Cascading Risks and Resilience Crescendos

Climate Security National Foresight Group

Report 3

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This report defines cascading risks, identifies potential pathways for risks, contextualises cascading risks in the UK using case studies and analyses the 'crescendo' of resilience following cascading risks. It finishes with a series of summary questions for the group to consider.

Reports by this group will provide key insights on topics of importance tasked by this group or key stakeholders. They intend to provide a context and start point for discussions. This specific report is useful for groups interested in understanding the outline of cascade risks and how groups can begin to consider how to map and understand these risks.

Contents

What are cascading risks?

Last meeting, we gave the following example of cascade risks from the POSTnote on Climate Security:

> *"Cascading risks occur when an adverse impact triggers or amplifies other risks. For instance, in 2010 western Russia experienced an unprecedented heatwave, drought, and series of wildfires, destroying 17% of the wheat harvest. Russia banned wheat exports, resulting in sharp international price rises. This led to increased food bank usage in the UK and a rise in poverty and political unrest in countries such as Egypt, Tunisia and Mozambique. This was one of many factors that contributed to the Arab Spring in 2011.*
>
> *Risk cascades can be triggered when a physical threshold is crossed. For example, reaching a specific temperature and dryness that cause widespread crop death. Climate change increases the likelihood of crossing thresholds and doing so in different regions simultaneously. For example, climate change is increasing the chance of co-occurring crop failure for many staple crops including wheat, soybeans, and maize across key agricultural areas, which would have a disproportionate global food security impact. This may pose systemic risks, in which entire systems collapse, such as political institutions or business sectors."*

Within the academic literature on cascade risks, there has been three broad approaches.

1. Firstly, to try and plot the cascade risks through approaches such as systems mapping. Whilst this produces a good representation of the interdependencies, it either is constrained because it is too sector bounded, or it becomes so interlinking that it is never completed and becomes a nebulous connection of spider webs.

2. The second approach is a modelling or algorithmic approach where code is written which aims to model the cascades, like Monte Carlo modelling or digital twins, fault and event trees, or simulations. However, this takes some skill to design, implement and interpret as they are usually advanced and complex data builds, but also have been critiqued to provide false precision. They are also, by design, bounded by the sector or by limits within the cascade event.

3. The last approach which we advocate as the most straight forward to do without specialist knowledge or skills, is an approach which tries to look at the main possibilities to develop reasonable working assumptions. This aims to recognise the geographical cross-border effects, and the social dependencies (significant impact to people and their behaviour), and then starts to consider the cross-sector impacts such as interdependencies. Working in this order tries to acknowledge the likely sector bounded and social dependencies within the multiple (first, second and third) order of impacts, before it then moves

outwards to establish interdependencies between sectors. Using this approach escalating impacts can also be captured. This allows the explicit identification of what 'chains' or 'paths' exist between interdependent critical infrastructure and therefore it should become possible to infer a priority order of criticality, cumulative risks and cascading failure through identifying the controls with the most power to disrupt the amplification of the risk, whilst preserving as much resilience and necessary interdependency as possible.

Academic reviews suggest that the reason why we should attend to cascade risks is because of the cross-scale accumulation of vulnerability paths that could happen and escalate into secondary emergencies. They reviewed the operational methods commonly used to identify the "complex, non-linear escalation of secondary emergencies.

Key topics addressed by the contributions include:

- cross-domain modelling of interdependent systems
- decision support systems
- economic impact assessment of critical events
- cascades in the built environment, in social domains, and in applied emergency management

Our conclusions support the work of academia, and of public and private stakeholders, by providing a comprehensive analysis of the topic for the improvement of theory, the assessment of resilience, the formulation of policies for managing crises, and operational planning for emergencies." (Alexander 2018) Alexander provides a good definition of an escalation point as "a critical juncture in the chain of reactions to a disaster impact at which the interaction of vulnerabilities, and the concatenation of influences leads to a bigger impact than mere reaction to the primary disaster would suggest." Consequently, from the academic literature we have reviewed and synthesised their approaches and have reported the most suitable for this group.

Cascade risks can be classified by size, reach, complexity and importance, in reference to the causal relationships (through interdependencies and chains/paths), that they share. Alexander (2018) developed a classification to compare the different scale and complexity of cascade risks.

A magnitude classification of cascading incidents, crises and disasters
Level 0 Simple incident or major incident.
No evidence of significant cascades or escalation points. Simple, direct, linear cause-and-effect relationships between the primary impact driver and its consequences. This level will mainly apply to geographically localised incidents of brief duration with no significant side-effects or knock-on consequences.
Level 1 Major incident of limited complexity.
Evidence of simple, short cascades--i.e., secondary effects of the main or starting impact-effect relationship. There are no escalation points, no major interconnections or interactions

beyond the early 'consequences of consequences' relationship. The most important relationship is that between the triggering event and its immediate consequences.
Level 2 Major incident or small disaster, with some complex consequences.
Limited cascade chains. The effects of the initial event propagate to tertiary levels in which there are significant complications or secondary emergencies at one remove or more from the triggering cause-effect event. The secondary emergencies may be as important or as pressing as the primary event. There may be escalation points, as new fields of vulnerability are penetrated by the extending chain of events.
Level 3 Disaster, with complex consequences.
Significant cascade chains can be detected, probably with at least one escalation point. Different sectors of vulnerability are involved (physical, environmental, institutional, economic, social, etc.), and interaction occurs between them in an identifiable manner. There are complex interconnections between subsystems. As these both act upon different fields of vulnerability and connect them, compound consequences are detectable, some of which may have the power to escalate the general emergency.
Level 4 Disaster, with substantially complex consequences.
Cascades are easily identifiable in the effects of the disaster. Escalation points exist where particular vulnerability fields and states are encountered. Cascades substantially prolong the emergency and lead to effects that may outlast or overshadow the initial triggering event. The consequences of the disaster are complex on a wide variety of levels and they extend into many different aspects of daily life, which changes very significantly for the duration of the emergency and a substantial part of its aftermath.
Level 5 Catastrophe, with overwhelmingly complex consequences.
A major initial impact sets off long causal chains of cascading consequences, some of which, through identifiable escalation points, generate secondary causal chains. All of these extend into many or most aspects of normal daily life and cause very substantial disruption or total shut-down. Concurrent events occur or are triggered by compounding interconnections. The catastrophe disrupts and damages over a very wide scale and for a long time. Some effects are essentially global, for example on intercontinental travel, international supply chains or global communications.

Table 1. The magnitude scale for cascading incidents, crises and disasters.

The image below offers a graphic view of this scale. It is important to note that this is for illustrative purposes only. The actual disposition of nodes, linkages and pathways will depend on the circumstances of the incident, crisis or disaster.

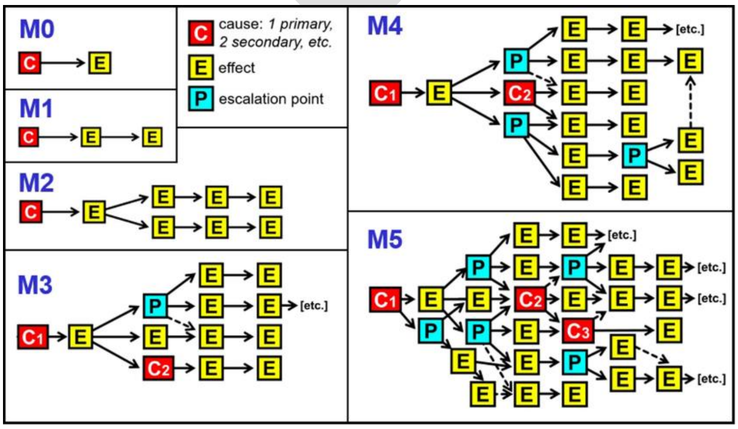

Figure. 1. A diagrammatic view of the cascading disasters magnitude scale.

A structured process is undertaken with key stakeholders to develop and test differing scenarios and outcomes. Further information on this process can be shared with the group. The second figure below outlines a representation of a methodology for assessing the impact on an area/region from cascading events.

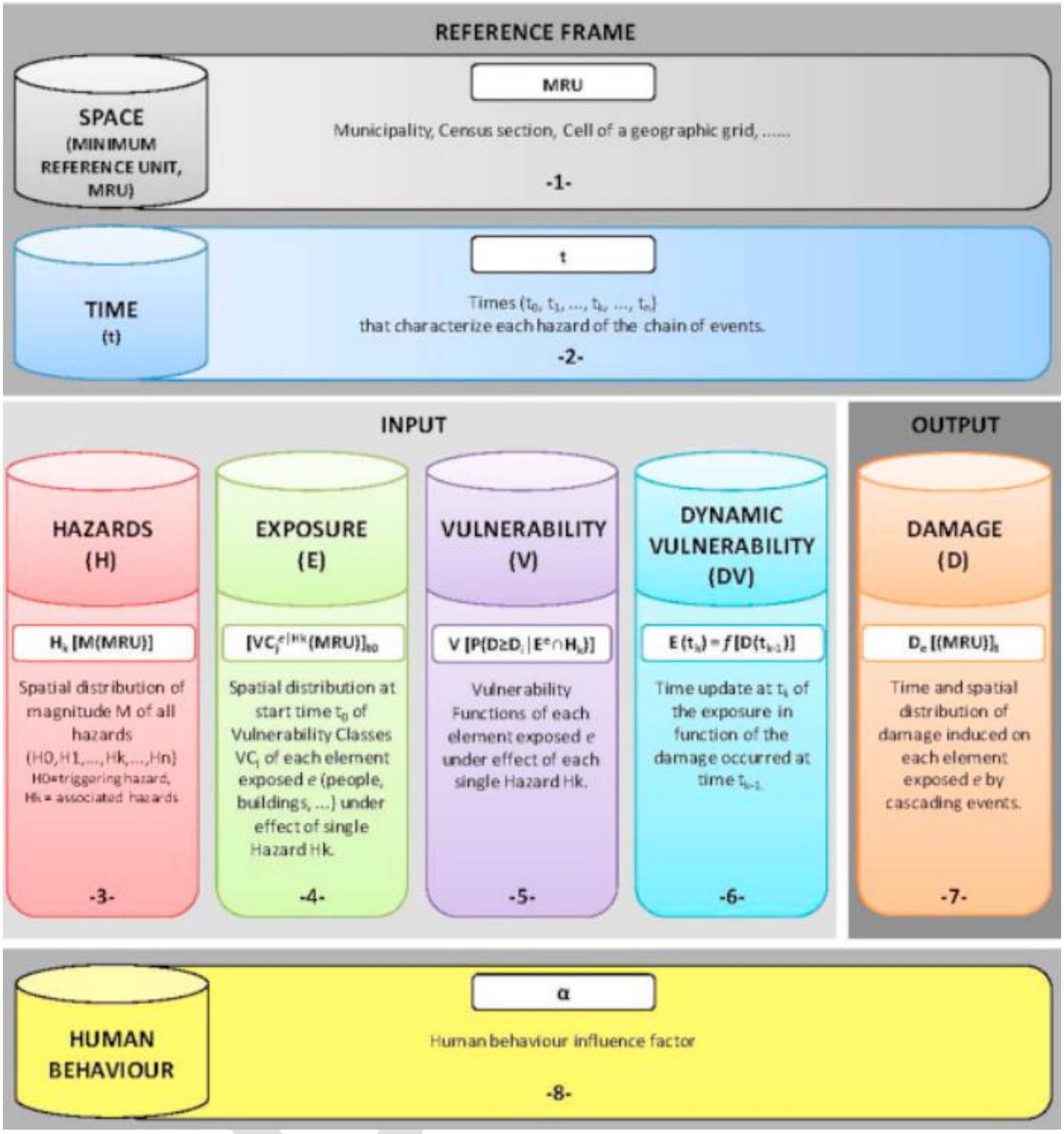

Figure 2. A theoretical model for cascading effects analyses from Zuccaroa, De Gregorioa and Leonea (2018)

What are cascading risks within the context of the changing climate?

Cascading risks have been defined by Zaidi (2018) as "a chain of causality that emerges when hazards, risk and accumulated vulnerabilities connect across multiple scales to produce a disaster". These have been interlinked and separated in different literatures to tipping points within the global systems. This next section will outline what published literature has suggested regarding cascade risks and the changing climate.

For clarity, the below table outlines some definitions of risk type.

Risk Type	Definition
Risk cascade	Chains of risk occurring when an adverse impact triggers a set of linked risks.
Systemic risk	The potential for individual disruptions or failures to cascade into a system-wide failure.
Latent risk	Risk that is dormant under one set of conditions but becomes active under another set of conditions.
Global catastrophic risk	The probability of a loss of 25% of the global population and the severe disruption of global critical systems (such as food) within a given timeframe (years or decades).
Global decimation risk	The probability of a loss of 10% (or more) of global population and the severe disruption of global critical systems (such as food) within a given timeframe (years or decades).
Extinction risk	The probability of human extinction within a given timeframe.

Table 2: Risk definitions from Kemp et al. (2022)

Key Literature Highlights

Perceptions of Cascading Risks and Resilience: a London case study (Pescaroli, 2018):

Main issues lie with a lack of clear definitions of tipping points and uncertainties, which lead to decreased response times and a lack of prioritisation of specific responses and inter-organisation coordination. It was suggested that hazard risk maps and critical infrastructure ranking should be incorporated into legislation, which could aid in the coordination of different sectors. Further, understanding of interdependencies and cross border impact of cascading risks was lacking, so both bigger picture and finer detail planning and policy is recommended. Knowledge of risks, interdependencies and vulnerabilities were suggested to be associated with higher community resilience, coordination, and information exchange. Shared responsibility of emergency management and collaboration between local and national government through increased dialog was recommended. This could potentially be achieved through increased access to information and training, as well as the utilisation of standard guidelines. Training could potentially centre around scenario and planning exercises, to increase understanding and experience with mitigating cascading risks. Loss of services causing risk to life was a key consideration, with strong implications about the need for coordination across sectors.

Climate Security Connecting Strong and Fragile States (Kivimaa, 2023):

Climate change has effects that can lead to greater negative impact on populations. For example, local food shortages as a result of adverse weather conditions may have greater impact on regional and national food supply chains. As such, cascading risks can impact even strong, resilient areas and across borders. Potential pathways by which cascading risks can cause a chain reaction are outlined:

1. Adverse weather conditions reduce food production and lead to food price shocks and social conflicts
2. Climate change and conflicts influence economic growth – it is suggested that there is a lack of research surrounding cascading risks and economic growth pathways
3. Migration as a result of climate change and its effects on intergroup conflict – this is also suggested to be an under-researched area
4. Climate disasters can negatively affect security via increased mortality rates and increase economic vulnerability.

Europe is suggested to be concerned about climate impacts but does not have sufficient response systems in place to deal with these impacts, and as such, horizontal policy coherence should be considered. Horizontal policy coherence between climate policy and other fields (i.e., foreign policy, security, defence and trade) could lead to an increase in shared knowledge and understanding of risks and magnitude of impacts. Public-private partnerships could also be considered to increase societal resilience. It is suggested that larger companies may have more up-to-date knowledge about their sector, global development and risks than government bodies and civil servants. Avoiding or reducing policy silos and collaborating cross-sector and cross-organisationally may lend to a stronger and more resilient nation, and as a result, strengthen more vulnerable areas.

Infectious disease pathways following natural disasters (Suk et al., 2020):
11 (of 17 papers reviewed) reported infectious disease outbreaks following flooding or earthquake events. The causes of outbreak ranged from food and water-borne diseases to vaccine-preventable diseases. This suggests that changes in climate and an increase of natural disaster events have the potential to lead to a larger number of outbreaks of infectious disease. For example, heavy rainfall can lead to the aggravation of certain types of pathogens. Reported prevention and mitigation measures were focused on specific diseases, and less so about raising public awareness of health risks after natural disaster events, particularly in vulnerable areas. This would allow for the protection of land and property. Further, it is recommended that more data is collected and distributed to populations, to understand where the highest risk areas are.

Catastrophic Cascading Risks (Kemp et al., 2022):
It is felt that there is a lack of literature surrounding potential catastrophic cascading risks, although IPCC reports identified 15 key tipping elements in biosphere, cryosphere and oceans, many of which had irreversible thresholds. Further, ‘reasons for concern’ reports conducted by the IPCC identify five key concerns:

1. Threats to endangered species and unique systems
2. Damages from extreme climate events
3. Effects that fall most heavily on developing countries and the poor within countries
4. Global aggregate impacts (i.e., various measurements of total social, economic and ecological impacts)
5. Large-scale high-impact events

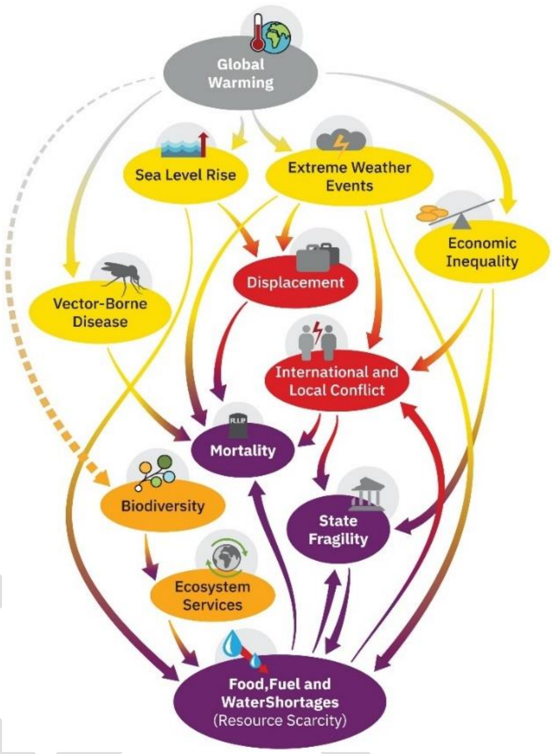

Figure 2: Cascading Risk Pathways. Image taken from Kemp et al. (2022)

Greater risks were found to be associated with higher global mean temperatures, with 'high' temperatures being noted as between 2 and 3 degrees of warming.

It is suggested that the key to understanding and preventing cascading risks is to research potential catastrophic risks. In particular, focusing on long-term impacts of climate change, specific pathways towards mass morbidity and mortality, and the systemic risks that could be triggered from climate change. Utilising modelling methodology could allow for the mapping of risks and identification of largest areas of vulnerability.

Further, it is suggested that the key areas for concern related to mass mortality and morbidity are famine and undernutrition, extreme weather events, conflict, and vector-borne diseases, but that the impact of these could be worsened by rising sea levels and air pollution.

Regional climate change is associated with greater transformation and collapse of societies, and as such, building resilience with a regional focus is key. Misinformation and disinformation are suggested to greatly inhibit climate action, and this should be accounted for in any measures and interventions.

Framework for Assessing Cascading Risks (Simpson et al., 2021):

Three categories of risk:

1. Only a single driver for each determinant of risk
2. Multiple interacting drivers within determinants of risk
3. Interacting risks (cascading effects)

Risk assessment should include response to risk as a determinant as they can often drive potential outcomes. For example, inaction is a response but also a driver of potential outcomes. Assessing risks separately can lead to underestimated risks. Risks should also be assessed dynamically, considering time and space to understand interactions between responses required. Climate risk assessments should be completed regularly to understand the interactions between risks. A Category 3 approach as opposed to Category 1 and 2 approaches is suggested to better enable risk assessment that considers interconnected socio-economic, environmental, and technological systems.

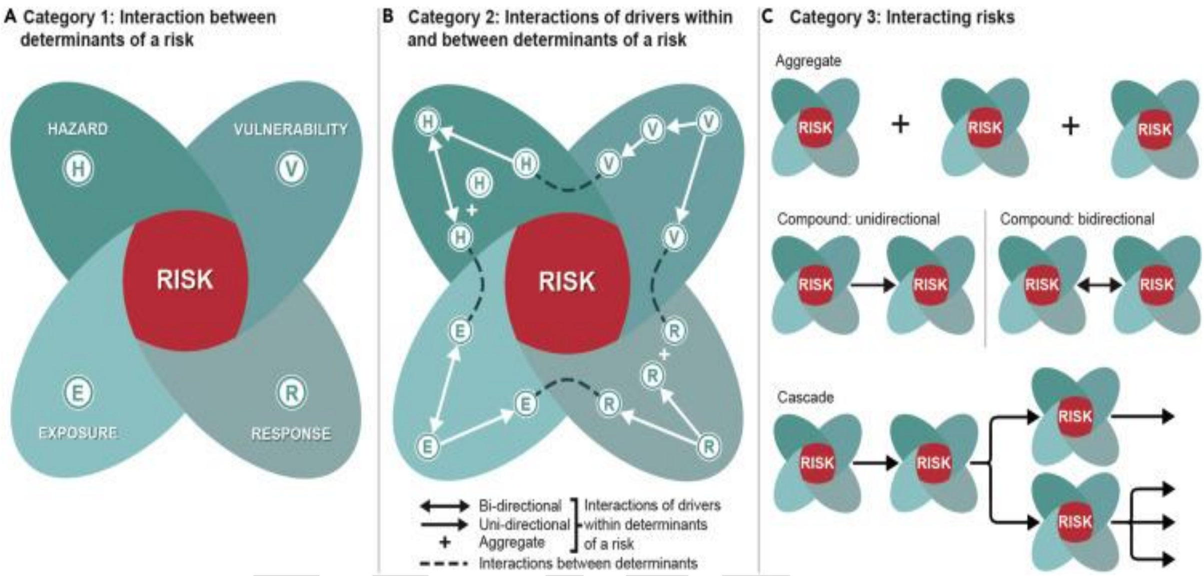

Figure 3: Category 1, 2 and 3 Assessment Frameworks. Taken from Simpson et al. (2021)

Cascading Risks in the UK

Background

In the UK, critical national infrastructure (CNI) assuming is highly interdependent, lending to the possibility of knock-on effects and greater impact to population safety, health and well-being and with increasing events, such as Storm Arwen in 2021 and summer heatwaves, three main recommendations for the UK are suggested (Moore, 2022):

- the establishment of a dedicated minister of state for CNI Resilience within the Cabinet Office, who should hold regular co-ordination meetings with the minister for climate adaptation
- the creation of a statutory forum between the regulatory bodies overseeing CNI sectors (for example Ofwat for water companies and Ofgem for energy), to address interdependencies, along with a review of whether regulators' price review processes encourage resilience-building

- a programme of regional 'exercises' to ensure that locally-based responders to crises – such as the emergency services, the NHS and local authorities – can prepare for and respond well to extreme weather events

Third National Adaptation Plan (NAP3) Cascading Risks

The third National Adaptation Plan outlined areas for managing and reporting about cascading risks. These focused on managing infrastructure and international cascading risks. A brief overview of these are outlined below.

Managing Infrastructure Cascading Risks

- Ensuring current regimes are fit for purpose
- Deliver action plans across the private sector and accounting for interlinkages across sectors
- Identifying and managing interdependencies
- Making climate data more available and unified
- Utilising bespoke tools (CNI mapping tool) to identify risks, cascading risks and develop data informed policy for decision making across government and infrastructure operators alike
- Conducting regular resilience exercises to stress test plans and capabilities, including local and regional and national actors

Managing International Cascading Risks

Key bodies/organisations: FCDO, the Cabinet Office and Defra

- UK's vulnerability to cascading risks is likely to increase due to climate impacts

Action plans centre around:

- Implementing resilience frameworks
- Investing in international climate security to reduce stress and possible cascading to the UK

Information plans centre around:

- Supporting the Cabinet Office developing and building processes to account for risk and vulnerabilities

- Engaging with international partners to develop measurement tools for adaptation progress

Coordination plans centre around:

- Utilise extensive international networks to identify emerging risks and escalating cascading risks using pre-established risk assessment products

Reporting on Cascading Risks:

- Adaptation reporting is crucial when looking to assess interdependencies and cascading risks, both through informing organisations about their own potential risks, but also informing the national CCRA
- There is a limited capacity to assess cascading risks, but some organisations have identified small interdependencies. Others have suggested that a lack of understanding and resources is a barrier to reporting about cascading risks and more guidance is needed
- Cross-sectoral working will be encouraged to fill knowledge gaps

Resilience Crescendos – Key Considerations

Resilience After Natural Disasters (Bakic & Ajdukovic, 2021)

Mitigating the impact of disasters after they occur through resilience building is crucial for ensuring mental and physical safety and well-being of communities. Although disasters can occur at local, regional, national and global levels, it is suggested that those communities with increased individual, interpersonal and community resources are less likely to experience psychosocial resource loss after disaster. This in turn, leads to less impact on mental health and well-being. Further, community social capital and engagement led to more positive adaptation after disaster.

Resilience Occurs in the Neighbourhood (Botkin-Kowacki, 2021)

Growing bodies of research suggest that resilience in communities is based on levels of connectedness, belonging and identity and that those who experience higher levels of these are more likely to rebound smoothly after disaster. This is suggested to occur through stronger connections to neighbours, emergency services and authorities and collective plans for disaster response. Understanding and being aware of services and key actors in local areas helps to build a sense of security through 'bonding ties'. It is suggested that in a tight-knit community, 20 times more lives are saved than those communities who experience less connectedness and a community that has ties to decision makers typically receive more funding for rebuilding after disaster.

Reducing Stress to Enhance Resilience (Sandifer & Walker, 2018)

Resilience can be formal through government and responsible parties, or inherent and adaptive through community and family. Four stages of resilience are suggested to be risk anticipation, reducing vulnerability, response and recovery.

Eight key recommendations to enhance resilience after disaster

1. Improve existing disaster behavioural and physical health programs to better address, leverage, and coordinate resources for stress reduction, relief, and treatment in disaster planning and response
2. Emphasize pre- and post-disaster collection of relevant biomarker and other health-related data to provide a baseline of health status against which disaster impacts could be assessed and continued monitoring of these indicators to evaluate recovery
3. Enhance capacity of science and public health early-responders
4. Use natural infrastructure to minimize disaster damage
5. Expand the geography of disaster response and relief to better incorporate the displacement of affected people
6. Utilise nature-based treatment to alleviate pre- and post-disaster stress effects on health
7. Review disaster laws, policies, and regulations to identify opportunities to strengthen public health preparedness and responses including for stress-related impacts, better engage affected communities, and enhance provision of health services
8. With community participation, develop and institute equitable processes pre-disaster for dealing with damage assessments, litigation, payments, and housing

Summary questions for consideration

- No one agreed model or system of identifying connected and cascade risks
- Cross-geographical and cross-sector impacts makes complex risk management especially difficult
- Climate cascade risks are many and potentially interdependent – change may well occur as a step change understood more like a dam burst rather than river course change
- Modelling cascade risks creates a multitude of pathway which make planning and exercising challenging for the development of functional strategies and mitigation planning against key assets and vulnerabilities

- Climate cascade modelling needs to better integrate and consider societal reactions and responses

- Scale of complex, cascade and compound risks will impact local communities but will occur at such a scale it is challenging to consider how local responses can be developed which may create inertia

- Strength of community may be a key factor in supporting adaptation when cascade events occur and requires further work to understand and develop it

Appendix

Cascading Risks and Resilience Crescendos - UK Case Studies

Cumbria Floods 2015

Event: Heavy rainfall across a 2-day period leading to widespread flooding

Impact: Several thousands of homes and businesses were flooded. Many homes across Cumbria and Lancashire were without power and several bridges were swept away. Two fatalities occurred and rail and road links were cut. Cascading failures led to homelessness, lack of available education and increased transport times over the whole of the UK.

Recovery and Responses: Responses were categorised into 5 themes. These are:

1. Strengthening Defences – Action was taken to repair and strengthen infrastructure, such as flood defences, roads, bridges, water, and sewage works, so that they were operational as soon as possible.
2. Upstream Management – Peatland was restored to absorb water and natural flood storage areas were created using an integrated approach to flood and land management.
3. Maintenance – Routines were updated, and flood defences were repaired. Communities were given more access to maintenance information.
4. Resilience – Community flood groups were developed to increase knowledge exchange and flood planning and warning were provided to properties. Local spatial plans were updated and a new approach for business insurance was developed.
5. Water Level Management Boards – New boards were set up in areas without.

Wainfleet Floods 2019

Event: Two months of rainfall in a two-day period

Impact: Flooding banks were breached and over 130 properties were flooded, with 600 being evacuated. Over 1000 people were impacted.

Recovery and Response: High-volume pumps were used to reduce water levels and repair the breach. RAF helicopters dropped 340 tonnes of ballast to shore up breaches. Lincolnshire populations were urged to reduce use of showers, dishwashers and washing machines. Airspace restrictions was placed over flood sites to reduce drone collision with helicopters. Independent reviews were conducted. Emergency services were criticised by residents for their response times.

Whaley Dam 2019

Event: Toddbrook Reservoir in Whaley Bridge began to collapse due to torrential rainfall

Impact: Over 1,500 people were evacuated due to risk of a catastrophic flood, with nearly a week passing before residents could return

Recovery and Response: Water was pumped from the reservoir to bring levels down and RAF helicopters were employed to drop sandbags and aggregate into the spillway to reinforce it. A year on, temporary repairs were made, with the permanent repair due to be completed by late 2024. An independent review was carried out, indicating that the collapse occurred due to poor design and maintenance. Quick responses allowed for the flood to be avoided, although residents are suggested to experience anxiety during heavy rainfall, suggesting a greater psychological impact.

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