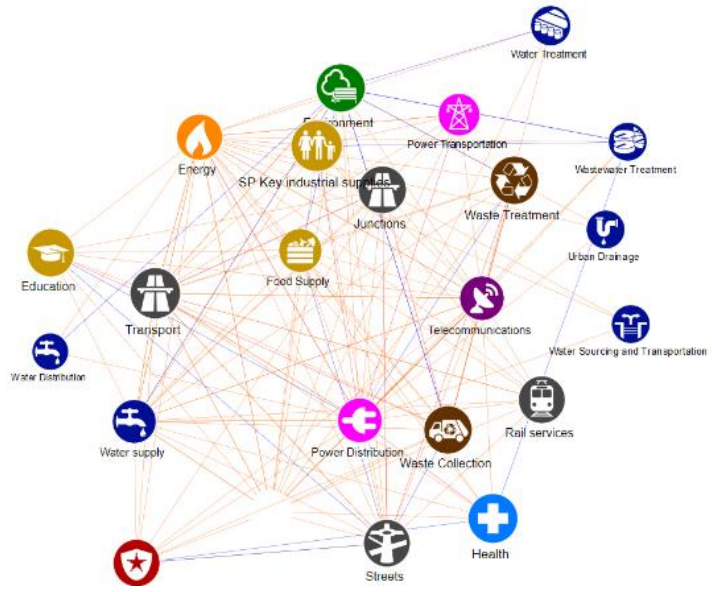


Figure 17: Bristol Interdependencies Map (Source: Resilience Map - HAZUR® project Bristol RESCCUE).

More focused interdependence relationships for the principal services have also been considered. These include energy, power, telecommunications, transport and water (supply, treatment) – typical city's "life-line" services; i.e. the essential ones during times of stress or catastrophe. Clearly particularizing these relationships to specific scenarios / geographical boundaries / system limits etc., enables the discussion to become very specific and actionable. In Bristol, the redundancies exercise in HAZUR® has not been performed.

Two impacts have been used to engage stakeholders in the different workshops: pluvial and high tide for an area and major 1:200 year tidal event for the other. The consequences of these impacts have been mapped on a risk matrix where columns are the different degrees of Impact/Consequence (from very low to very high) and rows the different degree of Likelihood/Probability (from very low to very high). The goal was to filter the impacts for further evaluation.

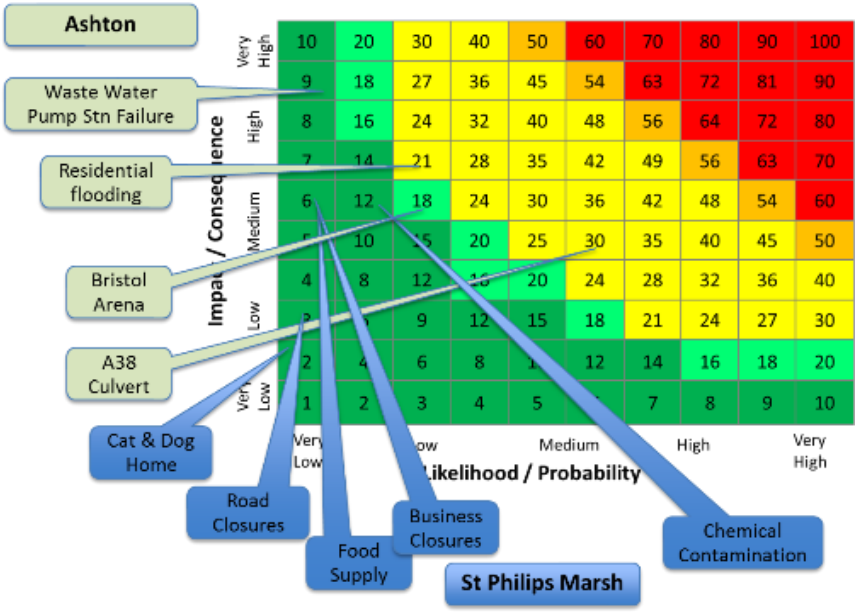


Figure 18: Ashton and St Philips Marsh Pragmatic Impact Evaluation

Additionally, **some further pan-city hot spots are under analysis**. They have emerged through the HAZUR® process – enabled through the very practical workshops addressing the two chosen areas – where it is evident that particular infrastructure owners or service providers see risks; where there may also be a lack of other infra/service provider information (which only adds to the risk); and where the interdependencies between services and infrastructures can create cascading effects of concern. This process of uncovering city-wide "Hot Spots" is ongoing, and offers further focused areas where multiple stakeholders can come together to address practical concerns in a collaborative manner; without overly raising concerns of overlaps, inefficiencies, data management, or over-burdening resources. Indeed, the process applied is enabling and liberating – allowing lingering concerns to be exposed in a focused manner and dealt with appropriately.

Two examples of hot spots include potential collapse of major aging sewer pipes that run across the city, that could affect (unknown) water mains, and would affect transport and health for a prolonged period, as well as implications of flooding in one of the areas of a food & vegetable business. This event would have significant impact on a city-wide basis as it is a major supplier to the city, and indeed to the broader south west region.

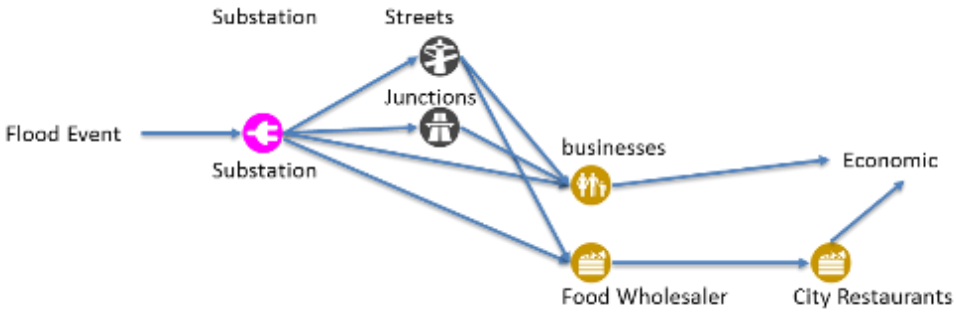


Figure 19: Cascading effect example in case of flooding event

Improvement projects are foreseen in both areas and will also occur as a result of further evaluation. Local experts propose the development of the improvement projects into specific business cases that support investment decisions or operational changes. This becomes an ongoing forward process.

Local experts propose that the development of the improvement projects into specific business cases that support investment decisions

It is important to highlight that more work on cascading effects, beyond the ones used to engage stakeholders in the discussion, is required to determine the level of detail to model. Moreover, no KPIR detection has been performed at this stage as the project approach is not reaching this level of detail (also influenced in the UK, by a lingering resistance to monitoring resulting from a heavy (over-)focus placed on measurement by prior Governments).

In conclusion, **the overall objective of the HAZUR® implementation in Bristol was to improve risk and investment analysis and decisions, and to strengthen pan-city stakeholders' cooperation**. The focus was thus more on how HAZUR® is complementary to, and dependent on, the approaches, methods and tools currently used by the city hall and its partners, like sectorial models. HAZUR® could then be seen as a means of connecting the various initiatives, across silos, to arrive at a holistic approach for city resilience as a complement, not a replacement, to the tools already in use. The process started within the RESCCUE project should continue as the Bristol City Council has shown interest in organizing stakeholders' workshops beyond the project lifecycle to improve the city resilience using the HAZUR® approach.

4. Conclusions and lessons learnt

The Task 4.1, aiming at assessing urban resilience in the several city cases using HAZUR® tool, has been accomplished as foreseen and its development has been traced within this report. Aquatec, Hidra and Urban DNA have applied the HAZUR® methodology and the HAZUR® Assessment tool using different approaches as detailed in section 3. Additionally, the HAZUR® implementation process in the three cities has resulted in the creation of a strong community formed by people from both the city councils and private or public companies providing services to the cities. Ideally it would have been preferable to be able to engage politicians or top management leaders, and representatives of more diverse organizations. However, the current commitment can be already considered as an additional achievement of this project.

A first conclusion is that **HAZUR® can be adapted to provide different forms of value to each city**. In RESCCUE, cities have different levels of maturity regarding urban resilience. Barcelona has a defined strategy and is implementing its own tool, Lisbon has not already developed its own solution and Bristol has an advanced strategy in resilience, which has been also discussed and included in the HAZUR® implementation. HAZUR® has proven to be adjustable and flexible for all cases and there is an opportunity to increase HAZUR® approach contribution to existing resilience frameworks when, after the political support, the adequate technical collaboration is well established.

The **second conclusion** is that **Task 4.1 has included very diverse approaches and implementation teams necessary to widely validate the HAZUR® methodology and tool**. As previously explained, the three local teams have chosen different approaches for the implementation of the HAZUR® Assessment tool, adapting the HAZUR® methodology with the support of Opticits. Thus, three implementation processes have been tested and validated in three different contexts since the local contexts of the study cases vary on several levels: the typology of the city and its environment, the hazards to which it is confronted, the organization of its municipal services and the governance of urban networks, the pre-project links that existed between local actors, the risk reduction or resilience initiatives already in place, the sensitivity of decision-makers and municipal services to these issues… It should also be noted that the local teams of the project were quite diverse. Thus, it is logical that the three teams did not have the same approach and did not present themselves in the same way to the local actors:

- Aquatec, in charge of the implementation in Barcelona, is a subsidiary of the Suez multinational corportion, i.e. private company, responsible for the water service in Barcelona.
- Hidra, in charge of the implementation in Lisbon, is a private international engineering company specialized in urban infrastructure, water services and related fields.
- Urban DNA, in charge of the implementation in Bristol, is a small and independent consulting organization in intelligent and innovative urbanism and planning.

The **third conclusion** is that, according the HAZUR® methodology, the **HAZUR® Assessment should select a limited number of priority infrastructures and services**. It is important to highlight that the goal of the HAZUR® Assessment is to access useful information on vulnerable elements that can be understood by the team to define KPIR and improvement projects. In this sense, using a fuzzy-based perspective on the risks associated with services and infrastructures within a whole city is a promising approach as first approximation. Once the high-risk areas are identified, situations can be analyzed in greater detail as and when more data becomes available (Evans, 2018). In this sense, limiting the analysis to an urban area such as done in Lisbon and Bristol or to perform an assessment on only the main services and infrastructures according to a strategic analysis would be more adequate. In case of analyzing several limited areas, further HAZUR® Assessments can be performed to complete the whole city and then integrate them in a general HAZUR® Assessment with some common infrastructures and services (such as power distribution) but after a selection of the other detailed

services (such as environmental services). In case of considering the whole city for the HAZUR® Assessment of wide services and critical infrastructures, the solution to get into the details is to perform the general HAZUR® Assessment and then to analyze also with HAZUR (zoom effect) the critical interdependencies in the city that have been previously identified, such as buses with metro or urban drainage with power network. This last approach, followed by Lisbon, would probably be the most advisable.

The **fourth general** conclusion is that **HAZUR® must include a strategic analysis as a framework for the project**. The HAZUR® methodology has shown that it can be flexible and adapted to perform urban resilience assessments with different approaches and that the formats of representation of the results in the HAZUR® tool are appreciated for their synthetic and conductive to communication appearance. Geolocation is also a major strength in this methodology. However, even if the HAZUR® tool has proven itself to be a useful tool supporting urban resilience assessment of the three cities, it should be used with the appropriate strategic guidance. Therefore, when Goals and the Service Score have not been agreed at strategic level, the tool outputs are not valuable enough. Unfortunately, strategic analysis has not been the starting point of the three projects and only in the case of Bristol strategic goals and a strategic vision has been presented in the HAZUR® implementation.

The **fifth conclusion** is that **constructive feedback of the HAZUR® tool that has been made by local experts, operators and the research teams should be integrated in upcoming versions**. In general terms, operators aim to have a tool that includes a very friendly interface. Local experts emphasize that the complexity of their urban landscape and function is sometimes difficult to model within the tool. For example, the HAZUR® version that has been used does not accept the interdependencies within the same urban service, nor easy modelling of the definition of linear networks like roads, pipes or cables. Finally, researchers note that the version of the tool that has been used does not take into account the uncertainties and inaccuracies of some data introduced and has some technical limitations in the tool capabilities. In Task 4.2, the assessment tool will be improved considering this feedback.

The **sixth conclusion** is **the importance of guaranteeing the confidentiality of data and key information** (such as vulnerabilities and improvement projects…) when implementing HAZUR®. The work carried out in the three cities also raised some difficulties concerning the collection of the data to be introduced in the tool. For example, there are recurring concerns and reluctance of service operators and private companies about the data considered sensitive, confidential and business-related. There are cases where the needed data are missing, incomplete, inaccurate or uncertain. For further studies, it is important to keep in mind that the reluctance of providing information has also been reported by other projects and initiatives from governments when dealing with operators of critical infrastructure, interdependencies and cascading effects.[3]

The **seventh conclusion** is **the importance of standardization initiatives in development that would have facilitated the work carried out** during this Task 4.1 as it would have given a common language or framework. Specifically, one of the crucial problems encountered by the persons in charge of the implementation of HAZUR® is the participation of local actors around this initiative. The construction of a strong network of actors is indeed a prerequisite for the smooth running of the process, the organization of successful workshops, the access to real and detailed data as well as the availability of significant means. The methodology proposed by

[3] See information related to the System thinking for critical infrastructure resilience and security - OECD/ JRC Workshop OECD Conference Centre, Paris, 24-25 September, 2018. (http://www.oecd.org/gov/risk/workshop-oecd-jrc-system-thinking-for-critical-infrastructure-resilience-and-security.htm)

HAZUR® for modelling the urban system of systems has proved its worth at this level. Therefore, it would be highly advisable to keep on working on standards for management of urban resilience.

Urban resilience is a continuous process. This part of the RESCCUE project has contributed in different ways to this process: providing additional analysis of urban resilience, urban resilience modelling, strengthening local stakeholders' involvement, collecting and organizing the improvement projects related to urban resilience, and more. The stakeholders' community created during this first assessment will participate in the upcoming workshops and the data gathered during the assessment will be used in the Resilience Action Plans that will be drafted for each RESCCUE city. Future WP4 activities will build upon this first implementation for the improvement of HAZUR® Assessment (Task 4.2) and for the monitoring and cascading effect simulation capabilities of the Manager mode of HAZUR® (Task 4.3).

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