Flood Resilience

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Introduction

Resilience is widely used in flood risk management policies, but still largely conceptually. Despite notable advances in social-ecological sciences and numerous attempts to make it operational, there is still a limited number of empirical and quantitative case studies to demonstrate the practical relevance in flood risk management. Nevertheless, the concept of resilience (as opposed to resistance) represents a new way of thinking about flood disaster mitigation embracing the philosophy that, as a society, we should learn to live with floods and to manage flood risk and not seek to avoid it. Resilient flood risk strategies aim at reducing flood risk through a combination of protection, prevention and preparedness spanning a wide range of flood probabilities (from regular to rare flood events).

Flood resilience is applied in at least two different ways. In the first, more traditional definition and applied in engineering, resilience is conceptualized as an outcome. It is defined as the ability of a system to resist or absorb disturbances (such as storm surges and cloudbursts) and to remain functioning under a wide range of flood wave or rainfall intensities. In this definition, continued functioning implies either withstanding the flood wave (resistance) or quick recovery with limited impact after being exposed to flood water (e.g. due to failure of the flood defense system) (e.g. De Bruijn, 2004; Gersonius et al., 2010) with the ultimate aim to avoid impacts from which recovery is extremely difficult (e.g. Mens et al., 2011). Here resilience depends on properties such as robustness, or the capacity to withstand a disturbance without functional degradation, redundancy or the extent to which system components are substitutable, and rapidity or the capacity to restore the system in a timely manner (Bruneau et al., 2003; Liao, 2012). Engineering resilience is increasingly being applied in the domain of architecture and building technology involving the deployment of flood resilient design and technologies to adapt or construct buildings that remain undamaged or unaffected by flood water (e.g. Garvin, 2012). It is also being used in the domain of disaster reduction aiming at recovering from shocks and preserving the status quo (Mayunga, 2007).

Building on the paradigm of multi-equilibria (or non-equilibrium) in ecology (Holling, 1973), in the

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2 Resistance in this context is often defined as the ability of the system to prevent floods
second definition, resilience has evolved into a broader concept of socio-ecological resilience and is typically defined from a holistic system’s perspective. It is being used as an approach for understanding the dynamics of social-ecological systems. In this emerging concept resilience is observed as a process, where the post-disruption state can be different than the pre-disruption state, but the whole recovery process is resilient (Folke, 2006; Wardekker et al., 2010; Linkov et al., 2014). This resilience approach recognizes non-linear dynamics, thresholds, uncertainty and surprise, how periods of gradual change interplay with periods of rapid change and how such dynamics interact across temporal and spatial scales (e.g. Folke, 2006; Gersonius et al., 2010). In this context resilience is defined as “the capacity of linked social-ecological systems to absorb recurrent disturbances such as floods so as to retain essential structures, processes and feedbacks” (Folke, 2006). In addition, resilience also reflects the degree to which complex adaptive systems are capable of self-organization and to which these systems can build capacity for learning and adaptation (e.g. Folke, 2006; Cutter et al., 2010). This broader concept of resilience has been adopted in the domain of climate change adaptation as a way to deal with both gradual, disturbing changes and shocks (resulting from climate change and variability, resp.) (Wardekker et al., 2010; Bahadur et al., 2010; Linkov et al., 2014).

<table>
<thead>
<tr>
<th>response</th>
<th>stress</th>
<th>aim/strategy</th>
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<tr>
<td>Resistance</td>
<td>Ability to withstand disturbance without responding</td>
<td>shock stability (preserve status quo) flood protection</td>
</tr>
<tr>
<td>Engineering resilience</td>
<td>Ability to bounce back and recover from disturbance recover</td>
<td>shock constancy (efficiency of function, preserve status quo) robustness Fail-safe design This definition is appropriate for engineering components and systems</td>
</tr>
<tr>
<td>Socio-ecological resilience</td>
<td>Capacity to absorb disturbance, recover and re-organize (adapt) while undergoing change</td>
<td>gradual/shock persistency (existence of function) learning, adaptive capacity, transformation</td>
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Table 1: Definitions and features of resilience used in flood risk management

**Objectives and instruments**

In many parts of the world flood risk management has focused primarily on the implementation of structural engineering solutions, favoring large-scale infrastructure systems, such as flood embankments and channelization (Brown & Damery, 2002; Ashley & Brown, 2009). These traditional approaches have not been designed for failure and as a consequence impacts of extreme flood
events may be catastrophic. In the recent past, major flood disasters have indeed acted as catalysts for changing flood risk management approaches. Currently, there is a growing recognition that flood risk management systems are complex systems. They bring together human, ecological and technical components. Contemporary thinking about the behavior of these systems has led to a paradigm shift in managing those systems (see Table 2). The broader concept of socio-ecological resilience has provided guidance for building more resilient FRM systems involving (e.g. Sayers et al., 2002; Dawson et al., 2011; Huntjens et al., 2011; Zevenbergen et al., 2013): (i) accepting that knowledge will never be perfect and that changes are uncertain and hence that there is no ‘optimal’ or ‘best’ solution, (ii) nurturing the capacity to adapt and allowing to learn from the outcomes of experimentation, (iii) taking into account all of the potential interventions that may alter flood risks and (iv) facilitating participation and collective action. These resilient approaches aim to establish a balance between flood protection, prevention and preparedness, both now and into the future (e.g. Zevenbergen et al., 2008; Gersonius et al., 2010; Aerts et al., 2014).

<table>
<thead>
<tr>
<th>Problem perception</th>
<th>Traditional (flood risk-based) approach</th>
<th>Flood resilient approach</th>
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</thead>
<tbody>
<tr>
<td>Changes in system are predictable</td>
<td>Changes in system are uncertain</td>
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<tr>
<th>Key objective</th>
<th>Traditional (flood risk-based) approach</th>
<th>Flood resilient approach</th>
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</thead>
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<tr>
<td>Control changes, stability (problem-solving)</td>
<td>Persistence, enhance capacity to adapt to uncertainties (anticipation)</td>
<td></td>
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<thead>
<tr>
<th>Governance perspective</th>
<th>Traditional (flood risk-based) approach</th>
<th>Flood resilient approach</th>
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<tr>
<td>Sequential process of planning</td>
<td>Continuous alignment of content and process with context</td>
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<td>Top-down strategy making</td>
<td>Bottom-up initiatives</td>
<td></td>
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<tr>
<td>Focus on flood probability reduction (protection)</td>
<td>Balance between protection, prevention and preparedness</td>
<td></td>
</tr>
<tr>
<td>Systems of static norms and standards</td>
<td>System of strategic alternatives (e.g. adaptation pathways)</td>
<td></td>
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Table 2: Features of the traditional flood risk-based approach and the flood resilient approach

 Metrics
Most of the frameworks to measure flood resilience focus on the relationship between probability and (direct) impact of flooding (engineering resilience), and factors that attribute to resilience such as economic resources, assets and skills, information and knowledge, support and supportive networks, and access to services (socio-ecological resilience). The factors are being used to select resilience surrogates as they relate to a particular component or notion of flood resilience. Flood models are being used to assess probabilities and consequences of flooding and the effectiveness of
management interventions. Attempts to quantify flood resilience are based on indicators which relate system response to flood waves (see Figure 1) (e.g. Termes et al., 1999; Klijn & Marchand, 2000; De Bruijn, 2004; Mens et al., 2011). For instance, De Bruijn (2004) provided an analysis of what makes river basins flood resilient and how resilience can be enhanced. She quantified resilience using three indicators that reflect the different aspects of the reaction. Gersonius (2008) has further extended this framework comprising the following indicators: the reaction threshold, amplitude, graduality, and recovery rate. The reaction threshold involves the recurrence time of the maximum load the system can withstand such as the maximum river discharge or rainfall intensity which is not expected to cause floods. The amplitude of the reaction indicates the severity of the expected (direct) damage resulting from a certain peak discharge or extreme rainfall event. The graduality reflects the extent to which the damage increases with increasing disturbances caused by flood waves. The recovery rate describes how fast a system will recover from the reaction to a disturbance.

The resilience of a system can only be assessed by considering the whole set of indicators as each indicator reflects only one aspect of the reaction of a system to flood waves. Although these resilient indicators reveal relevant information on the system’s performance, they cannot be aggregated and expressed in one numerical value (Zevenbergen, 2007).

![Theoretic response curve, showing system response as a function of disturbance magnitude (e.g. magnitude of flood wave), indicating resistance and resilience (adapted from Mens et al., 2011)](image)

**Figure 1**

Annotated bibliography of flood resilience studies


The study described in this paper is a nice example that uses a combination model for storms and floods, damages and protections, to evaluate flood resilience planning and investments for
coastal cities using New York City as a case study.


To enable the evaluation of resilience and resistance strategies under different conditions, the concepts of resilience and resistance must first be sufficiently understood. The above-mentioned papers discuss the meaning of resilience and resistance and apply the concepts to flood risk management systems.

References


Gersonius, B. (2008). *Can resilience support integrated approaches to urban drainage management?* 11ICUD.


