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A definition of cascading disasters and cascading effects: Going beyond the “toppling dominos” metaphor

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Abstract – The consequences of the 2011 Tohoku earthquake persuaded the global community to consider more realistically the problem of ”cascading disasters”. Since then, the concept has been widely used among scholars and practitioners but its definition remains vague. In order to explain a chain-sequence of interconnected failures, the word ’cascading’ is often associated with the metaphor of toppling dominoes, which may have a bearing on the cause-and-effect relationship that is a feature of most catastrophic events. Our paper aims to avoid this grey area and offer a clear definition that is suitable for field and theoretical use. A review of the literature is employed to point out the specific features that differentiate ”cascading disasters” and ”cascading effects” from other forms and dynamics of disaster. Glossaries are surveyed and past disasters analysed in order to reflect on which are the critical elements of a ’cascade’ and how best to investigate them. Our conclusions suggest that interdependencies, vulnerability, amplification, secondary disasters and critical infrastructure are important factors that need to be addressed in risk reduction practices in order to limit cascading during disasters.

Keywords – *cascading, vulnerability, secondary disasters, interconnection, critical infrastructures, amplification*

1. Introduction

Constructing definitions and glossaries is a challenge for all organizations and institutions involved in major projects. In defining terms they may establish criteria for financing a project, determine the focus required by funders, or address the domain of policies, practice and research. In other words, the precision and aptness of definitions and glossaries can determine the success or failure of initiatives and investments. Anyone who is committed to the field of disaster risk reduction will sooner or later experience the moment at which failure adequately to define terms starts to complicate objectives and fill up precious time with meetings and discussions. A typical example is the question of how how one can quantify resilience in order to have tangible outputs from a project on safety. Alternatively, another critical question may concern whether one is dealing with reduction in vulnerability or increase in resilience. In recent years, two other concepts have become increasingly popular in a broad range of enquiries: ”cascading effects” and ”cascading disasters” (Franchina et al. 2011, Peters et al. 2008). International glossaries propose no definition that could distinguish cascades from the complex causal chain that is present in all large disasters. Moreover, the analogy of toppling dominoes (Genserik 2009) that is commonly used to explain the phenomena may be misleading. It could be argued that disasters do not need to be conceptualised as cascades, which offer no particular challenge of understanding or management in this respect. However, there do appear to be circumstances in which vulnerability reduction strategies depend on the ability to develop a proper understanding of cascades.

We believe that some significant patterns differentiate ”cascading disasters” from ”ordinary” disasters. This paper aims to create evidence-based definitions that may help scholars and practitioners address the challenges posed by cascading events. First, we provide an analysis of the current glossaries and the state of art, including a reflection on the specific features of the cascade metaphor. Secondly, the specific drivers that distinguish the phenomena are addressed and tested by development of an overview of disasters that involve cascades. We conclude by offering an improved definition of ”cascading disasters” and ”cascading effects” in disaster.

2. A Review of Cascading Definitions

International glossaries propose no specific definition of 'cascading disasters'. The only freely available overview appears to be that provided by May (2007), which is strictly limited to cases produced by the US Federal Emergency Management Agency (FEMA). Table 1 reports some example quotations from the literature which are pertinent to the problem of how to define cascades in the context of disasters, incidents and emergencies. The phenomenon considered is associated mainly with events in which a primary threat is followed by a sequence of "secondary hazards". May's conclusion is that cascades tend to be dependent on their context and are dynamic systems, in which a branching tree structure originates from a primary event. This follows the analogy of the topping dominoes: the first domino is toppled, it strikes the next in line and topples follow as far as the end of the sequence. In disasters there may also be branching networks. Each branch can be considered to be event on its own and may be isolated from the main impetus, resulting in something with its own importance, its own degree of damages, and its own consequences. The cascading phenomena are thus primary, secondary, tertiary, and so on. However, May also argued that, other than this broad overview, the cascade concept remains vague and lacks precise explanation.

Another example of the general lack of clear definitions is given in FEMA's Facilitator Guide (2011). This document describes "cascading" as a form of general dynamic that may multiply the effects of a combination of different hazards, such as an earthquake that produces a breakdown in infrastructure, whose failure contaminates water and causes disease to spread, which disrupts the local economy. However, it can be argued that most disaster situations are inherently complex, and in all disasters a primary event causes a sequence of effects that could in turn cause damage and other adverse consequences, regardless of whether one uses a cascade model or not. To understand the meaning of the term properly, it is necessary to enquire further into what is meant by 'disaster' and then return to the original metaphor of the 'cascade' in order coherently to integrate the two ideas.

The first glossary to discuss is that published by the United Nations Office for the Co-ordination of Humanitarian Affairs (UNOCHA 1992). Although it offered no definition of 'cascade', it defined disaster as "a serious disruption of the functioning of society, causing widespread human, material or environmental losses, which exceed the ability of affected society to cope using only its own resources. Disasters are often classified according to their cause (natural or manmade)" (UNOCHA 1992, p. 27). This definition showed that disruption could affect the functioning of society as a whole, and implied that broader co-operation among different organisations and countries would be needed so as to provide the resources needed to cope with the event. Subsequently, the United Nations International Strategy for Disaster Reduction (UNISDR 2009) again provided no definition of cascading but offered a broader definition of disaster as "a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" (UNISDR 2009, p. 9). Disasters thus result from a combination of exposure to hazards, local vulnerabilities and insufficient capacity to reduce or cope with the consequences of events. The impacts may include "loss of life, injury, disease and other negative effects on human physical, mental and social well-being, together with damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation" (UNISDR 2009).

In the UNISDR definition, the key word again seems to be 'disruption', but it stressed also both the direct and indirect impacts of events, while introducing vulnerability as a fundamental element of losses. Finally, a definition was adopted by the Intergovernmental Panel on Climate Change (IPCC 2012). 'Cascading' is not reported in this organisation's glossary and disasters are referred as "severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery" (IPCC 2012, p. 558). In this instance, the relationship between society and the physical event is given more weight than is general disruption. The interaction between physical events and vulnerability is taken into consideration, and the need for cross-border emergency response is implied. The literature at large makes it clear that that disaster involves the interaction of natural and human systems, in which the latter could act as an amplifying factor. The nature of the "risk society" itself requires a more dynamic understanding of the global interdependence of human, natural, and technological systems, which can produce hazards and disasters (Perry and Quarantelli 2005). A relevant source of complexity is the evidence that many disasters are "composite or concurrent", as for example when a single earthquake causes "tsunami waves at sea, landslides or avalanches on slopes, dam failures at reservoirs, and building damage and fires in urban areas" (Alexander 1993, p. 9). In other words, the relationship between geophysical impact and human vulnerability means that naturally induced effects are difficult to separate from anthropogenic ones, and the different elements can interact and amplify each other. This seems to be a vital factor of the definition of cascades (see table 1).

3. Complex Systems, Vulnerabilities and the Cascade Metaphor

The evidence from the literature reported above suggests that cascades can be considered as a direct output of the evolution of complex systems. Primary disasters can generate secondary disasters as joint artefacts of the causal chain and the interaction between anthropogenic systems and ecological ones (Helbing 2005). New vulnerabilities are derived from "the increasing interdependencies be-

Table 1: Definitions of 'cascading' from the disaster management literature, as reported by May (2007).

Reference	Quote
FEMA Independent Study Course, IS 230, Principles of Emergency Management	p. 3.17. Cascading events are events that occur as a direct or indirect result of an initial event. For example, if a flash flood disrupts electricity to an area and, as a result of the electrical failure, a serious traffic accident involving a hazardous materials spill occurs, the traffic accident is a cascading event. If, as a result of the hazardous materials spill, a neighborhood must be evacuated and a local stream is contaminated, these are also cascading events. Taken together, the effect of cascading events can be crippling to a community.
FEMA Independent Study Course, IS 393, Introduction to Mitigation	p. 1-6. Cascading emergencies—situations when one hazard triggers others in a cascading fashion— should be considered. For example, an earthquake that ruptured natural gas pipelines could result in fires and explosions that dramatically escalate the type and magnitude of events.
U.S. Department of Homeland Security National Response Plan, December 2004	p. 4 Additionally, since Incidents of National Significance typically result in impacts far beyond the immediate or initial incident area, the NRP [National Response Plan] provides a framework to enable the management of cascading impacts and multiple incidents as well as the prevention of and preparation for subsequent events.
FEMA for Kids Website, Resources for Parents and Teachers, How Schools Can Become More Disaster Resistant. `http://www.fema.gov/kids/schdizr.htm`	. . . disasters can have a cascading effect—forest fires can bring mudslides; earthquakes cause fires; tornadoes cause downed power lines
Resource Materials: Integrating Manmade Hazards into Mitigation Planning Risk Management in a Multi-Hazard World 2003 All-Hazards Mitigation Workshop June 12, 2003 Emergency Management Institute `http://www.fema.gov/txt/fima/antiterrorism/resourcematerials.txt`	Indirect attacks: infrastructures are really interconnected systems of systems; an attack on one can lead to cascading losses of service (ranging from inconvenient to deadly) and financial consequences for government, society, and economy through public- and private-sector reactions to an attack.
FEMA 428, Asset Value, Threat/Hazard, Vulnerability, And Risk	p. 2-11. What is the likelihood of cascading or subsequent consequences should the asset be destroyed or its function lost?
Hazard Analysis and Risk Assessment, 2003 Local Guide, Iowa Homeland Security and Emergency Management Division,	Hazards create direct damages, indirect effects, and secondary hazards to the community. Direct damages are caused immediately by the event itself, such as a bridge washing out during a flood. Indirect effects usually involve interruptions in asset operations and community functions, also called functional use. For example, when a bridge is washed out due to a flood, traffic is delayed or rerouted, which then impacts individuals, businesses, and public services such as fire and police departments that depend on the bridge for transportation. Secondary hazards are caused by the initial hazard event, such as when an earthquake causes a tsunami, landslide, or dam break. While these are disasters in their own right, their consequent damages should be included in the damage calculations of the initial hazard event. Loss estimations will include a determination of the extent of direct damages to property and indirect effects on functional use.
Regional All-Hazards Mitigation Plan, City of St. Louis and counties of St. Louis, Jefferson, Franklin and St. Charles, Missouri, November 2004.	Cascading hazards could include interruption of power supply, water supply, business and transportation.

tween our energy, food and water systems, global supply chains, communication and financial systems, ecosystems and climate" (Helbing 2013, p. 52). Non-linear interactions can combine with network effects and randomness in increasing sensitivity to small changes, in which one event triggers others, thereby creating amplification and cascade effects. In order to understand the path of a cascade, three contributing factors must be taken into account: "the interactions in the system, the context (such as institutional or boundary conditions), and ... a triggering event" (Helbing 2013, p.54).

Helbing also noted that randomness may determine the temporal evolution of the system, which further complicates matters. The propagation of the cascade is funda-

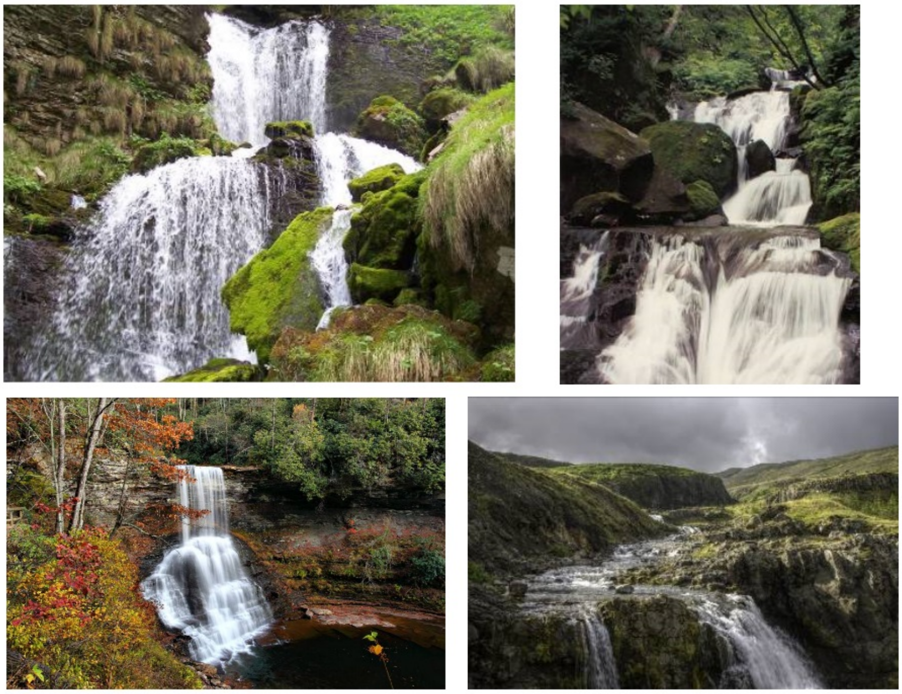

Figure 1: Samples of cascades, in clockwise order: the spring of Enna stream, Italy (Source: Marco Fleming, Wikicommons, 2006); Oirase waterfall, Japan (Source Wikicommons, 1992), waterfall on the Fossá River, Iceland (Source: Wikicommons, 2009); Cascade Falls, Virginia (Source: www.ForestWander.com 2011).

mentally related to vulnerability. D'Ercole and Metzger (2009) suggested that some particular spaces act as "generators of vulnerabilities" in social systems. They act by two different mechanisms of propagation, namely, dependency (function) and localization (space). Thus, it can be argued that critical infrastructures and facilities are important because they act as sources of amplification. They involve particular services that are critical to emergency response and recovery, as well as to the maintenance or restoration of normal activities. As the complexity of human space increases with the urbanization process, there is a need to find redundancy and reliable alternatives to activities affected by disaster (Jha et al. 2013).

The interdependent nature of many systems significantly increases the potential for cascading effects that could spread from one kind of infrastructure to another. Little (2002) provided two clear examples of this. On the one hand, electricity is conveyed by generators and substations, which are susceptible to cascading failures when power fluctuations exceed the margin of tolerance, and this affects many other activities. On the other hand, the damage to the road system can be related to simultaneous failures in water and gas supplies that lie underground, while because of the lack of water supply and pressure, any fires generated by the damage could not be fought effectively. Vulnerability in infrastructure can be caused by physical elements and can be passed directly on to human activity, as for example when loss of electricity supply causes meetings to be cancelled and results in a variety of modifications to normal activities. Social and political decisions can determine, not only the vulnerability of infrastructure, but also that of society itself: the relationship between vulnerability, politics, policies and crisis management capacities determines how escalating events are managed. For example, the adoption land use planning against floods, the will to respect the regulations, and the instruments to limit contraventions are integral parts of flood disaster risk reduction. Alexander (2000) explained that the feedback process in political, technological, social and cultural realms can favour unprotected development and inhibit mitigation when the abating factors related to knowledge and good governance are overwhelmed by negative factors such as corruption and negligence. If attention is focussed more on abating hazard than reducing vulnerability in complex processes, the problems may escalate into secondary disasters such as that which occurred when the 2011 Japanese tsunami struck the nuclear plant at Fukushima Dai'ichi. This leads us to ask what can be added by the use of the cascading metaphor.

The Oxford English Dictionary relates the term 'cascade' to a waterfall or to a series of small falls formed by water in its descent. This can be given a figurative meaning, as when electrical devices are connected in a manner that each operates the next one in turn. The term is also used to mean a succession of stages or processes in particular operations or events in scientific disciplines, such as physics or chemistry. The Encyclopaedia Britannica uses a similar meaning, but it specifies that cascade may be natural or artificial. Figure 1 shows various images that may help integrate the observation of nature with the definitions reported here. Cascades are generated from a flow of water, whose behaviour results from its interaction with contextual features, such as its general geographical location or rocks and barriers at the micro scale. Their formation is dependent on long-lasting processes such as erosion, or specific human activities, such as water basin management. The main stream can be divided in smaller rivulets, and it can be assumed that the force of water is dictated by mass and gravity.

In terms of disaster risk reduction, these points can be cross-checked with the definitions provided in the literature. What emerges is that cascades are events that depend, to some extent, on their context, and thus their diffusion is associated with enduring vulnerabilities. They are subject to a process of amplification of damage over time, and this can be distinguished by the presence of subsidiary disasters. These may be derived mostly from failures of human subsystems and the disruption of critical infrastructure. The path is non-linear, and branches are visible in terms of sub-disasters. For example, an 'ordinary' disaster can stem from an industrial explosion that generates loss of life and injuries, damages other buildings in the nearby, affects the local economy, and creates other intangible effects such as psychological distress. Similarly, the consequences of 'ordinary' floods can be loss of life, economic and social disruption, contamination of water supplies, and intangible effects. Instead, cascading could be perceived as an industrial explosion that affect a chemical supply storage nearby, which casuses a major toxic cloud that becames a critical emergency (subsidary disaster) to be manged on its own. Another example could be a flood that involves a major electric or telecommunication station, which service interruption generates major problems that affect a larger area than the one physically involved by the primary event, becoming an emergency (subsidary disaster) on its own. Figure 2 shows (a) a linear sequence of events, and (b) a non-linear path of cascading.

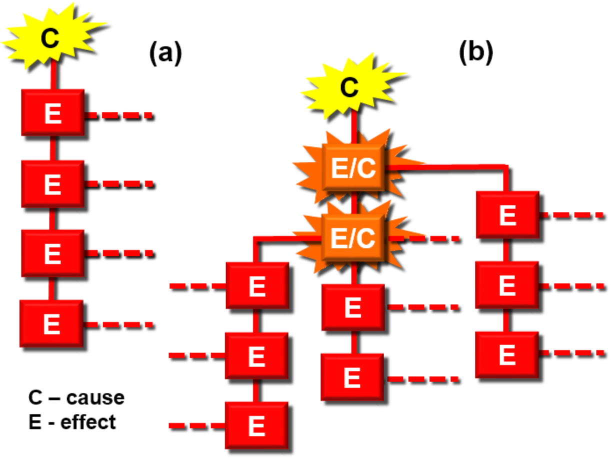

Figure 2: (a) Linear path of events in disasters, and (b) non-linear path of cascading, including amplification and subsidiary disasters.

4. Case Study Analysis: A Short Overview of some Events

The following examples illustrate cascading disasters in the modern world. Each has a distinctive message for students of the phenomenon, as we will explain in the concluding part of the section.

The 2001 Baltimore freight rail crash is reported as an example of a cascading incident in the FEMA training manual (2011). A train consisting of three locomotives and 60 cars derailed in the Howard Street Tunnel of Baltimore on Wednesday 18th July 2001. This caused the rupture of a tanker railcar that transported 1182 hl of liquid triproplylene, which is not considered hazardous to human health or the environment but nevertheless caught fire. The flames interacted with other hazardous materials carried by the train including hydrochloric acid, a highly corrosive substance that can produce irreversible damage to the human body. As result, a black toxic smoke spread across the Baltimore downtown area, forcing the authorities to close off access to this part of the city and to ask to residents to remain indoor for two days. A burst water main flooded local streets and freight traffic was heavily affected for more than five days. Finally, the joint effect of water, fire and wreckage compromised three major fibre-optic lines that lay in the tunnel, generating severe disruption of Internet services in the northeast United States (FEMA 2011). In this case, the spatial setting is concentrated but it is revealed a strategic point in networks, communication, transportation and water supply. Cascading became evident as time progressed: an 'ordinary' incident escalated due to the interaction among vulnerable elements, including the presence of chemicals.

The 2002 floods in Prague, capital of the Czech Republic, were part of a cross-border event of extreme magnitude that involved several states in Central Europe. Heavy rainfall during early August triggered sequential waves of flooding. The main rivers, the Oder, Neiss, Elbe, Mulde, Danube and Vltava, broke their banks and severely inundated the Czech Republic, Germany, Austria, and Slovakia. Physical impacts were visible also in Poland, Hungary, Romania and Croatia. The floods caused lives to be lost and injuries to occur, plus economic damages on the scale of billions of euros, and significant damage to cultural heritage and unique historical sites. The main cascades were visible in the cessation of activity of two large power stations along the Danube River in Slovakia, a chlorine gas cloud released by the Spolana chemical plant outside Prague, and the thousands of inhabitants of Prague and Dresden who had to be vaccinated against hepatitis (Ekengren et al. 2006). The impact on the capital of the Czech Republic was particularly strong, and it necessitated a strong commitment on to help the part of the international community. At the time, it was reckoned to be the greatest flood damage in the history of the nation (Hladny et al. 2004).

In order to understand the different facet of the cascade, some aspects of the disaster need to be analysed in more detail. First, the Spolana chlorine and mercury chemical spill did not caused loss of life but required a large commitment of emergency resources, constant monitoring and the intervention of special units (Nato 2002b). It created long-term pollution and led to ad hoc legislation on curbing the problem. Secondly, 124 wastewater treatment plants and industrial sites were inundated and damaged. Contaminants were released into the water supply, while aquifers experienced increases in levels of organic pollution (Haldney et al. 2004). International relief began mainly by providing portable dryers, floating pumps and submersible electric pumps and then shifted to address the emerging cascade related to water contamination, by providing hepatitis vaccines, gamma globulin and chlorine-based disinfectants (NATO 2002a, b, c). As per its specialisation, Italy offered support for the restoration of cultural artefacts (Nato 2002c). Vulnerabilities in critical infrastructures were determinants of the cascading: dams and mobile barriers were built according to models that did not consider major floods of medium or long return periods (Haldny et al. 2004), while the vulnerability of the Spolana plant was noted as critical by Greenpeace long before the event. Police investigations after the flood concentrated on water basin management and chloride leakage.

The 2003 black-out in North America. On 14th August 2014 the sudden breakdown of a power station caused generation to switch to others in north-east America. In the United States and Ontario, 55 million people were left without electricity for up to 48 hours. The cost in the United States was estimated to be between $4billionand10$ billion, while in Canada GDP was down by 0.7

Hengchun earthquake (Taiwan, 2006). This event principally affected Taiwan and involved limited loss of life and injury. Buildings collapsed, fires broke out, telephones ceased to function and the Maanshan Nuclear Power Plant was affected, but the situation was kept under control. In terms of cascading, the key aspect was that the earthquake damaged the submarine communication cables that served much of east and south-east Asia, with profound effects on communications and financial transactions in the area (Smith and Petley 2009). In other words, it shows that an event of limited impact had amplified effects on damage to a single and localized infrastructure. It shows how the interdependencies of communication can contribute to the escalation an event from the local to the regional and potentially global levels.

The eruption of the Icelandic volcano Eyjafjallajökull in April 2010 led to the shut-down of civil aviation over most of Europe for almost a week. This highlighted the dependency of modern society on functioning global networks (Alexander 2013). Eight and a half million people were temporarily stranded. There was severe pressure on other forms of transport and major imbalances occurred in hotel occupancy. Airlines risked bankruptcy and both tourism and business travel were severely disrupted. International commerce in perishable goods was disrupted, as was the urgent air freight transportation of medical supplies, including bone-marrow for transplants. Orchestras had to cancel foreign tours and thus lost vital revenue. Businesses had to reorganise, and international conferences were suspended or cancelled. Eyjafjallajökull showed that secondary events in cascades can even become the main vector of crisis. On the one hand, the physical damages directly associated with the eruption were limited. On the other hand, the shut-down of civil aviation became the driver of major disruption because of the dependencies and interconnections that global society has developed through its use of the transportation sector.

The Tōhoku earthquake of 11 March 2011 is considered to be an outstanding example of a cascading disaster. It affected three prefectures in northeast Honshu, the main island of Japan. Although only about 100 people died as a direct result of the earthquake, about 18000 were killed by the ensuing tsunami. The most enduring consequence of this may be radioactive contamination resulting from tsunami damage to the Fukushima Dai'ichi nuclear reactors which, in the short term, caused the evacuation of 200000 people from the surrounding area. As a result of damage to the global supply chain, vehicle production was affected, not only in Japan, but also in Europe. Fruit, vegetable and meat production from the agricultural areas of Fukushima was contaminated with radioactivity. Dams, utilities and coastal defences were destroyed, which complicated the recovery process. Outmigration compromised the labour force required to reconstruct the 443 sq. km of coastal land and settlements that had been devastated by the tsunami. Worldwide, the political agenda was heavily influenced by a heated public debate on nuclear safety: immediately after the disaster Germany decided to phase out its reactors by 2022, while in Italy more than 94 per cent of electors voted in a referendum to block the creation of new nuclear power plants. In other words, this event shows the occurrence of the probable worst scenario for the interaction between natural and technological hazards. The same physical event generated three different impacts that affected the vulnerability of humans and their geographical spaces, and hence, in effect, three different disasters occured that amplified the impact while they progressed through time. On the one hand, the primary trigger (the earthquake) caused limited damages and its effects were reduced by preparedness and mitigation measures. On the other hand, it generated a clear chain of cascading effects that increased complexity in time and space due to the interaction of different hazards, threats, and vulnerabilities. In particular, the Fukushima Nuclear Accident was ”was a profoundly manmade disaster – that could and should have been foreseen and prevented”(National Diet of Japan 2012).

Hurricane Sandy, or super storm Sandy, developed as tropical depression in the Southwest Caribbean Sea on 22nd October 2012. It increased in strength and on 29th October made landfall in the United States which was the country most affected by the storm. It caused a catastrophic sea surge on the New Jersey and New York coastlines. In New Jersey, hurricane-force winds exceeded 280 km/hr, and over a diameter of 1610 km, winds exceeded 65 km/hr. The US Federal Emergency Management Agency defined Sandy as the second largest Atlantic storm on record (FEMA 2013). A long sequence of cascading effects can be discerned since the early phases of the event. Sandy made landfall on 29th October, generating a major storm surge that critically affected the coast of New

Jearsey and New York states. The overall impact of the joint event was amplified because the extreme weather affected the region of the USA with the densest population, where much critical infrastructure vital to the nation's economy is concentrated (FEMA 2013, p. 4). The global economy was affected in terms of the shut-down of NASDAQ and the New York Stock Exchange. Direct damage to residential and industrial buildings was high, while there were many power outages that lasted between several days and two weeks. Fires of electrical origin broke out and could not be controlled (Kunz et al. 2013). The composite nature of the disaster is reflected in the report by Blake et al. (2013), which showed how the hurricane caused 72 fatalities in the USA, 41 of which were linked to the storm surge. At least 87 other losses of life were indirectly attributable to the event in the United States, 50 of which were apparently related to the joint effect of extended power outages and cold weather.

At least 650000 houses were damaged or destroyed and about 8.5 million customers lost power supply. Damages were estimates at more than 50 billion dollars. Sandy originated many subsidiary disasters that amplified the emergency as time progressed. The storm surge, and associated flood damage, can be considered as a secondary disaster generated by the hurricane, after the direct effects of wind damage. The joint physical effects of storm surges and winds interacted with the vulnerability of critical infrastructures and generated subsidiary events. A major leak involved the Shell Oil and Saudi refining storage facility in Sewaren, where a large tank that ruptured under pressure from the storm allowed 12700 hectolitres of fuel to leak into the Arthur Kill waterway. Many wastewater treatment plants were affected, with the worst event at the Passaic Valley wastewater treatment plant in Newark, New Jersey, were 37 million hectoliters of untreated sewage flooded the bay. Disruption in communication infrastructures generated cascading effects on electronic trading and consequent global scale effects of the crisis as a whole (AON Benfield 2013). However, a subsidary crisis that become primary emergency is the severe energy-supply interruption generated by hurricane and surge:it required the direct attention of President Obama from November 2 and the mobilization of all the instruments available, including ad hoc emergency purchases, oil reserves. All the levels of the production and distribution chain were heavily damaged, including substations, refineries and petroleum product supply such as terminals or strategic hub for petroleum delivery in New England, New York, and New Jersey (EIA 2012). Indeed, the area affected encompasses approximately 8 per cent of total refining capacity of the United States and disruptions were reflected in a reduction in shipments of gasoline and distillate, which in the post-storm period were respectively 54 per cent and 46 per cent below ordinary levels (AON Benfield 2013). The internal dependencies of energy chain amplified effects because infrastructure, such as pipelines, oil terminals, storage tanks and filling stations, could hardly function without a safe and constant energy supply (Comes and Van der Walle 2014). On 7 November, more than 600000 people were still without electricity, and on 9 November gas rationing started in New York City, Nassau and Suffolk (CNN 2014). Furthermore, other subsidary disasters were generated from the interaction between energy infrastructure and physical triggers. In many areas electrical grids were disrupted by high winds and fires were generated by live wires disrupted by the storm surge. Emergency workers were struck by weather condition, and the event was allowed to escalate. In the sole New York City, at least 21 fires developed, and they destroyed or damaged more than 200 homes and businesses (AON Benfield 2013). In conclusion, Sandy shows how the context can determine the structure of the cascade in term of complexity, gravity and time propagation. The high concentration of critical infrastructrues in space created a large number of subsidiary emergencies, one of which in particular lasted smore than the physical trigger and contribute to raise the total amount life losses. Differently from Fukushima case, the vector of amplifiction was not a single structure of high rank and hazard but a diffused presence of medium –high rank energy facilities interconnected among each others. In other words, Sandy joins togheter the cascading effects of floods to the ones reported in the North America Blackout of 2003.

In conclusion, our case studies confirm that society is entering a new era—that of global information, characterized by increasing interdependency, interconnectivity and complexity, and a life in which the real and digital world can no longer be separated. However, as interactions strengthen and consolidate, the behaviour of system components may seriously alter or impair the ability of other components to function. In this sense, typical properties of strongly coupled systems are: (a) dynamic changes tend to be fast, and can potentially outstrip the rate at which one can characterise system behaviour, or react to it; (b) one event can trigger further events, thereby creating amplification and cascading effects, which implies a large vulnerability to perturbations, variations or random failures. Cascade effects accompany transitions of system variables from a stable to an unstable state, thereby driving the system out of equilibrium; and (c) extreme events tend to occur more often than would be expected if the distribution of all events were Gaussian.

5. Conclusion: A Coherent Definition of Cascading Effects and Disasters

We have argued that cascading effects are common in disaster, as the chain of interaction can amplify the effects of an impact as it progresses through different states. This is corroborated by the dynamics of many widely differing events. Moreover, it seems to be correlated with two particular elements: the involvement of critical infrastructure that increases the cascade effect, and the spread of impacts in the light of pre-existing vulnerabilities that determine consequent failures. Hence:

> Cascading effects are the dynamics present in disasters, in which the impact of a physical event or the development of an initial technological or human failure generates

> a sequence of events in human subsystems that result in physical, social or economic disruption. Thus, an initial impact can trigger other phenomena that lead to consequences with significant magnitudes. Cascading effects are complex and multi-dimensional and evolve constantly over time. They are associated more with the magnitude of vulnerability than with that of hazards. Low-level hazards can generate broad chain effects if vulnerabilities are widespread in the system or not addressed properly in sub-systems. For these reasons, it is possible to isolate the elements of the chain and see them as individual (subsystem) disasters in their own right. In particular, cascading effects can interact with the secondary or intangible effects of disasters.

In this definition, our view embraces the multidimensional and complex nature of cascades. The different possible failures that can generate chain effects are integrated, while progression and magnitude become important. As it provides a mechanism for spreading cascades in space and time, vulnerability is considered critical. This is related to the technique of isolating single effects and seeing them as possible autonomous cause-effect sequences, while in some events cascading effects coincide with secondary or intangible ones. However, a proper definition of ”cascading disasters” should be employed to differentiate the various levels of ”cascading effects.” Indeed, the eruption of the volcano Eyjafjallajökull , the Tōhoku earthquake of 2011, and Hurricane Sandy shows that amplification can acquire so much complexity that the main impact is associated or nearly to subsidiary events. On the basis of such evidence, we can offer the following definition of cascading disasters:

> Cascading disasters are extreme events, in which cascading effects increase in progression over time and generate unexpected secondary events of strong impact. These tend to be at least as serious as the original event, and to contribute significantly to the overall duration of the disaster’s effects. These subsequent and unanticipated crises can be exacerbated by the failure of physical structures, and the social functions that depend on them, including critical facilities, or by the inadequacy of disaster mitigation strategies, such as evacuation procedures, land use planning and emergency management strategies. Cascading disasters tend to highlight unresolved vulnerabilities in human society. In cascading disasters one or more secondary events can be identified and distinguished from the original source of disaster.

6. Acknowledgements

This work has been carried out under the aegis of the EC FP7 FORTRESS project. FORTRESS is funded by the European Commission within FP7- Area 10.4.1 Preparedness, prevention, mitigation and planning, TOPIC SEC-2013.4.1-2 SEC-2013.2.1-2, Grant 607579.

We wish to thank our partners at EDF for useful dialogue that helped us improve definitions. We are also grateful to our colleagues at the UCL Institute for Risk and Disaster Reduction (UCL) for the precious feedback that they have given us.

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Citation

Pescaroli, G. and Alexander, D. (2015): A definition of cascading disasters and cascading effects: Going beyond the "toppling dominos" metaphor. In: Planet@Risk, 2(3): 58-67, Davos: Global Risk Forum GRF Davos.