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SUPPORTING DECISION –
MAKING FOR RESILIENT CITIES

Climate Change Impact Chains: a Greater Manchester Case Study

Deliverable No.	NA
Work Package	WP4
Dissemination Level	PU
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Date	16/5/2018
Status	Final Draft
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This document has been prepared in the framework of the European project RESIN – Climate Resilient Cities and Infrastructures. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 653522.

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This project is co-funded by the Horizon 2020 Framework Programme of the European Union.

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1. Introduction

Critical infrastructure is central to Greater Manchester's (GM) future. The achievement of the city's growth and public sector reform ambitions, as set out in the Greater Manchester Strategy (GMCA, nd), requires an effective critical infrastructure network. Climate change and extreme weather events such as flooding and heat waves pose risks to critical infrastructure assets and the provision of related services. As a result, the EcoCities project identified adapting and building the resilience of critical infrastructure to climate change as a key task for GM (EcoCities Project, nd).

Increasing understanding and awareness of the impacts of climate change and associated extreme weather on critical infrastructure can increase capacity to adapt. With this goal in mind, two climate change 'impact chains' were developed within the Greater Manchester (GM) RESIN case study. The impact chains provide a detailed look at two critical infrastructure themes, transport and green infrastructure, and complement the broader critical infrastructure climate risk assessment undertaken within the GM case study. Impact chains are an approach for exploring cause-effect relationships between different elements of a system (in this case critical infrastructure) that drive climate change risks (BMZ 2014). Impact chains can help to improve the understanding and assessment of, and response to, extreme weather and climate change risks. In particular, impact chains can help to uncover the interconnected cascading effects that result from the interaction between extreme weather and climate change and critical infrastructure. This report summarises the process, outputs and learning from this element of the GM RESIN case study.

2. Impact Chain Selection

The first stage of this task was to identify the thematic focus of the impact chains to be developed within the GM RESIN case study. Given the time and effort that was to be invested in the development of the impact chains, it was important to ensure that relevant themes were selected for further analysis. The following climate change and extreme weather hazards and critical infrastructure types provided the scope for potential impact chain options.

- Hazards – fluvial flooding, pluvial flooding, drought, high temperatures and cold events. Sea level rise and storm surges were excluded as they are not relevant to GM. Storms (particularly related to high winds) were excluded due to a lack of data on this hazard.
- Critical infrastructure types – There are various definitions of critical infrastructure. For the GM case study, we followed the definition set out within the draft GM Spatial Framework. This covers three categories of infrastructure. For the purpose of this study we separated green and blue infrastructure from social infrastructure to make a fourth category. This was to reflect the distinct nature of this form on critical infrastructure. The critical infrastructure categories were:
    1. Transport infrastructure – air (Manchester), rail, port (Salford) tram (metrolink), road, walking and cycling.
    2. Utilities infrastructure – gas, electricity, heat, digital connectivity, water and waste water.
    3. Social infrastructure – schools and education, health services, community facilities, recreation provision.
    4. Green and blue infrastructure – (semi) natural green spaces, artificial green spaces, (semi) natural blue spaces, artificial blue spaces.

A questionnaire was completed by 38 stakeholders working on critical infrastructure and climate change resilience related issues in and around GM in order to help identify critical infrastructure and climate risk themes to explore. The questionnaire results provided an insight into themes of potential interest to local stakeholders, either due to the perceived magnitude of consequences to critical infrastructure from weather and climate hazards or because knowledge and awareness of these issues is low and could therefore be usefully enhanced. Table 1 outlines the results of the questionnaire relating to these two issues.

The selection of impact chains was also shaped by the GM RESIN steering group, who met several times to discuss this element of the case study. It was agreed that one impact chain would focus on a hazard that is currently impacting on GM, which climate projections indicate is likely to intensify in the future. Here, pluvial (or surface water) flooding was chosen. The focus of the second impact chain would be on a hazard that is rare at present but climate projections indicate is likely to intensify in the future. Here, an extended period of hot dry weather was selected. In addition to the distinction between current and emerging hazards, a second principle guiding the selection of impact chains concerned related levels of knowledge, awareness and activity. The GM RESIN Steering Group recommended that the impact chains focus on themes that could raise awareness of, and build capacity to address, issues that are currently under-acknowledged or poorly understood locally.

Table 1: Key themes emerging from the RESIN case study questionnaire.

Top 3 highest consequences for infrastructure from weather/climate hazards	***Top 3 'don't knows' regarding the consequences of weather/climate hazards for infrastructure***
Fluvial flooding	
1. Electricity systems (generation and supply) 2. Risk management infrastructure (e.g. flood defences) 3. Transportation systems (e.g. tram, road, rail)	1. Heat networks (and associated infrastructure) 2. Artificial green and blue infrastructure 3. Natural green and blue infrastructure
Pluvial Flooding	
1. Transportation systems (e.g. tram, road, rail) 2. Risk management infrastructure (e.g. flood defences) 3. Electricity systems (generation and supply)	1. Heat networks (and associated infrastructure) 2. Artificial green and blue infrastructure 3. Natural green and blue infrastructure
Heatwave	
1. Hospitals and health care services 2. Schools and education 3. Water (supply and treatment)	1. Artificial green and blue infrastructure 1. Natural green and blue infrastructure 2. Heat networks (and associated infrastructure)
Water Availability	
1. Water (supply and treatment) **2.** Schools and education **3.** Hospitals and health care services	1. Heat networks (and associated infrastructure) 1. Artificial green and blue infrastructure 2. Natural green and blue infrastructure

Based on these considerations, the following impact chains were selected.

- Pluvial flooding to transportation systems.
- An extended period of hot dry weather on green infrastructure.

With the themes identified, two workshops were set up to develop the impact chains. These were attended by local stakeholders from GM and surrounding areas, who were invited based on their knowledge and expertise of the themes being considered. RESIN project partners were also invited to contribute to and observe the workshops. The first workshop was held on the 17th November 2016, and focused on pluvial flooding to transportation systems. It was attended by individuals from GM including representatives from the Low Carbon Hub, Transport for Greater Manchester and the Civil Contingences and Resilience Unit. The second workshop was held on the 21st February 2017, and focused on an extended period of hot dry weather on green infrastructure. It was attended by individuals from GM including representatives from the Low Carbon Hub, the Civil Contingences and Resilience Unit, ARUP, Natural England and City of Trees.

The two impact chain outputs developed as a result of this process are now presented. Before doing so, and to support the interpretation of the impact chains, the themes and concepts that the impact chains are based around are defined below. Unless otherwise stated, all definitions are taken from the latest Assessment Report from the Intergovernmental panel on Climate Change (IPCC 2014).

- **Stressors:** Events and trends, often not climate-related, that have an important effect on the system exposed and can increase … climate related risk Adapted from Oppenheimer et al. (2014 :1048).
- **Hazard:** The potential occurrence of a natural or human-induced physical event or trend, or physical impact, that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources…the term hazard usually refers to climate-related physical events or trends or their physical impacts.
- **Impacts:** Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes of hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system.
- **Vulnerability:** The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
- **Sensitivity:** The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct … or indirect.
- **Coping capacity:** The ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term.

3. Impact chain 1: Pluvial flooding to the road network

The EcoCities project identified pluvial flooding as GM's key emerging weather and climate related hazard (Carter and Lawson 2011). Also, the GM RESIN Steering Group indicated that fluvial flooding (or surface water flooding) is, relatively speaking, better understood and mapped in GM than fluvial flooding (from rivers and other watercourses). Transport was selected as the critical infrastructure theme for several reasons including:

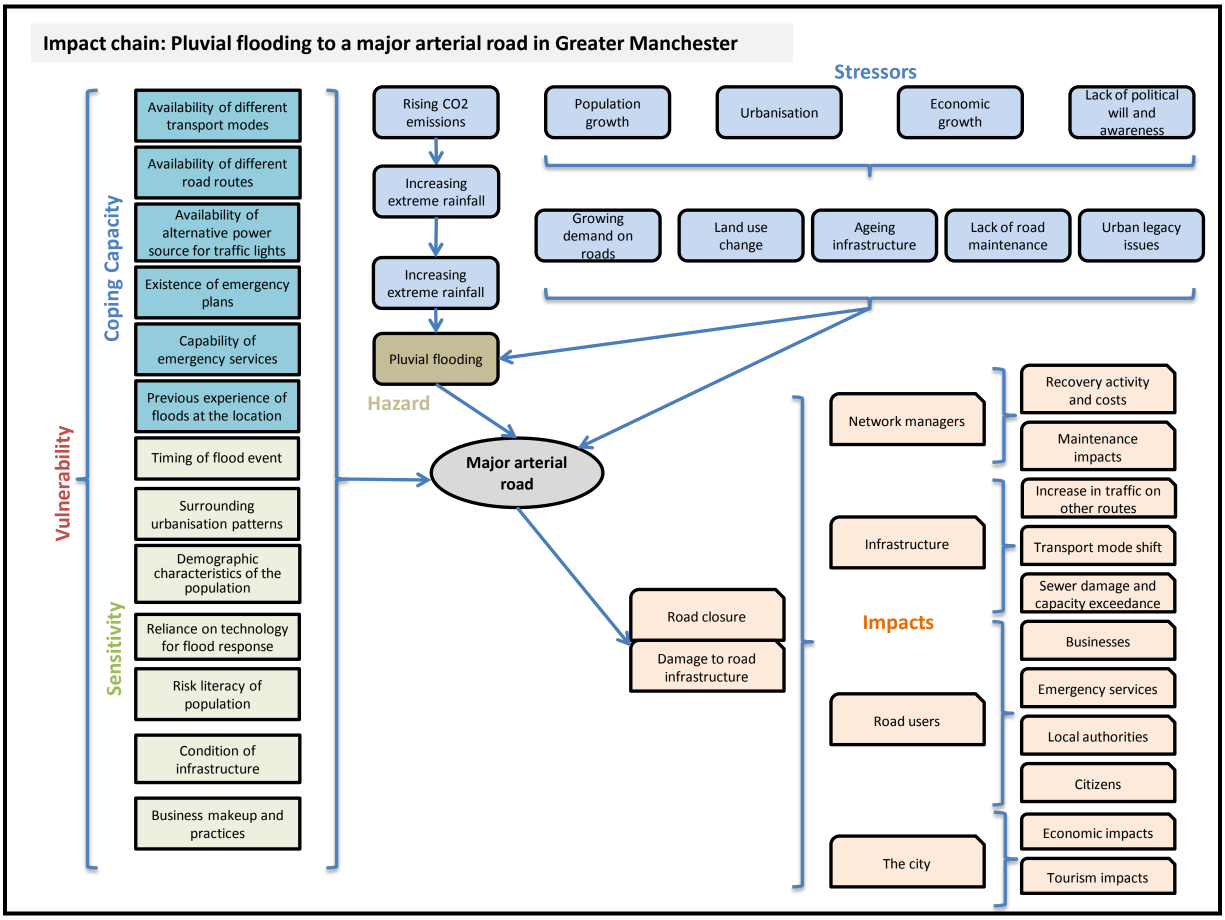
- Transport was identified by the questionnaire as the infrastructure theme where the consequences of pluvial flooding are perceived to be the highest.
- Transport is central to GM's economic and social growth aspirations, and is driving current policy debates and investments.
- Elements of GM's transport network have been impacted by recent pluvial flood events (and related storms and heavy rain) including the road and metrolink networks.

Transport was considered too broad a theme for the impact chain, and several decisions were taken in order to further refine the scope. These included:

- Infrastructure type: The road network was selected, as the majority of journeys in GM are taken by road (TfGM 2017).
- Spatial scale: For this impact chain, the focus was placed on a main arterial road serving the city centre; in other words an important strategic route. The location remained hypothetical, and was not based around a specific road. The impact chain scenario – pluvial flooding to a main arterial road serving the city centre – was selected during the workshop with input from the attendees.

The impact chain below was developed as an outcome of a workshop held on the 17th November 2016 (Figure 1).

Figure 1: Impact chain for pluvial flooding affecting a major arterial road in Greater Manchester.



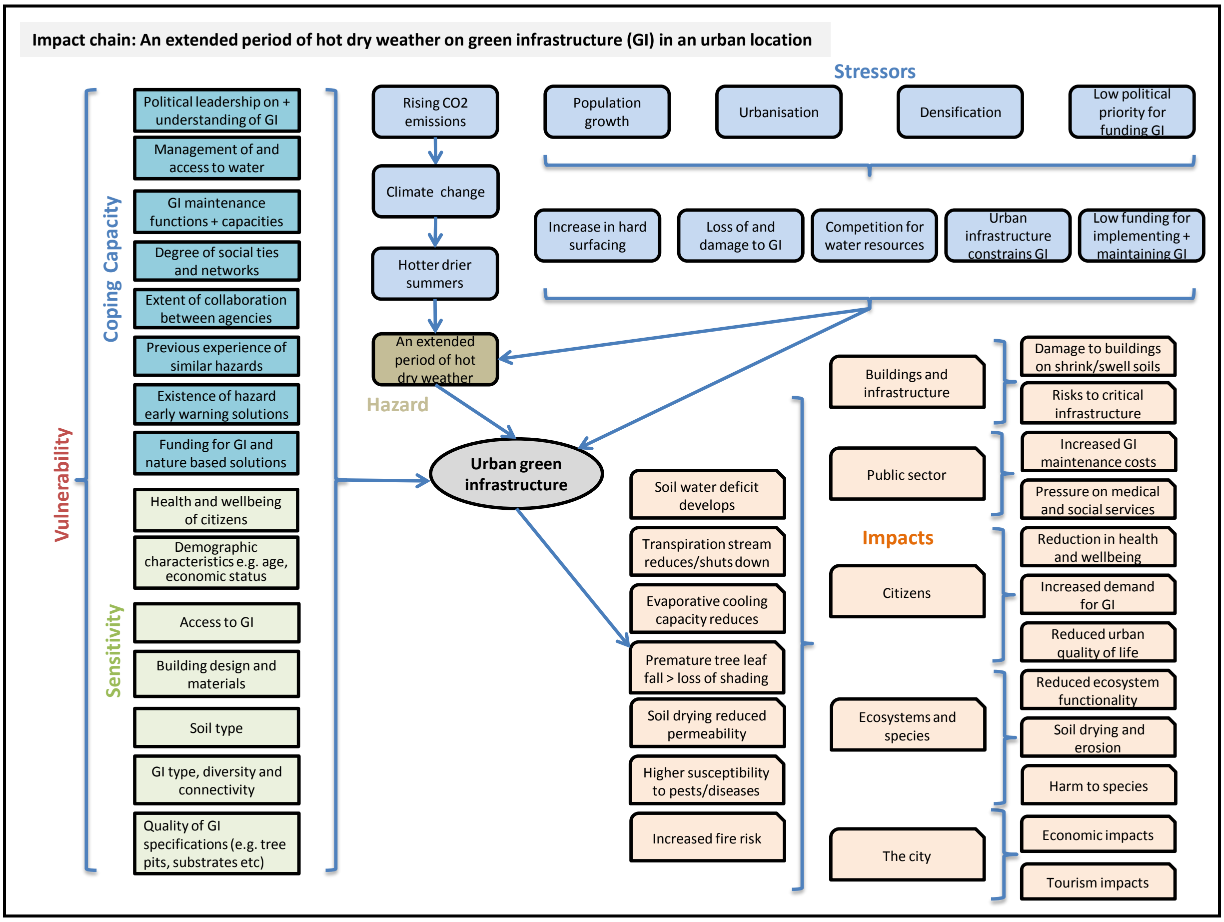
Key themes raised by this impact chain are:

- The impact chain highlights that climate change, and related increases in extreme rainfall, is only one of the forces (referred to as stressors in the impact chain) underlying the pluvial flooding hazard event. Factors relating to the demographic, economic and topographic characteristics of the city, are also important stressors.
- Direct impacts arising from the flooding event, which concern damage to and closure of the road, generate a cascade of impacts across other sectors and groups. A range of these secondary impacts are captured on the impact chain diagram. However, this list does not claim to be comprehensive. The cascade of impacts will extend in scope and depth and it is not feasible to include all possible impacts. Further, these impacts will relate to factors including the timing, severity and duration of the hazard event.
- The vulnerability of the affected road to the flooding event will have a significant bearing on the nature of the associated impacts. If the sensitivity of the road is high due to factors including its poor condition or because it connects people to an important area (e.g. city centre or science park), the magnitude of impacts are likely to be greater. Equally, if coping capacity is high, for reasons such as the existence and implementation of effective emergency plans or availability of alternative transport modes, this could moderate impacts. Equally, the opposite may also be true where sensitivity is low and/or coping capacity is also low.

4. Impact chain 2: an extended period of hot dry weather on green infrastructure

The focus of this impact chain was on a combination of two emerging hazards that climate change projections suggest are likely to intensify in GM (Cavan 2011), namely extended periods of high temperatures and low water availability. The Steering Group recommended that the impact chains focus on hazard and infrastructure themes where awareness, understanding and action are less advanced in GM. The questionnaire indicated that there is a gap in stakeholder knowledge concerning the consequences of weather/climate hazard events on green (and blue) infrastructure and heat networks (see Table 1). GM has several heat networks, with several feasibility studies also on going. However, given data limitations and the relatively small scale of this infrastructure at present, the decision was taken to focus on green infrastructure which does not have these constraints. Rather than addressing a specific aspect of green infrastructure (e.g. an urban park, river corridor, a woodland), the decision was taken to look at this critical infrastructure theme from a more general perspective. However, during the impact chain workshop, it was noted that the focus was on green infrastructure located within the ring road that encircles the central districts of GM.

Figure 2: Impact chain for an extended period of hot dry weather to green infrastructure (GI) in Greater Manchester.



This impact chain raises issues that resonate with the analysis of the first impact chain addressing pluvial flooding to the arterial road. These include that multiple stressors combine to influence the nature and magnitude of impacts arising from the extended period of hot dry weather to green infrastructure. For example, urbanisation processes and a low priority ascribed to funding green infrastructure within the public sector have a bearing on the extent and quality of green infrastructure in the city, which in turn influence the impacts arising from the hazard event. It is also apparent that the direct impacts of the hazard event on green infrastructure in turn generate a cascade of secondary impacts to different sectors and groups, the nature of which are only partially covered by this impact chain due to their scope and complexity. Indeed, the impact chain is solely formed around the workshop outputs and follow-up discussions with some of the participants. Further, the specifics of these impacts will be affected by the characteristics of the hazard event and factors influencing the vulnerability of green infrastructure to an extended period of hot dry weather. Also, the range of impacts will depend on the area of focus of the impact chain exercise. The RESIN workshop concentrated on green infrastructure in the urban centre. If the scope was extended to the Greater Manchester conurbation, other green infrastructure related impacts such as moorland wildfires would have been in scope.

5. Learning from GM's climate change impact chains

The climate change impact chains developed within the GM RESIN case study offer several functions that can support climate change adaptation and resilience building strategies and actions. These centre on their communication and awareness raising functions, in addition to their role in supporting the development of adaptation and resilience responses. Organisations with responsibilities related to climate change adaptation and resilience could therefore benefit from developing and using impact chains. The use of the impact chains to inform GMs 100 Resilient Cities programme suggests that they have a positive role to play in this respect. Given the potential benefits offered by climate change impact chains, other individuals and organisations may be interested in developing them for their own purposes. Related issues are introduced below.

5.1. Utilising climate change impact chains

Based on analysis of the GM RESIN impact chains, in addition to discussions with individuals who attended the two workshops and others who didn't attend but were shown the final outputs, climate change impact chains appear to offer several key functions linked to supporting adaptation and resilience planning. These include:

- *Awareness raising:* Impact chains provide a useful resource for engaging people in discussion on climate change adaptation and resilience themes. This value is enhanced where people are involved in the process of developing impact chains.
- *Encouraging a systems perspective:* In particular, impact chains provide a mechanism to illustrate the complexity of extreme weather and climate risk to urban critical infrastructure. Impact chains highlight cascading chains of cause and effect where extreme weather and climate change is a key factor driving negative impacts to critical infrastructure. Impact chains help to communicate the reality of the complex and interconnected nature of cities, which extends to their relationship with extreme weather and climate change.

- *Broadening the scope of adaptation and resilience responses:* By encouraging a systems perspective to be taken, impact chains can support the identification of a wider range of climate change adaptation and resilience building response options. Here, impact chains can highlight the importance of addressing both the stressors underlying and the impacts resulting from extreme weather and climate change hazard events. The impact chains also emphasise that reducing vulnerability is also a strategy that can be employed to adapt and build resilience to extreme weather and climate change hazards.

Although impact chains have a useful role to play in climate change adaptation and resilience strategy and planning processes, there are caveats to be aware of.

- It is important to guard against the perception that impact chains are comprehensive (i.e. that they encompass all possible impacts) and linear (i.e. that there is a defined one-way trajectory between the stressors and impacts of extreme weather and climate change on critical infrastructure).
- The full extent of an impact chain will, in many cases, be unknowable as a result of the multiple cascading impacts between critical infrastructure and other socio-economic and biophysical themes. This raises the question of where one impact chain ends and another starts.
- An impact chain will only represent a snapshot of the current situation, framed by current knowledge of those involved in developing it, and also the underlying local conditions at the time. Both of these factors are subject to change.
- Impact chains may not be readily transferable due to differences in socio-economic and biophysical conditions between different areas engaged in adaptation and resilience planning. Nevertheless, the impact chain developed for GM may help to identify themes that resonate with other urban areas planning to adapt critical infrastructure to climate change.

5.2. Developing further impact chains

This report has provided examples of two climate change impact chains developed within the RESIN GM case study, and has highlighted the potential benefits associated with creating these impact chains. Individuals and organisations may wish to develop their own impact chains to support adaptation and resilience planning. In order to guide this process, an 'impact chain editor' has been created within the RESIN project in order to assist the development of impact chains. This can be accessed via the RESIN webpage - http://www.resin-cities.eu/home/

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