Common cascade risk models and how to build them

Climate Security National Foresight Group

Report 4

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This report outlines a review of the current literature on modelling cascade risks for climate security. It outlines the three distinct model types and shares common and distinct requirements for each. Following this the report outlines key requirements for others considering their own cascade risk process modelling.

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.

Contents

Who is this report for?

This report has been developed for **strategic decision makers or leaders within sectors or government departments**. Designed to be used when commissioning work on cascade risks, we identified a need to streamline the complexity of cascade risk methods. These methods are frequently presented in complex, highly technical academic publications, where the main focus is on developing the approach, rather than the outcomes or consequences of the cascade risks.

The report aims to provide a step by step description of how to work out cascade risks, rather than providing the answers. It is designed this way to help strategic decision makers to understand the size and scope of the task, in order to develop a business case to commission the work.

It can also be used by **analysts or researchers** who might deliver this work. This can be used as an introductory overview of the approaches on offer. There is more information on how you might want to use this document in the section called 'Cascade Modelling User Personas' on page 17.

What is cascade risk and why is it important?

In order to understand the impact of the risks within the UK the National Security and Risk Register ensures that the likely or impactful risks and hazards are considered. The third (2022) Climate Change Risk Assessment considers the sixty one UK-wide climate risks and opportunities to be considered by society and agencies.

However, these do not consider what the impact and consequences of these risks are. The POSTNOTE 680 on Climate Change and Security defines cascading and systemic risks in the following way (page 2):

"Cascading and systemic risks: 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."

If we can define the likely triggers, cascades and consequences ahead of time, we might be able to prepare and plan to respond and disrupt or mitigate the cascade if and when it happens. Rather like understanding where a domino line might split in two, three or four parallel lines, which domino we can take out to prevent all of the parallel lines falling down. We might be able to limit it to three lines rather than four. Whilst there is no magic bullet, a better understanding of connectedness leads to a better understanding of possible consequences to plan for.

Defining cascade risk within the wider risk definitions

When considering work in this area, it is easier to understand and use a shared terminology from the start. For example, if one member of a team talks about the consequences of a risk – do they mean the direct cause and effect (first tier) or do they mean the cause, effect and the new risks that emerge because of the consequences of the effects (second tier). The terms themselves, unhelpfully, differs slightly between agencies, academic disciplines and approaches. Having a set of explainers that differentiate between these is helpful to aid clarity and help communicate the specific aims of the projects you might be trying to undertake.

To understand the difference between a risk, a hazard, a threat, a multi-hazard and Gallina et al. (2016) provide the following table which differentiates the terminology contained within risk:

Reproduced from Gallina et al. (2016), page125:

Concept	Definition	References
Hazard	It represents the physical phenomenon related to climate change (e.g. sea level rise, storm surges) that has the potential to cause damage and loss to property, infrastructure, livelihoods, service provision and environmental resources.	UNISDR 2009; IPCC 2012
Exposure (i.e. elements potentially at risk)	It represents the presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social or cultural assets in places that could be adversely affected.	UNISDR 2009; IPCC 2012
Vulnerability	It represents the propensity or predisposition of a community, system, or asset to be adversely affected by a certain hazard. In a broad sense it should include economic, social, geographic, demographic, cultural, institutional, governance and environmental factors.	UNISDR 2009; IPCC 2012
Risk	It quantifies and classifies potential consequences of a hazard events on the investigated areas and receptors (i.e. elements potentially at risk) combining hazard, exposure and vulnerability. It can be expressed to a probabilistic or relative/semi-quantitative terms.	IPCC 2012
Disaster Risk	The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.	UNISDR 2009

Multi-hazard	It refers to: •Different hazardous events threatening the same exposed elements (with or without temporal coincidence). •Hazardous events occurring at the same time or shortly following each other (cascade effects).	Carpignano et al., 2009; EC 2011; Garcia-Aristizabal and Marzocchi 2012a; 2012b
Multi-vulnerability	It refers to: •A variety of exposed sensitive targets (e.g. population, infrastructure, cultural heritage, etc.) with possible different vulnerability degree against the various hazards. •Time-dependent vulnerabilities, in which the vulnerability of a specific class of exposed elements may change with time as consequence of different factors (e.g. the occurrence of other hazardous events).	Kappers et al., 2010, 2011; Carpignano et al., 2009; Garcia-Aristizabal and Marzocchi 2012a; 2012b
Multi-hazard risk	It refers to the risk arising from multiple hazards.	Kappers et al., 2012a
Multi-risk	It is related to multiple risks such as economic, ecological, social, etc. It determines the whole risk from several hazards, taking into account possible hazards and vulnerability interactions entailing both a multi-hazard and multi-vulnerability perspective.	Kappers et al., 2012a; Carpignano et al., 2009; Garcia-Aristizabal and Marzocchi 2012a; 2012b

If we can align our language, then hopefully we can then become more specific in our asks and shared understanding of what a team might need to create. This should also help teams to find and use sources that describe these methods and how they are carried out.

The literature on cascade processes

There is currently a lack of literature available that comprehensively models cascading risks and indirect impacts from natural hazards and climate events. However, multiple methods have been proposed for modelling cascading risks. Each of the methods used in the literature offer different processes and potential outputs.

Cutter (2018) suggests that the gap in cascade risk modelling literature is due to:

- The increasing interconnectedness of global economies that have interdependencies with one another
- The apparent increase in hazards over time
- The differential theories and methodological approaches to defining and assessing compound threats and hazards, which are being developed now across professional and academic disciplines

Nevertheless, emerging academic literature outlines some of the ways in which cascading risks can be modelled and analysed. According to Arvidsson et al. (2022), there are three main approaches to cascade risk modelling. These are:

1. Expert-based: These typically focus on predicting cascading impacts of future events, using expert knowledge, perceptions and awareness of interdependencies and cascading impacts to create visual or descriptive probable scenarios

2. Empirically based: These typically focus on producing a database or stored collection of information from past events, which is then utilised to analyse key infrastructure interdependencies, potential cascading pathways and the strength of impacts from cascading effects
3. Simulation-based: These typically focus on analysing the impact of natural hazards and climate events on interdependent critical infrastructure systems and identifying how cascading events may occur

Each of the above approaches and respective processes require a different skillset, level of expertise and specialised software.

Review of examples from the literature

To identify key methods used, a review of literature was conducted. This focussed on academic resources and articles that modelled a natural hazard or climate event and the subsequent impacts. Of the literature reviewed, 13 papers were found to model cascading impacts, using real-world natural hazard examples. The most modelled climate event was found to be drought (n = 4), followed by flooding (n = 3).

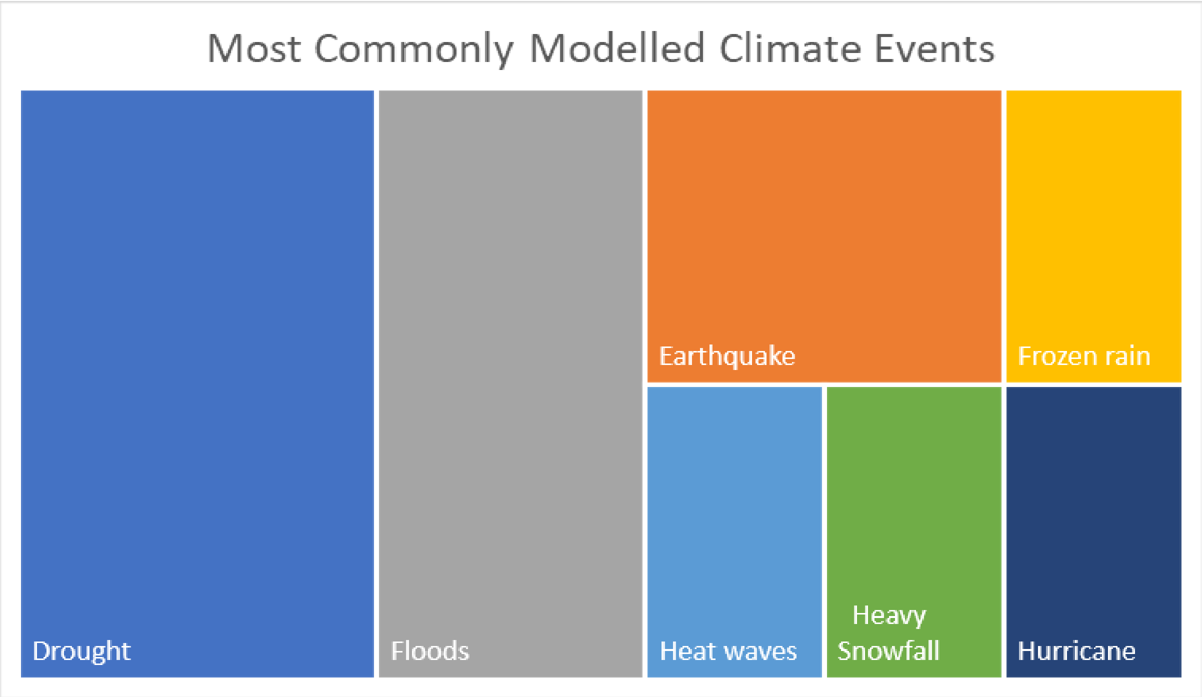


Table one contains key information extracted from the review of literature. This includes the climate event modelled, the method used, what type of data was used and if any specific software was highlighted.

Key information from reviewed literature

Paper Title, Author(s) and Year	Case Study Used	Climate Event	Method	Data Source(s)	Software Used	Outcome/ Product
Multihazards Scenario Generator: A Network-Based Simulation of Natural Disasters (Dunant et al. 2021)	Kaikōura earthquake, 2016	Earthquake	Simulation	Data from pre and during the event. Note that post-event data was not used to avoid biased outcomes.	OpenQuake (to generate stochastic earthquake event simulations), Flow-R (to develop landslide run-out maps for earthquake and rainfall triggers), Gephi (a geographical information system software)	A large database with possible impacts from the climate event analysed.
Caught between extremes: Understanding human-water interactions during drought-to-flood events in the Horn of Africa (Matanó et al. 2022)	Kenya and Ethiopia Drought, 2017-2018	Drought	Empirical	A review of literature, time series data (rainfall and socio-economic), online survey data collected from stakeholders and stakeholder interview data.	No specific software mentioned. Data analysis, online survey and mapping and modelling software was used.	Heat and Cognitive maps identifying hazards, exposures and vulnerability, as well as spatiotemporal interactions between these.
Heatwaves, droughts, and fires: Exploring compound and cascading dry hazards at the pan-European scale (Sutanto et al. 2020)	Europe 1990-2018	Drought	Empirical	Historical data - public weather datasets, hydrological data, fire danger.	No specific software mentioned. Software was used to map XY coordinates to a cell to calculate occurrence of hazards.	Several heatmaps identifying cascading risk hotspots, as well as tabulated and organised cascading risk patterns based on frequency of occurrence.

Paper Title, Author(s) and Year	Case Study Used	Climate Event	Method	Data Source(s)	Software Used	Outcome/ Product
Anticipating cascading effects of extreme precipitation with pathway schemes - Three case studies from Europe (Schauwecker et al. 2019)	Switzerland, 2012; Slovenia, 2014; Catalonia, 2010	Frozen rain	Empirical	Historical forecast data, a review of literature and expert knowledge	No specific software mentioned. Software was used to visualise pathways with flowchart-style graphics.	A generalised pathway scheme outlining potential cascading effects of a climate event, with a consideration for temporal elements.
A generalized natural hazard risk modelling framework for infrastructure failure cascades (Mühlhofer et al. 2023)	Hurricane Michael, 2018 (Across 3 US States)	Hurricane	Simulation	Open-source road data, Homeland Infrastructure Foundation-Level Data (HIFLD)for Hospital, power line, power plant, educational facilities, cell towers, wastewater and people related infrastructure. HIFLD data for power supply data and International Energy Agency (IEA) Word Energy Balances demand data. Outage reports and historical data were also used.	CLIMADA software (open source and access)	An open-source modelling framework; A series of geographical heat maps, graphs and charts identifying impact hotspots, as well as cascade failure dynamics.
Towards improved understanding of cascading and interconnected risks from concurrent	Europe, 2003; Australia, 2009; European Russia, 2010; Australia 2012/13; Europe,	Drought	Empirical	A review of literature and historical data	No specific software mentioned. Software was used to visualise pathways with	A scheme of cascading impacts and interdependencies affected by heat and drought events, as well as the

Paper Title, Author(s) and Year	Case Study Used	Climate Event	Method	Data Source(s)	Software Used	Outcome/ Product
weather extremes: Analysis of historical heat and drought extreme events (Niggli et al. 2022)	2015; Cape Town, 2015-18; Europe, 2018; Australia, 2019/20				flowchart-style graphics and tabulate data.	impact of adaptation actions on these.
Interdependencies and Risk to People and Critical Food, Energy, and Water Systems: 2013 Flood, Boulder, Colorado, USA (Romero-Lankao & Norton, 2018)	Boulder, Colorado Floods, 2013	Floods	Expert-based	Interview data from 17 experts in food, energy and water system sectors at local, county and state levels.	NVivo (qualitative analysis programme); Mental Modeler (to create real-time maps)	Two fuzzy cognitive maps - one identifying interdependencies and cascading effects of social-institutional elements, one identifying cascading effects of physical-infrastructural elements. A table outlining amplifying/mitigating impacts to multiscale socio-demographic, economic, techno-infrastructural, environmental and governance (SETEG) factors during the event.
Indirect flood impacts and cascade risk across interdependent linear infrastructures (Arrighi et al. 2021)	Florence, Italy.	Floods	Simulation	Local river authority provided data and maps for hydraulic modelling, data about piping networks provided by the authority in charge of the integrated water cycle. Road network	Freeware EPANET software (This calculates pressures at the nodes given a set of initial water tank levels, pump switching criteria, base node demands and patterns of demand)	A comparison between different flooding scenarios with a calculated annual average loss for each (silo-based approach) and an analysis of areas of vulnerability during a cascade events (systemic approach).

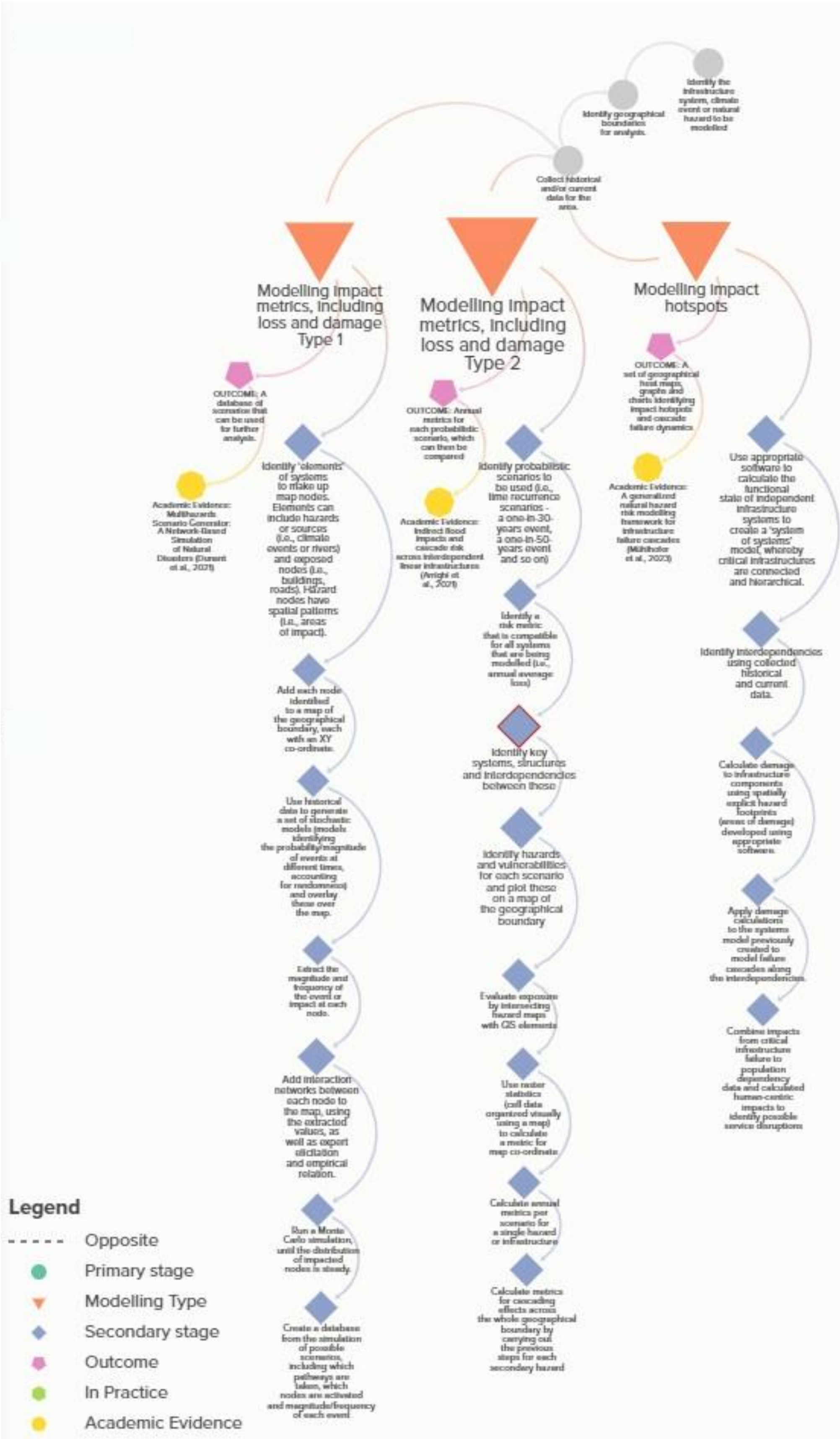
Paper Title, Author(s) and Year	Case Study Used	Climate Event	Method	Data Source(s)	Software Used	Outcome/ Product
				information was open source from the regional geographic data portal.		
A methodological approach for mapping and analysing cascading effects of flooding events (Arvidsson et al. 2022)	Sweden - Pilot Study	Floods	Empirical	Historical event data, local and regional expert input (through interviews, workshops or informal talks)	GIS software such as Arc Hydro or specialised software such as MIKE 11, HEC-RAS or LISFLOOD-FP. Excel is used for database creation and management.	A detailed database with all consequences outlined and a series of detailed visualisations and summarisations of expected consequences of a cascade risk.
Beyond the Sendai indicators: Application of a cascading risk lens for the improvement of loss data indicators for slow-onset hazards and small-scale disasters (Zehra Zaidi, 2018)	2002 European floods and 2003 European heat wave	Heat waves	Empirical	A sample of historical studies on the impact of extreme heat events	No specific software mentioned. Mapping software was used to create CLDs and software to record and create database indicators was used.	A series of Causal Loop Diagrams (CLDs) that can be translated into database indicators to identify both quantitative (i.e., numerical values) and qualitative (i.e., yes/no data) loss and damage from cascading events.
Cascading vulnerability scenarios in the management of groundwater depletion and salinization in semi-arid areas (Parisi et al. 2018)	Lecce Province	Drought	Expert-based	Semi-structured Interviews - 12 expert participants	No specific software mentioned. Text analysis can be carried out using a variety of software (e.g., SAS Visual Text Analysis, MonkeyLearn, RapidMiner) and cognitive maps can be created using a variety	Descriptive scenarios that aid in the identification of solutions to coordinate integrated processes.

Paper Title, Author(s) and Year	Case Study Used	Climate Event	Method	Data Source(s)	Software Used	Outcome/ Product
					of software (Mental Modeller, FCMapper).	
Theoretical model for cascading effects and analyses (Zuccaro et al. 2018)	Santorini, 2012	Earthquake	Empirical	Past event disaster databases, literature review, local studies or databases, expert elicitation	No specific software mentioned. Software was used to produce matrices for probabilistic assessment and visualisations of timelines.	A cascading effects timeline using probabilistic-based tools to help to predict and manage cascade risks from climate events.
Dynamic interdependencies: Problematising criticality assessment in the light of cascading effects (Hempel et al. 2018)	Storm Thorsten, Munsterland, 2005	Heavy Snowfall	Empirical	Print newspaper articles, reports from the internet and television, statements and interviews from business, research and politics actors	FORTRESS Model Builder (FMB) - it should be noted that it is not available to the public but can be obtained by contacting the author. Analysis was carried out using MAXQDA software to create code lists for chronological events.	A network map denoting nodes (or elements) of the event, assessed on their criticality (measured using centrality).

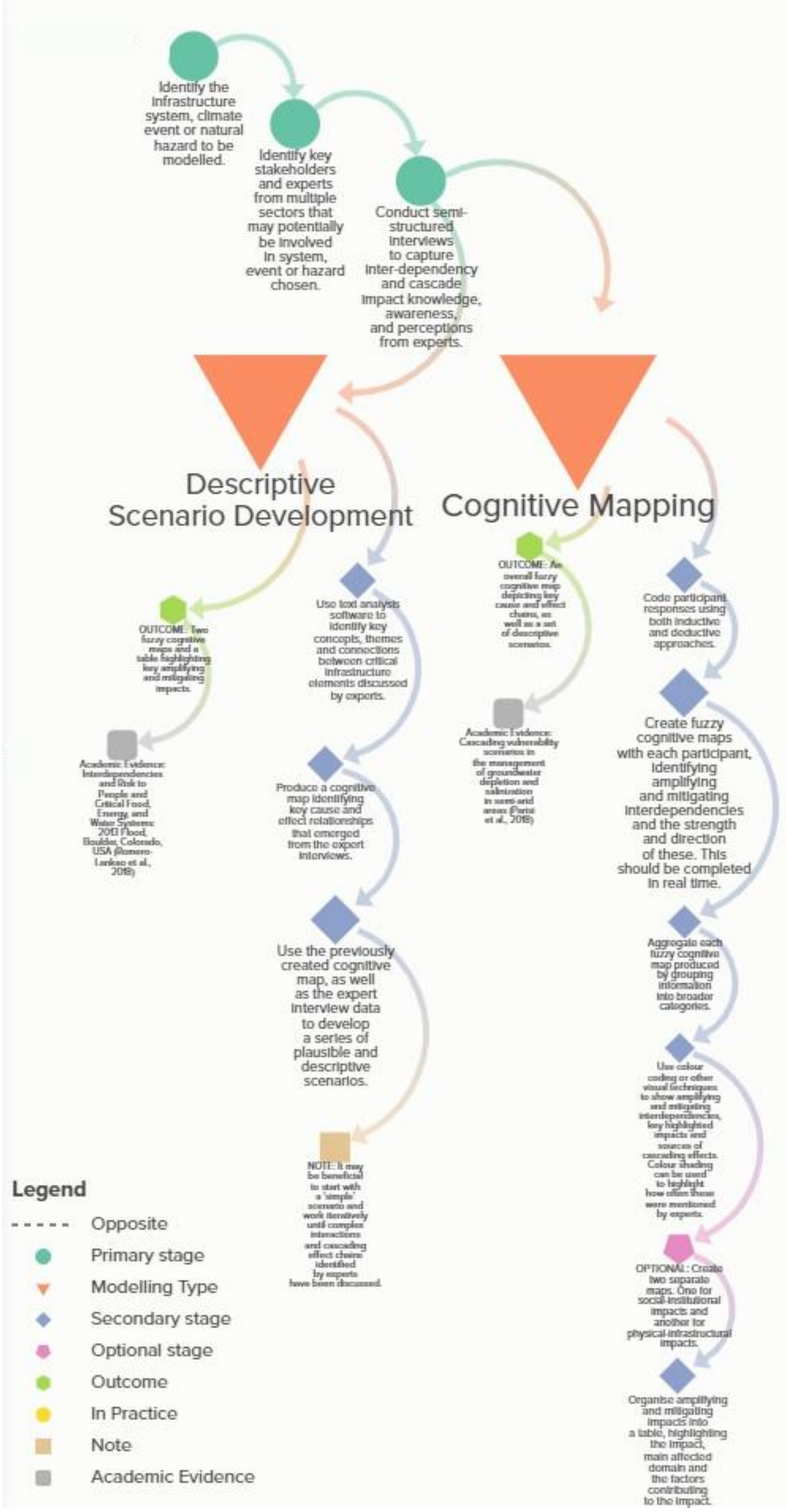
Following the literature review, step-by-step flowchart-style graphics were produced, outlining the process for each method used in the reviewed articles. These are categorised based on the three main approaches previously identified by Arvidsson et al. (2022). Due to the complexity of each approach type these have been produced as interactive visuals which can be viewed using the web links below allow an in-depth review of the requirements and steps needed to undertake this work.

Simulation method	Expert method	Empirical method

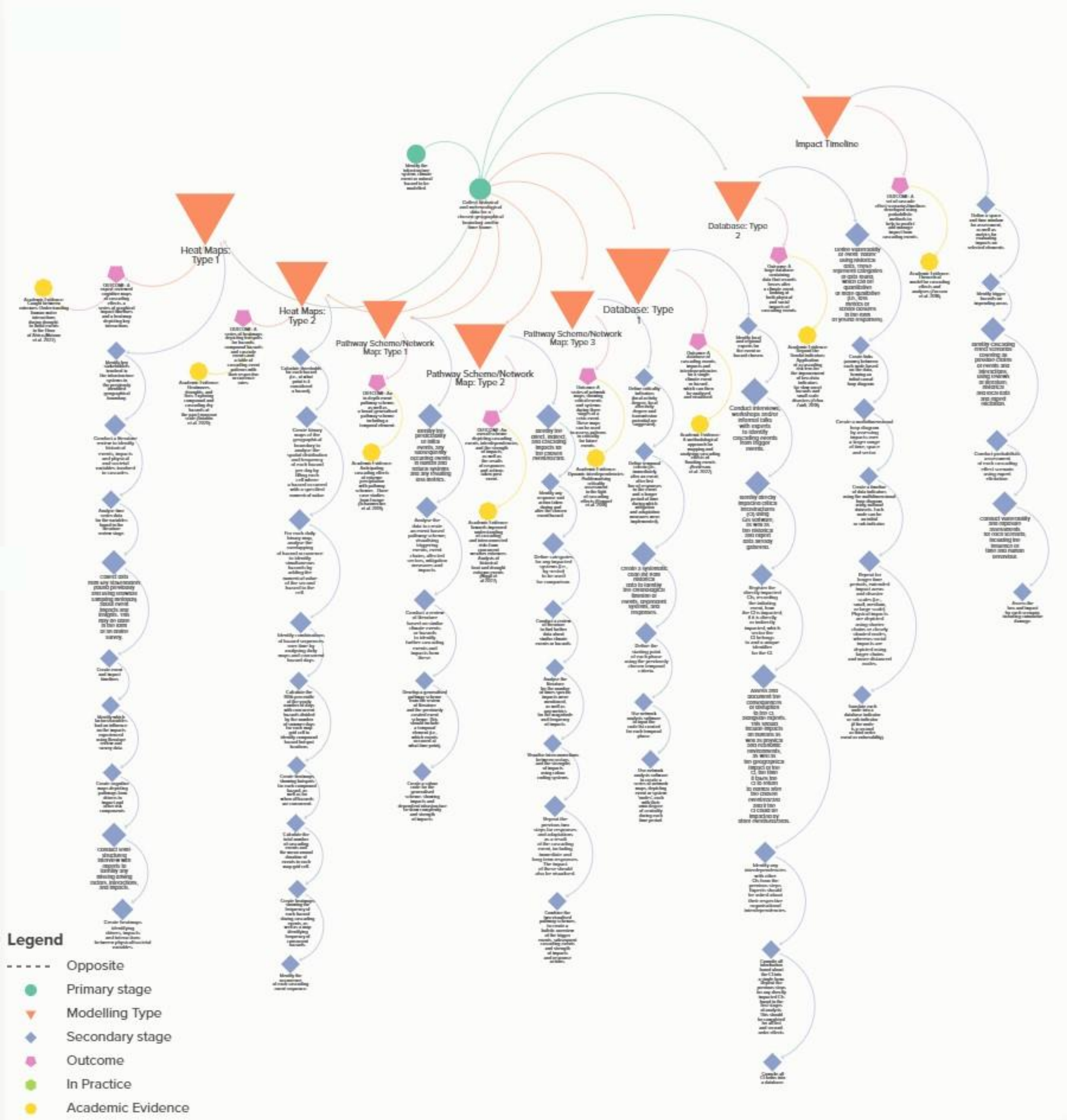
Flow chart for simulation-based methods



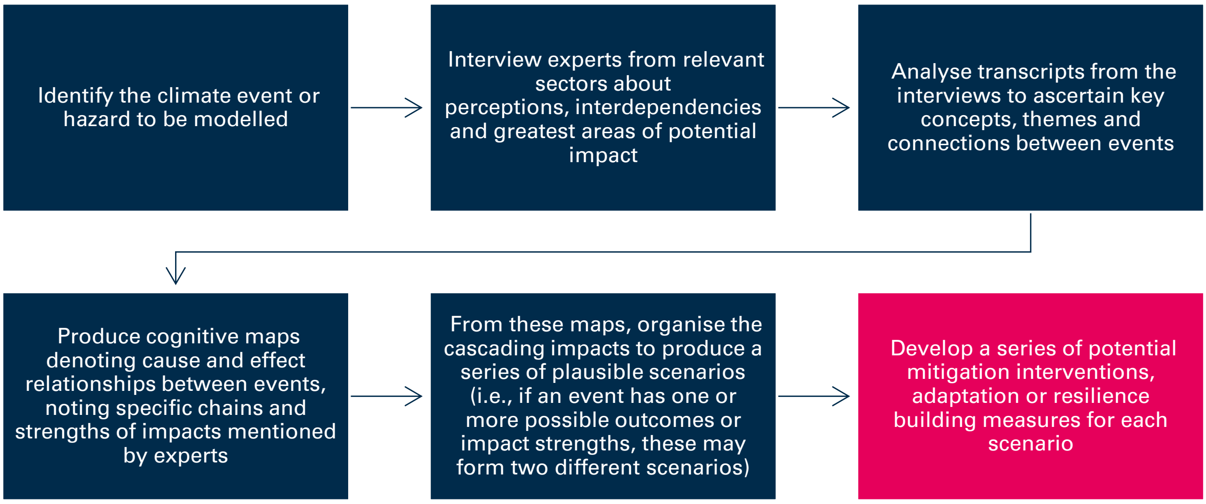
Flow chart for expert-based methods



Flow chart for empirically based methods



An integrated approach to combine elements of these methods and next steps



What do you need to know to enable your teams to commission work?

Decisions before a commissioning process:

- What is it that you are asking them to explore? Defining the work either by a specific risk, a sector, an infrastructure system, or a specific interaction between two hazards gives them a bounded piece of work to explore. You can also bound the work by stating a specific geographical region you are interested in

- There is lots of nuances between words such as hazard, risk, interaction, cascade, compound… which mean very different things when exploring them to this level. So being specific about what it is you are needing their focus on is useful. There are resources at the end of this document to help with this

- The next step is to assure your data sets and the stitching together of the data according to data quality assurance steps (your teams should know how to do this)

- Selecting the time frame will impact on the corresponding data sets selected and the corresponding demographic and societal assumptions that are included in the model

- Including appropriate information on Critical National Infrastructure is sometimes challenging due to their sensitivity (both security and commercial)

- Going beyond the ‘workings out’ and then using that information to judge what the loss of life, economic loss, impacts on the population, impacts on agriculture, infrastructure and buildings are then completed in different ways. The loss of economic productivity and loss of lives is the most used. But impact on health and related wider (local) recovery sectors such as tourism is often not included

- Some teams have been very specific about the steps they do with the cascade risk information after the linkage models have been generated. Some have developed resilience frameworks or resilience matrix to then try to assess the impact these cascades would have on different domains of society. **Resilience frameworks** consider the model structure and use of the 'answers' against the phases of resilience; prepare, absorb, recover, adopt. Others use a **resilience matrix** to consider the impacts on the different domains of society; physical built and natural environment, information management and flow, cognitive flow of making decisions and governance of action, and the social impacts across the communities

What would your business case look like?

- For two natural hazards, across one sector, or
- one hazard across two sectors or
- a science network approach

Assuming you want interrelationships plotted, sector specific information and sector specific data built in, assuming data agreements are in place, you would be looking at a minimum of (circa):

- 5 months FT of a Bayesian modeller
- 6 months FT of a mixed methods researcher who is skilled in grounded theory (qualitative) and basic quantitative statistics (up to t-tests and regression analysis) and debrief/policy reviews for 8 months

This would build a good start across that knowledge gap. Within the flow charts in the links, there are indicative timings for each step within the flow charts and also indicative costs for these steps.

What will cascade modelling do and not do for you?

To support decision makers engagement with cascade risk modelling we have developed a series of clear outlines of what these models can and can't do.

Cascade risk modelling can:

- Identify dependencies between infrastructure systems in a set geographical boundary
- Help to develop probable scenarios for better regional and national resilience and adaptation planning

- Identify potential impact and vulnerability hotspots, based on historical data collected during previous climate events

Cascade risk modelling does not:

- Provide detailed localised insight to perform in-depth planning for area specific adaptation measures
- Produce a holistic picture of cascade risk impacts – modelling is often limited by data availability, time restraints and software capabilities
- Identify the specific adaptation measures needed to improve resilience and security

Cascade Modelling User Personas

To help the CSNFG consider how different audiences may need to consider and engage with our work on modelling cascade risks for climate adaptation we have built up a picture of three personas to explore their probable starting positions, information needs and future steps to undertake this type of modelling work for different individuals.

- **The novice** – Junior Analyst new in post
- **The informed user** – LRF Risk Register Lead
- **The expert** –Modelling expert with a thorough knowledge of one area

The novice

As a recent graduate/apprentice in data science they have joined a government department or related agency and have been tasked with scoping the impact of climate change at a system level. Whilst they have a lot of the statistical know how they are unclear on both the best methods or the right sources of data. They also have very limited experience of engaging with stakeholders and bringing in their views and ideas to such a wide-ranging piece of work having only focused on discreet and well understood topics and issues before. Their knowledge of the different definitions around climate change and security are also not well developed.

Knowing what data is both available and robust enough is their first task alongside trying to outline what they have been asked to do. The broad nature of cascade risk modelling has left them a little lost because what they have read up so far talks only in terms of historic incidents rather than to look to the future.

Colleagues are talking to them about needing to take a high-level system level approach but also keep asking that the results produce something that can accurately pinpoint both the right levers and when to pull them but who and what will be most affected and can be worked on.

This has led them in circles and has led to a state of inertia especially as they are also now being asked to work out how they would cost this work and have never done this before.

What they need
Alongside some valued collegiate support this individual needs to focus on clarifying the focus. They need to explore and review the different methods available and outline what is possible for the team they work in. They also need to flag that this isn't a quick or short piece of work and will need significant resource. Having reviewed the CCC report on interacting risks they are clear this is at least a year long project requiring data science and qualitative expertise and resource to be done correctly. Clear briefing on the purpose and focus of the project will be needed – are they looking to understand at a system level what may happen and when or at a local level what needs to be done. Whilst one can follow the other they are different projects.

The informed user

As an experienced risk professional running the creation, management and delivery of the localisation of the NSRA for their LRF this professional is aware of the current situation and need for better cascade risk modelling. They are embedded in both national, regional and local debates and are well informed but they have never seen or engaged with cascade modelling before. Their experiences of modelling have come from training at the MET Office but with a focus on weather forecasting. They have a strong background in managing and delivering projects with multi-agency groups and can see that this work is complex and multi-faceted so will need clear objectives and tasking but they are concerned about how to connect all the different aspects and data sets together having struggled to bring partners together to consider complex affects relating to NSRA threats with their partners. This professional's experiences come solely from a webinar and a few public facing reports on cascades and they really aren't clear on the methods and implementation needed.

What they need
As a well networked professional they have the capability to engage broadly but they need senior buy-in to create the space to explore this issue and how it may impact on BAU across their LRF. Examples of how this work has been done before and what it brings to their role are lacking. They want a roadmap of the process and a series of planning assumptions and probably outputs to help them build the business case to undertake this work or engage with others to join wider projects. They are also aware that examples from the past are helpful but don't appear to be what key people are asking them for because they don't provide the key tipping point or infrastructure node that needs managing within their context which would prove the value of this work to their senior team.

The expert

This experienced modeller has worked across academia and civil society/government to model and manage risk relating to flooding/storms. They are fully immersed in the theory and practice of modelling across this topic area and have pioneered a number of technics to improve accuracy. They are well read on the importance of cascades and tipping points are recognise how it could be done and the value it will bring to understand and learn from previous incidents and for future forecasting of effects created by a more complex climate system. As a subject matter expert they are well versed in the data sources available across their field along with a number that cross-over from other areas such as heat and fires but don't have detailed awareness of data and processes used from built environment, people, and infrastructure. This has left them a little uncertain on how to combine this different as yet unknow data sources. They are also aware of the growing number of indices on vulnerability and risk that are being developed. Through colleagues in weather forecasting they are trying to work out if the future models need to operate at this scale but have not seen the resource that would be needed. They feel they could offer key insights and expertise but have yet to see any developed work underway at a large-scale system level that connects both the historic review methods with future forecasting needs that must be critical to planning for the likely scenarios and making the business cases for adapting to these likely futures.

What they need
The individual needs clarity of purpose on who will lead this work and what direction it will take. They don't hold a leadership position to shape current projects but also don't hold all the pieces to make the best decision. They are interested in fully immersing themselves in this new way to model but don't yet have a clear view on the direction of travel. Should this work be led by an emergency service, a government department or as a research project and who would pay for the work to be done and how would it feed into decision makers to shape spend and policy development.

Additional interdependency options

Following the Royal Academy of Engineers review of the NSRA methodology in 2021 six methods and case studies were shared to help consider interdependencies which occur:

- "**between risks** – for example, rainfall may trigger flooding and landslides
- **between systems** – for example, flooding may hinder transport services, or electricity outages may affect communications networks
- **between response capabilities** – for example, emergency services provision depends on transport services and communication networks
- **across the wider consequences** – for example, disruption of transport services may disrupt the provision of goods, or fatalities may cause public outrage" (Royal Academy of Engineering 2023)

To help inform the reader of future ways forward when considering risk these methods are shared below.

- **Network mapping**
    - Analyses that explore the dependencies and interdependencies within components of a system to create network maps to support the review

of risk and vulnerability as well as to support further modelling of risk probability
    - The case studied shared highlighted the use of network mapping by the National Infrastructure Commission to identify vulnerability characteristics in the architecture of the UK infrastructure network

- **Interaction frameworks**
    - This process brings together varies data to create hazard matricies which can be used to explore the interaction and influences of hazards within a system
    - The case study highlighted discusses using this model to explore natural hazards across the various regions of Guatemala which drew together multiple stakeholders and data which not only created the matrices but also reduced silos and increased the outputs use across organisations

- **Impact modelling**
    - Hazard impact models are based on using data related to vulnerability and geography to create forecasting models that can predict risk based on differing scenarios
    - The case study shared highlights the Met Office's vehicle overturning model which combines weather, traffic and other local contextual factors from partners to understand where and when the risk may be high to inform action

- **Bayesian networks**
    - This method develops relational numerical weightings between different system elements to calculate the level of dependency both between elements and within the system. They are often viewed as a way to model cascade failures but require detailed work and/or assumptions to determine the relational probabilities
    - They have been used in a range of systems including supply chain, environmental and health risk modelling to explore system risks and the location of vulnerabilities and failure

- **Interdependencies and data**
    - Data plays a central role to all methods discussed and through assessments of interdependencies new data can be identified and added to models and approaches on risk
    - During the Covid-19 pandemic various data sources were brought together to model and explore risk which highlighted the value of data but also the inherent limitations where gaps were found

- **Scenarios and narratives**
    - As with the personas shared in this document the review of the NSRA methodology highlights the importance of scenarios and narratives to

    - communicate and explore the complexity, uncertainty and risks related to interdependencies
    - The use of multiple scenarios is explored in the report through insurance companies who often assess the risk through a spectrum of scenarios that help inform the policies they offer

Summary of cascade methods and approaches

- There are three core approaches identified from the literature – each have merits and disadvantages as outlined and all take at least 12 months to deliver results
- There are a set of core questions to consider when embarking on a commissioning process which focus on time, cost and user requirements
- Each model process requires initial work to do at least three of these:
    - Identify the infrastructure system, climate event or natural hazard to be modelled
    - Identify key stakeholders and experts from multiple sectors that may potentially be involved in system, event or hazard chosen
    - Conduct semi-structured interviews to capture inter-dependency and cascade impact knowledge, awareness, and perceptions from experts.
    - Collect historical and meteorological data for a chosen geographical boundary and/or time frame
- Commissioners need to consider a minimum staffing and expertise threshold for this work alongside the differing starting positions within their team and the wider supporting network alongside the accessibility to data and how this work will feed into ongoing work of the sponsoring and supporting departments, groups and agencies
- Each method will not provide you with a defined set of at-risk locations, infrastructure or populations but will highlight a range of specific outcomes from your process which are defined in the outcome node of each process visual
- Whilst modelling cascade risks is a valuable task for those wishing to develop climate security there are a series of interdependency options available that provide value

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