Urban Insight
By Sweco

Expect the unexpected:

Floods and critical infrastructure

Building resilience to rainfall-induced floods in European cities

SWECO

Being prepared and resilient requires collective action.

To get more insight into the vulnerabilities, impact and strategies of cities when dealing with the influence of the climate on critical infrastructure, Sweco studied the policies of 26 cities in Europe.

The Critical Entities Resilience Directive (CER) requires EU Member States to ensure undisrupted provision of critical services and lists 11 critical infrastructure sectors; failure to do so brings risks to public services, economic activities, public health, safety, and environmental effects.

How to plan and design to increase resilience? Learn how infrastructure sectors and cities can drive change.

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Background

Critical infrastructure failures resulting from rainfall-induced floods pose substantial risks to society, public health, economies, and the environment. Recent heavy flooding in Europe proves that rainfall is able to shut down cities leading to enormous damage and costs. Studies show more intense and frequent heavy precipitation will hit European cities. This emphasises the need for comprehensive risk assessment and management, also in relation to critical infrastructure. The European Union's new Critical Entities Resilience Directive (CER) mandates measures to ensure uninterrupted essential services across 11 critical sectors. Sweco explores the vulnerability of critical infrastructure to rainfall-induced floods in European cities.

Methods

To investigate vulnerabilities, impact, and mitigation strategies, the report employed a multifaceted approach. First, policy analysis: An examination of climate adaptation policies and water management plans from 26 European cities provided a foundation for understanding the existing framework for managing climate risks. Second, stakeholder interviews: Complementing policy analysis, interviews were conducted with city representatives. These insights offered practical perspectives on critical infrastructure vulnerability and the specific challenges cities face.

Key findings

This study has shown that cities were not designed for our changing climate. In addition, factors such as urbanisation, outdated infrastructure, and geographical location significantly influence exposure to climate risks. Planning for these rain events is an extremely complex and demanding task for local governments and their partners. It is crucial to study critical infrastructure both on the district level and asset level.

Sweco's research finds that local governments predominantly prioritise technical infrastructure (e.g. transport and electricity systems) over social infrastructure like hospitals, nurseries, and elderly care facilities. Surprisingly, critical elements like banks, data centers, and crisis centers are often overlooked yet they are the backbone of our financial system. The study also highlights the often-overlooked psychological impacts of infrastructure failures, including stress and fear among affected populations.

Infrastructure systems are interdependent, so failure of one system can cause other systems to fail as well. These cascade effects can have unexpected and serious societal consequences. With Sweco's combination of policy analysis and stakeholder input, we formulated these actionable recommendations:

- Assess Vulnerability and Impact: Beyond exposure, risk assessments should delve into asset-level vulnerability, considering location, construction, and design.
- Study Cascade Effects: Acknowledge the interdependence of infrastructure systems and assess cascade effects through cooperation among managing entities.
- Include Social Infrastructure: Recognise the significance of social infrastructure in resilience efforts and address the emotional and psychological impacts of infrastructure failures.
- Set Clear Goals: Establish action-oriented goals, accounting for acceptable risk levels and cost-effective investments.
- Create Synergies on the Asset Level: Combine actions for exposure reduction, vulnerability mitigation, and impact reduction, focusing on timing and cost-effectiveness.
- Choose the Right Location: Prioritise construction in less hazardous areas and consider relocation during upgrades.

- Set Functional Requirements: Develop sector-specific standards for climate-resilient infrastructure.

The way forward

At Sweco, we know from our projects that building resilience is an iterative process and requires a holistic, interdisciplinary approach. The city is in constant flux, so hazards will also change. In addition, our understanding of climate change is evolving – all good reasons to assess risks and update measures at regular intervals. Policymakers at city level and managers of critical infrastructure must collaborate to assess and mitigate climate risk comprehensively. Each iteration in this process will produce more data and insight to better support investment decisions in resilient critical infrastructure. Starting the analysis is essential. This report presents seven steps towards a more resilient future.

Introduction

On the night of July 14, 2021, a devastating catastrophe struck multiple areas in Europe, including Germany, Belgium, and the Netherlands. It disrupted essential services, such as hospitals and fire departments, and caused extensive damage to roads, railways, bridges, and utility systems. The recovery process will take months to years.

This disaster was not triggered by seismic activity but rather by an unprecedented force of nature: extreme rainfall. The affected regions experienced an astonishing 100 to 200 millimeters of rain in a short timeframe, exacerbating the situation as the land was already saturated from prior rains. This event served as a stark reminder of the threat of climate change.

Increase in heavy rainfalls
An international team of experts, known as World Weather Attribution (WWA), conducted a comprehensive analysis of how climate change influenced extreme summer rainfall, like the events in July 2021 across Germany, the Netherlands, and Belgium. Researchers predict that such extreme rainfall will become a once-in-400-years occurrence in specific areas in the region between the North Sea and the Alps. Climate models indicate that these heavy summer downpours may increase by up to 6% by 2040.[1]

Extreme precipitation has been on the rise in Europe, with further increases in frequency and intensity expected due to climate change. High emissions scenarios are likely to see the most significant increase in heavy rainfall, especially in Northern Europe. By 2050, extreme summer rainfall events are projected to bring about approximately 25% more rainfall than they do today.[2]

Damage
Such extreme rain events lead to substantial direct and indirect damage, as evidenced by the 2021 summer floods in Europe, which resulted in damages exceeding €38 billion.[3]

These examples highlight the immense damage that rain-induced floods can inflict on cities. In a warming climate, Europe must contend with heavier rainfall, which current drainage systems are ill-equipped to handle.

As the examples in the figure show, rain-induced floods can cause an enormous amount of damage to cities. One thing is clear: whatever the exact statistics, a warming Europe must deal with heavier rainfall that current drainage and critical infrastructure systems were not always designed to manage.

Damage costs of past rainfall-induced floods in Europe.

	Copenhagen	Malmö	Netherlands, Germany & Belgium	Glasgow
Year	Summer 2011	Summer 2014	Summer 2021	Summer 2021
Rainfall 24 hours	135.4 mm in 24h[6]	85.5 mm in 6h[7]	150 mm in 24h[8]	15 mm – 30 mm 1h[9]
Damage (€)	€800 million + 30% for citizens and local companies	€50.2 million	€38 billion[3]	€15.7 million

> We face increasing hybrid attacks and climate-change impacts. Being prepared and resilient requires collective action. With today's adoption, we are taking another step to ensure that our societies and industries are prepared to face security challenges and disruptions in the provision of essential services.

Ylva Johansson, EU Commissioner for Home Affairs, July 25, 2023 on the adoption of the Critical Entities Resilience (CER) Directive.

Critical infrastructure and the CER directive
In response to these challenges, the European Union recently adopted the Critical Entities Resilience (CER) directive, effective from January 16, 2023.[4] While this directive primarily targets national critical infrastructure, it also addresses city officials tasked with maintaining local critical infrastructure.[5]

This report delves into cities' preparedness to withstand the impact of rainfall-induced floods on critical infrastructure. It explores how cities can prepare for unforeseen events, and proactively plan to enhance both urban and critical infrastructure resilience. Extreme rainfall serves as a prime example of a risk that can strike anywhere and at any time, underscoring the importance of readiness even in the face of unidentified risks.

Our study therefore underscores the necessity of being prepared for unexpected challenges and safeguarding critical infrastructure within cities. Rainfall events are localized but can trigger cascading failures that affect entire cities and societies. These localized incidents have far-reaching impacts on society.

Sweco conducted interviews with representatives from eight European cities and assessed the policies of 26 others to gain insights into their approaches to managing and preparing for extreme rainfall events. By sharing the perspectives and findings from these cities, along with our research outcomes, we aim to provide valuable insights into bolstering critical infrastructure resilience against increasingly frequent and severe rainfall events.

Understanding vulnerability in critical infrastructure

The assessment of climate risk in cities should not only focus on the exposure of assets, but also on their vulnerability and the impact of any critical infrastructure failures. Currently, many cities tend to assess risks on an area-by-area basis, which only considers whether assets are exposed to floods. However, in order to perform reliable risk assessments, stakeholders need to assess the vulnerability of their assets based on data and knowledge on the assets themselves. For instance, the true risk of a hospital or a transformation station depends on various factors, such as the height at which it is constructed, the location of vital installations and its construction. Therefore, water managers cannot perform this analysis alone, as they need to consider both the location and depth of possible floods, as well as the vulnerability of the infrastructure.

Critical sectors in infrastructure

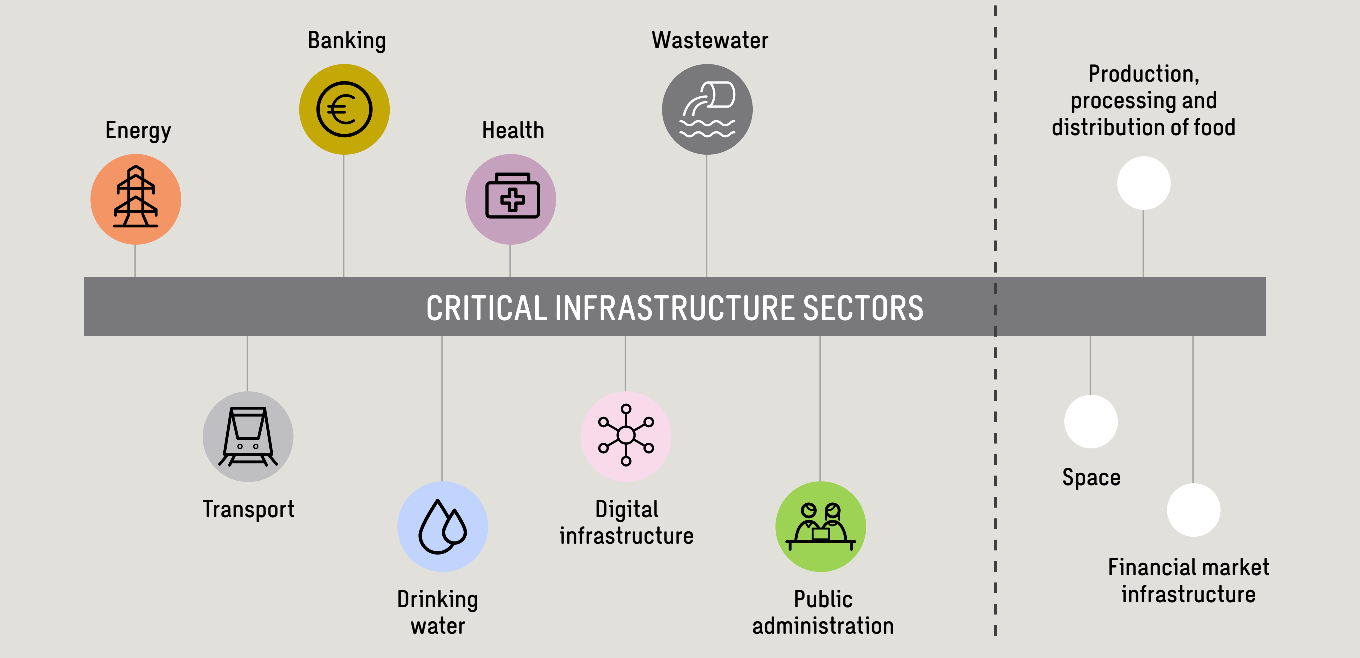
The CER directive sets out certain obligations for EU Member States requiring them to take specific measures to ensure that essential services for the maintenance of vital societal functions or economic activities are provided in an unobstructed manner in the internal market.

The European Commission has adopted a list of essential services in 11 sectors that are covered by the Critical Entities Resilience Directive (CER). These include energy, transport, banking, financial market infrastructure, health, drinking water, wastewater, digital infrastructure, public administration, space, and production, processing and distribution of food. Both physical and human elements of critical infrastructure are explicitly identified and should be integrated throughout all steps in order to create greater resilience.

According to the CER, 'critical infrastructure' means an asset, a facility, equipment, a network or a system, or a part of an asset, a facility, equipment, a network, or a system, which is necessary for the provision of an essential service. 'Essential service' means a service which is crucial for the maintenance of vital societal functions, economic activities, public health and safety, or the environment.[3]

Critical infrastructure sectors mentioned in the CER directive

(the sectors marked with colours have been part of this research)

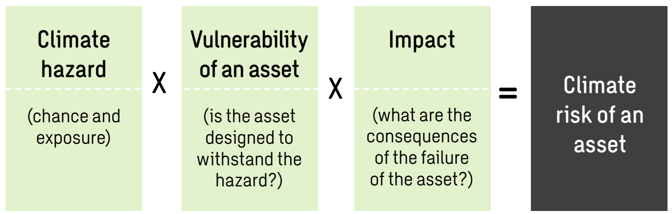


Any failure of these elements of critical infrastructure directly affects vital societal functions. How can we measure risk to get a comprehensive picture of the impacts on infrastructure?

Let's first examine what climate risk is. Climate risk related to critical infrastructure depends on three factors:

- The climate hazard and its chance of occurring. Extreme rainfall is such a hazard, which has a certain chance of occurring in a specific location and exposes a certain area to floods.
- The vulnerability of the assets. Will a flood result in the failure of an asset to operate? This very much depends on how the asset itself is built.
- The impact of any failure. Who or what will be impacted if the asset fails? This includes impacts on society, the environment and the economy.

Combining these factors leads to a formula that is widely used to comprehensively assess climate risks.



Since the failure of critical infrastructure can result in the failure of vital societal functions, economic activities, public health and safety, or the environment, the impact will be great. This results in a higher risk, even if the chances of such a failure occurring might be small.

Vulnerabilities investigated

To get more insight into the vulnerabilities, impact and strategies of cities when addressing the impact of climate change on critical infrastructure, Sweco studied the policies of 26 cities in Europe in the field of climate change adaptation. The policies of the following cities were examined: Amsterdam, Antwerp, Athens, Barcelona, Berlin, Bruges, Brussels, Copenhagen, Dortmund, Glasgow, Greater Manchester, Helsinki, Heidelberg, Lisbon, London, Maastricht, Oslo, Paris, Poznan, Prague, Rotterdam, Rome, Stockholm, Stavanger, Vejle and Warsaw.

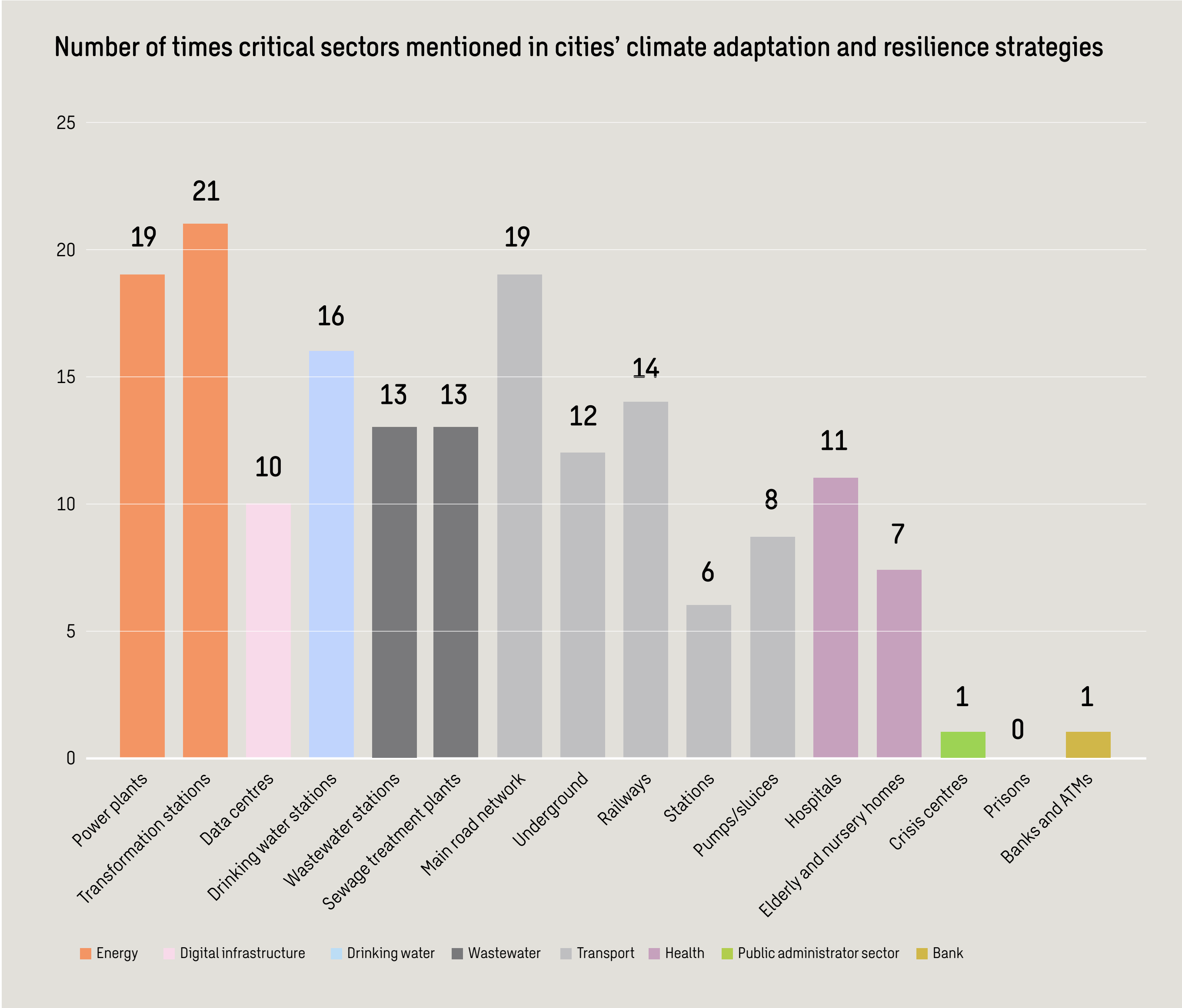
It is worth noting that the focus in this analysis was on overarching resiliency and water management policies and not on sector-specific policies from all 11 sectors from the directive.

In addition, representatives from eight cities in Europe (Brussels, Copenhagen, Glasgow, Helsinki, Maastricht, Poznan, Stavager and Stockholm) were interviewed to provide more in-depth insight. In the interviews, the eight cities shared fascinating insights regarding recent climate-related events, their policies, their concerns and how they plan to deal with similar events in the future. The results also highlight how many different aspects need to be taken into account when trying to make critical infrastructure more resilient.

The focus of climate adaptation policies

So, what do cities currently focus on when it comes to critical infrastructure? We analysed the water management and resilience policies of 26 cities.

The analysis revealed that current policies predominantly emphasise technical and hard critical-infrastructure elements such as road networks and electricity/water supply and demand systems. Often, the social infrastructure that is fundamental for promoting health and well-being, such as hospitals, nurseries, elderly care facilities and crisis centres, was not addressed.



The graph illustrates the number of times the 26 cities studied mention the different types of critical infrastructure in their climate adaptation policies and water management plans. Each infrastructure sector in the table is represented by a colour.

Most vulnerable infrastructure
The results of the eight interviews with city representatives show that the policies do cover the sectors that are considered most vulnerable to floods, as shown in the table below.

In all eight interviews, main road networks, electricity stations and transportation were mentioned as the most vulnerable critical-infrastructure elements. Besides the physical networks, three cities indicated that health and dealing with groups of people who are not self-reliant are also among the most vulnerable sectors.

Interestingly, banks, crisis centres and prisons were not mentioned as the most vulnerable elements in any of the case cities. Even data centres were not mentioned at all. Nevertheless, these infrastructure elements also play a crucial role in maintaining public services and safety.

From these interviews, it also became clear that cities tend to look mainly at the hazard side of risks. Are assets exposed to floods, and what can we do about it? The other side of risks, the vulnerability of the assets themselves, is hardly mentioned at all. Focusing on decreasing the vulnerability of the assets can, therefore, make a valuable contribution to increasing resilience.

Most vulnerable infrastructure per city as revealed from the interviews

Brussels	1) Underground 2) Sewage treatment plants 3) Main road network	**Maastricht**	1) Main road network 2) Electricity transformation stations 3) Hospitals 4) Elderly homes 5) Care homes
Copenhagen	1) Main road network 2) Electricity transformer stations 3) Railways 4) Hospitals	**Poznan**	1) Wastewater stations 2) Pumps/sluices 3) Main road network 4) Drinking water stations 5) Sewage treatment plants
Glasgow	1) Main road network 2) Railways 3) Underground 4) Schools and nurseries 5) Care homes	**Stavanger**	1) Main road network 2) Wastewater stations 3) Electricity transformation stations 4) Drinking water stations 5) Stations
Helsinki	1) Main road network 2) Electricity transformation stations 3) Pumps/sluices 4) Sewage treatment plants 5) Hospitals	**Stockholm**	1) Main road network 2) Railways 3) Underground 4) Electricity transformation stations 5) Schools and nurseries

References to vital objects in cities' climate adaptation and resilience strategies.

Quotes from the interviews and an overview of the hot topics

Interviews were conducted with representatives from eight European cities (Brussels, Copenhagen, Glasgow, Helsinki, Maastricht, Poznan, Stavanger, and Stockholm) to gain a deeper understanding of their climate-related events, policies, concerns, and plans for the future.

The results demonstrate the various factors that must be considered when aiming to increase the resilience of critical infrastructure.

It is important to acknowledge the interdependence of infrastructure systems and assess cascade effects through cooperation among managing entities.

Exposure to floods in cities

In the interviews, cities provided various reasons for the exposure of infrastructure to flooding. Factors that contribute to a city's exposure included, of course, climate change and the occurrence of extreme rainfall over a short time.

However, exposure is also influenced by other factors, such as urbanisation. Many European cities are focusing on urban densification, sometimes at the expense of green and blue structures in the city.[10] Additionally, outdated or poor infrastructure and geographical location are contributing factors that have been identified both in policy analyses and interviews.

A city's location makes it unique and brings its own risks that must be considered. For example, Helsinki is particularly vulnerable due to its geographical location, as there is a high risk of coastal flooding in combination with rainfall-induced floods.

While the geographical location of a city can't be changed, it is possible to take the water and soil system into account when choosing the location of critical infrastructure. For example, when rebuilding a hospital, consider locating it on a hill instead of a floodplain. In the Netherlands recently, new policies have been adopted to make spatial planning more 'soil and water-based'. Making sure spatial planning, and the planning of critical infrastructure, takes into account the natural constraints of certain locations (e.g. flood-prone areas, weak soils, erosion) will require fewer technical solutions during the construction phase.

Impact of failing infrastructure – hidden effects

Cascade effects

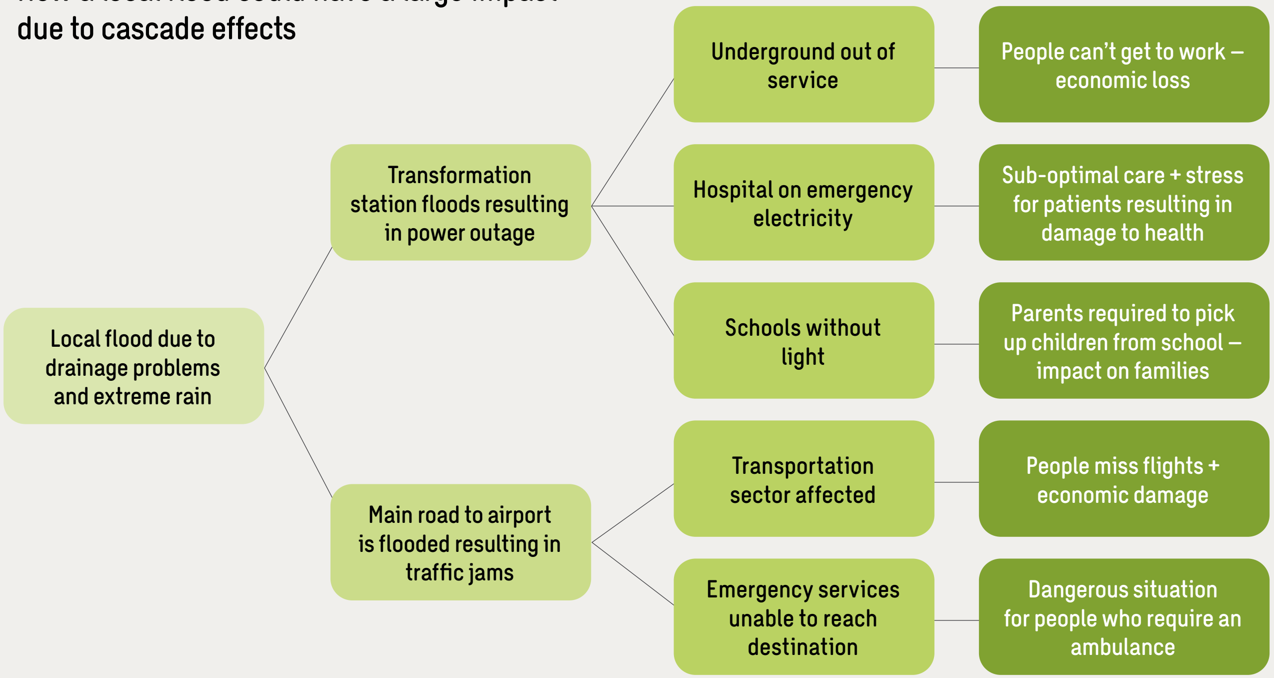
An important reason why the impact and resulting risks are higher with regards to critical infrastructure is because of cascade effects. Infrastructure systems are interdependent. Failure of one system can cause other systems to fail, like dominoes falling one after the other.

One of these events causing cascade effects occurred in the summer of 2007 in the UK. Tens of thousands of people endured extended power outages, with an additional 350,000 people being deprived of access to potable water for up to 17 days.[10] As a result, a considerable number of people also became stranded due to the disruptions in transportation networks. Therefore, understanding the resilience of one system is not enough. Interdependencies should be set out clearly to truly understand the impact of a failure of a system.

According to the respondents, the sectors that are most vulnerable to cascade effects are:

1. Transportation
2. Water chain
3. Electricity
4. Health care
5. Groups of people who are not self-reliant.

How a local flood could have a large impact due to cascade effects



But what can happen if one of these sectors fails due to extreme rainfall? The possible resulting cascade effects are illustrated in the figure below.

In our policy analysis, we came across the example of the city of Glasgow, which has extensively researched cascade effects and interdependencies among networks. This was first mapped at the national level. The city region is now collaborating with the University of Edinburgh, Scottish Water, the Scottish Power Energy Network, BT (telecommunications), SGN (gas) and SEPA (Scottish Environment Protection Agency), among others, to understand these interdependencies. The project has highlighted a range of dependencies among road, rail, water, gas, electricity, and telecommunications infrastructure. As a result, a conversation on how to address these issues was started.

As illustrated in figure to the left failure of infrastructure systems results in impacts on people, the economy, and the environment. For economic loss this could unfold as follows: As a result of power cuts, or direct inundation of subway stations as seen in New York, transportation in the city comes to a standstill, preventing a significant number of residents from being able to commute to work. This means that employees do not reach their workplace resulting in economic losses.

In 2019, in a report titled 'How to Survive Without Electricity', Sweco calculated the costs per hour of being without electricity in a workplace.[11] Of course, the cost structure varies in each country, especially given inflation over the past few years. The expectation is that the costs will turn out to be much higher, but this study provides a good overview of how quickly the costs escalate.

Example of cost calculation:

What would a 1-hour power outage cost for companies, organisations and institutions?

A 1,000-employee office without power	EUR 67,000
A supermarket without power	EUR 6,000
A shopping mall without power	EUR 100,000
An industrial production line without power	EUR 100/employee

Real-world costs of a power outage per hour[11]
For example, in September 2003, a tree fell on a key power line in Switzerland. The effects rippled down to southern Italy, causing around €1.2 billion in damage. About 56 million people, mainly in Italy but also in Switzerland, were without power for several hours.[12]

Unfortunately, several cities have first-hand experience of cascade effects. In the following examples several recent events are highlighted. The experts we spoke to could remember these moments like it was yesterday.

Copenhagen, July 2011.

Let's go back to Copenhagen in 2011, when 15 centimetres of rain fell within just a few hours.

The consequences of this cloudburst for people were severe. Several areas in Copenhagen were inundated, causing flooding in homes, businesses and public spaces. The city's infrastructure and public spaces suffered considerable damage.

Critical infrastructure systems were also affected. Transportation networks, including roads and public transportation, were disrupted, causing travel delays and difficulties; train traffic was disrupted for a week. Power outages occurred in some areas due to equipment failures and water got into electrical systems. 10,000 households suffered power outages for up to 12 hours and 50,000 homes lost heating and hot water for up to a week. These facilities are the backbone of a city's ability to function safely. Without electricity, business, traffic and life itself all come to a grinding halt.

At that time, Copenhagen's emergency call centre services were in a basement. At the last minute, all the servers had to be raised up onto pallets to prevent any breakdowns. Additionally, they were 15 minutes away from the Danish National Hospital, which was in the process of evacuating patients to another hospital.

To give an idea of the impact, let's take a closer look at what happens when a hospital is flooded. The extent of the impact might vary depending on the location. Just a few centimetres of water can cause the normal arrangements for the supply of water, electricity and food to stop functioning. Hospitals usually have emergency provisions in place for power outages, but if there is no access to drinking water, the hospital needs to be evacuated. If the roads in the immediate vicinity are affected, it becomes very challenging for the hospital to provide care to patients, maintain the daily food supply and deliver medicines. In addition, a flood might prevent patients from reaching the nearest hospital.

> **"The servers for Copenhagen's emergency call centre were in a basement in 2011. In the last minute we got the servers lifted up onto pallets and made sure they didn't break down.**

Since 2011 Copenhagen is implementing large-scale measures to prepare for next rainfall events using a blue-green approach. At that time, there were only three policy personnel working in this field, but now there are 55 people working to implement the cloudburst plan. They have now identified how and where to take measures.

Poznan, 22 June 2021

On 22 June 2021, during extreme rainfall in Poznan, Poland, many of the city's main roads were flooded, making it impossible to cross them.

On 22 June 2021, extreme rainfall hit the Polish city of Poznan with an intensity of 79.6 mm in one day of which 90% fell within 1.5 hours. As a result, the city was flooded in many locations and paralyzed for about 5-7 hours.

Many of the city's main roads were flooded, making it impossible to cross them. Moreover, many passages under viaducts, such as the Kobylepole and Podwale viaducts, were also flooded. This led to significant communication problems, particularly for car transport and for public transport due to flooded tram tracks.

Furthermore, municipal institutions like hospitals and schools were flooded, in particular facilities with basements. Private rooms located below ground level and parking garages were also flooded. An overload of pollutants on roads and pavements from mixed sewer systems impacted traffic in Poznan, as roads had to be closed by the city for repair and cleaning. Due to the mixed sewer system, large amounts of water-borne pollutants were deposited after the system overflowed.

The intensity of the rainfall took all services by surprise, impacting the municipal organization. On the day the rain fell, municipal services worked tirelessly to minimise the effects of the intense rainfall. In the weeks after event, additional efforts to clean up and remediate the damage were needed. In addition, the city has to deal with many people and institutions that look for compensation for damage caused by flooding.

The city is already focusing on building a more robust green blue structure to decrease exposure from rain-induced floods (maintenance and reconstruction of reservoirs and water courses and creating more local small-scale infiltration areas).

> The roof of a recently built gymnasium collapsed. All the children were evacuated before the roof collapsed, so no one was hurt.

Maastricht, July 2021 and September 2023

A cluster of heavy and slow-moving showers hit the city of Maastricht, the Netherlands, in July 2021 and again in September 2023. This extreme weather resulted in damage and disturbance.

In Maastricht in 2021, the flooded basements of people's homes in the southwestern part of the city were the primary concern. However, Maastricht was not the worst hit area. Its critical infrastructure did not suffer much damage, as the rain fell over a long period of time and the water system was able to cope with it. It was feared that the large Maas River would potentially flood, leading to the evacuation of 10,000 people from the area.

On 12 September 2023, extreme rainfall once again caused flooding and flooded streets in places like Maastricht, Geleen and Valkenburg. The local newspaper reported that residents were shocked by the amount of water. The station hall in Maastricht and the basements of several schools were flooded causing water damage. Due to the flooding, certain sections of the A2 highway in the direction of Eindhoven were temporarily closed off.

Additionally, the A76 highway towards Aken was closed near Geleen due to water overflows, and a number of local roads were also closed. The basement of the UMC hospital in Maastricht was even flooded, but the damage was minor and the flooding did not cause any problems for continued healthcare.[13]

The example of Maastricht shows that the exact location, duration and amount of rain can make all the difference in the extent of critical infrasturcture disturbances.

> There are people who have experienced a flood and check the rainfall radar every hour when rain is on its way.

Sweco believes it is vital to share the stories of people who experienced these events. It helps us to understand the processes that take place as a consequence of extreme rainfall events that were once thought impossible.

Sharing these stories is not about passing judgement. It can be extremely difficult to understand a worst-case scenario and to foresee the cascade effects that might occur. That is why sharing experiences is essential. Sweco was very pleased that these experts were willing to share their experiences to help other cities prepare more effectively for such situations.

Hidden effects on citizens

During rainfall-induced floods, people can be affected by failing infrastructure in a wide range of ways. The damage to infrastructure or, for example, buildings like schools or the disruption of a subway line is clearly visible and often quickly quantifiable in terms of financial losses.

However, psychological damage is less conspicuous. The city representatives interviewed, who had experienced such disasters, indicated that this aspect is often overlooked.

A respondent in Maastricht confirmed that emotional damage can occur and that people are aware that their homes, properties and immediate surroundings are vulnerable. “The impact on people’s psyche is underestimated. Some people check the weather radar every hour because they fear that they are vulnerable”.

The hidden effect is that many people experience prolonged stress with every new rainfall. In summary, extreme rainfall and subsequent flooding can impact individuals on multiple levels of Maslow’s hierarchy of needs.[14] These natural disasters endanger basic needs and feelings of safety, stability and well-being. When social infrastructure is affected, the consequences can be grave since people’s physiological and safety needs can be put at risk. This is especially true for facilities like schools, hospitals, elderly care homes and prisons, where people who are not self-reliant are being cared for. When these facilities are affected, emergency services have to scale up significantly. And resources for large-scale evacuations might not be at hand on time.

Also, longer-term effects should be taken into account. After a flood, people worry about the likelihood of a recurrence and the safety of their community. This can lead to ongoing fear and stress, even during normal rainfall.

What stands out is that the human impact of any failure of critical infrastructure, including emotional damage, is often not given enough attention in policy documents and is sometimes completely overlooked. In addition to rebuilding homes and infrastructure, attention to mental resilience is essential for the proper functioning of a city.

Conclusions and key insights

What are the main insights from the study?

The resiliency of urban infrastructure is gaining more and more attention. And rightly so, as failure can have severe consequences. Based on our research, here are the main insights that we believe policymakers and project managers in cities should consider in their work:

- **Study not only exposure but also vulnerability and the impact of critical infrastructure failure.**
  In climate risk assessments, cities should also study critical assets and networks. Cities nowadays tend to follow an area-per-area approach when it comes to climate risk assessments, which examine whether assets can be exposed to floods. However, for reliable risk assessments, more knowledge and data are needed on the vulnerability of the assets themselves. Often the true risk for a transformation station or hospital depends on where and how it is built. Is it build on higher ground, is it equipped with waterproof doors, are electrical installations located in the basement or on the first floor? For example, 30 centimetres of rain poses a problem for some hospitals, but not all. This does, however, make any analysis more complicated. Water managers cannot perform this analysis alone, as not only knowledge about the location and depth of possible floods is required, but also knowledge about the vulnerability of the infrastructure.

- **Study cascade effects.**
  Infrastructure systems are interdependent, so failure of one system can cause other systems to fail. These cascade effects can have unexpected and serious societal consequences. Studying cascade effects requires combining information and knowledge from all the agencies and companies that operate vulnerable infrastructure. An important first step is for these organisations to assess the vulnerabilities and impact of extreme rainfall on their own assets. When organisations have insight into the risks posed to their own assets, results can be combined and cascade effects can be studied and discussed. Almost no cities from this report studied cascade effects in detail.

- **Assess risks to both technical and social infrastructure.**
  To increase resilience, cities often focus on preventing the failure of technical infrastructure that is (at least partly) managed by the city itself. However, the failure of social infrastructure often has very direct and far-reaching consequences. If, during a rain event, a retirement centre/nursing home, hospital, jail or zoo is affected, this has significant consequences and requires the large-scale deployment of emergency services.

- **Strengthen disaster risk governance and set clear and action-oriented goals.**
  Based on the assessment of risks and possible measures for each sector, action-oriented goals should be established in accordance with each organisation's responsibilities. 100% protection against climate risks doesn't exist. But what level of risk is acceptable? And what is an acceptable level of investment to reduce risks? This is, in the end, a political decision. It is important to realise that not all assets will need to be protected to the same standard. In addition, considering the complexity of the risk analysis, a level of uncertainty will have to be accepted to move forward. Increasing resiliency can be achieved by taking structural measures and making systems more robust. However, other capacities should not be forgotten. The emergency response capacity and the capacity to quickly repair and replace components should be part of the strategy.

- **Create synergies on the asset level.**
  Actions to create resilient systems can focus on 1) reducing exposure to climate hazards; 2) decreasing vulnerability; or 3) decreasing impact. When taking action on the asset level to decrease its own vulnerability, actions can be combined with other measures on the asset level to simultaneously tackle multiple issues. Electrotechnical and mechanical components often have a depreciation period of about 25 years. Buildings last much longer, 50-100 years or more. Taking action when components need to be replaced anyway is much cheaper than doing so earlier. This increases the cost-benefit ratio of measures considerably. Also, a lot of money will be invested in new infrastructure in the coming years, such as electricity infrastructure, to facilitate the energy transition. This is a once-in-a-lifetime opportunity to do things right: build new infrastructure to new, climate-proof standards from the outset.

- **Resilience starts with building in the right location.**
  Build in a location that has low exposure to potential extreme rainfall. It is a lot easier and cheaper to climate proof critical infrastructure in a location that is not exposed to hazards. Building a transformation station or a data centre on higher ground is more climate proof and often cheaper than taking technical measures to waterproof the building. Also, when existing infrastructure needs to be upgraded or replaced, consider relocating the building. This might be a good option for increasing resiliency.

- **Set functional requirements for new infrastructure.**
  The CER directive already mentions 11 sectors of critical infrastructure. Within each of these sectors, there are numerous types of assets that make up the critical infrastructure. It is, therefore, impossible to set a one-size-fits-all standard for resiliency. However, standards are necessary when developing new areas. We recommend that experts develop a set of functional requirements related to climate change for each infrastructure type. In the Netherlands, a framework for climate-adaptive and green urban development was established including some standards for critical infrastructure. Sweco is currently involved in the development of more specific standards for each sector.

- **Be aware that there are hidden effects.**
  What stands out is that the human impact of the failure of critical infrastructure, including emotional damage, is often not given much attention in policy documents and is sometimes overlooked completely. If a person was severely affected by flooding once, the fear of a new flood can cause significant stress and anxiety. In addition to rebuilding homes and infrastructure, attention to mental resilience is essential for the proper functioning of a city.

Recommendations

Building resilience: a two-way street

How to plan and design to increase resilience?

Now that we have the insights, how can we best take action? The CER directive sets out a path towards more resilient critical infrastructure. By 2026, all countries should have a strategy for enhancing the resilience of critical entities. Implementing the CER directive is a decisive step forward towards organising governance around resilient critical infrastructure. But action needs to be taken on multiple levels in order to achieve a higher level of resilience. Cities have a role to play, too.

The complicating factor is that the many institutions and companies that manage critical infrastructure, whether the underground, the electricity network or critical water-management infrastructure, only see part of the puzzle. Therefore, the road to resilience requires both the individual assessment of risks and actions by these institutions and the coordination of different levels by the government.

Untying the knot of improving the resilience of critical infrastructure may seem a daunting task. It requires much specialist knowledge and is truly multi-disciplinary:

- **Assessing exposure** to rain-induced floods requires setting up detailed hydrological models and feeding them with rainfall data based on climate scenarios.
- **Assessing vulnerability** requires sector-specific knowledge about what is critical for the operation of an asset. Consider the knowledge necessary to understand how a hospital is built, with its special systems for electricity, oxygen and safe drinking water and specific demands for the functioning of, for instance, first-aid and intensive-care units. Or an understanding of how an underground station is designed. How much water will come in before it becomes unsafe to operate?
- **Assessing impact** requires an understanding of the human impact of failure. Who is affected and how severe are the consequences? It also requires understanding the environmental impact of failure. When a water-treatment plant stops operating, untreated sewage can end up in the streets causing health issues, but it can also cause damage to vulnerable nature. In addition, assessing the economic impact of failure can be relevant. How much economic damage will result from blackouts, blocked roads or trains that are not running?

So, assessing risks for one sector is a multi-disciplinary task. Combining these analyses to identify cascade effects is the next challenge that requires leadership from the city or city region itself. Exposure analysis is usually done by the city. The city can encourage sectors to use this information to perform risk assessments and take the lead in planning and combining these analyses.

Therefore, we urge cities and local governments to begin by proactively approaching the affected sectors. Based on current knowledge and information, valuable steps can be taken and knowledge and data gaps can be identified. When both sectoral institutions and government bodies take responsibility and invest in interaction, risk assessments will become more accurate. As a result, investments in resilience can be made more effective. For example, should investments be made in reducing exposure? Or will investing in asset-level measures be more effective?

Starting points and responsibilities for both sectoral and city levels.

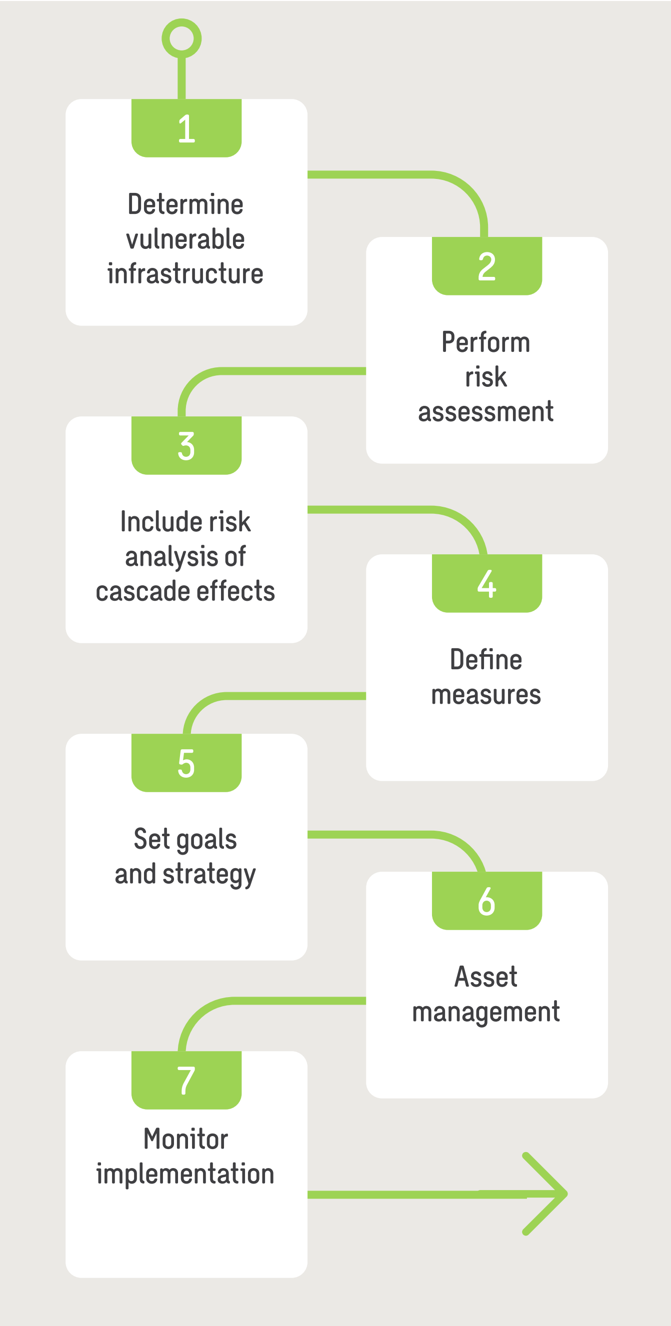
Sector – Asset-management level
- Establish a list of critical infrastructure
- Assess exposure to risks
- Assess vulnerability of infrastructure
- Assess impact of risks
- Set goals: what is an acceptable level?
- Integrate measures in asset management

Integration– City level
- Identify critical city infrastructure
- Provide information on exposure to hazards
- Stimulate individual risk assessments by managers of critical infrastructure
- Bring sectoral information together to study cascade effects
- Develop policies and standards for critical infrastructure in new build areas
- Take critical infrastructure into account in zoning plans
- Develop an knowledge agenda or plan which shows what extra research is required
- Take action on exposure to hazards

The way forward

At Sweco, we know from our projects that building resilience is an iterative process. The city changes constantly, so hazards will also change. In addition, our understanding of climate change is also evolving. The IPCC regularly publishes new climate scenarios, and much research on hazards is based on these scenarios and is therefore also updated. These are all good reasons to assess risks and update measures at regular intervals. Each iteration in this process will produce more data and insights to better support investment decisions in resilient critical infrastructure.

Aiming for more resilient vital infrastructure is a process of taking decisions in the face of uncertainty. The system being managed is complex and the possible climate scenarios infinite. Therefore, our most important advice is to start the analysis but realise that risk analyses and risk assessments alone are far from comprehensive, and other actions are needed. The steps presented here can serve as guidance in this process.



Guide – 7 steps towards resilient infrastructure

1 On a national level, countries should assess what critical entities they have and what critical infrastructure they manage. Cities should make sure they know where this critical infrastructure is located and assess which infrastructure might not be critical on a national level but is worthy of consideration locally.

2 Each sector should perform its own risk assessment checking for 1) exposure to climate hazards; 2) vulnerability of assets; and 3) impact of asset failure. The city can assist by providing data on exposure and standardised systems and methods for assessing risks. This will also benefit comparability.

3 After sector risk assessments have been completed, interaction between systems can be analysed on a system level to assess cascade effects and their impact. This can be done on a generic qualitative level during working sessions. If possible interactions are identified and are considered important enough, more precise studies can be carried out examining specific scenarios and with higher technical detail. Using this information, assets can be classified based on their associated risk.

4 The next step should be for each sector to assess possible measures to protect the identified assets that are at risk. It will become clear that the required investments to mitigate the risks can vary greatly. For example, one watertight door costing just 1,000 euros can, in some cases, prevent the failure of a complete asset and entail all associated risks. In other cases, failure can only be prevented by relocating the asset, costing millions of euros. In addition, as mentioned before, the timing of the measure can make all the difference.

5 Insight into both risks and possible measures and their costs makes it possible to establish goals. For some assets, a political decision about the acceptable level of risk and a strategy to increase resilience can be made by the city itself since it directly manages the assets. For other sectors, cities will only have a limited say. However, cities should be involved in the process, as they can influence the exposure of assets through water-management measures. In addition, they can establish goals and regulations to reduce the vulnerability of assets that are yet to be built through building and zoning regulations.

6 When goals are set, measures can be worked out in more detail. This is also the moment to see how measures can be integrated into the asset management cycle and where synergies with other measures are possible.

7 A monitoring and reporting system should be established per sector to monitor progress. This requires logging the measures that have been taken to increase resilience. In addition, risk assessments should be updated regularly, say every four to six years. This includes changes in land use or climate scenarios that can influence exposure and should include the measures taken that influence vulnerability.

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Reference list

1) KNMI. 23 August 2021. Kans op zware regenval zoals op 13 en 14 juli neemt verder toe door klimaatverandering. https://www.knmi.nl/over-het-knmi/nieuws/kans-op-zware-regenval-zoals-op-13-en-14-juli-neemt-verder-toe-door-klimaatverandering
2) EEA. (2021). Wet and dry — heavy precipitation and river floods. Europe's changing climate hazards – an index-based, interactive EEA report
3) Van Laarhoven, K. 27 December 2021. Overstromingen Nederland, België, Duitsland op een na duurste natuurramp 2021. NRC. https://www.nrc.nl/nieuws/2021/12/27/overstromingen-nederland-belgie-duitsland-op-een-na-duurste-natuurramp-2021-a4072393
4) European Parliament and the Council of the European Union. 13 December 2022. Directive (EU) 2022/2557 of the European Parliament and of the Council of 14 December 2022 on the resilience of critical entities and repealing Council Directive 2008/114/EC. EUR-Lex. https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32022L2557&qid=1696515920879
5) C40. (2017). Infrastructure Interdependencies + Climate Risks Report. In C40. https://www.c40knowledgehub.org/s/article/C40-Infrastructure-Interdependencies-and-Climate-Risks-report?language=en_US
6) University of Copenhagen. 15 September 2022. Global warming doubled the risk for Copenhagen's historic 2011 cloudburst. https://science.ku.dk/english/press/news/2022/global-warming-doubled-the-risk-for-copenhagens-historic-2011-cloudburst/
7) Mobini, S., Nilsson, E., Persson, A., Becker, P., & Larsson, R. (2021). Analysis of pluvial flood damage costs in residential buildings – A case study in Malmö. International Journal of Disaster Risk Reduction, 62, 102407. https://doi.org/10.1016/j.ijdrr.2021.102407
8) KNMI. 20 July 2021. Onderzoek naar hevige regen en overstromingen in Limburg, Ardennen en Eifel. https://www.knmi.nl/over-het-knmi/nieuws/onderzoek-naar-hevige-overstromingen-in-limburg-ardennen-en-eifel
9) The Guardian. 9 August 2021. Torrential rain brings flooding and travel disruption to UK. The Guardian. https://www.theguardian.com/uk-news/2021/aug/09/weather-torrential-rain-brings-flooding-travel-disruption-to-uk
10) Van Ruiten, K., Bles, T., & Kiel, J. (2016). EU-INTACT-case studies: Impact of extreme weather on critical infrastructure. In E3S Web of Conferences (Vol. 7, p. 07001). EDP Sciences.
11) Härö, E., Järvensivu, S. M., Alilehto, J., & Haravuori, P. (2019). Electricity: How long could we survive without it? Sweco Group. https://www.swecogroup.com/urban-insight/energy/report-electricity-how-long-could-we-survive-without-it/
12) Youris.com. 27 April 2016. The cost of blackouts in Europe. Phys.org. https://phys.org/news/2016-04-blackouts-europe.html
13) 1Limburg. 13 September 2023. Hevige buien: Zuid-Limburg getroffen door wateroverlast. 1Limburg. https://www.1limburg.nl/nieuws/2285265/hevige-buien-zuid-limburg-getroffen-door-wateroverlast
14) McLeod, S. (2007). Maslow's hierarchy of needs. Simply psychology, 1(1-18).

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