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RESCCUE

RESILIENCE TO COPE WITH CLIMATE CHANGE IN URBAN AREAS.

Deliverable 4.6

Report from HAZUR® re-assessment in each city

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Document history

DATE	VERSION	AUTHOR	COMMENTS
10/12/2019	1.0	M. Velasco (Aquatec)	First draft circulated for the implementators in the three cities
30/01/2020	2.0	M. Velasco (Aquatec)	Compilation of the contributions of the three cities
10/09/2020	3.0	M. Velasco (Aquatec)	Final version submitted to the reviewers
15/10/2020	Final	M. Velasco (Aquatec)	Final version implementing all the feedback from the reviewers

1. Changes with respect to the DoA

The bankruptcy of Opticits not only implied some changes in the tasks to be carried in WP4 and other WPs, together with some redistribution of funds, but also the disappearance of HAZUR tool. The tool ceased to be available on the 1st of January 2020 and thus, the last part of the work carried out in WP4 was considerably restricted because of not being able to use it. This is why the submission of this report was postponed, as it was not considered critical for the advancement of the rest of the project.

2. Dissemination and uptake

Confidential.

3. Short Summary of results (<250 words)

The Reassessment was intended to test the updated HAZUR® tool and methodology. This Re-assessment had the objective to apply the different new functionalities but also incorporated the different results from the other WP to apply the HAZUR method and tool based on the consulting services from the different implementators.

As it happened on the initial assessment, HAZUR® allowed each research site to focus the study in a different way in order to align it to the specific technical and strategic needs of each case. For example, Lisbon undertook a detailed analysis focusing on floods in some specific areas of the city, whereas Bristol undertook a strategic analysis of two areas and Barcelona focused on the whole city, but simplifying the approach initially used.

The methodology and tool proved to be able to function in these different situations and some of the improvements showed a lot of potential if some more work was put in improving the tool. Nevertheless, Hazur tool ceased to exist on the 1st of January 2020 and thus, there will be no more improvements or implementations with it. This is why the efforts from this WP4 were moved to other WP so the whole RESCCUE consortium could benefit from it.

Since no confidential information appeared in this deliverable, D4.6 will be exactly as D4.5, but it will be publicly available.

4. Evidence of accomplishment

This report

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1. Overview

This document is developed as part of the RESCCUE (RESilience to cope with Climate Change in Urban arEas - a multisectorial approach focusing on water) project, aiming at delivering a framework enabling city resilience assessment, planning and management by integrating into software tools new knowledge related to the detailed water-centred modelling of strategic urban services performance into a comprehensive resilience platform. The RESCCUE project is funded by Horizon 2020, the EU Framework Programme for Research and Innovation, under Grant Agreement 700174.

The present deliverable, *Report from HAZUR® re-assessment in each city – considering a new approach regarding stakeholders involvement and climate change and adaptation strategies*, in the frame of Work Package 4 (Integration in a Software Tool), which aims at assessing Urban Resilience in the several city cases using the available version HAZUR® software.

In the initial plan of WP4, the deliverables D4.5 and D4.6 about the re-assessment with Hazur were not included. As it can be seen in Figure 1, the plan of tasks and deliverables in this WP was the following:

- Task 4.1: Assessment of Urban Resilience in the several city cases
- Task 4.2: Development of new functionalities of HAZUR® Assessment
- Task 4.3: Development and feed-back implementation of the HAZUR® Manager to monitor and manage Urban Resilience

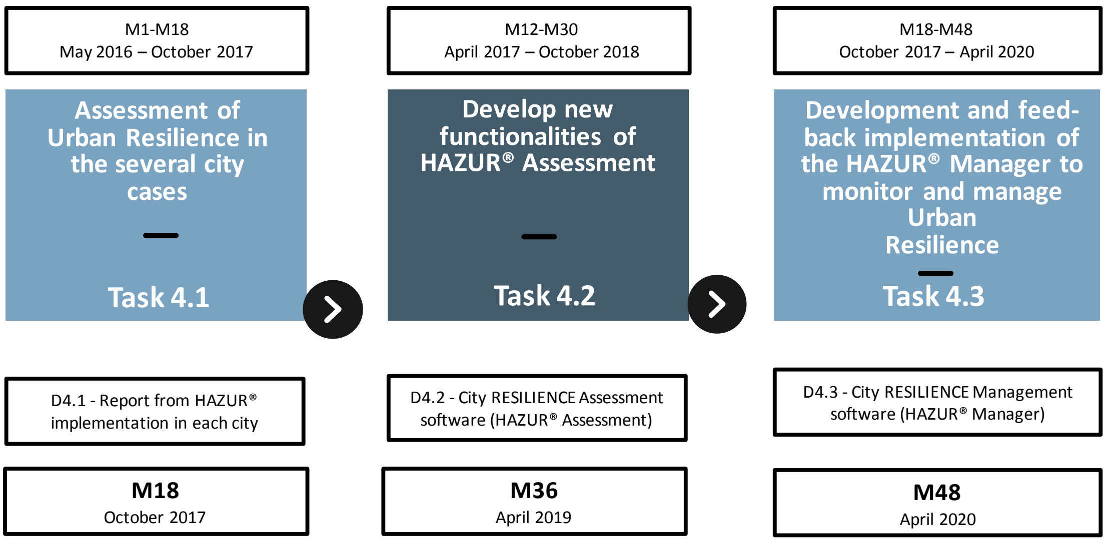


Figure 1: Initial plan of WP4 tasks and deliverables.

After the initial assessment with Hazur in the three cities (Task 4.1), several improvements were identified to be done in the tool. These improvements, together with some new functionalities to include climate change scenarios, adaptation strategies and many others, were included in an updated version of the Hazur tool (Task 4.2).

However, as initially planned, after this update, the new version of Hazur was not going to be tested in the three RESCCUE cities, missing a perfect opportunity to test the robustness of the tool and to integrate the results of other RESCCUE work packages such as the climate change scenarios, the hazard and impact simulations and the adaptation strategies. This is why in November 2018 and Amendment to the Grant Agreement was done (AMD-700174-21), including amongst others D4.5 and D4.6 to undertake a re-assessment in the three cities.

This re-assessment intends to test the updated Hazur tool and methodology. This Re-assessment has the main objective of applying the different new functionalities but also incorporates the different results from the other WP to apply the HAZUR method and tool based on the consulting services from the different implementators.

In Section 2, a justification for this re-assessment is presented, mainly focusing on the new-developments done on the Hazur tool in Task 4.2 and how they tested in the several cities. Then, Section 3 presents the re-assessments in Barcelona, Bristol and Lisbon. These three chapters are considerably different, because the approaches chosen in each city were also very varied. While Lisbon undertook a detailed analysis focusing on floods in some specific areas of the city, Bristol did a strategic analysis of two areas. On the other hand, Barcelona focused on the whole city, but simplifying the approach initially used. Finally, in Section 4 the final set of conclusions of the work done can be seen.

In addition, it is worth noting that Opticits declared bankruptcy after the completion of the second reporting period, and because of that the partner was terminated, implying huge changes to this WP4. In the last amendment (AMD-700174-30) Task 4.3 was removed, and thus, the budget that Opticits had for this was redistributed to other partners to do the new tasks in WP5, WP6 and WP7.

The role of leader of WP4 was assumed by Aquatec, with the sole intention of closing the re-assessment process in the three cities, by submitting D4.5 and D4.6. The bankruptcy of Opticits not only implied some changes in the tasks to be carried in WP4 and other WPs, together with some redistribution of funds, but also the disappearance of HAZUR tool. The tool ceased to be available on the 1st of January 2020 and thus, the last part of the work carried out in WP4 was considerably restricted because of not being able to use it.

Nevertheless, deliverables D4.5 and D4.6 were completed, compiling all the information introduced in the tool before it disappeared, with the main goal of showing the potential that a tool such as Hazur could have, as well as linking WP4 with the rest of the work done in the RESCCUE project.

2. Why a re-assessment?

As explained before, as the RESCCUE project advanced, it was identified that there was the need for a re-assessment in the three RESCCUE cities. The reason to undertake a re-assessment was threefold: first of all, it was necessary to test the updated version of Hazur, and in particular, the climate change and strategies modules. Secondly, it allowed to improve and expand the results of the initial assessment, which in some cases were not enough due to the lack of capabilities of the initial version of the tool or because the scope of the analysis was too complex to be modelled with Hazur. And finally, it allowed to include the results of other WPs, such as climate scenarios, results from the hazard and impacts assessments and the adaptation strategies identified in each case.

The “new performances” integrated in the “Resource Centre”, “Preassessment” and “Assessment” modules of Hazur software, result from the suggestions gathered during the elaboration of D.4.1.

In addition, in Task 4.2 the updated Hazur version intended to include new results on the impacts of climate change scenarios and strategies implementation on the services and infrastructures.

The re-assessment of Hazur in the three cities took into consideration the abovementioned new features, following the same methodology as in the initial assessment, considering the updated Hazur methodology diagram shown in Figure 2.

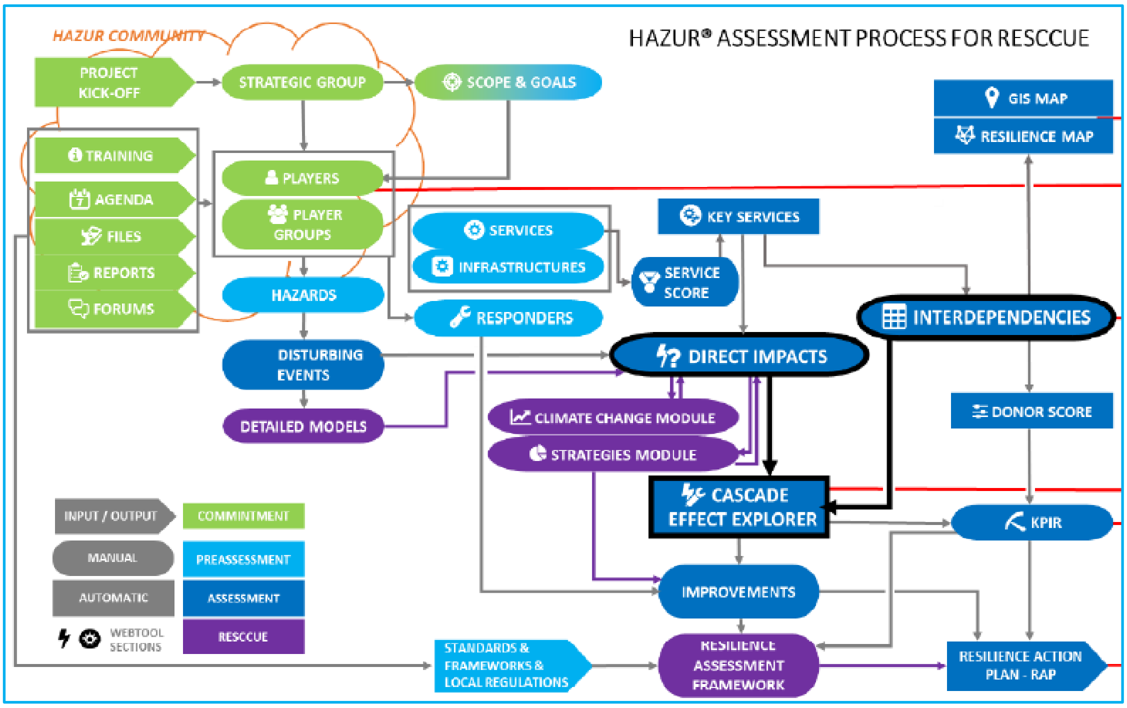


Figure 2. Hazur® software “Preassessment” and “Assessment” new diagram.

One of the key issues with the re-assessments done, is the integration of several outcomes from other RESCCUE Work Packages which generate useful results regarding the city performance that support the Resilience Assessment Framework (RAF) and, consequently, the Resilience Action Plan (RAP), as schematized in Figure 3.

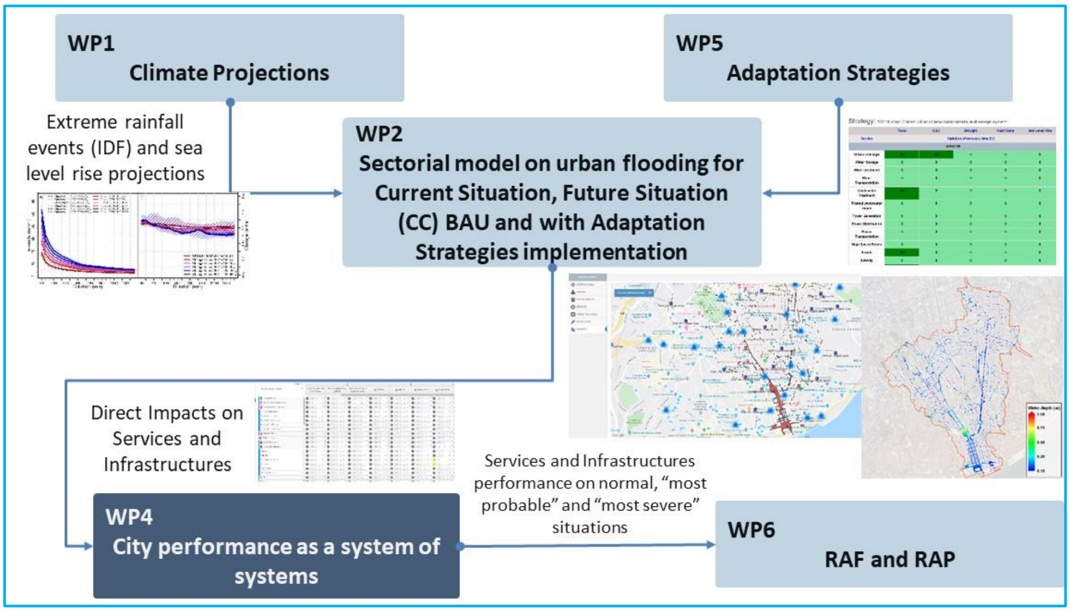


Figure 3. Integration of the different work packages with Hazur®.

As it can be seen, the possibility of including climate change scenarios and adaptation strategies has allowed to close the whole cycle of RESCCUE in a holistic way, taking advantage of Hazur new capabilities.

2.1.1 New performances (LIS)

In the new version of the "Resource Centre", the "Preassessment" and the "Assessment" modules, some new features were included to support the updated methodology presented in Figure 2. Terminology used in the previous version of Hazur® was also a point of discussion and a few changes were made.

Regarding the "Resource Centre" module, the main features considered are listed in Table 1.

Table 1. Resource Centre module main uses for the re-assessment.

SECTION	FUNCTIONALITIES USED
TRAINING	A few videos were added, not only to support the new users of Hazur, but also dissemination videos related to the three cities and other general ones of the RESCCUE project.
AGENDA	Some events were added, namely meetings from the RESCCUE Project, such as PCMs, local case study meetings or others.
FILES	Some folders and files were created, including some deliverables of the RESCCUE project.

Forums	Not used along the Hazur implementation in RESCCUE because no external actors were included in the Hazur process for the re-assessment and thus, the needed interactions to complete the analysis were mostly achieved through meetings with the involved players.
Permissions	Three levels of permissions were set: Admin: given to implementers, with full access; City Council: given to representatives of the municipalities; Service Providers: given to services players.

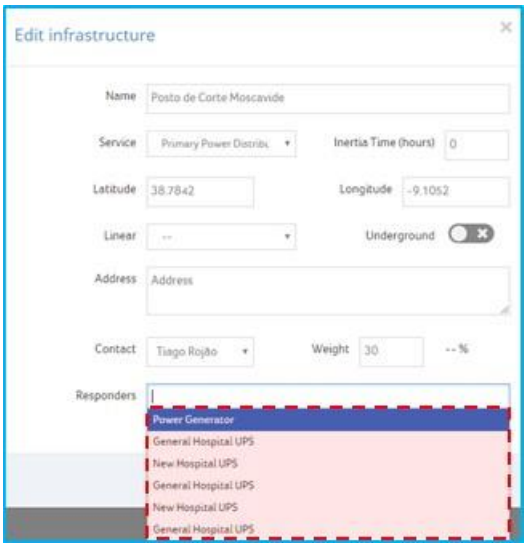
Regarding the "*Infrastructures"* section, new properties to specify if infrastructures were "underground" or "linear" were created.

In this sense, some of the uploaded infrastructures were updated to consider the "underground" property, namely, water and wastewater pumping stations, power substations and subway stations, although at the time, Hazur was not able to add new functionalities regarding this, so it was just an extra information field for the selected infrastructures.

The "linear" property, which allowed to assign a polygon to a given infrastructure, was not considered in the re-assessment since it did not add any extra simulation results, whereas it was a lot of extra work to change all the roads, metro lines, etc., initially included as points

Another new possibility included was the "weight" property of infrastructures. This was also tested, for example in the Power Sector, by attributing higher weights to switching stations because its failure is considered more severe regarding cascade effects. However, this property did not seem to differentiate or enhance the analysis performed on the tool.

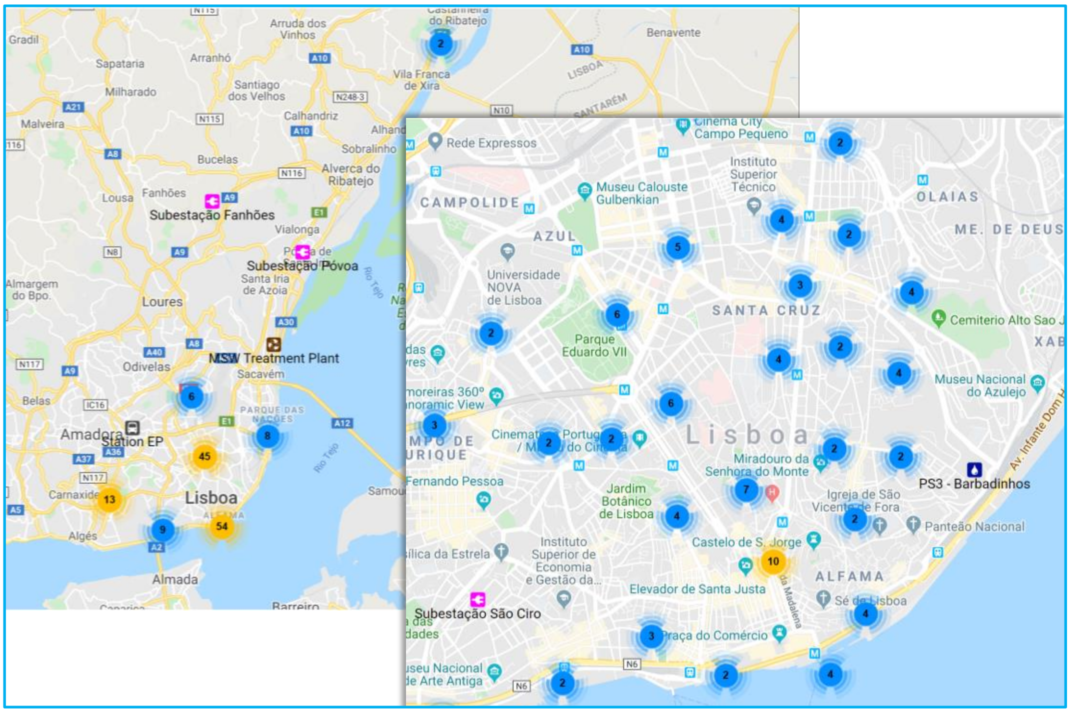
Figure 4 shows an example of an infrastructure edition window on HAZUR® software. To stress that the responders available to associate to the infrastructure does not correspond to those inserted in the "responders" section (which is a HAZUR® software bug).



(Source: Infrastructures - HAZUR®, project Lisbon RESCCUE)

Figure 4. Infrastructure editing example

Also the georeferenced data uploaded was improved and is now visible on GIS Data module the "aggregated" total number of infrastructures, as observed in Figure 5.



(Source: GIS Map - HAZUR®, project Lisbon RESCCUE)

Figure 5. Location of the considered infrastructures in Lisbon

The main improvement on the "**Assessment Module**" relates to the definition of the interdependencies between services and infrastructures, which is the core of the Hazur assessment methodology. The new version of Hazur software includes the possibility to define interdependencies between infrastructures of the same service, otherwise not considered in the previous version. This is a relevant improvement that has been thoroughly tested in the city cases.

In the previous assessment phase, the lack of this functionality was surpassed by considering different "sub-services" within a service. This means that the previous results are identical to the results of the re-assessment, but the new approach considerably reduces the number of total services to be created and simplifies the data acquisition and processing processes.

Another new functionality included in the interdependencies matrix is the "essential infrastructure property/critical infrastructure"", *i.e.*, if the infrastructure fails the respective service fails and vice-versa. This situation is indeed relevant, if the service depends almost exclusively on a specific and critical infrastructure and no redundancies to that infrastructure are in place, which might be the case in some urban areas (but it was not the case for the three RESCCUE sites).

The new interdependence matrix also allows for the direct setup of the redundancies, which is considered easier to apply by the user.

When performing the first assessment, a common struggle was the definition of failure degree of a given infrastructure/service. In fact, infrastructures can be affected in different degrees which may depend on multiple and more or less complex situations. Therefore "not-affected" or "complete failure", as considered in the Hazur previous version, are only the extreme ends of several possibilities. Therefore, the new functionality designated as "variants", which allows to specify a particular degree of failure of an infrastructure/service, was considered a good improvement. An example of this functionality was applied to the power substations in Lsibon, as shown in Figure 6. However this change was not integrated with the other features and does not hold an impact on cascade effects.

Variants	Tags
Affected < 50%; Reconfiguration time < 10 min	<50%
Affected > 50%; Reconfiguration time > 10 min	>50%

(Source: Interdependencies - HAZUR®, project Lisbon RESCCUE)

Figure 6. Variants setup for Power Sector

The definition of "Disruptive events" in the updated version of Hazur, also experienced a few relevant changes. In order to generate scenarios for a given disruptive event (such as different return periods for a flood event), this module of Hazur allowed the definition and grouping of disruptive events and its scenarios (Figure 7). This eases the definition and study of this disruptive events, as they can be easily copied, compared and analyzed. In addition, by including disruptive events and scenarios including climate change and adaptation strategies, their effects can be easily set-up and assessed.

Name	Disruptive Event
01. Duration of a Sea water pollution event X < 0.5 days	CSO caused by rainfall event
01. Heat waves event duration 3 days < X < 5 days	Heat waves
01. Rainfall event with 1 year return period (T1)	Floods
01. Rainfall event with 1 year return period (T1)	Traffic affections
01. Rainfall event with 1 year return period (T1)	Electrical affections
01. Severe droughts event (6 monts)	Droughts
02. Severe droughts event (12 monts)	Droughts
02. Duration of a Sea water pollution event 0.5 days < X< 1 day	CSO caused by rainfall event
02. Heat wave event duration X > 5 days	Heat waves
02. Rainfall event with 10 years return period (T10)	Floods
02. Rainfall event with 10 years return period (T10)	Traffic affections
02. Rainfall event with 10 years return period (T10)	Electrical affections
03. Duration of a Sea water pollution event 1 day < X < 1.5 days	CSO caused by rainfall event
03. Rainfall event with 50 years return period (T50)	Floods
03. Rainfall event with 50 years return period (T50)	Traffic affections
03. Rainfall event with 50 years return period (T50)	Electrical affections
03. Severe droughst event (24 months)	Droughts
04. Duration of a Sea water pollution event X > 1.5 days	CSO caused by rainfall event
04. Rainfall event with 100 years return period (T100)	Floods
04. Rainfall event with 100 years return period (T100)	Traffic affections
04. Rainfall event with 100 years return period (T100)	Electrical affections
05. Rainfall event with 500 years return period (T500)	Floods
05. Rainfall event with 500 years return period (T500)	Traffic affections
05. Rainfall event with 500 years return period (T500)	Electrical affections

Figure 7: Considered Disruptive Events and Scenarios in the Re-Assessment in Barcelona

Overall, the newest Hazur® tool version does not change significantly the outcomes and results obtained, since the majority of the changes are related either with terminology (*e.g.* the former "What If" matrix is now the "Direct Impacts" matrix and the "Impacts" are now referred to as "Disruptive Events") or with the features related to organization and information (*e.g.* "redundancies" are now filled within the "interdependencies matrix").

The main relevant features in the new version of the tool, and which would have an impact on the previous assessment, consider the interdependencies of infrastructures of the same service and the capacity to include different degrees of failure of a service or infrastructure.

3. Re-assessment in the three cities

3.1 Barcelona Research Site

3.1.1 Approach

The scope of Hazur implementation for Barcelona is citywide. In addition, some infrastructures that are outside the administrative boundaries of the city, have also been considered due to their importance (such as the airport, commuter train stops, waste collection parks and pump station, to name a few).

On the initial Hazur Assessment presented in D4.1, this scope led to a very complex system with a high number of services and infrastructures introduced in the tool. In total, there were 56 services and 786 infrastructures in the system, with a huge number of independencies making it very difficult to analyse the results and at time, even to run the Hazur tool itself.

Taking advantage of the improvements done in the Hazur tool as part of Task 4.2, the Re-assessment in Barcelona has been done in a more efficient way, by merging services that were split (due to the limitation of not being able to set interdependences between the same service and its infrastructures). As it will be explained in detail in section 3.1.2.1, the total number of services was reduced to 34. A clear example of this is the case of the metro, where initially, each metro line was a service on its own. By being able to establish interdependencies between infrastructures of the same service, all the lines were introduced in a single service, being able to considerably reduce the number of services. Additionally, the number of infrastructures has been reduced from 786 to 563, by removing all the information that on the initial assessment proved not be relevant.

Taking advantage of the work done in WP1, 2, 3 and 5, this re-assessment is not only an update of the initial assessment done, but also includes all the analysed hazards (3.1.2.3), climate change scenarios (3.1.2.4) and adaptation strategies (3.1.2.5). As explained before, the new functionalities of the tool did not allow to automatize the analysis of the climate change scenarios and adaptation strategies, but nevertheless, by including all these scenarios separately, comparisons have been made to understand the problems and plausible solutions related to climate change impacts in urban areas.

3.1.2 Barcelona Re-assessment

3.1.2.1 Services and infrastructures

The re-assessment carried out in Barcelona allows analyzing the resilience of Barcelona as a city against different impacts. These have been simulated under different hypothesis of climate change and adaptation measures proposed in RESCCUE.

To centre the simulation on the infrastructures with the greatest impacts, the re-assessment model for Barcelona started with a simplification of the data analysed. The response of the city under different climate extreme situations and hypothesis of resilience has been simulated (baseline, future under climate change effects, and adopting some adaptation strategies).

To achieve this, services have been reduced from 56 to 34, and infrastructures from 786 to 563, as explained before.

Figure 8 shows the GIS interface of Hazur® where all the infrastructures submitted for study in this project are located in the city map.

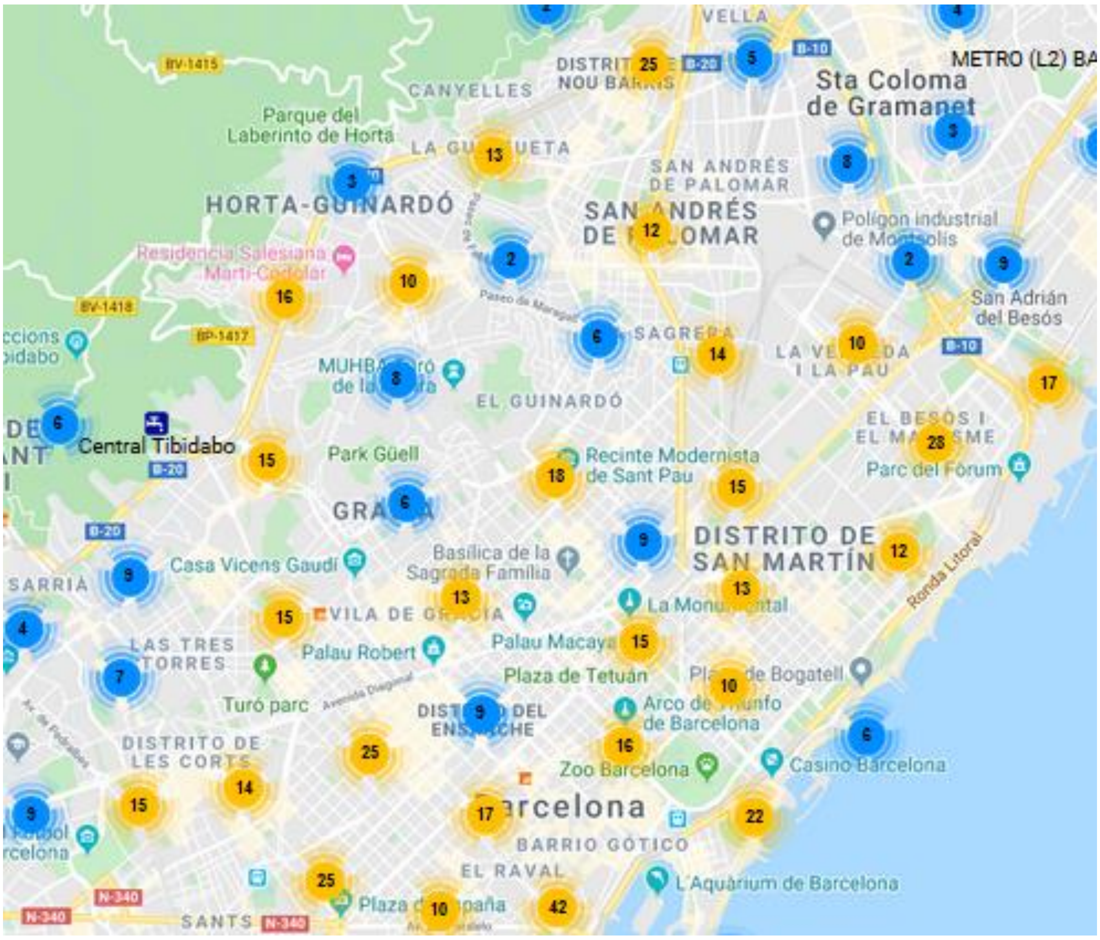


Figure 8: Re-assessment GIS map for Barcelona's infrastructures

All the services and infrastructures considered in Hazur® to analyze Barcelona resilience in the re-assessment are summarized in Table 2.

Table 2: Summary of services and infrastructures implemented in re-assessment Barcelona's resilience Hazur® model

SECTOR NAME	SERVICE NAME	INFRASTRUCTURES
WATER (4 Services) (96 I Infrastructures)	WATER DISTRIBUTION (40 Infrastructures)	- 2 Control Center - 2 Distribution Station - 16 Water distribution central - 20 Water Storage Tanks
	WATER TREATMENT (3 Infrastructures)	- 1 Desalination Plant - 2 Water Treatment Plant
	URBAN DRAINAGE (46 Infrastructures)	- 7 Urban Drainage Gates - 26 Urban Drainage Lift Stations - 12 Urban Drainage Storm Tanks - 1 Urban Drainage Control Center

	WASTEWATER TREATMENT (7 Infrastructures)	- 2 Wastewater Plants - 5 Wastewater Lift Stations
MOBILITY **(16 Services)** **(304 Infrastructures)**	METRO LINES AND CONTROL CENTERS (13 Infrastructures)	- 3 Metro Control Centers - 10 Metro line
	METRO STATIONS (132 Infrastructures)	-132 metro stations, some of them shared by different lines - 30 L1 Stations - 18 L2 Stations - 26 L3 Stations - 22 L4 Stations - 26 L5 Stations - 9 L9N Stations - 15 L9S Stations - 6 L10N Stations - 6 L10S Stations - 5 L11 Stations
	TRAM T1-T2-T3 (TRAM BAIX) (38 Infrastructures)	-38 Tram stations, some of them shared by different lines - 29 T1 Stations - 32 T2 Stations -27 T3 Stations
	TRAM T4-T5-T6 (TRAM BESÒS) (35 Infrastructures)	-35 Tram stations, some of them shared by different lines - 20 T4 Stations - 19 T5 Stations - 16 T6 Stations
	TRAIN (34 Infrastructures)	-34 Tram stations, some of them shared by different lines - 7 R1 Stations - 6 R2 Stations - 7 R2N Stations - 5 R2S Stations - 8 R3 Stations - 8 R4 Stations - 8 R7 Stations - 10 L6 Stations - 8 L7 Stations - 7 L8 Stations
	BUS (0 infrastructures)	- 0 Infrastructures associated
	AIRPORT (2 Infrastructures)	-2 Airport Terminals
	HARBOURS (5 Infrastructures)	- 5 Harbors
	HIGH SPEED RINGS - RONDA DE DALT (10 Infrastructures)	- 10 “Ronda de Dalt” Sections
	HIGH SPEED RINGS - RONDA LITORAL (15 Infrastructures)	- 15 “Ronda Litoral” Sections
	HIGH SPEED RINGS - C32 AND C33 (3 Infrastructures)	- 2 C32 sections - 1 C33 sections
	TRAFFIC (30 Infrastructures)	- 13 Street Sections affecting “Ronda de Dalt” - 17 Street Sections affecting “Ronda Litoral”
	TRAFFIC LIGHTS (0 infrastructures)	- 0 Infrastructures associated
	TRAFFIC - SURVEILLANCE CENTER (0 infrastructures)	- 0 Infrastructures associated
	TRAFFIC INFORMATION SYSTEMS (0 infrastructures)	- 0 Infrastructures associated
	TRAFFIC SAFETY WARNING (0 infrastructures)	- 0 Infrastructures associated
	REE	- 0 Infrastructures associated

POWER (2 SERVICES) (25 INFRAESTRUCTIRES)	(0 infrastructures)	
	POWER DISTRIBUTION (25 Infrastructures)	- 25 Electrical Substation
WASTE (2 Services) (9 Infrastructures)	STREET CLEANING (4 Infrastructures)	- 4 Street cleaning Parks
	WASTE COLLECTION & TREATMENT (5 Infrastructures)	- 4 Waste Collection Parks - 1 Waste Treatment Plant
TELECOMMUNICATION (1 Service) (0 Infrastructures)	TELECOMMUNICATIONS (0 infrastructures)	- 0 Infrastructures associated
ENVIRONMENT (3 Services) (17 Infrastructures)	GREEN INFRASTRUCTURES (8 Infrastructures)	- 8 Parks
	BEACHES (7 Infrastructures)	- 7 Beaches
	RECEIVING WATERS (2 Infrastructures)	- 2 Barcelona Rivers
EMERGENCY (4 Services) (42 Infrastructures)	FIRE & CIVIL PROTECTION (7 Infrastructures)	- 7 Fire Stations
	MEDICAL EMERGENCY (11 Infrastructures)	- 11 Hospitals
	LOCAL POLICE (10 Infrastructures)	- 10 Local Police Stations
	REGIONAL POLICE (14 Infrastructures)	- 14 Regional Police Stations
HEALTH (1 Service) (57 Infrastructures)	PUBLIC HEALTH (57 Infrastructures)	- 56 CAP's (Primary Care Centers) -1 Dispensary
SOCIAL (1 Service) (0 Infrastructures)	CITIZEN (0 infrastructures)	- 0 Infrastructures associated
TOTAL	**34 SERVICES**	**563 INFRESTRUCTURES**

3.1.2.2 Interdependence matrix

The new developments done in Hazur® software as explained in D4.2, have implied some changes in the interdependences matrix that allow the user to define internal relationships between same services infrastructures. This allows to also use the matrix diagonal, as showed in Figure 9, Figure 10 and Figure 11.

By clicking on the diagonal, the interdependencies between infrastructures of the same service can be defined. See some examples in Figure 12 and Figure 13. When the diagonal shows blanks, it means that these services do not have infrastructures inside, so they are only defined as service.

On the other hand, the interdependencies are now presented considering different definitions than before, which allows to determine the infrastructure or service as Operative (not affected), Affected or Down. This last one also allows to define if the service or infrastructure falls immediately or after few hours, days or weeks.

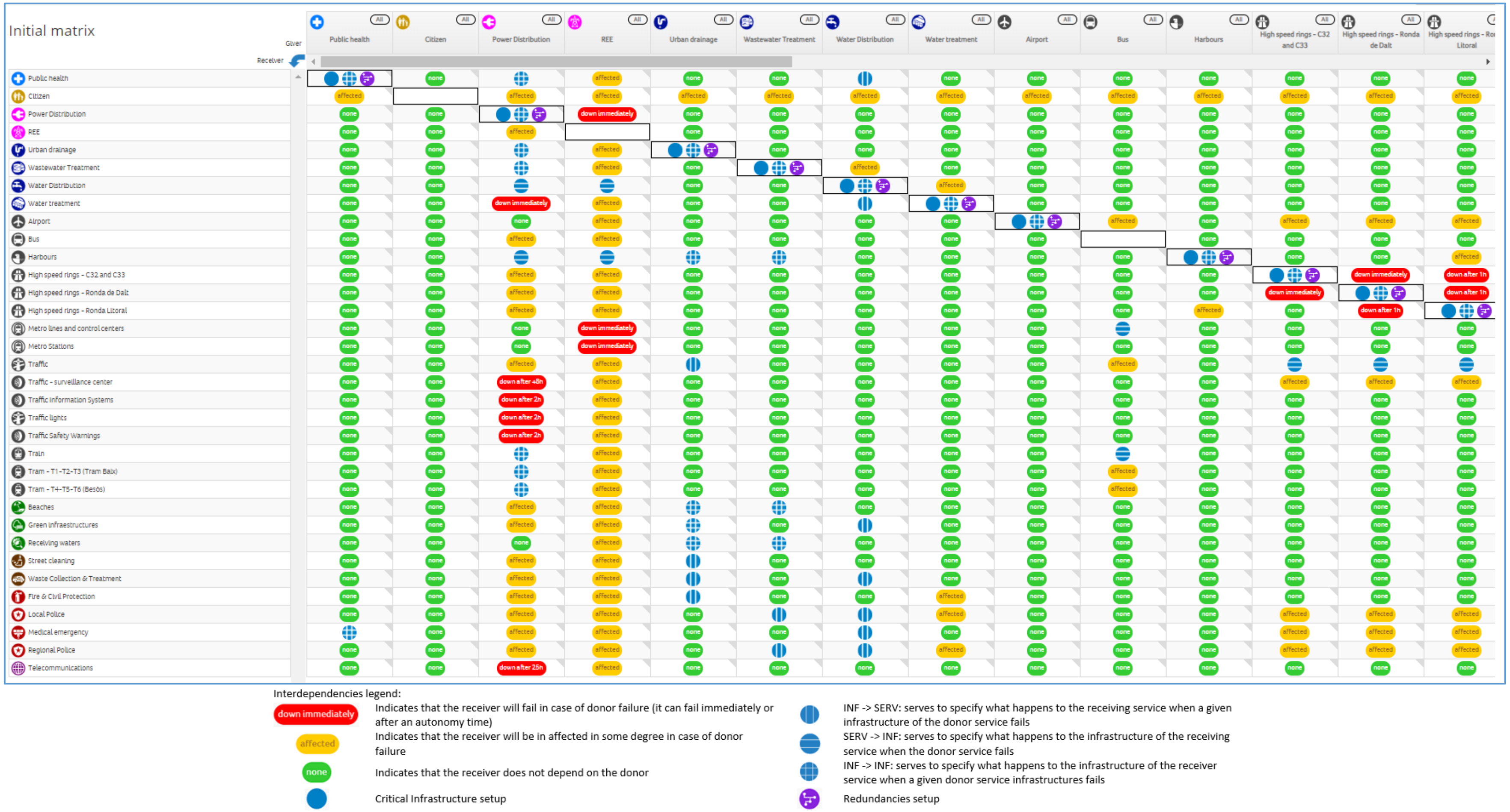
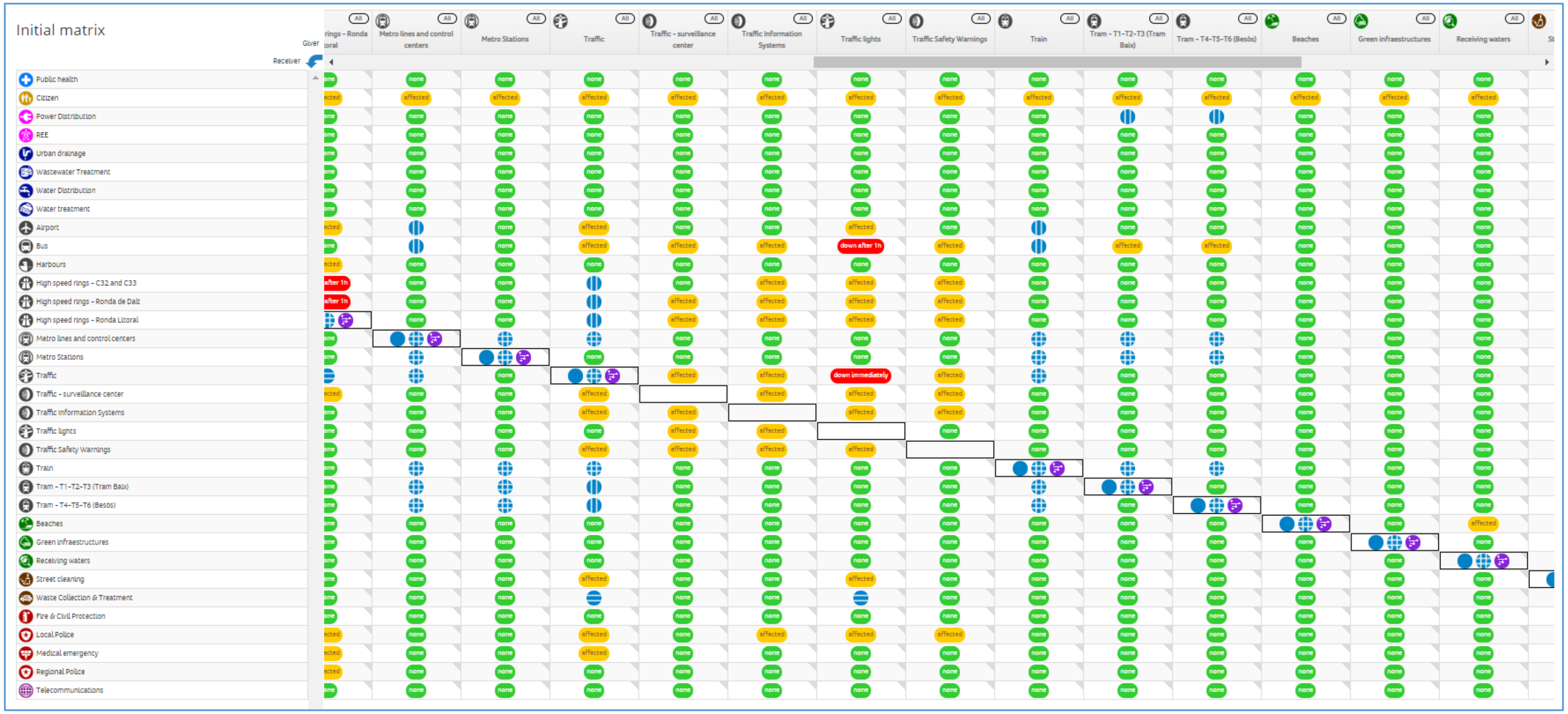


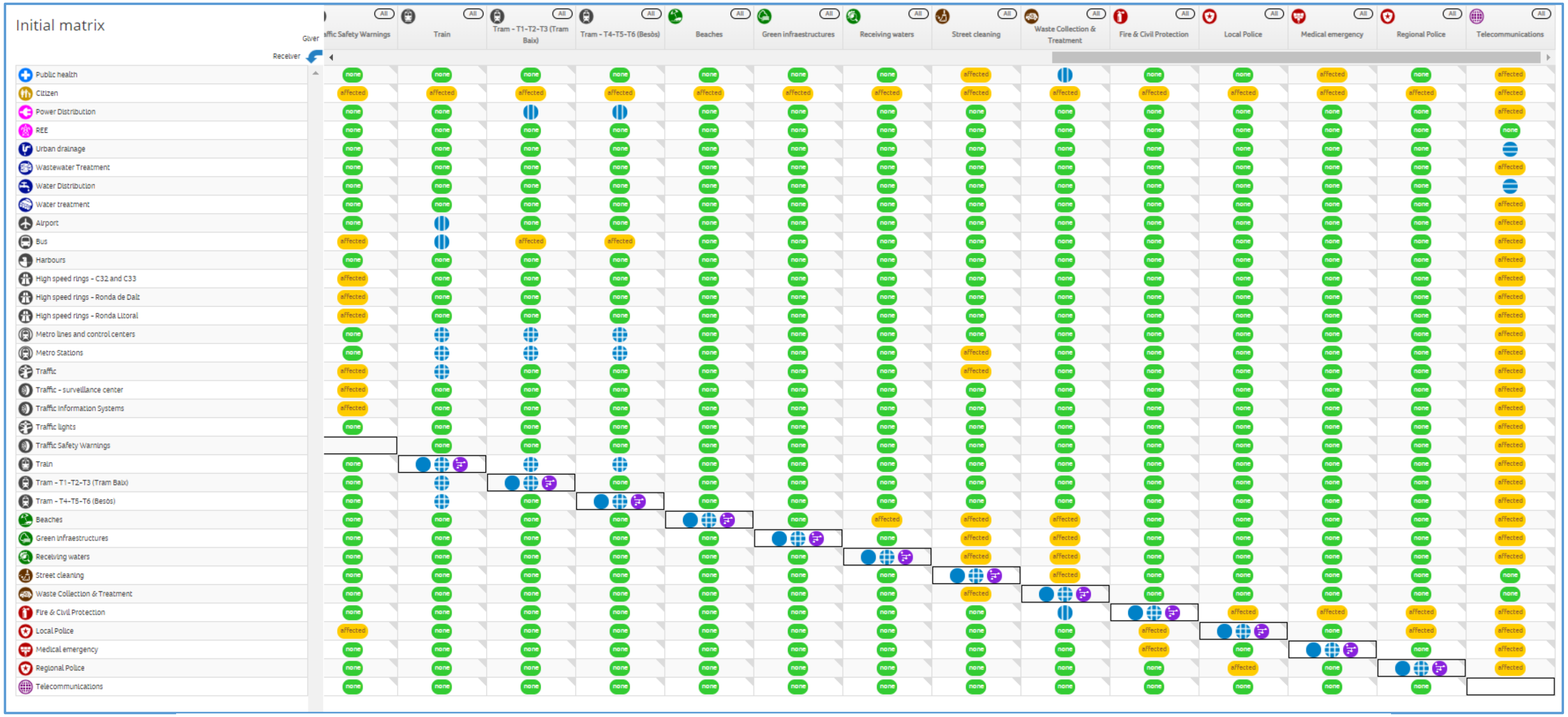
Figure 9: Re-assessment interdependencies matrix for Barcelona (1/3) (Source: Interdependencies - Hazur®, project "Re-assessment of Barcelona RESCCUE")



Interdependencies legend:

- down immediately — Indicates that the receiver will fail in case of donor failure (it can fail immediately or after an autonomy time)
- affected — Indicates that the receiver will be in affected in some degree in case of donor failure
- none — Indicates that the receiver does not depend on the donor
- Critical Infrastructure setup
- INF -> SERV: serves to specify what happens to the receiving service when a given infrastructure of the donor service fails
- SERV -> INF: serves to specify what happens to the infrastructure of the receiving service when the donor service fails
- INF -> INF: serves to specify what happens to the infrastructure of the receiver service when a given donor service infrastructures fails
- Redundancies setup

Figure 10: Re-assessment interdependencies matrix for Barcelona (2/3) (Source: Interdependencies - Hazur®, project "Re-assessment of Barcelona RESCCUE")



Interdependencies legend:

down immediately	Indicates that the receiver will fail in case of donor failure (it can fail immediately or after an autonomy time)		INF -> SERV: serves to specify what happens to the receiving service when a given infrastructure of the donor service fails
affected	Indicates that the receiver will be in affected in some degree in case of donor failure		SERV -> INF: serves to specify what happens to the infrastructure of the receiving service when the donor service fails
none	Indicates that the receiver does not depend on the donor		INF -> INF: serves to specify what happens to the infrastructure of the receiver service when a given donor service infrastructures fails
	Critical Infrastructure setup		Redundancies setup

Figure 11: Re-assessment interdependencies matrix for Barcelona (3/3) (Source: Interdependencies - Hazur®, project "Re-assessment of Barcelona RESCCUE")

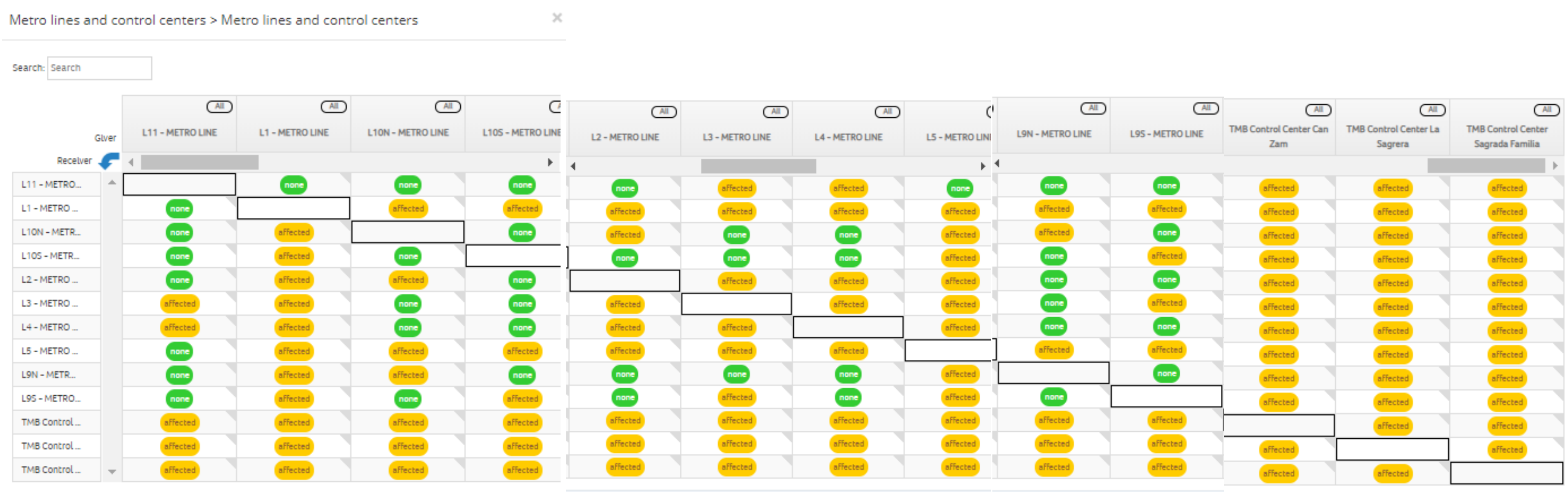


Figure 12: Internal interdependencies between the infrastructures of “Metro stations and TMB Control Centers” service

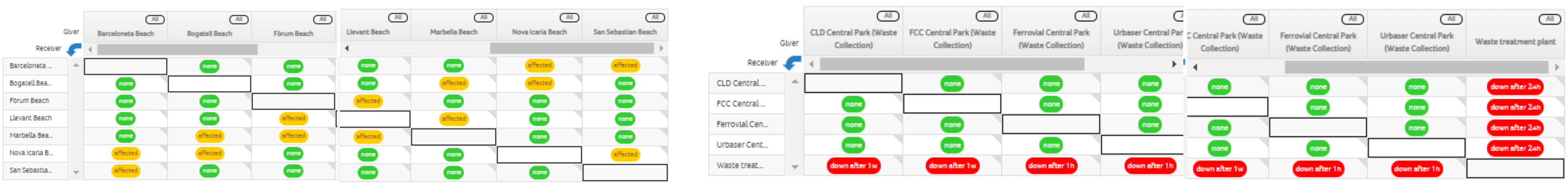


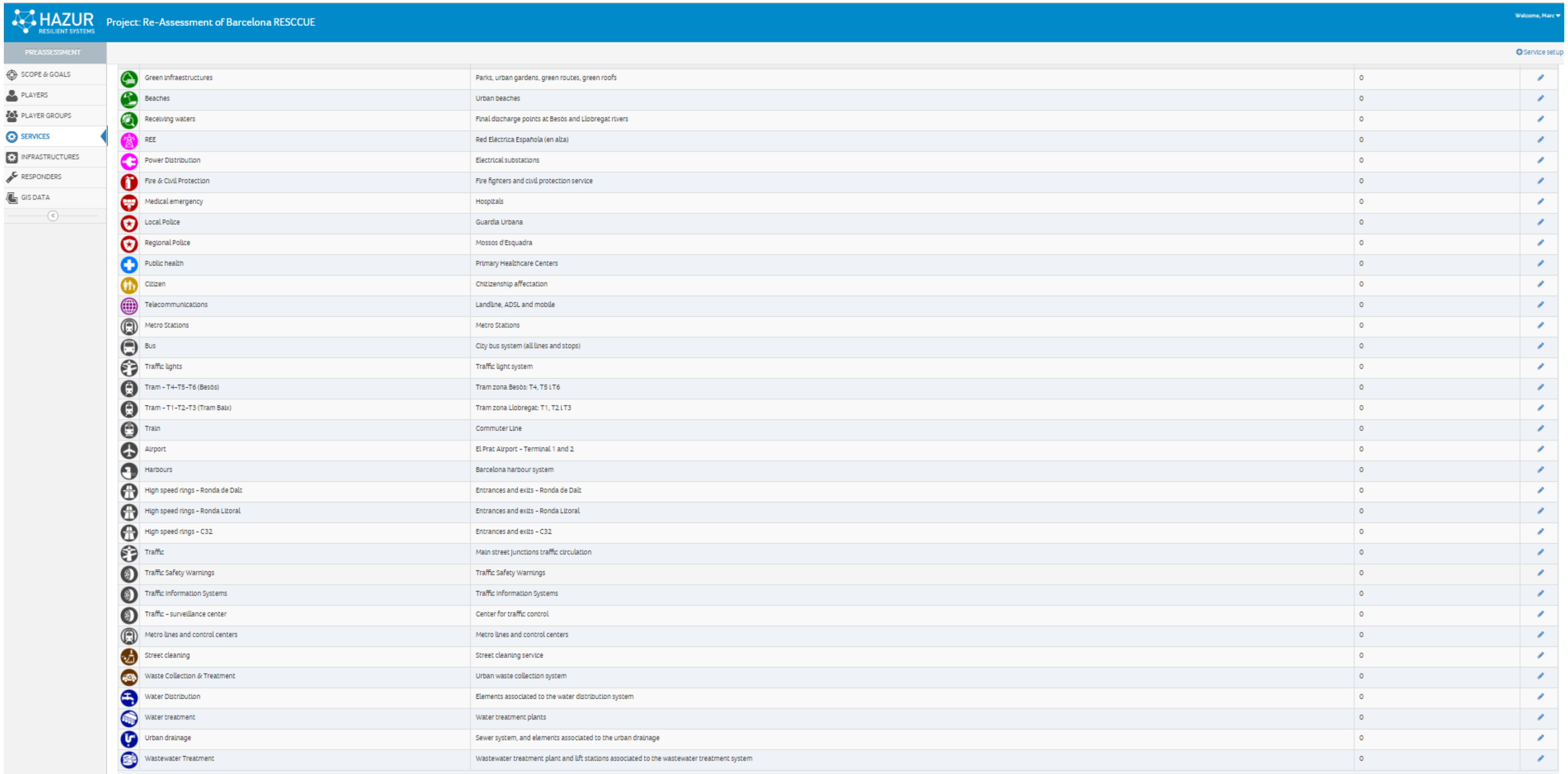
Figure 13: Internal interdependencies among infrastructures of the same services “Beach” (left) and “Waste Collection and Treatment” (right)

Thanks to this new functionality, the re-assessment in Barcelona has been able to reduce the total number of services by grouping some of the previous services (from the initial assessment) into one single service (Table 2). Figure 14 presents all the services that have now been considered.

On the other hand, some new services without infrastructures have been included, such as citizens or traffic information systems, whereas some others from the initial assessment that did not provide any relevant information have been eliminated.

Following, the main changes with regards to services and infrastructures in this re-assessment can be seen in detail:

- Mobility services have been reduced from 32 to 16:
    - Ten services related to metro (nine metro lines and TMB control centers) have become two services: "Metro Stations" and "Metro lines and control centers). Metro infrastructures have been reduced from 165 to 132.
    - The service "metro-screens and accesses" and its corresponding 110 infrastructures have been removed.
    - The nine services defining several train lines have been united to one single service called "train". Train infrastructures have been reduced from 53 to 34.
    - The three high speed rings were previously defined by all their entrances and exits, which didn't add any value to the analysis. Instead, some relevant sections of the rings have been created, reducing the number of infrastructures from 108 to 28.
- Water sector has reduced its number of services from 10 to 4, by joining some of them. In this case, the number of infrastructures has not changed:
    - "Wastewater Treatment-Plants" and "WWT-Lift Stations" are joined into one service "Wastewater Treatment".
    - Service "Water Distribution" now contains the former services "AB Control Center", "Water Distribution" and "Water Storage".
    - On the other hand "Urban Drainage" re-assessment service contains the old services "Urban Drainage-Gates", "Urban Drainage-Lift Stations", "Urban Drainage-Storm Tanks" and "Control Center Bcasa".



Green infraestructures	Parks, urban gardens, green routes, green roofs	0
Beaches	Urban beaches	0
Receiving waters	Final discharge points at Besos and Llobregat rivers	0
REE	Red Eléctrica Española (en alta)	0
Power Distribution	Electrical substations	0
Fire & Civil Protection	Fire fighters and civil protection service	0
Medical emergency	Hospitals	0
Local Police	Guardia Urbana	0
Regional Police	Mossos d'Esquadra	0
Public health	Primary Healthcare Centers	0
Citizen	Chitizenship affectation	0
Telecommunications	Landline, ADSL and mobile	0
Metro Stations	Metro Stations	0
Bus	City bus system (all lines and stops)	0
Traffic lights	Traffic light system	0
Tram - T4-T5-T6 (Besòs)	Tram zona Besòs: T4, T5 i T6	0
Tram - T1-T2-T3 (Tram Baix)	Tram zona Llobregat: T1, T2 i T3	0
Train	Commuter Line	0
Airport	El Prat Airport - Terminal 1 and 2	0
Harbours	Barcelona harbour system	0
High speed rings - Ronda de Dalt	Entrances and exits - Ronda de Dalt	0
High speed rings - Ronda Litoral	Entrances and exits - Ronda Litoral	0
High speed rings - C32	Entrances and exits - C32	0
Traffic	Main street junctions traffic circulation	0
Traffic Safety Warnings	Traffic Safety Warnings	0
Traffic Information Systems	Traffic Information Systems	0
Traffic - surveillance center	Center for traffic control	0
Metro lines and control centers	Metro lines and control centers	0
Street cleaning	Street cleaning service	0
Waste Collection & Treatment	Urban waste collection system	0
Water Distribution	Elements associated to the water distribution system	0
Water treatment	Water treatment plants	0
Urban drainage	Sewer system, and elements associated to the urban drainage	0
Wastewater Treatment	Wastewater treatment plant and lift stations associated to the wastewater treatment system	0

Figure 14: Services defined into Hazur® for Re-Assessment version

3.1.2.3 Hazards

The Re-Assessment of Barcelona has considered six different disruptive events: Floods, Droughts, CSO caused by a rainfall event, Heat waves, Traffic impacts and Electrical impacts.

Figure 15 shows how these hazards and their impacts have been introduced into the tool Hazur® as Disruptive Events.

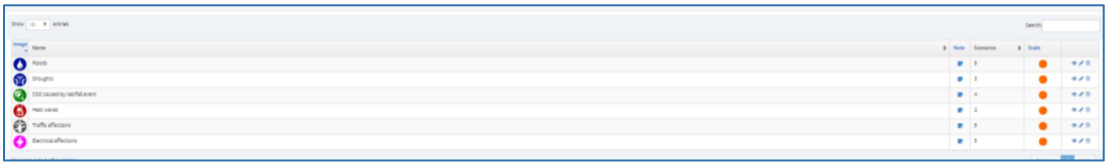


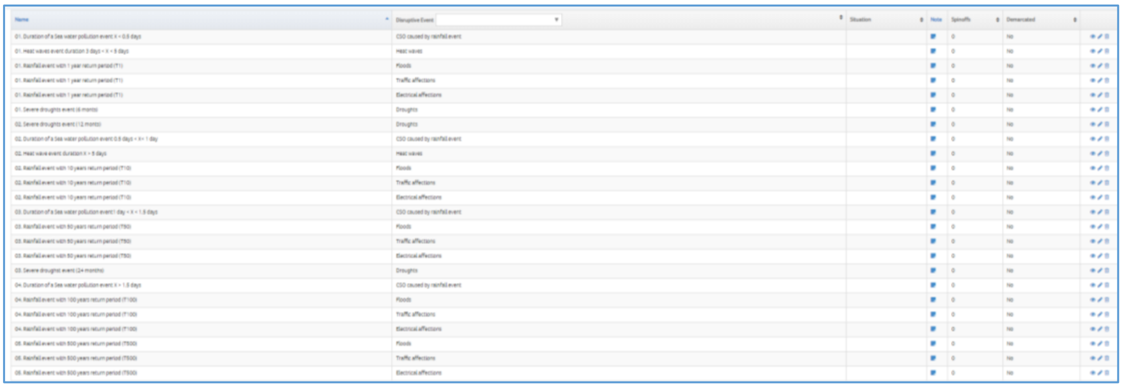
Figure 15: Hazards considered in "Re-Assessment Barcelona RESCCUE" project

Each Hazard has been analyzed considering different scenarios as presented in Table 3, considering climate change and adaptation scenarios. Figure 16 shows how the Disruptive events and their scenarios are introduced within Hazur® tool for their simulation.

The scenarios considered are: Baseline, which defines the current situation; Business As Usual (BAU), the future with climate change effects without the implementation of adaptation strategies; and Adaptation 1 and 2, future situations adopting adaptation strategies.

Table 3: Disruptive events and scenarios introduced into Hazur® software to simulate the hazards object of study

HAZARDS OR IMPACTS	DISRUPTIVE EVENTS	SCENARIOS
1. Floods **- 5 disruptive events** **- 4 scenarios**	01. Rainfall event with 1 year return period (T1) 02. Rainfall event with 10 years return period (T10) 03. Rainfall event with 50 years return period (T50) 04. Rainfall event with 100 years return period (T100) 05. Rainfall event with 500 years return period (T500)	- Baseline - BAU -Adaptation 1 -Adaptation 2
2. Traffic impacts **- 5 disruptive events** **- 4 scenarios**	01. Rainfall event with 1 year return period (T1) 02. Rainfall event with 10 years return period (T10) 03. Rainfall event with 50 years return period (T50) 04. Rainfall event with 100 years return period (T100) 05. Rainfall event with 500 years return period (T500)	- Baseline - BAU -Adaptation 1 -Adaptation 2
3. Electrical impacts **- 5 disruptive events** **- 4 scenarios**	01. Rainfall event with 1 year return period (T1) 02. Rainfall event with 10 years return period (T10) 03. Rainfall event with 50 years return period (T50) 04. Rainfall event with 100 years return period (T100) 05. Rainfall event with 500 years return period (T500)	- Baseline - BAU -Adaptation 1 -Adaptation 2
4. CSO caused by rainfall event **- 4 disruptive events** **- 4 scenarios)**	01. Rainfall volume <2 mm 02. Rainfall volume 2 mm <= X < 8 mm 03. Rainfall volume 8 mm <= X < 16 mm 04. Rainfall volume X >= 16 mm	- Baseline - BAU -Adaptation 1 -Adaptation 2
5 Drought **- 3 disruptive events** **- 4 scenarios**	01. Mild drought event 02. Moderate drought 03. Severe drought	- Baseline - BAU -Adaptation 1 -Adaptation 2
4 Heat waves **- 2 disruptive events** **- 4 scenarios**	01. Heat wave event duration 3 days < X < 5 days 02. Heat wave event duration X > 5 days	- Baseline - BAU -Adaptation 1 -Adaptation 2

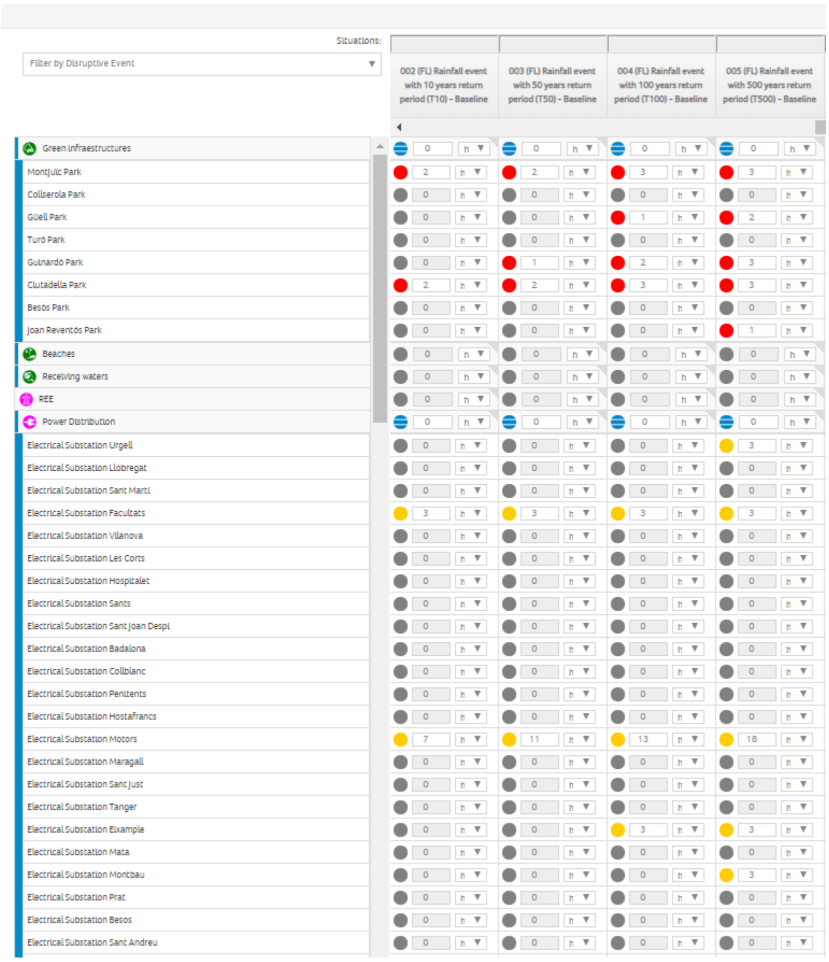


Name	Disruptive Event	Situation	Note	Spinoffs	Demarcated
01. Duration of a Sea water pollution event X < 0.5 days	CSO caused by rainfall event			0	No
01. Heat waves event duration 3 days < X < 5 days	Heat waves			0	No
01. Rainfall event with 1 year return period (T1)	Floods			0	No
01. Rainfall event with 1 year return period (T1)	Traffic affections			0	No
01. Rainfall event with 1 year return period (T1)	Electrical affections			0	No
01. Severe droughts event (6 monts)	Droughts			0	No
02. Severe droughts event (12 monts)	Droughts			0	No
02. Duration of a Sea water pollution event 0.5 days < X< 1 day	CSO caused by rainfall event			0	No
02. Heat wave event duration X > 5 days	Heat waves			0	No
02. Rainfall event with 10 years return period (T10)	Floods			0	No
02. Rainfall event with 10 years return period (T10)	Traffic affections			0	No
02. Rainfall event with 10 years return period (T10)	Electrical affections			0	No
03. Duration of a Sea water pollution event1 day < X < 1.5 days	CSO caused by rainfall event			0	No
03. Rainfall event with 50 years return period (T50)	Floods			0	No
03. Rainfall event with 50 years return period (T50)	Traffic affections			0	No
03. Rainfall event with 50 years return period (T50)	Electrical affections			0	No
03. Severe droughst event (24 months)	Droughts			0	No
04. Duration of a Sea water pollution event X > 1.5 days	CSO caused by rainfall event			0	No
04. Rainfall event with 100 years return period (T100)	Floods			0	No
04. Rainfall event with 100 years return period (T100)	Traffic affections			0	No
04. Rainfall event with 100 years return period (T100)	Electrical affections			0	No
05. Rainfall event with 500 years return period (T500)	Floods			0	No
05. Rainfall event with 500 years return period (T500)	Traffic affections			0	No
05. Rainfall event with 500 years return period (T500)	Electrical affections			0	No

Figure 16: Considered Disruptive Events and Scenarios in "Re-Assessment Barcelona RESCCUE" project

The simulations of the six disruptive events simulated come from the analysis done in WP2 and WP3. For the case of floods, the 1D-2D model of the drainage system has been used to identify the flooded areas corresponding the 1, 10, 50, 100 and 500 years return period.

Once the flooded areas are defined, the several infrastructures that lay within the affected areas are assigned a down time, corresponding to the duration of the event (Figure 17).



Situations:

Filter by Disruptive Event

	002 (FL) Rainfall event with 10 years return period (T10) - Baseline	003 (FL) Rainfall event with 50 years return period (T50) - Baseline	004 (FL) Rainfall event with 100 years return period (T100) - Baseline	005 (FL) Rainfall event with 500 years return period (T500) - Baseline
Green infraestructures	0 h	0 h	0 h	0 h
Montjuïc Park	2 h	2 h	3 h	3 h
Collserola Park	0 h	0 h	0 h	0 h
Güell Park	0 h	0 h	1 h	2 h
Turó Park	0 h	0 h	0 h	0 h
Guinardó Park	0 h	1 h	2 h	3 h
Ciutadella Park	2 h	2 h	3 h	3 h
Besòs Park	0 h	0 h	0 h	0 h
Joan Reventós Park	0 h	0 h	0 h	1 h
Beaches	0 h	0 h	0 h	0 h
Receiving waters	0 h	0 h	0 h	0 h
REE	0 h	0 h	0 h	0 h
Power Distribution	0 h	0 h	0 h	0 h
Electrical Substation Urgell	0 h	0 h	0 h	3 h
Electrical Substation Llobregat	0 h	0 h	0 h	0 h
Electrical Substation Sant Martí	0 h	0 h	0 h	0 h
Electrical Substation Facultats	3 h	3 h	3 h	3 h
Electrical Substation Vilanova	0 h	0 h	0 h	0 h
Electrical Substation Les Corts	0 h	0 h	0 h	0 h
Electrical Substation Hospitalet	0 h	0 h	0 h	0 h
Electrical Substation Sants	0 h	0 h	0 h	0 h
Electrical Substation Sant Joan Despí	0 h	0 h	0 h	0 h
Electrical Substation Badalona	0 h	0 h	0 h	0 h
Electrical Substation Collblanc	0 h	0 h	0 h	0 h
Electrical Substation Penitents	0 h	0 h	0 h	0 h
Electrical Substation Hostafrancs	0 h	0 h	0 h	0 h
Electrical Substation Motors	7 h	11 h	13 h	18 h
Electrical Substation Maragall	0 h	0 h	0 h	0 h
Electrical Substation Sant Just	0 h	0 h	0 h	0 h
Electrical Substation Tanger	0 h	0 h	0 h	0 h
Electrical Substation Eixample	0 h	0 h	3 h	3 h
Electrical Substation Mata	0 h	0 h	0 h	0 h
Electrical Substation Montbau	0 h	0 h	0 h	3 h
Electrical Substation Prat	0 h	0 h	0 h	0 h
Electrical Substation Besos	0 h	0 h	0 h	0 h
Electrical Substation Sant Andreu	0 h	0 h	0 h	0 h

Figure 17: Definition of the disruptive event of floods for the 1, 10, 50, 100 and 500 years return periods, with the several down and affected times to services and infrastructures

The same flooded areas have been used to identify which streets and roads are affected, defining these infrastructures as “down” when they belong to the flooded areas (with heights of more than 10 cm) or “affected” when they are less than 50 m away from these flooded areas, considering that the circulation slows down.

To analyze electrical impacts, the same flood simulations are used, but also taking into account data from IREC considering the electrical substations affected (Figure 18). The polygons of Figure 18 show which infrastructures depend on each substation, which can be translated into cascading effects. Therefore, when an electrical substation is flooded, all the infrastructures that depend on it are down because of lack of electrical service (these relations of infrastructures and substations were introduced before via the interdependence matrix, whereas the disruptive events in this case are only related to the duration that each substation is down).

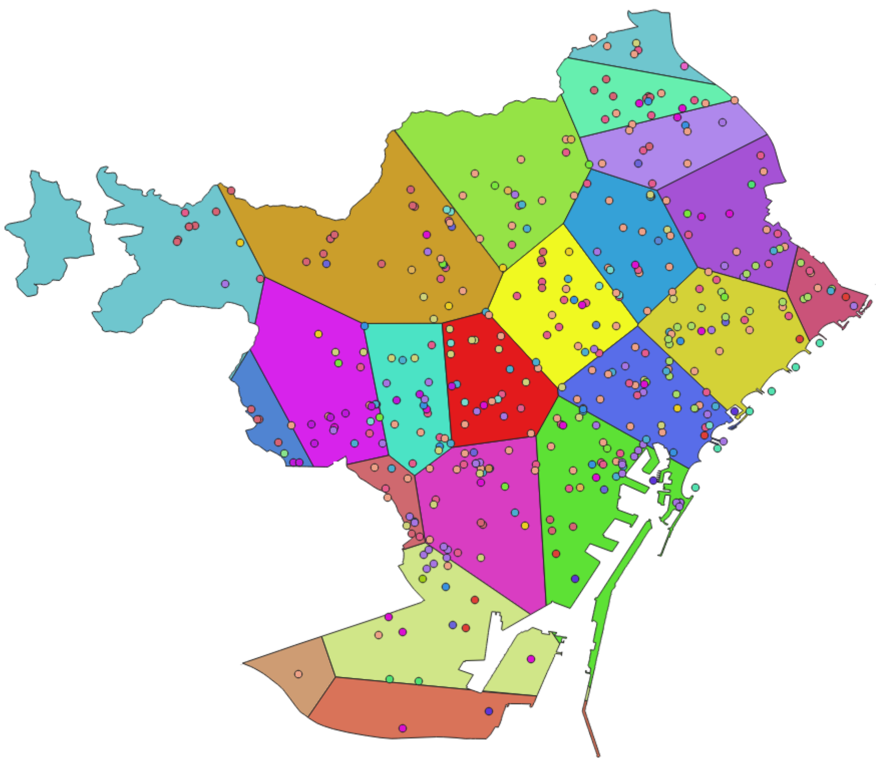


Figure 18: Electrical Substations with their influence areas and the infrastructures contained into each of them

For the case of Droughts, Heat waves and CSO, public available information coming from other projects or local plans has been used to define the different down or affected times to the several infrastructures.

For example, as it can be seen in Figure 19, the definition of heat waves from the Barcelona Climate Plan has been used to define two different scenarios of heat waves: a more severe a long one, and another shorter and less severe. Since these heat waves are defined with a specific duration, this can be easily translated to the affected times to services such as Citizens, Public Health, Medical Emergency and Fire and Civil Protection (Figure 19).

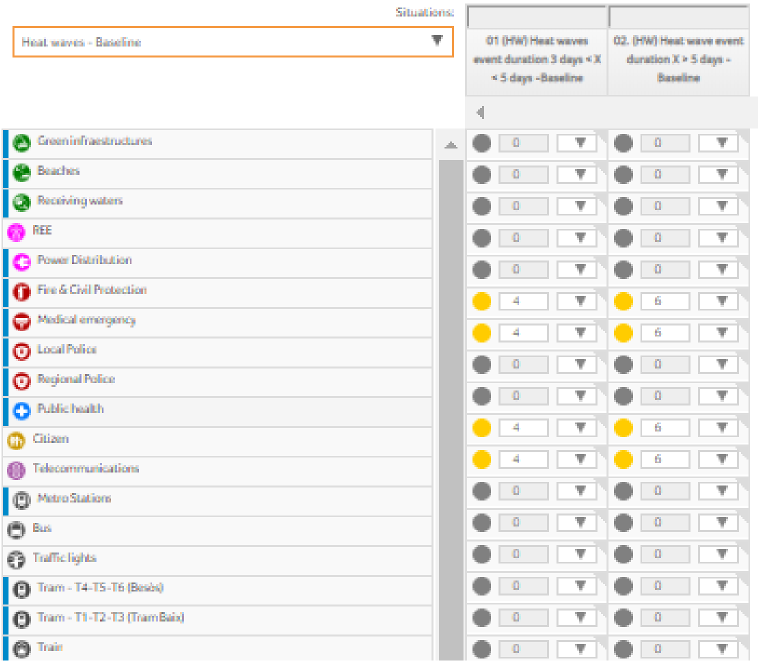


Figure 19: Definition of the disruptive event of floods for the 1, 10, 50, 100 and 500 years return periods, with the several down and affected times to services and infrastructures

3.1.2.4 Climate change scenarios

As presented in Table 3, in addition to the current scenario (Baseline), future scenarios have also been considered. When no adaptation measures are considered, the future scenarios are called Business As Usual (BAU).

These BAU scenarios are considered in different ways depending on the hazard analysed. When models are available, the scenarios created in WP1 can be directly used as input data of these models. This is the case of the urban drainage model created in WP2, which allows to use the updated synthetic rainfall events considering climate change, to simulate the new flooded areas for the 5 selected return periods (1, 10, 50, 100 and 500 years).

These simulations will generate updated flood maps, which not only provide new flooded areas, but also new durations related to the generated floods. Therefore, by using the same methodology presented before, and assigning the according down or affected durations to the infrastructures within the flooded areas, the impacts of the climate change effects can be seen.

On the other hand, as presented before, some other disruptive events do not have models to undertake simulations, and on those cases the assessment has to be undertaken by using information from other projects, reports or some kind of expert appraisal. In these cases, the information used allowed to obtain new durations of the disruptive events, which in some cases remained the same (CSOs) but on some others implied multiplying the affected durations by a given value.

In Table 4, a summary of all the disruptive events, climate change scenarios and adaptation strategies implemented can be seen. In there, when the simulations have been obtained by a model, it can be seen as “Modelled”, whereas in some other cases, the multiplyonh factor is presented, showing how will the affected times change (for example, the droughts will be longer and thus, the affected times related to droughts should be multiplied by 1,8 - Figure 20).

Table 4: Impacts description in function of the different climate change scenarios

	Scenarios			
Hazards	**Baseline**	**BAU**	**Adaptation 1**	**Adaptation 2**
Floods	Modelled	Modelled	M04	M01, M02, M03, M04
CSOs	Other	x1,0	M04	M04, M09
Drought	Other	x1,8	M14+M18	M12+M15+M19
Heat waves	Other	x1,74	M002 HEATWAVE	
Traffic impacts	Modelled	Modelled	M04	M01, M02, M03, M04
Electrical impacts	Modelled	Modelled	M04	M01, M02, M03, M04

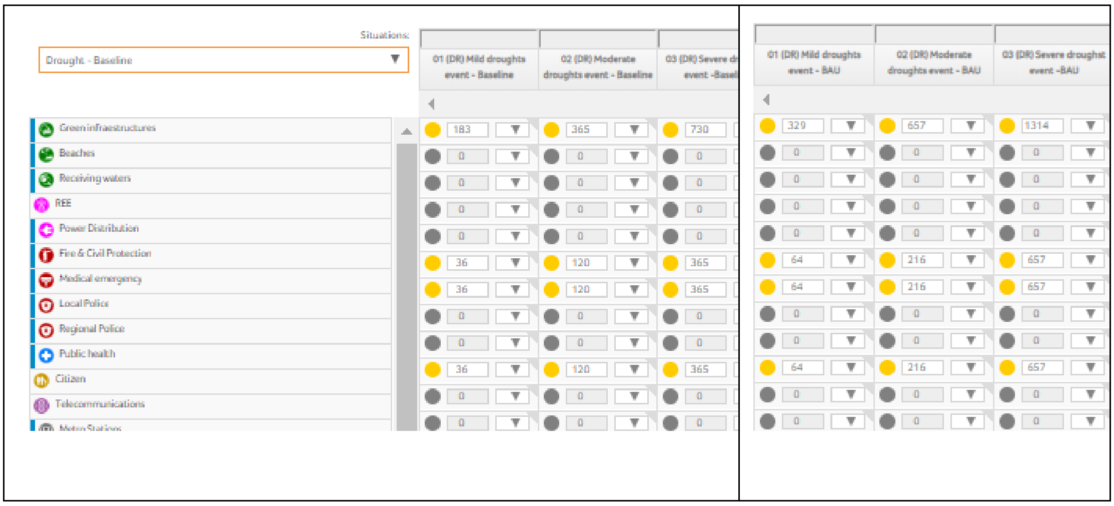


Figure 20: Example of how the changes of down and affected times for droughts events in the baseline (left) and BAU scenarios (right) are represented in Hazur.

3.1.2.5 Adaptation scenarios

The implementation of adaptation strategies is done in the same way as the climate change scenarios. In some cases, the simulations extracted from models are used, whereas in some others, the changes of the recovery time from the database of WP5 are taken into account.

On the first case, the approach is very straightforward: the selected measures are introduced in the model, the model is run with the previous climate change scenarios and the simulations are directly translated to the down or affected times in Hazur. This same methodology was applied for floods, traffic impacts and electrical impacts as explained in the previous sections.

For this cases, the strategies defined in Table 4 were used, which are M04 for the scenario Adaptation 1, and the combination of M01, M02, M03 and M04 for the scenario Adaptation 2. These two adaptation scenarios are the same ones as defined in WP2, because as explained, the simulations coming from the model have been used. M04 corresponds to the implementation of SUDS (Sustainable Urban Drainage Systems) in Barcelona.

For the case of Adaptation 2, the same SUDS are considered, but additionally other strategies to improve the infrastructures are also implemented (M01, M02 and M03). More details on these strategies can be found in D2.6.

The other disruptive events that did not have a model associated, took advantage of the work done in WP5 to define the database of measures and adaptation strategies. In there, the matrices for the variations of recovery time (VRT) were created for all the adaptation measures included, which allowed to easily modify the down or affected times in Hazur. An example of the VRT matrix for droughts can be seen in Table 5. As it can be seen in the table, in this task from WP5 the different adaptation measures included in the database were assigned different percentages of reduction (and in some few cases, also increase) of the recovery time for each sector. This means that if during a drought the public health sector is affected for a certain amount of time, e.g. 30 days, the implementation of measure M12 (related to the optimizations a desalinization plant) will reduce this time to 20 days (since the reduction of VRT in this case was established in 33%).

As Table 5 shows, many of these VRT are 0%, which means that the sector is not going to be benefitted by the implementation of this measure, and as said before, some of these values might even be positive (meaning that a strategy aimed at improving the capacity for flood protection, for example, could have a negative effect on the green infrastructures service by increasing the down time of the infrastructures that belong to it).

Using these matrices for the corresponding measures presented in Table 4, the new down and affected times were introduced to Hazur, and thus being able to compare the baseline, BAU and adaptation scenarios.

Table 5: Example of the VRT changes when implementing adaptation measures related to droughts

ID	Drought measures description	Water storage	Water Treatment	Water transportation	Public health	Green Infraestructures
M12	Optimize desalinization plant production	-66%	0%	0%	-33%	-33%
M14	Continue reducing leakage in distribution networks	0%	0%	-66%	0%	0%

M15	Study the feasibility of producing regenerated water at the Besòs WWTP to feed the Besòs aquifer	0%	-33%	0%	0%	-33%
M18	Promote rainwater collection and its reuse in buildings	0%	-33%	0%	0%	0%
M19	Inter-basins connections	-33%	0%	-33%	0%	0%
M20	Increase the water cost for specific uses	0%	0%	0%	0%	0%

For the case of droughts, all the down and affected times for the baseline, BAU and the two adaptation scenarios can be seen in Figure 21.

3.1.2.6 Impacts and cascading effects

As it has been presented in the previous sections, the impacts have been analysed in Hazur by establishing the down and affected times for all the key services and infrastructures defined in the Barcelona area. Once these disruptive events are introduced in Hazur, they are propagated via the relationships defined in the interdependencies matrix. Consequently, when an infrastructure is down for a certain amount of time, all the others that depend on this one will also be down until the first one recovers its initial state.

This process generates what are called cascading effects, which in Hazur are presented as diagrams of chained infrastructures that fail (red) or that are affected (yellow) for a certain amount of time (Figure 22). The analysis of cascading effects is very interesting to comprehend how the chain of cause-effect propagates downstream, especially for complex systems that might imply a lot of intermediate steps. However, as it can be seen in Figure 22, the Hazur analysis of cascading effects does take into account the duration of the events, but only focuses on the state: when it is set as “down”, the interdependencies downstream are activated, and if it is only “affected”, the cascading effects stop there.

In the previous sections, the main feature that has been used to present the hazards, climate change and adaptation scenarios was the duration. Establishing the down or affected times was key for the modelling part of WP2 and WP3, and understanding how these times could be reduced was also the main aim of the strategies from WP5. Therefore, since the cascading effects in Hazur do not take into account the recovery time, the differences between the several cascading effects diagramas between the baseline, BAU and Adapation scenarios are minor.

The only cases in which this diagrams can change is when the more infrastructures are affected (for example when the flooded areas increase due to the impacts of climate change, widening the affected areas and thus having more infrastructures that are down), or when some of the times are reduced to zero (because the adaptation strategies improve the situation so much that the infrastructure is no longer affected).

As explained earlier, the disruptive events in this study were considered in two different ways, with the simulations from models or with data and information coming from other sources. For the latter, since there were no affected areas defined, but only diferent times were considered for specific services and infrastructures, all the cascading effects related to droughts, CSOs and heatwaves have remained the same for the baseline, BAU and adaptation scenarios.

Situations:

Drought - Baseline

Service	01 (DR) Mild droughts event - Baseline	02 (DR) Moderate droughts event - Baseline	03 (DR) Severe drought event -Baseline
Green infraestructures	183	365	730
Beaches	0	0	0
Receiving waters	0	0	0
REE	0	0	0
Power Distribution	0	0	0
Fire & Civil Protection	36	120	365
Medical emergency	36	120	365
Local Police	0	0	0
Regional Police	0	0	0
Public health	36	120	365
Citizen	0	0	0
Telecommunications	0	0	0
Metro Stations	0	0	0
Bus	0	0	0
Traffic lights	0	0	0
Tram - T4-T5-T6 (Besòs)	0	0	0
Tram - T1-T2-T3 (Tram Baix)	0	0	0
Train	0	0	0
Airport	0	0	0
Harbours	0	0	0
High speed rings - Ronda de Dalt	0	0	0
High speed rings - Ronda Litoral	0	0	0
High speed rings - C32 and C33	0	0	0
Traffic	0	0	0
Traffic Safety Warnings	0	0	0
Traffic Information Systems	0	0	0
Traffic - surveillance center	0	0	0
Metro lines and control centers	0	0	0
Street cleaning	0	0	0
Waste Collection & Treatment	0	0	0
Water Distribution	45	120	365
Water treatment	0	0	0
Urban drainage	2	6	14
Wastewater Treatment	2	6	14

Situations:

Drought - BAU

Service	01 (DR) Mild droughts event - BAU	02 (DR) Moderate droughts event - BAU	03 (DR) Severe drought event -BAU
Green infraestructures	329	657	1314
Beaches	0	0	0
Receiving waters	0	0	0
REE	0	0	0
Power Distribution	0	0	0
Fire & Civil Protection	64	216	657
Medical emergency	64	216	657
Local Police	0	0	0
Regional Police	0	0	0
Public health	64	216	657
Citizen	0	0	0
Telecommunications	0	0	0
Metro Stations	0	0	0
Bus	0	0	0
Traffic lights	0	0	0
Tram - T4-T5-T6 (Besòs)	0	0	0
Tram - T1-T2-T3 (Tram Baix)	0	0	0
Train	0	0	0
Airport	0	0	0
Harbours	0	0	0
High speed rings - Ronda de Dalt	0	0	0
High speed rings - Ronda Litoral	0	0	0
High speed rings - C32 and C33	0	0	0
Traffic	0	0	0
Traffic Safety Warnings	0	0	0
Traffic Information Systems	0	0	0
Traffic - surveillance center	0	0	0
Metro lines and control centers	0	0	0
Street cleaning	0	0	0
Waste Collection & Treatment	0	0	0
Water Distribution	81	217	657
Water treatment	0	0	0
Urban drainage	4	11	25
Wastewater Treatment	4	11	25

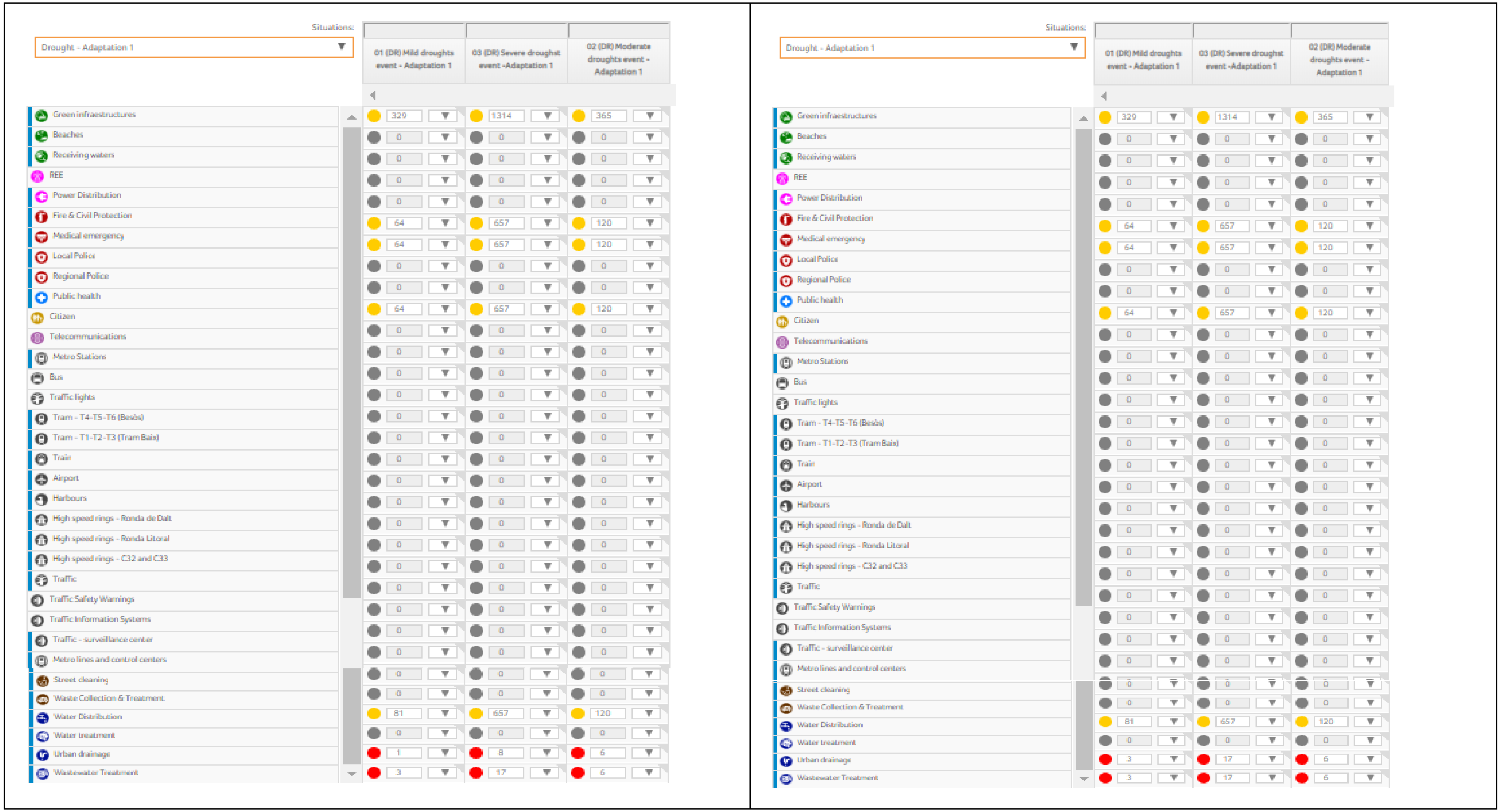


Figure 21: Changes of down and affected times for droughts events in the baseline, BAU and Adaptation scenarios.

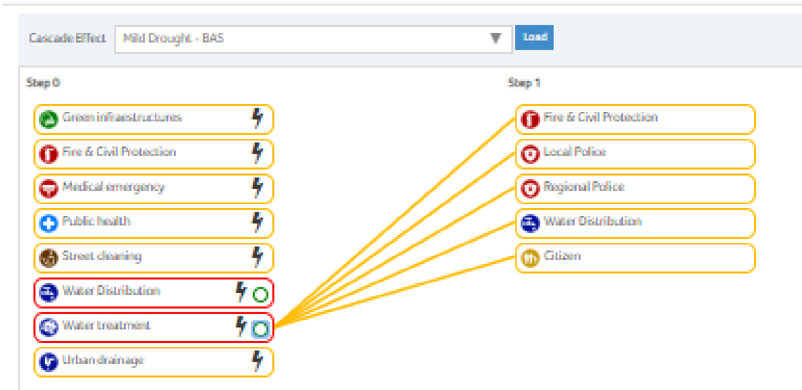


Figure 22: Example of how Hazur presents the cascading effects (in this case for a mild drought)

For the disruptive events that use as a starting point the 1D-2D model simulations of the urban drainage system, some minor changes in the cascading effects have been identified because of the changes in the sizes of the flooded areas. Still, in these cases, the analysis was done at the level of infrastructures, going in depth in the anaylsis understanding which specific roads, hospitals or metro station were affected. Consequently, the minor changes in the flooded areas can't be appreciated in the cascading effects diagrams such as the ones from Figure 23.

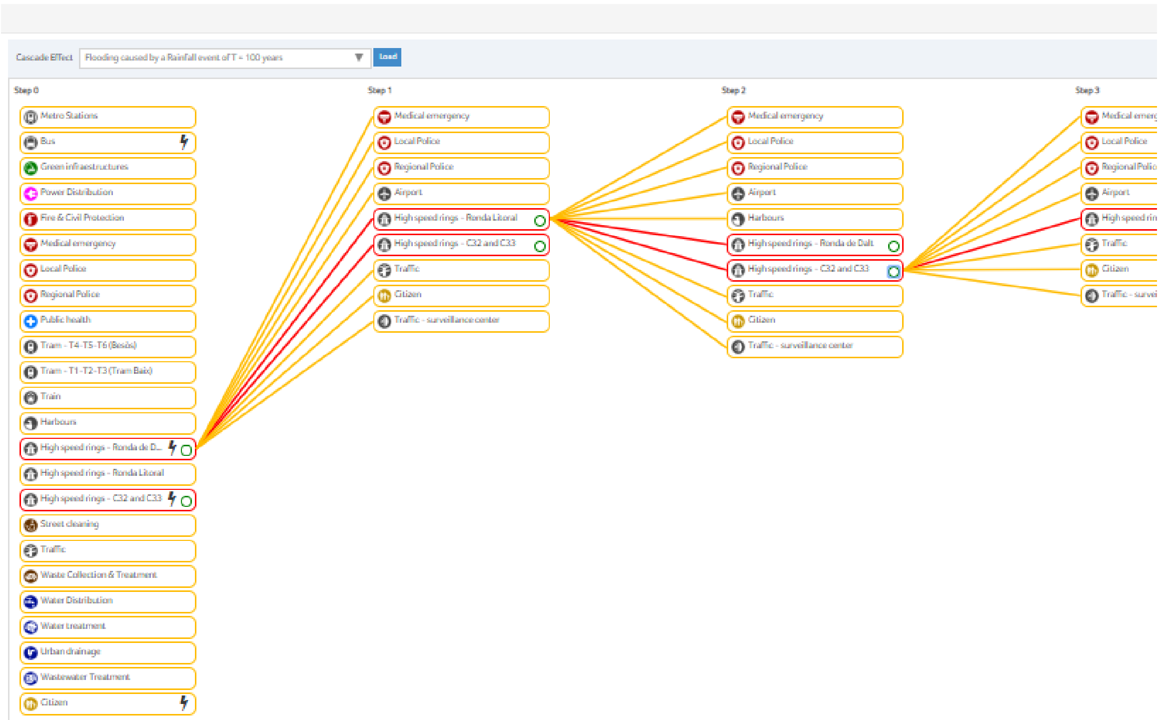


Figure 23: Example of cascading effects for a flood event of T = 100 years (baseline scenario).

3.1.2.7 Results discussion

The re-assessment for Barcelona research site was focused on simplifying the analysis initially presented in D4.1 by taking advantage of the new functionalities of Hazur, as well as including the results from other RESCCUE WPs to simulate the climate change impacts and adaptation scenarios.

The re-assessment was initiated by considerably reducing the number of services and infrastructures, unifying some of the services that previously had to split. This allowed to have a more comprehensive analysis while reducing the time that the tool spend on the simulations.

The Barcelona case was analyzed at a city scale, and varied hazards such as floods, droughts, heatwaves, CSOs, electrical impacts and traffic impacts. Some of these disruptive events were modelled via WP2, whereas some others were analyzed by taking information from other sources.

This allowed to define all the down and affected times for the several scenarios corresponding to the baseline, BAU and Adaptation scenarios, being able to understand how the city was affected by these events. Then, Hazur propagated these initial impacts through the relationships defined in the interdependence matrix to produce the cascading effects.

The new functionalities in Hazur showed the increased potential of the tool, easing the analysis and including new possibilities to undertake a holistic urban resilience analysis. Nevertheless, the presentation of results related to the cascading effects, comparison of scenarios, etc., still need to be improved so the tool can be more helpful to undertake a resilience assessment.

3.2 Bristol Research Site

3.2.1 Approach

The Bristol HAZUR modelling was undertaken in a consistent fashion to the other two other cities in terms of the general use of the tool, process, features, and the like. Bristol city did however undertake the resilience analysis differently to Lisbon and Barcelona, in terms of overall approach, as was noted in prior deliverables, and summarised in the subsequent section.

The HAZUR tool upgrade included a number of new functionalities as recorded in deliverable D4.2. These were developed based on regular and close collaboration with the tool developers / WP lead, as part of the issue fix and enhancement process. All key desired new functionalities were built into the HAZUR upgrade. The use of the new features within the Bristol modelling process is itemised in the table below. This identifies the enhancement (as per D4.2); whether it was used by the Bristol team; whether it was particularly useful; and includes commentary of note. These comments may be useful for any subsequent functional specification of a tool (given the demise of HAZUR).

Table 6: Bristol Use of New HAZUR Features

Enhancement	Used?	Useful?	Commentary
Resource Centre			
Training	Y	Y	The tool has a wide range of functionalities and the training component provided a clear way of learning how to use the tool effectively.
Common Agenda Mgmt.	N	-	Tested only. Strong logic in multi-user settings
File Uploads	Y	Y	Useful access during development/workshops etc
Editable Report Generation			Tested. Vital for stakeholder engagement
Forums for Network Exchange	N	-	Tested only
Collecting Feedback	N	-	
Managing Permissions			Tested only
Pre-Assessment			
Player Personal Data Mgmt.	Y	Y	Good for GDPR/general trust

Player Grouping (by Organisation)			Tested only
Services Section upgrade			
Infrastructure upgrade: linear, undergrounds	Y	Y	Substantially improves analysis & player engage't
Fixed/Mobile Responder distinction	N		
GIS Layout optimisation (& groups)	Y	Y	Visually important for engagement
Assessment			
Interdependencies – - Infrastructures in service area - Differing temporally - Minimum/Affected	 Y Y Y	 Y Y Y	A particularly helpful feature to inform and enrich the analysis
Disturbing Events (ex-Impact) & Notes	Y	Y	
Filter by type of Disturbing Event	Y	Y	Useful in emergency prep for small more frequent events, and planning long term interventions for less frequent extreme events
Cascade Effect Explorer	Y	Y	For specific scenario
Resilience Map ("balls") per situation	Y	Y	Provides a clear means of visualising complex indirect interactions between services
Labelling of Infra on GIS Map	Y	Y	Easier user interface
KPIR – adding of notes	N		
Climate Change Scenario Module			
Climate change (e.g. WP1) data import	Y	Y	Facilitates assessment of potential consequences of Climate Change
Strategies Module			
Integrating WP5 DBase	Pt		

Creation of Spin-Off Scenarios	N		

There are a number of features of the Bristol strategy for undertaking the resilience analysis which are worthy of note:

1. Purpose

From the outset our goal in undertaking the project, and therefore in implementing HAZUR, has been, *firstly*, to ensure that an approach and tools were set in place that the city would adopt / adapt and would endure beyond the project. And, *secondly*, to ensure delivery of project promises.

This strategic focus on sustaining outcomes, resulted in emphasis on engagement of the actors within the city that would use the tools on an ongoing basis. It also sought to ensure capacity building was in focus for the user community (that presently apply a variety of tools).

2. Averting "Black Box" Syndrome

We consciously sought *not* to risk the 'black box' syndrome, whereby key actors within City Hall (e.g. CRO, Councillors, Service Heads), or the multiple players from public or other sectors, felt that the HAZUR tool was too complicated, and thus would not engage. This risk emerged at the very outset of the project (from the CRO), which was a helpful warning signal to reinforce the pragmatic approach taken. As such HAZUR was positioned as the 'approachable' common tool that everyone could see, value, and build comfort and confidence with. The more detailed tools that were applied (e.g. simulation tools) remained in the (more hidden and specific) domain of functional experts.

3. A Complement not a Substitute

The needs of a city in addressing resilience are to *facilitate* communication amongst a wide group of multiple stakeholders that have very varying levels of intertest in, time for, and competence to address resilience. Consistent with the above points, we therefore sought to mitigate the risk of barriers being introduced in dialogue with stakeholders, that might for instance risk that HAZUR was being positioned as a *replacement* for existing competent tools (where competent tools were in place). This proved valuable both within city hall (e.g. in discussion with the transport team where the discussion was about seeking synergies and appreciate linkages), and with (particularly industry) partners. Also, with the likes of the national Environment Agency, this provided a collaborative setting from the outset.

4. Key Issue and Area Focus

The team elected to address two physical areas within the city that were of different and mixed uses, where there were very real risks: St Philips Marsh (commercial) and Ashton (principally residential). The idea being to demonstrate the value of a new complementary approach – that connected to and built upon the (at the time) new Bristol Resilience Strategy, together with its 42 Action Lines (6-12 of which were pertinent to RESCCUE).

From this, plans to expand to other geographical areas of, or thematic challenges within the city would be *desired* ('pulled') by stakeholders, not seen to be thrust upon them. Specifically, the intentions (and actions) have been to expand from the two recognised issue areas to identify 'hot spots' in the city where specific challenges are experienced by different groupings of players.

In the long-term the intention therefore was that this approach would lead to use of the HAZUR approach and tool in other domains beyond climate change. In other words, genuine sustained actions owned across a community of stakeholders within the city, applied as a cross-cutting approach and tool in support of strategic and tactical needs, complementing more detailed tactical and operational projects; all convened by city hall.

5. Data Sensitivities

Data sharing sensitivities emerged from the outset, however the approach that was proposed swiftly mitigated these risks. It did not make them go away, however sharing of data could become a less emotive, guarded, or legal process – which would only add time and resistance, rather than have people focused on very real challenges.

In terms of the experiences as the HAZUR tool was implemented; both in its initial form, and noting more particularly the enhanced features, we have captured below positive and negative experiences.

Positive Experiences

- The overall strategy as regards approach was well received (points 1-5 above)
- Alignment with the strategy helped set the context and integrate activities well, so the project was seen to be supportive of leadership plans (see counter points below)
- HAZUR's strengths are / were in its ability to provide an easy-to-engage with visual approach and generally intuitive output that considerably helped intrigue and engage players – as well as systemically analysing resilience of the city systems
- The city has established an Operations Centre that continued to be enhanced with additional players, and new tools and approaches. In addition to the city established an adjacent Situation Room. In discussion with the leadership of these facilities, HAZUR was seen to be a particularly helpful tool to (i) address tactical needs and (ii) be enhanced to provide a dashboard for both the operations and situation rooms
- An ongoing national initiative, led by British Standards Institution (BSI), involving a wide variety of actors (including Bristol / RESCCUE partners) during the RESCCUE project, delivered the new "BS 67000 City Resilience – Guide". This helped bring focus and attention to resilience, and inform the project thinking – and vice versa. The guide includes half a dozen Bristol caselettes regarding: stakeholder engagement, data sharing, flood risk assessment, equality and societal engagement, snow mgmt., city metrics and dashboard.

Less Positive Experiences

- In mid-2018 the 1-year extension to the 100RC-funded CRO role which was funded by the city ceased. No clear accountability for city-wide resilience emerged. Individual teams therefore dealt with resilience at a discipline / service level
- In 2016 there was a Mayoral change. Such change (as noted by World Bank) can cause disruption to progress particularly for topics like resilience because of its complex and cross-cutting characteristics

- The combination of the above two points puts pressure on sustaining leadership focus and support within city hall, which can affect the general support of other sector players and resources
- Engagement of stakeholders has generally continued to be a chronic challenge, not helped by the above or a decade of budget cuts experienced by UK cities that has tended to take the focus off matters like resilience for many known reasons. This has been particularly challenging for some of the resilience 'life-line' services (e.g. communications, and energy)

3.2.2 Bristol Re-assessment

In terms of re-assessment, beyond the earlier feature-specific table and more general experiences captured above, we offer the following points.

3.2.2.1 Summary

The new HAZUR features were all generally very welcomed and aided both analysis and stakeholder engagement. The demise of HAZUR as an approach and tool has a significant impact on Bristol's overall resilience potential.

3.2.2.2 Hazards

The hazards identified in the initial assessment remained similar to those identified for the focused areas in question.

3.2.2.3 Climate change scenarios

Analyses from physical based impact assessments on different services and infrastructures were captured within HAZUR using the "WhatIf?" component. The impact assessments were carried out with respect to a number of return periods for both current and future climate change predictions (derived from UK Climate Change Projections (UKCP09). This approach allowed for a comparative holistic analyses of the additional stresses the city's infrastructure and services could experience in relation to possible climate futures.

3.2.2.4 Adaptation scenarios

<u>Ashton</u>

- Increased storm pumping capacity at Ashton Avenue SPS (increased from 7.5 m3/s to 10.0m3/s)
- Regrading of Colliters Brook to alter gradient and widen channel
- Amended weir level at the bifurcation – weir set 0.3m higher
- Impermeable area in sub catchment upstream of Ashton Drive reduced by 20% achievable through introduction of SuDS measures

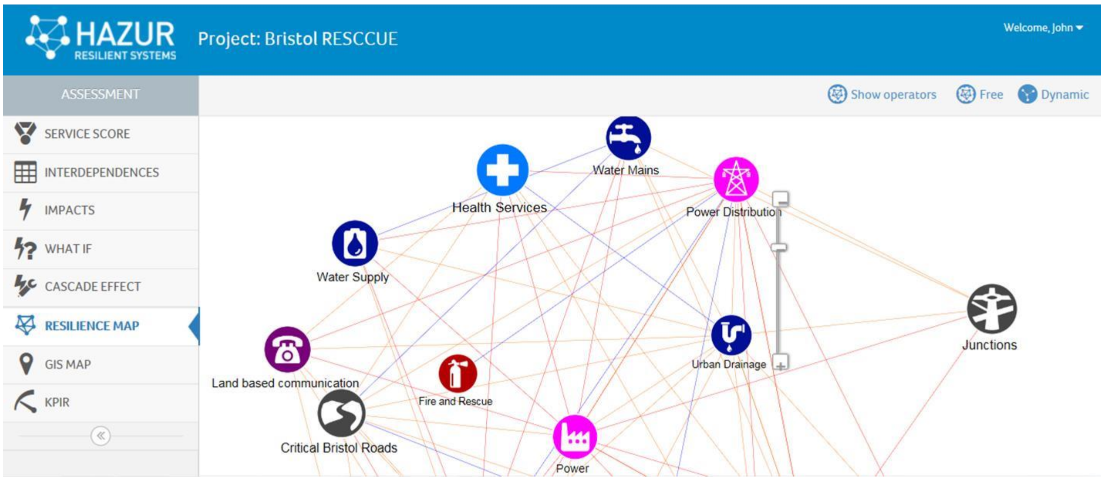
<u>Central area and St Philips Marsh</u>

- Riverside flood defence walls addressing low spots

The first bullet points for these two areas have the impact of reducing flood risk which in turn helps to reduce the cascading effects experienced. These direct and related impacts consequently have monetary values associated with them which enhances the cost benefit ratio for implementing such measures, thus promoting the business case for introducing them. Regulating the disruption and disturbances observed in the Hazur simulation of the city network and systems therefore provides further justification and validation of the need for essential infrastructural improvements.

3.2.2.5 Impacts and cascading effects

The modelling improved, and more detailed modelling and better joined-up modelling could and did occur – e.g. Ashton flood risk measures, which have led to a business justification proposal.



3.2.2.6 Results discussion

The results from the re-assessment, given that the focus of the project remained somewhat unchanged, did not result in any major changes. The experience of the new features was positive. The ability to move data across project systems better and the like, all helped ease-of-use for the project team, and better engagement with stakeholders.

Agreement was reached at the Dec 2019 workshop between RESCCUE partners and key city resilience stakeholder organisations to propose to city (resilience) leadership groups to tackle a number of specific scenarios, that go beyond the two area-based evaluations. These include:

- Major Event Resilience – e.g. the annual Balloon Fair or Harbour Festival
- Alignment with planned Local Resilience Forum (LRF) / Civil Protection Unit (CPU) Exercise
- Major Re-development, where major funds are intended (10s/100s of million), in areas at flood risk under future climate change scenarios
- A number of “Hot Spots” that can bring in a broader and different mix of stakeholders
- Continued evaluation of the more operational remedial measures within the two focused areas (e.g. potential glass wall around the ‘Cut’)

In addition, there is a clear interest to further align activities of the flood resilience team and the City Operations Centre.

We anticipate ongoing alignment with the next wave of BSI city intentions to launch a national multi-themes cities programme, within which Resilience is an identified theme. The fact that this proposed programme includes multiple themes can help (i) build capacity overall and expand the RESCCUE knowledge capture across UK cities (ii) address in a managed way the learning, actions, tools and solutions regarding cross theme/sector/service interdependencies.

Importantly too, there is a clear intent to shift from a technical debate only, and put far greater emphasis on the financial implications of resilience. That engages political, officer, and private sector leaders and stimulates the debate and decision-making process. That does not mean non-financial aspects will be neglected; more that the focus on money ensures the necessary level of leadership attention, from which non-financial implications can be layered on top.

3.3 Lisbon Research Site

3.3.1 Approach

Specifically in RESCCUE Project, in addition to other integrated urban resilience approaches, detailed throughout the Project, city resilience was assessed through HAZUR® methodology, supported by HAZUR® software (designated from this point forward as Hazur®). This methodology aimed to help city decision makers and urban resilience professionals in the task of studying and analyzing the resilience of a city and making fully informed and structured choices about how to improve city resilience. The methodology was focused on understanding the interdependencies between the different services and critical infrastructures of the city and the consequences of one service/infrastructure disruption on the other(s) ("cascade effects"), due to a climate-change events.

The overall resilience approach in Lisbon, following Hazur® methodology, considered the following aspects:

1. Definition of resilience goals, with the actors involved
2. Ranking the services, to understand the perception of stakeholders on the relevance of each service per se and their impact on achieving the resilience goals
3. Understand the interdependencies between services and infrastructures considered
4. Set redundancy networks between same service and infrastructure, which would help minimize the impact of a climate-change event
5. Climate-change events identification/Hazards – mainly flooding
6. Impact evaluation of climate-change events on services and infrastructures
7. Key indicators, to help measure the impact of climate-change events on services and infrastructures
8. Cascade effects between services/infrastructures, resulting from a climate-change event
9. Responder allocation, to understand how they impact on reinstate the baseline situation
10. Identification of resilience sectorial projects to understand if and how the stakeholders are considering resilience improvement to climate change

The resilience assessment was carried out at two different levels: at a citywide level, where the analysis was broader and at a service level; and at a detailed level, which included main services and infrastructures. The detailed analysis was carried out for a critical vulnerable to climate-change related risks area - catchments J & L (Figure 24).

> Hazur® implementation in Lisbon is developed at two different levels of detail. A detailed analysis is performed at service and infrastructure level for a critical and representative area of Lisbon, corresponding to the drainage catchment basins J and L of Lisbon Drainage Masterplan. This area was selected due to its high importance for the city daily life, being the centre of its economic and touristic activities and the core of its urbanistic and demographic development. (…) it is vulnerable to many risks like flooding, tidal effects, slope movements, earthquakes and tsunamis, being some of these aggravated by climate change effects like extreme precipitation, storm surges and wind events. However, services and infrastructures beyond this area are considered as long as they provide services to it. From this analysis as a starting point, a citywide analysis is made at service level, based on the knowledge of the city and on the conclusions drawn from the detailed analysis.
>
> *D4.1 - Annex 2: Report from HAZUR® implementation in Lisbon, Scope and Approach of the HAZUR® implementation*

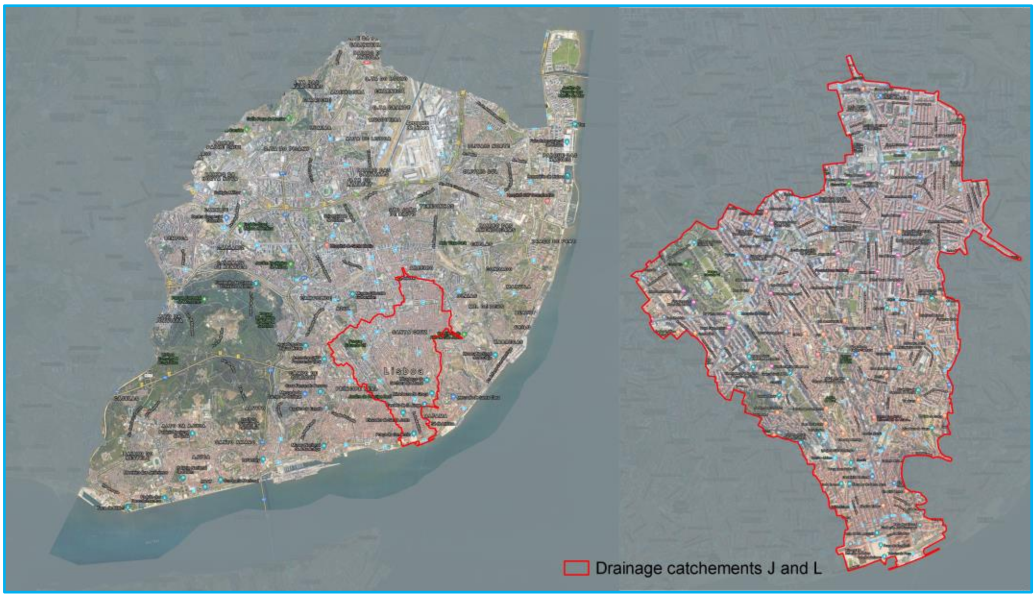


Figure 24. Lisbon city boundaries and drainage catchments J and L

The implementation of Hazur® was supported by relevant city actors from different service sectors, namely, Hidra, Lda (city implementer), CML working group coordinated by the Municipal Civil Protection Service in articulation with several municipal departments/divisions (waste, mobility and urban planning), RESCCUE partners (LNEC, Lisbon Municipality – Civil Protection, EDP - Distribuição, AdTA) and stakeholders from the mobility sector (METRO, CARRIS) and water sector (EPAL).

> In Lisbon, 26 players from 4 city council departments and 5 companies, both private and public, participated in the main steps of the HAZUR® implementation.
>
> *D4.1 - Annex 2: Report from HAZUR® implementation in Lisbon, Scope and Approach of the HAZUR® implementation*

The Hazur® methodology was implemented in Lisbon and considered the main services and critical infrastructure interdependencies, although minimizing the potential several sectorial and compartmentalize assessments which would not lead to a holistic resilience overall city analysis.

Apart from a common agreed set of services to include in the analysis, among the three research sites, several other services were considered, mainly from past experiences associated to climate related events and respective disruptions in Lisbon. The list of services and infrastructures considered is presented in Table 7. It is important to highlight that the included infrastructures were considered either due to its importance to the respective service performance, namely critical infrastructures, or due to the impact on the performance of other services or infrastructures due to their interdependencies. The full description of the services and infrastructures characterization and assumptions made can be found in the RESCCUE Deliverable 4.1, in Annex 2 (Report from HAZUR® implementation in Lisbon).

Table 7. Services and Infrastructures analysed under HAZUR® in Lisbon

Sector		Service	Infrastructures	Nr
Water Sector	**Water Supply System**	Water Sourcing and Transportation	Water Intake Tower	1
			Collected Water Pumping	1
		Water Treatment	Water Treatment Plant	1
		Water Storage	Reservoirs	6
		Water Pumping	Water Pumping Stations	4
		Water Distribution	DMAs	37
	Wastewater Drainage System	Urban Drainage	Wastewater Pumping Stations	11
		Wastewater Treatment	Wastewater Treatment Plant	1
Power Sector		Primary Power Distribution	Switching station	5
		Secondary Power Distribution	Power substation	31
Mobility Sector		Subway	Subway stations	15
			METRO Power Substation	3
			Control Room	1
		Bus	Control Room	1
			Stations	4
		Public Transport Hubs	Hubs	6
		Traffic Management	Traffic Control Room	1
Waste Sector		Unselective Municipal Waste Collection	Routes	13
		Waste Vehicles Operation and Maintenance	Maintenance Garage	1
			Parkins Space	1
		Waste Treatment	MSW Treatment Plant	1
Telecommunication Sector		Mobile Telecom *(analysed only as a service provider, "donor", and no characterisation will be provided.)*	-	-
Environment Sector		Receiver Waters	Tagus River	1
Social		Citizens	-	-
		Total Services = 19	**Total infrastructures = 146**	

The services and infrastructures data necessary to analyze city resilience was mainly gathered during meetings held at an operational level (13 meetings were held) and workshops (5 workshops) held at strategic and steering levels, where the main stakeholders were involved. The process of data gathering and validation is illustrated in Figure 25. Available public information was also considered in the assessment.

The necessary data was collected in meetings with the companies/organisations responsible for the services (...). These meetings were conducted mostly at the operational level and tried to fulfil not only the needs of the WP4, but also of the WP6, so that the data and results can be coherent and better integrated between the different Work Packages. Moreover, the involvement of the CML/Urban Planning Department in some of these meetings had the purpose of improving and updating 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.

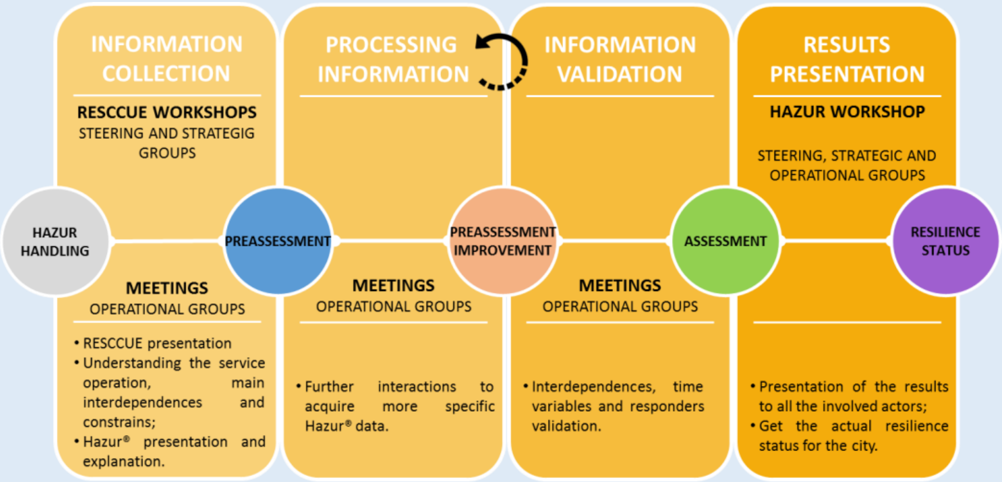


Figure 25. Process of data gathering and validation for Lisbon.

Additionally, RESCCUE workshops have been held, with the purpose of dissemination of RESCCUE project and to discuss resilience under different scopes and involving more stakeholders. These workshops were held mainly at steering and strategic levels, involving department directors and managers, both from private and public companies.

D4.1 - Annex 2: Report from HAZUR® implementation in Lisbon, Tasks performed during the implementation process

The data gathered was compiled and integrated in Hazur® Software in the modules developed during the beginning of the Project, namely "Preassessment" and Assessment", as illustrated in Figure 26.

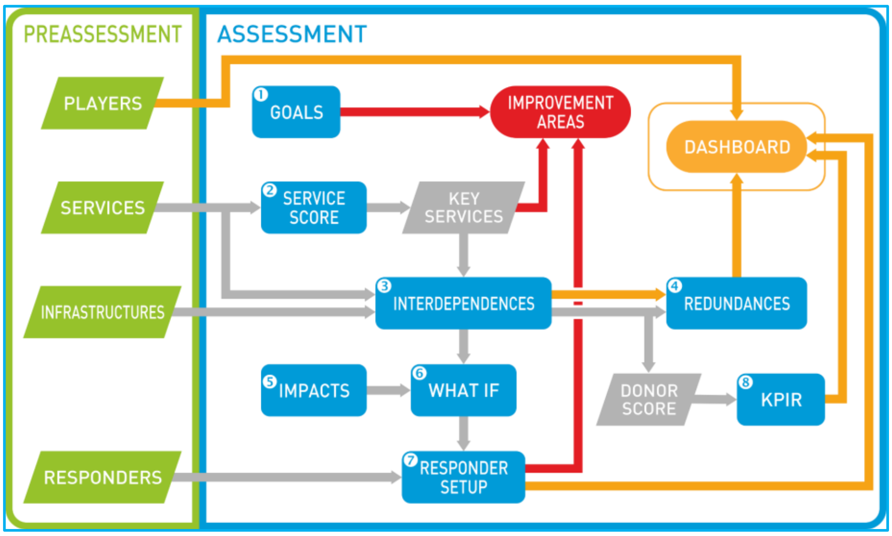


Figure 26. Hazur® software "Preassessment" and "Assessment" diagram.

The analysis of the resilience of the city was mainly focused on water-related risks, namely urban flooding, although, a scenario of power failure was considered due to the high dependency of the other services on power supply. For urban flooding, the results from hydraulic modelling carried out in WP2 (D.2.1) were integrated in Hazur®, and an analysis of the impact on services and infrastructures, for the current situation/scenarios, was performed.

The analysis of the cascade impacts due to flooding or power failure through the Hazur® software, helped understand the interdependencies between service and infrastructures and how a "failure" or "minimum service" (now designated as "affected") would impact on one another. Moreover, this analysis helped understand the critical path between the services/infrastructures and where to act.

However, during the use of Hazur® software, namely "Preassessment" and "Assessment" modules, the need for several improvements were highlighted and further on integrated in the new version of Hazur® (designated as "new performances"), as indicated in sub-chapter 2.1.1.

Additionally, and more importantly to highlight, the reassessment of the city allowed to consider the impacts of climate change scenarios and the adoption of strategies (to minimize those impacts) on the services and infrastructures considered in Hazur®.

3.3.2 Lisbon Re-assessment

3.3.2.1 Summary

As above-mentioned the re-assessment for Lisbon research site was mainly focused on analysing the consequences of climate change and adaptation strategies implementation into the services and infrastructures considered, taking into account the interdependencies and cascading effects between the services/infrastructures.

Naturally, the most recent developments available in the tool, when applicable, were considered. However, the new functionalities do not have a direct consequence on the analysis and on the results of the assessment carried out.

The re-assessment was carried out considering the new resilience map and interdependence matrix shown trough Figure 27 to Figure 29.

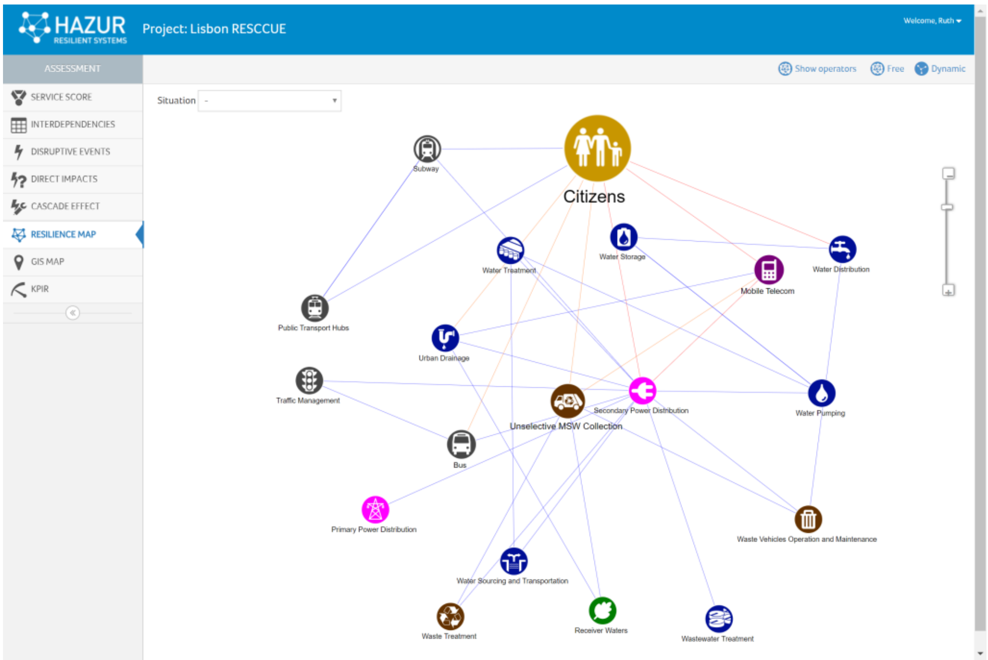
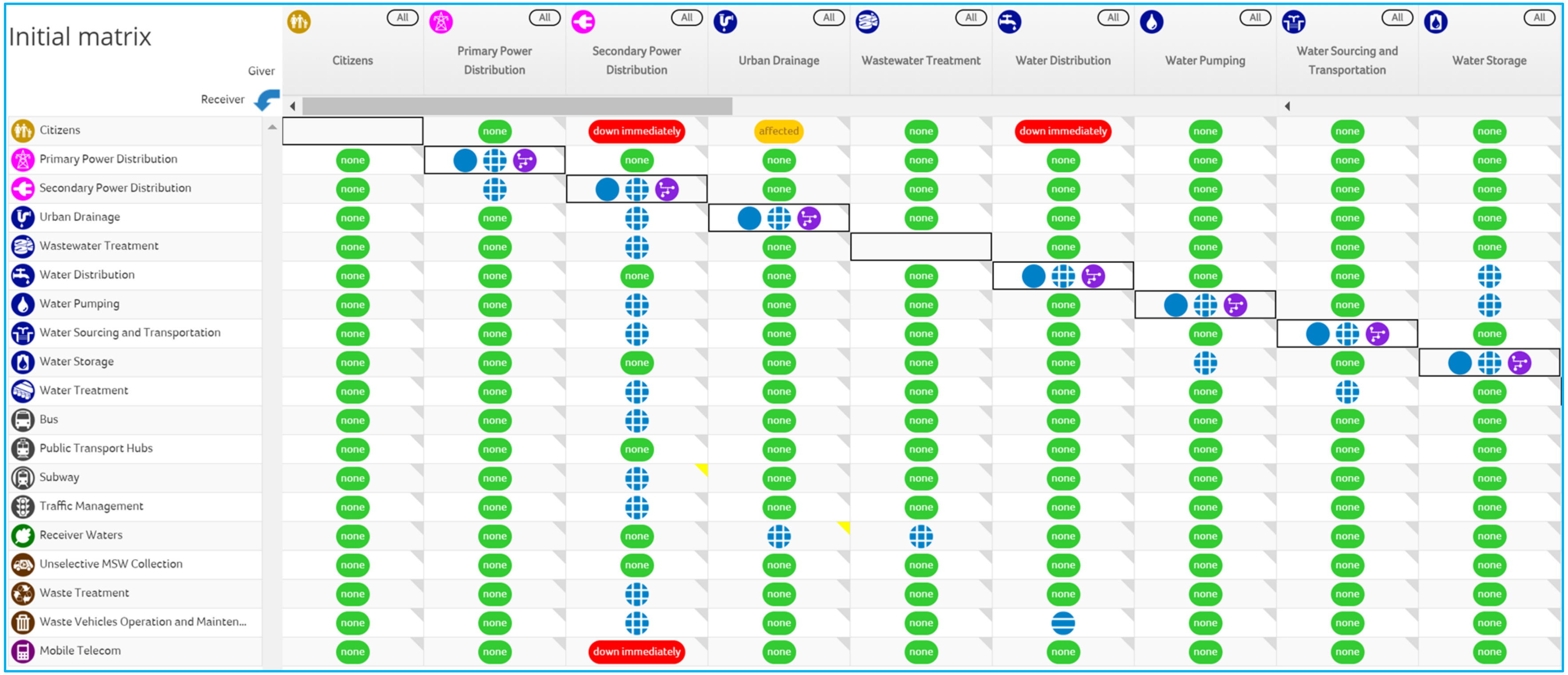


Figure 27. Re-assessment resilience map for Lisbon

The re-assessment was carried out considering the main climate change hazard for Lisbon, namely urban flooding, for different climate change scenarios taking into account no adaptation measures implementation (FS-BAU) and with adaptation measures (FS-ST).

The cascade effects were mainly analysed for the catchments J&L, especially since the outcome of 1D/2D model are affected area and superficial water level. These two variables helped identify not only the infrastructures/services within the flooded area, but also as if the water level is sufficient to cause an impact on the service/infrastructure considered in Hazur®.



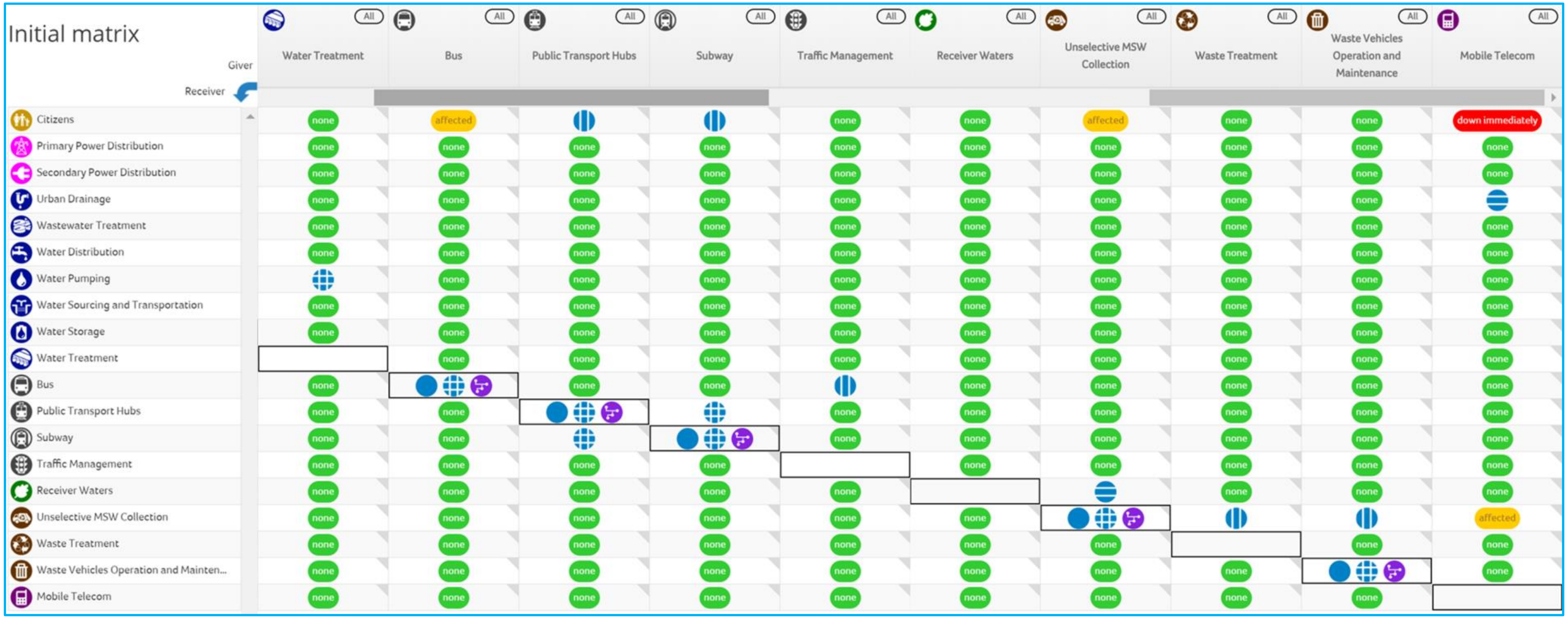
Initial matrix

Receiver \ Giver	Citizens	Primary Power Distribution	Secondary Power Distribution	Urban Drainage	Wastewater Treatment	Water Distribution	Water Pumping	Water Sourcing and Transportation	Water Storage
Citizens		none	down immediately	affected	none	down immediately	none	none	none
Primary Power Distribution	none		none	none	none	none	none	none	none
Secondary Power Distribution	none			none	none	none	none	none	none
Urban Drainage	none	none			none	none	none	none	none
Wastewater Treatment	none	none		none		none	none	none	none
Water Distribution	none	none	none	none	none		none	none	
Water Pumping	none	none		none	none	none		none	
Water Sourcing and Transportation	none	none		none	none	none	none		none
Water Storage	none	none	none	none	none	none		none	
Water Treatment	none	none		none	none	none	none		none
Bus	none	none		none	none	none	none	none	none
Public Transport Hubs	none	none	none	none	none	none	none	none	none
Subway	none	none		none	none	none	none	none	none
Traffic Management	none	none		none	none	none	none	none	none
Receiver Waters	none	none	none			none	none	none	none
Unselective MSW Collection	none	none	none	none	none	none	none	none	none
Waste Treatment	none	none		none	none	none	none	none	none
Waste Vehicles Operation and Mainten...	none	none		none	none		none	none	none
Mobile Telecom	none	none	down immediately	none	none	none	none	none	none

Interdependencies legend:

- down immediately — Indicates that the receiver will fail in case of donor failure (it can fail immediately or after an autonomy time)
- affected — Indicates that the receiver will be in affected in some degree in case of donor failure
- none — Indicates that the receiver does not depend on the donor
- Critical Infrastructure setup
- INF -> SERV: serves to specify what happens to the receiving service when a given infrastructure of the donor service fails
- SERV -> INF: serves to specify what happens to the infrastructure of the receiving service when the donor service fails
- INF -> INF: serves to specify what happens to the infrastructure of the receiver service when a given donor service infrastructures fails
- Redundancies setup

Figure 28. Re-assessment interdependencies Matrix (1/2) (Source: Interdependencies - HAZUR®, project Lisbon RESCCUE)



Initial matrix

Receiver \ Giver	Water Treatment	Bus	Public Transport Hubs	Subway	Traffic Management	Receiver Waters	Unselective MSW Collection	Waste Treatment	Waste Vehicles Operation and Maintenance	Mobile Telecom
Citizens	none	affected			none	none	affected	none	none	down immediately
Primary Power Distribution	none	none	none	none	none	none	none	none	none	none
Secondary Power Distribution	none	none	none	none	none	none	none	none	none	none
Urban Drainage	none	none	none	none	none	none	none	none	none	
Wastewater Treatment	none	none	none	none	none	none	none	none	none	none
Water Distribution	none	none	none	none	none	none	none	none	none	none
Water Pumping		none	none	none	none	none	none	none	none	none
Water Sourcing and Transportation	none	none	none	none	none	none	none	none	none	none
Water Storage	none	none	none	none	none	none	none	none	none	none
Water Treatment		none	none	none	none	none	none	none	none	none
Bus	none		none	none		none	none	none	none	none
Public Transport Hubs	none	none			none	none	none	none	none	none
Subway	none	none			none	none	none	none	none	none
Traffic Management	none	none	none	none		none	none	none	none	none
Receiver Waters	none	none	none	none	none			none	none	none
Unselective MSW Collection	none	none	none	none	none	none				affected
Waste Treatment	none	none	none	none	none	none	none		none	none
Waste Vehicles Operation and Mainten...	none	none	none	none	none	none	none	none		none
Mobile Telecom	none	none	none	none	none	none	none	none	none	

Interdependencies legend:

down immediately	Indicates that the receiver will fail in case of donor failure (it can fail immediately or after an autonomy time)
affected	Indicates that the receiver will be in affected in some degree in case of donor failure
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	Critical Infrastructure setup
	INF -> SERV: serves to specify what happens to the receiving service when a given infrastructure of the donor service fails
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	INF -> INF: serves to specify what happens to the infrastructure of the receiver service when a given donor service infrastructures fails
	Redundancies setup

Figure 29. Re-assessment interdependencies Matrix (2/2) (Source: Interdependencies - HAZUR®, project Lisbon RESCCUE)

3.3.2.2 Hazards

Under the RESCCUE Project scope, in Lisbon Research Site, the main hazard analysed was urban flooding, which is of extreme importance for the city due to the frequent occurrence of flooding events that result from the combination of extreme rainfall events and high tide levels, leading to socio-economic and environmental damages and affecting services and citizens (including tourists). Additionally, even though the failure is unlikely, “power distribution” failure (*e.g.* Praça da Figueira substation, locate in an area prone to flooding) was also analysed due to the high “donor score” of this service. The infrastructures considered are those that may be affected by flooding and/or sea level rise. These main hazards are considered in Hazur® as two disruptive events: “Flooding” and “Power Failure”, as shown in Figure 30.

> (...) Besides the specific analysis carried out with Hazur® regarding flooding, it is important to understand in a large spatial and temporal scale, that Lisbon has a history record of several flooding events. According to DISASTER - GIS database on hydro-geomorphological disasters in Portugal, in the period of 1865 up to 2010, there have been 411 documented occurrences of floods in the Lisbon metropolitan area. According to the same source, this district accounts for 25.3% of all flooding events with damaging effects (deaths, evacuees and dislodged people) in the aforementioned period in all of Portugal (*in* Vasconcelos, 2017).
>
> *D4.1 - Annex 2: Report from HAZUR® implementation in Lisbon, Scope and Approach of the HAZUR® implementation*

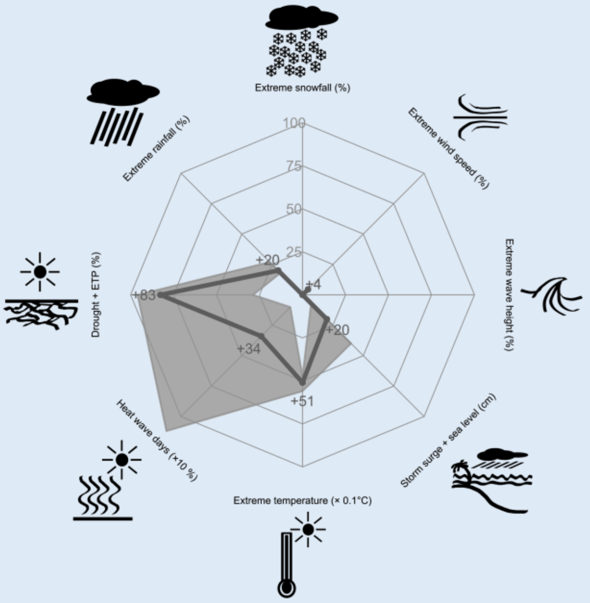
Image	Name	Note	Scenarios	Scale	
	Flooding		5		
	Power Failure		4		

Name	Disruptive Event	Situation	Note	Spinoffs	Demarcated	
BAU-T010	Flooding			0	Yes	
BAU-T100	Flooding			0	Yes	
CS-T010	Flooding			0	Yes	
CS-T100	Flooding			0	Yes	
Flooding (PDM Very High Risk)	Flooding			0	Yes	
Power failure Posto de Corte Zambujal	Power Failure			0	No	

Figure 30. Considered Disruptive Events and Scenarios
(Source: Disruptive Events - HAZUR®, project Lisbon RESCCUE)

3.3.2.3 Climate change scenarios

Within the RESCCUE Project framework, the tasks of WP1 resulted in concrete outcomes regarding not only climate projections but also extreme events predictions (summarised in Figure 31), being the latter, at the urban scale and considering the services under analysis, of most importance due to its consequences at immediate and local scale, *i.e.*, when and where events occur.



Results obtained regarding the maximum point change in climate extreme events along the century (return periods between 2 and 100 years). The zero, in the centre, represents no changes, while the edge corresponds to an increase of 100% for every variable, except for heat wave days and extreme temperature, which borders represent +1000% and +10°C, respectively. The thick lines represent a median scenario, and the shaded area the uncertainty region (5-95%).

Figure 31. Extremes compass rose for Lisbon

D1.3 - Report on extreme events prediction, Summary of changes in extremes for Lisbon

The results from WP1, in particular the impact on rainfall intensity and on sea-level, were considered and the results were integrated in the urban models developed under WP2. The scenarios simulated in WP2 are summarized in Table 8 and considers the "current situation" and "future situations" with no adaptation strategies implemented (BAU) and with adaptation measures applied (ST). The strategies modelled are indicated in the following subchapter.

Table 8. Simulation Scenarios from WP2

Scenarios		Identification Code	WP2 Deliverable
Current Situation T = 2, 10, 20, 50, 100 Tide level = 1.95 m $I_{\text{máx}}$ (1h) = 32.8 mm (T=10 years)	Baseline situation	CS	D2.2
Future Situation with Climate Change (2071-2100) T = 2, 10, 100 Tide level = 2.81 m $I_{\text{máx}}$ (1h) = 38.3 mm (T=10 years)	Business as usual (BAU), *i.e.*, with no adaptation strategies implemented	FS(BAU)	D2.3
	With implementation of adaptation strategies	FS(ST)	D2.6

The results from the 1D/2D model were considered in Hazur®, namely the flooded area and the height of the surface water table, considering a return period of 100 years was considered (worst case scenario) to analyse the cascade effects on the services/infrastructures

3.3.2.4 Adaptation scenarios

Under WP5 tasks, Lisbon proposed a total of 20 adaptation strategies evolving both structural and not structural measures. From the proposed measures, three were selected for simulation purposes in order to assess quantitatively its direct benefits regarding hazard reduction, namely *S005Lisbon: Adaptation of green infrastructure*, *S015Lisbon: Peak flow attenuation through the construction of two retention basins* and *S016Lisbon: Construction of new components in drainage system*. Naturally, these measures are quite different in what respects to its application scope, design criteria, objectives and, therefore, expected hazard decrease efficiency. A more comprehensive description of the strategies modelled can be found in Deliverable 2.6.

> The city of Lisbon has been considering the future climate impacts and is actively committed with climate change adaptation, integrating initiatives and measures to reduce the risks of natural and human systems against the effects of climate change, whether effective or expected.
>
> (…) The measures considered (…) in RESCCUE project are aligned with the implementation of a number of municipal strategies including the Municipal Climate Change Strategy (2017), the Sustainable Energies and Climate Action Plan (2018) and the Metropolitan Plan for Climate Change Adaptation (2019).
>
> *D2.6 - Multi-Hazards Assessment Related to Water Cycle Extreme Events for Future Scenarios (With Adaptation Strategies), Assessment of climate hazards reduction for Lisbon Research Site*

From the simulation results, the measure *S016Lisbon: Construction of new components in drainage system* proved to be the most effective for flooding reduction and was selected to assess under Hazur®. Additionally, the implementation of this strategy is currently undergoing in Lisbon. This strategy integrates four measures, namely, rehabilitation of sewer pipes, inlet devices increase, construction of two diversion tunnels and construction of an anti-pollution basin.

3.3.2.5 Impacts and cascading effects

The obtained results from the 1D/2D simulations, for the scenarios abovementioned and for a return period of 100 years (rainfall) are presented in Figure 32. As indicated these results were imported to Hazur® and the direct impacts on the services/infrastructures were analysed.

The urban flooding model results, namely, the area affected and the surface water level have a direct impact on the services/infrastructures affected and on the time of recovery of these services/infrastructures.

> It should be pointed out however, that although there are services/infrastructures within the flooded areas, these services / infrastructures maybe not effectively be affected by the event. In fact, most of the services analysed herein do not fail because of the floods but may have their routine operations affected (…).
>
> *D4.1 - Annex 2: Report from HAZUR® implementation in Lisbon, Impacts*

The time of recovery considered for each scenario "current situation" (CS), "business as usual" (BAU) and "strategies" (ST) are presented in Figure 33 (image from Hazur®) and summarized in Table 9.

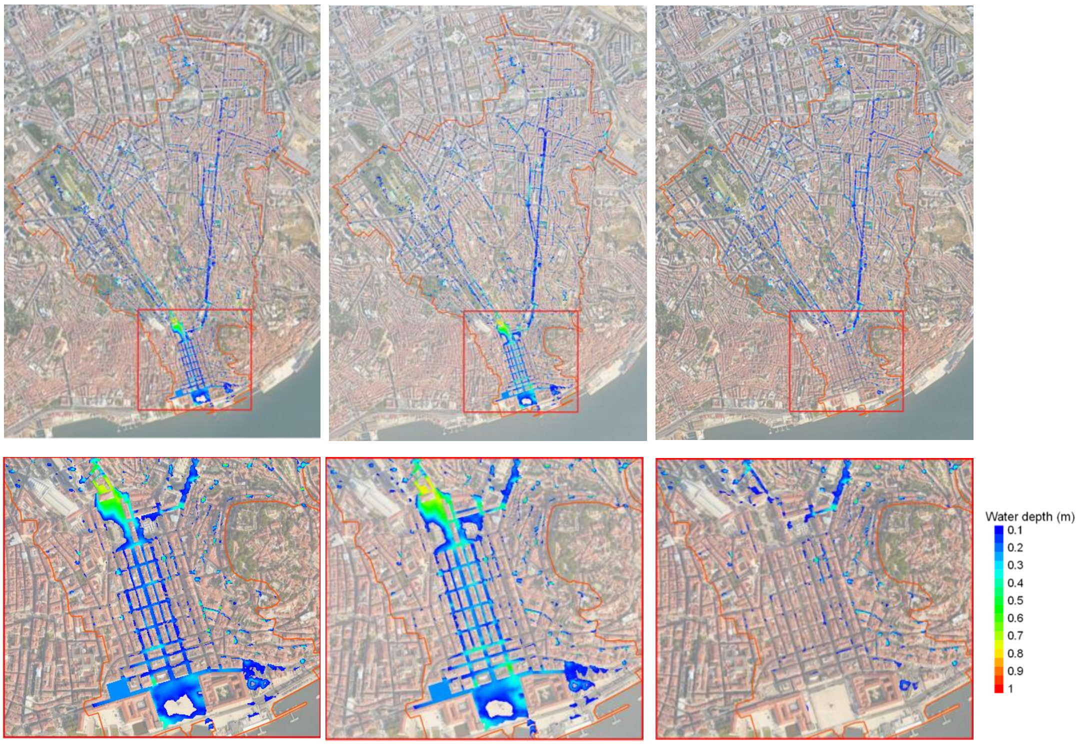
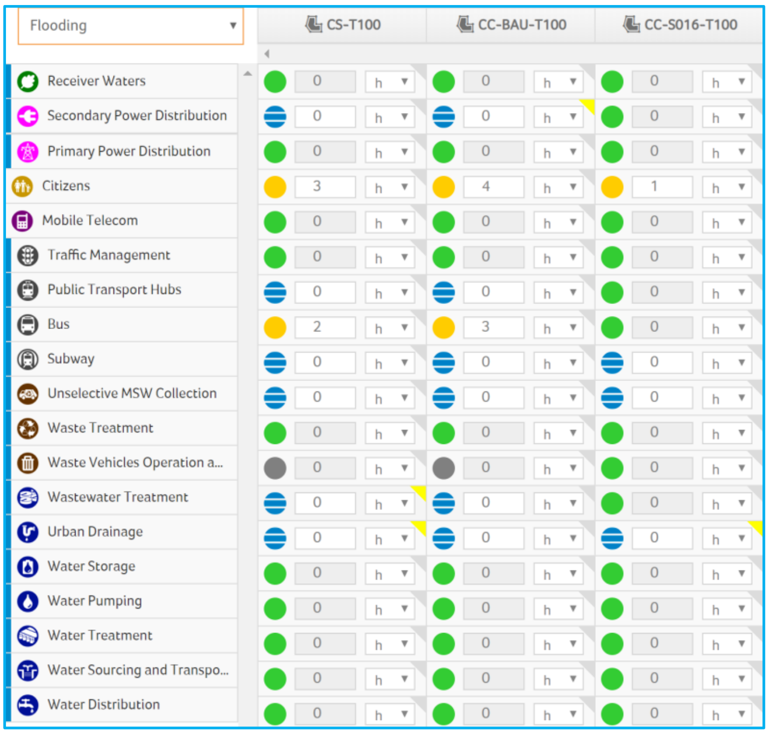


Figure 32. 1D/2D simulation results regarding water depth at critical time step for current situation (left), future BAU situation (middle) and future situation with S016Lisbon implementation (right)



Flooding	CS-T100	CC-BAU-T100	CC-S016-T100
Receiver Waters	0 h	0 h	0 h
Secondary Power Distribution	0 h	0 h	0 h
Primary Power Distribution	0 h	0 h	0 h
Citizens	3 h	4 h	1 h
Mobile Telecom	0 h	0 h	0 h
Traffic Management	0 h	0 h	0 h
Public Transport Hubs	0 h	0 h	0 h
Bus	2 h	3 h	0 h
Subway	0 h	0 h	0 h
Unselective MSW Collection	0 h	0 h	0 h
Waste Treatment	0 h	0 h	0 h
Waste Vehicles Operation a...	0 h	0 h	0 h
Wastewater Treatment	0 h	0 h	0 h
Urban Drainage	0 h	0 h	0 h
Water Storage	0 h	0 h	0 h
Water Pumping	0 h	0 h	0 h
Water Treatment	0 h	0 h	0 h
Water Sourcing and Transpo...	0 h	0 h	0 h
Water Distribution	0 h	0 h	0 h

Figure 33. Direct impacts at service level for 100-year return period flooding events
(Source: Disruptive Impacts - HAZUR®, project Lisbon RESCCUE)

Table 9. Direct Impacts and Average Recovery Times for Flooding Disruptive Events

Service	CS	FS BAU	CF S016	Description
Secondary Power Distribution				This specific substation is located in an area prone to flooding and has already been affected due to flooding events in the past. The recovery time considered is greater than the rainfall event due to the implemented procedures to restore the service.
Subestação Praça da Figueira	● *12h*	● *12h*	●	The recovery time for the substation (after flooding) was set as 12 h due to the fact that some electric components may burn, therefore the recovery time is not aggravated in BAU. When the S016 is fully implemented the probability of the area flooding is highly reduced, therefore it is considered that this substation will be no longer affected in the future.
Citizens	● *3h*	● *4h*	● *1h*	From the simulation results developed under WP2, it is possible to estimate the direct consequences of flooding on citizens. The hazard for pedestrian is highly dependent on the water level on the streets and of the surface water velocity, therefore the time of recovery of the “service” is highly dependent on the rainfall event and on the capacity of the drainage sewers. Since the water level of BAU is expected to be slightly higher than for CS and because the capacity of the drainage system is reduced considering climate change, the recovery time for BAU was set higher than for CS. The recovery time in this case is basically the time estimated for the water level on the streets to reduce to a level where poses no risks for pedestrian. When the strategy is implemented, there will still be some areas prone to flooding (in particular low depression areas) where both the water level and velocity are considered as having impact on citizens. However, and since the capacity of the drainage system is improved if the tunnel upstream is built alleviating the drainage system, it is considered that the time for recovery of the “service” is less than of the current situation.
Public Transport Hubs				Being at the downstream of the catchment, it is expected a high volume of water to converge to this area. Since this infrastructure is almost at the same level of the Tagus River, when in the higher tides the flood can be aggravated due to the difficulties to make the accumulated water flow downstream.
Restauradores – Rossio	● *2h*	● *3h*	●	The recovery time was set to 2 h to 3 h (higher water level) , which are the average estimated time to the water level descends to levels that the transports and citizens can resume their routes and daily life. With the strategy, the area is less prone to flooding and the probability of affecting the service is minimum

Bus	🟡 1.5h	🟡 2.5h	🟢	Service do not fail due to flooding, but when the water level reaches a certain height, the buses must finds alternative routes, and citizens may need to go to different stops. The recovery time for the current situation and for the BAU was set to 1.5 h and 2.5 h, respectively, due to the average estimated time for the water level to lower to levels that buses can resume their routes. To mentioned that the water level on the street is higher in some parts of the city, due to climate change (BAU). The citizens may be affected longer than the estimated time herein due to the level and velocity of the water, and will probably need to find other stops, even if the buses can reach them. However if S016 is implemented, the probability of routes being affected is minimized within the studied area.
Subway				Most of the subway stations have retaining walls near the entrances. Nonetheless, due to the configuration of the subway stations, there's a tendency for the superficial runoff to flow through the entrance stairs, flooding the station atriums and platforms. The Recovery Time is set to between 2 and 3h due to the possible need of cleaning, maintenance and repair works. The Terreiro do Paço station is still potentially affected in the strategy scenario due to its location at a low level, being exposed to high tides.
Rossio	🔴 3h	🔴 3h	🟢	
Restauradores	🔴 3h	🔴 3h	🟢	
Terreiro do Paço	🔴 2h	🔴 2h	🔴 2h	
Unselective MSW Collection				These specific routes are in areas where flooding occurs and considerable water heights are observed, such that the waste collection vehicles might not be able to collect the waste at certain collection points. This situation is particularly important at night, since it is when most waste collection procedures occur. The recovery time in this case is basically the time estimated for the water level on the streets to reduce to a level where poses no risks for the trucks With the implementation of the strategy only one route will be affected.
I0211	🟡 2h	🟡 3h	🟡 1h	
I0212	🟡 2h	🟡 3h	🟢	
I0306	🟡 1h	🟡 2h	🟢	
I0503	🟡 2h	🟡 3h	🟢	
Wastewater Treatment				The flows that reach the WWTP are higher than the design flows, being the wastewater in excess discharged into the river. The service does not fail "per si" (the WWTP still continues treating the design flow). The recovery time estimated to 3 h, indicates the time needed for the event to pass.
WWTP Alcântara	🟡 3h	🟡 3h	🟢	
Urban Drainage				The flows that drain to the drainage system are high, causing the surcharge of the conduits and pumping systems. For this reason, the pumping stations by-passes might be activated and the wastewater is discharged directly to the Tagus River. The Recovery Time is such that allows the cleaning, maintenance and repair works.
PS4	🟡 4h	🟡 4h	🟡 4h	
PS21	🔴 5h	🔴 6h	🟢	

Legend: 🟢 *not affected;* 🟡 *affected;* 🔴 *down.*

Comparing the current situation (CS) with the climate change scenario (BAU), it is noteworthy the slight increase on the area prone to flooding and on the height of the water table at the surface, as shown in Figure 32. In this particular case, the increase on the flooded area does not bare an impact on the number of infrastructures affected (due to the infrastructures analysed), but the time of recovery is aggravated due to the increase of surface water level, namely for the services/infrastructures where the decrease on this variable is the main factor contributing for the recovery of the service (*e.g.* citizens, public transport hubs and bus and waste collection). Other services where the restoration of the service depends more on the procedures implemented when an emergency occurs than on the water level, the recovery time was set as the same as in CS as in BAU. Regarding, the impact of flooding on "citizens" a detailed analysis on the risks for pedestrian, considering both water level and velocity, was set on WP2. Although more the 60% of the flooded area was categorized as "low risk area", some streets such Avenida da Liberdade and Avenida Almirante Reis and downtown are considered of high and very high risk, representing a potential problem for the most vulnerable groups such as children, elderly and those with reduced mobility. Naturally, there are also direct or indirect consequences for the "citizens" if other services are affected or fails (*e.g.* mobility, waste collection).The "citizens" are, in Hazur® terminology, as a main "receiver", which indicates the high dependency on other services/ infrastructures (Figure 34).

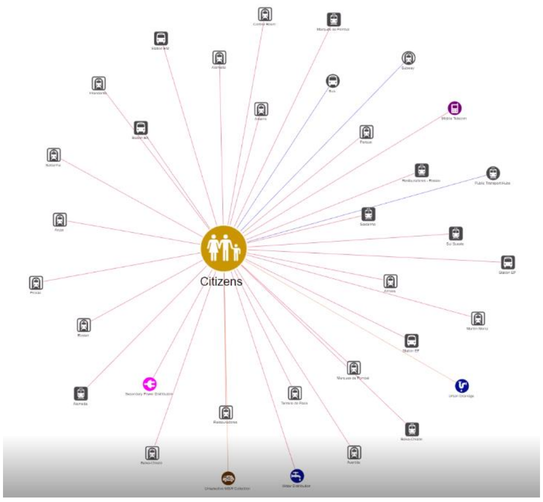
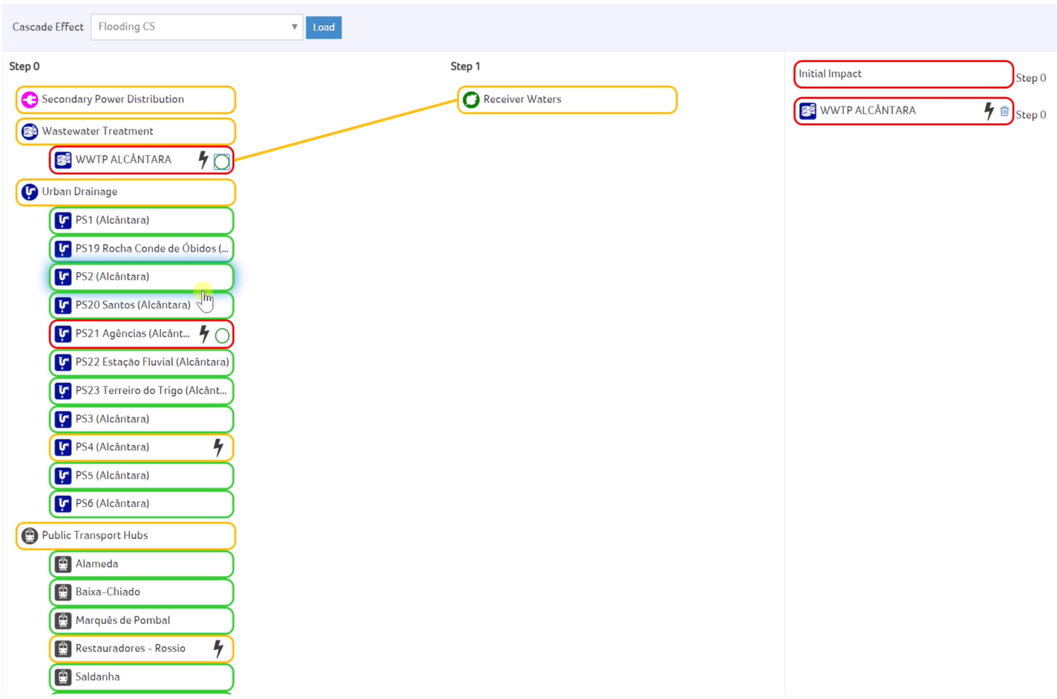
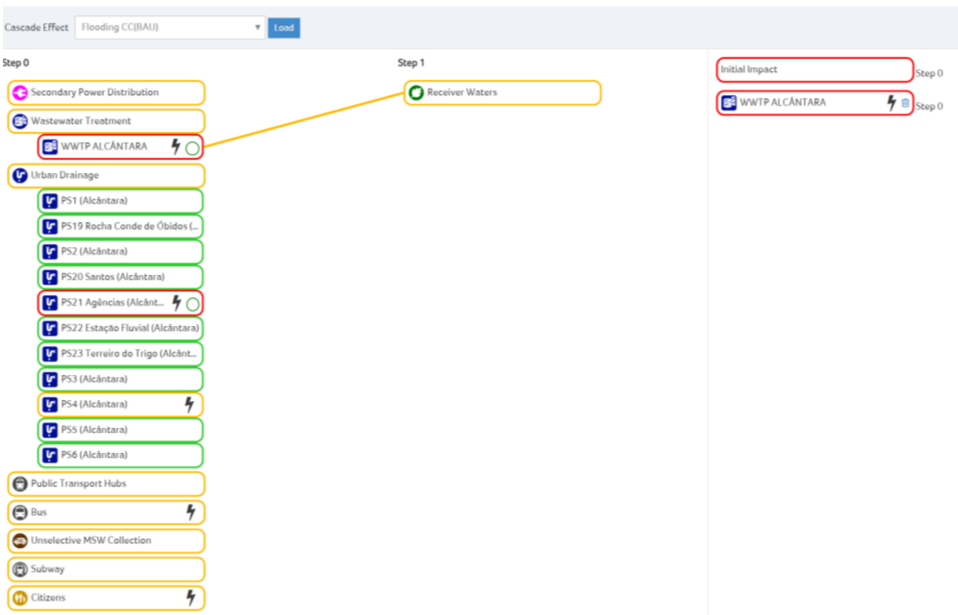


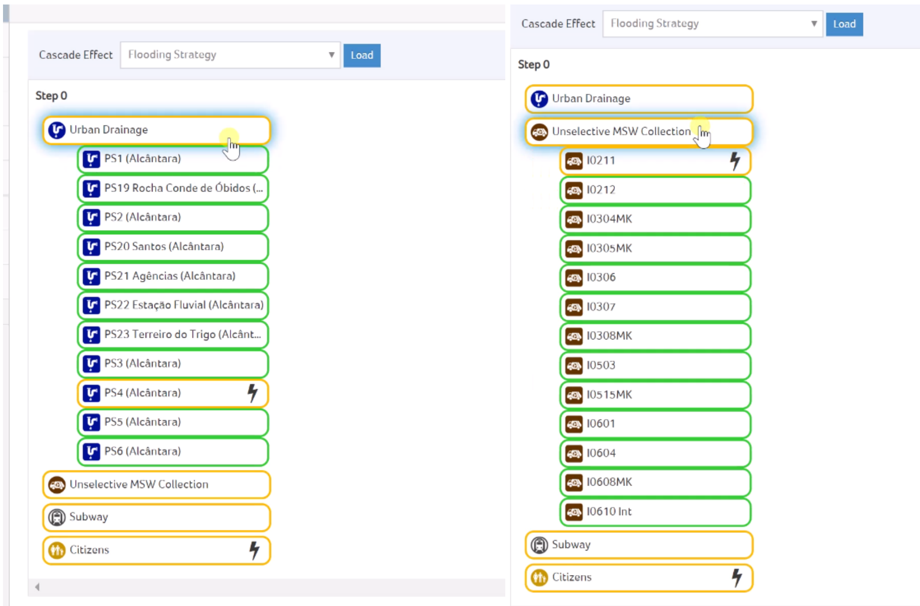
Figure 34. Resilience map for citizens
(Source: Disruptive Events - HAZUR®, project Lisbon RESCCUE)

As shown, as well in Figure 32, both the prone area to flooding and surface water level are really reduced when adopting the implementation of S016Lisbon strategy, therefore, the number of infrastructures affected and the time of recovery of those that maybe affected are significantly reduced. Therefore, most of the services/infrastructures considered in the analysis are "not affected". The time of recovery to flooding is mainly due to the lower level of the water table and due to the increase of the sewer drainage capacity, which easily can accommodate the overflows.

The cascade effects due to flooding, for the three scenarios are shown in Figure 32. As illustrated, the cascade effects reduce significantly when the strategy is considered, as expected. It should be pointed out that since the cascade effect in Hazur® does not take into account the recovery time, the differences between CS and BAU are limited. However, if this time would be considered the cascade effect on the BAU scenario would worsen. Note as well, that the cascade effect is only shown when there is a complete "failure" of the service/infrastructure.







(Source: Cascade effect - HAZUR®, project Lisbon RESCCUE)

Figure 35. Example of cascading effects due to flooding, for the current scenario (CS), business as usual scenario (BS) and for the scenario where strategy is adopted.

As expected, if the power substation Central Tejo fails, several services and infrastructures fail or are affected, as shown in Figure 36. Noteworthy is the fact that the redundancies and the strategies implemented by EDP Distribuição makes this failure improbable.

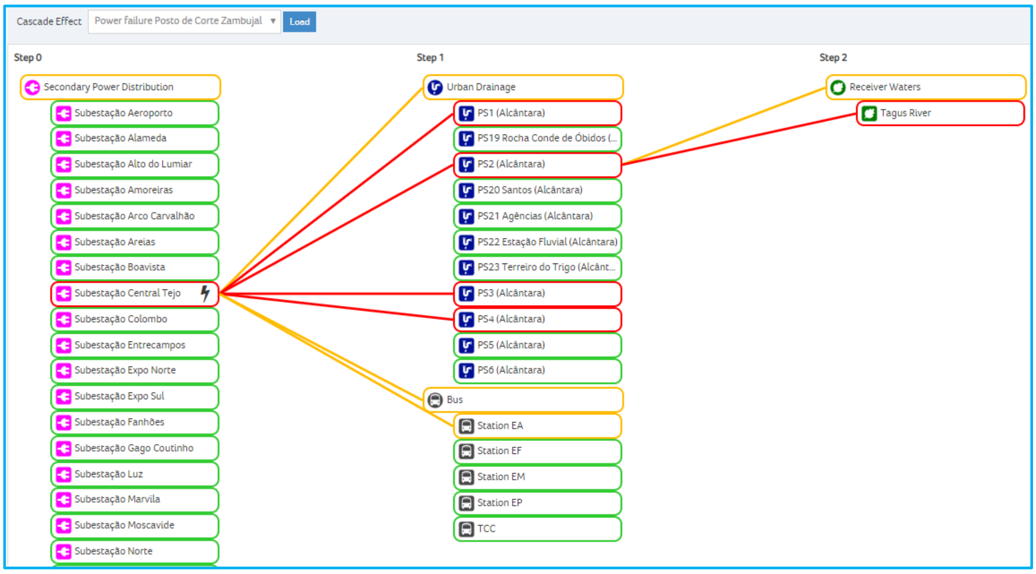


Figure 36. Cascading effects due to Power failure of a Secondary Power Distribution infrastructure
(Source: Cascade effect - HAZUR®, project Lisbon RESCCUE)

3.3.2.6 Results discussion

The re-assessment for Lisbon research site was mainly focused on analysing the consequences of climate change and adaptation strategies implementation into the services and infrastructures considered, taking into account the interdependencies and cascading effects between the services/infrastructures.

Naturally, the most recent features available in the Hazur® software were considered, however, the new functionalities had no consequences for the assessment carried out.

The re-assessment was carried out for 19 services and 146 infrastructures from water (supply and drainage systems), power, mobility, waste, and telecommunication and environment sectors. This number of services and infrastructures revealed to be interesting and feasible for the Hazur® implementation, not impacting on overall analysis of the city resilience. The same approach and methodology as the adopted for the first assessment was considered.

The re-assessment was carried out considering the main climate change related hazard for Lisbon, namely, urban flooding, caused by heavy rainfall and sea-level.

Different climate change scenarios (results from WP1) were taken into account, namely: a) the current situation (CS); b) the business as usual with no adaptation measures implementation and the effect of climate change (FS-BAU) and; c) climate change scenarios considering the implementation of adaptation measures (FS-ST), in particular the S016Lisbon which contemplates the construction of new components in the drainage system and which is currently being implemented in Lisbon. These scenarios were integrated in the urban flooding models and the results, namely flooded area and surface water level were considered in Hazur®.

The cascade effects from Hazur® were mainly analysed for the catchments J&L, especially since the outcome of 1D/2D model are affected area and superficial water level. These two variables help identified not only the infrastructures/services within the flooded area, as well as, if the water level at the street level is sufficient to cause an impact on the service/infrastructure considered in Hazur®.

Comparing the current situation (CS) with the climate change scenario (BAU), it is noteworthy the slight increase on the area prone to flooding and on the height of the water table at the surface. In this particular case, the increase on the flooded area does not bare an impact on the number of infrastructures affected (due to the infrastructures analysed), but the time of recovery is aggravated due to the increase of surface water level, namely for the services/infrastructures where the decrease on this variable is the main factor contributing for the recovery of the service (*e.g.* citizens, public transport hubs and bus and waste collection). Other services where the restoration of the service depends more on the procedures implemented when an emergency occurs than on the rainfall event and water level, the recovery time was set as the same as in CS as in BAU. Regarding, the impact of flooding on "citizens" a detailed analysis on the risks for pedestrian, considering both water level and velocity, was set on WP2. Although more the 60% of the flooded area was categorized as "low risk area", some streets such Avenida da Liberdade and Avenida Almirante Reis and downtown are considered of high and very high risk, representing a potential problem for the most vulnerable groups such as children, elderly and those with reduced mobility. Naturally, there are also direct or indirect consequences for the "citizens" if other services are affected or fails (*e.g.* mobility, waste collection). The "citizens" are, in Hazur® terminology, as a main "receiver", which indicates the high dependency on other services/ infrastructures.

When adopting the implementation of S016Lisbon strategy both the prone area to flooding and surface water level are really reduced, therefore, the number of infrastructures affected and the time of recovery of those that maybe affected are significantly reduced. Therefore, most of the services/infrastructures considered in the analysis are "not affected". The time of recovery to flooding is mainly due to the lower level of the water table and due to the increase of the sewer drainage capacity, which easily can accommodate the overflows.

4. Conclusions

This re-assessment intended to test the updated Hazur tool and methodology, by applying the different new functionalities in the three cities, while incorporating the different results from the other WPs.

As it happened on the initial assessment, Hazur allowed each research site to focus the study in a different way in order to align it to the specific technical and strategic needs of each case. For example, Lisbon undertook a detailed analysis focusing on floods in some specific areas of the city, whereas Bristol undertook a strategic analysis of two areas and Barcelona focused on the whole city, but simplifying the approach initially used.

The methodology and tool proved to be able to function in these different situations and some of the improvements showed a lot of potential if some more work was put in improving the tool. Nevertheless, Hazur tool ceased to exist on the 1st of January 2020 due to the bankruptcy of Opticits and thus, there will be no more improvements or implementations with it. This is why the efforts from this WP4 were moved to other WPs so the whole RESCCUE consortium could benefit from it.

The analysis presented in this report shows that many improvements could still be done to Hazur tool and methodology, but unfortunately, all this was truncated some time ago due to these unfortunate events.

However, through the RESCCUE project it has been clear that the need for tools such as Hazur is still there. As the time goes by, more and more cities are interested in increasing the resilience of their systems. The market is demanding tools such as Hazur and in the near future, the work done in RESCCUE and in particular in this WP4, should be picked up again to build from it learning from the past.