Flood Resilience[i]

Chris Zevenbergen[1]

[1]TUDelft & UNESCO-IHE

Contact: C.Zevenbergen@unesco-ihe.org

Keywords: Flood risk management, Engineering resilience, Socio-ecological resilience

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[ii]) 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

---

[i] This paper is part of the IRGC Resource Guide on Resilience, available at: https://www.irgc.org/risk-governance/resilience/. Please cite like a book chapter including the following information: IRGC (2016). Resource Guide on Resilience. Lausanne: EPFL International Risk Governance Center. *v29-07-2016*

[ii] 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).

	response	**stress**	**aim/strategy**
Resistance	Ability to withstand disturbance without responding	shock	stability (preserve status quo) flood protection
Engineering resilience	Ability to bounce back and recover from disturbance recover	shock	constancy (efficiency of function, preserve status quo) robustness Fail-safe design This definition is appropriate for engineering components and systems
Socio-ecological resilience	Capacity to absorb disturbance, recover and re-organize (adapt) while undergoing change	gradual/shock	persistency (existence of function) learning, adaptive capacity, transformation

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).

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

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).

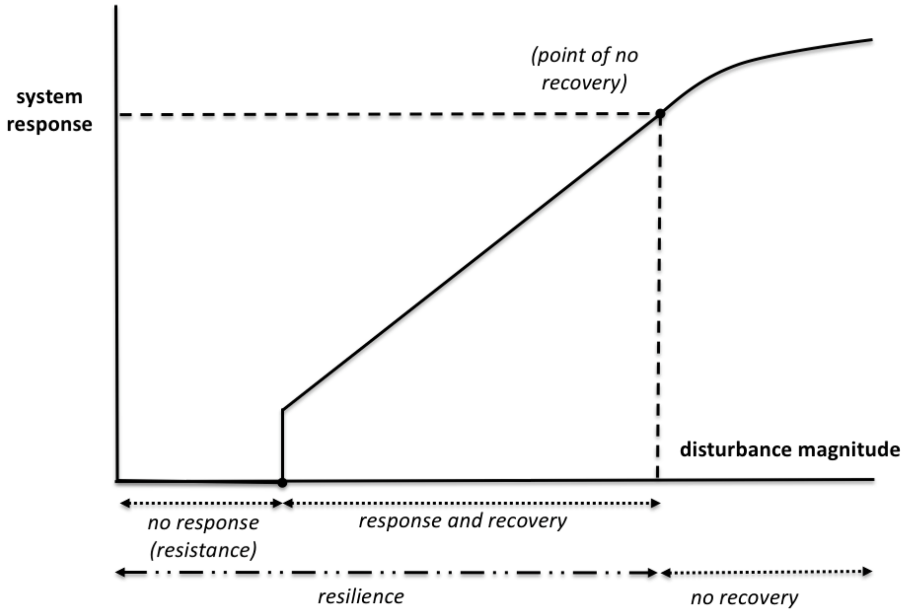

Figure 1: Theoretic response curve, showing system response as a function of disturbance magnitude (e.g. magnitude of flood wave), indicating resistance and resilience (adapted from Mens et al., 2011)

Annotated bibliography of flood resilience studies

Aerts, J. C. J. H., Botzen, W. J. W., Emanuel, K., Lin, N., Moel, H. de & Michel-Kerjan, E. O. (2014). Evaluating Flood Resilience Strategies for Coastal Megacities. *Science*, 344(6183), 473-475. doi: 10.1126/science.1248222

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.

De Bruijn, K. M. (2004). Resilience and flood risk management. *Water Policy* 6(1): 53-66.

Gersonius, B., Ashley, R., Pathirana, A., & Zevenbergen, C. (2010). Managing the flooding system's resiliency to climate change. *Proceedings of the ICE-Engineering Sustainability* 163(1): 15-23.

Zevenbergen, C., Veerbeek, W, Gersonius, B., & van Herk, S. (2008). Challenges in urban flood management: travelling across spatial and temporal scales. *Journal of Flood Risk Manag*ement 1(2): 81–88.

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

Aerts, J. C. J. H., Botzen, W. J. W., Emanuel, K., Lin, N., Moel, H. de & Michel-Kerjan, E. O. (2014). *Evaluating Flood Resilience Strategies for Coastal Megacities.* *Science*, 344(6183), 473-475. doi: 10.1126/science.1248222

Ashley, R. M., &Brown, R. R. (2009). Entrapped in common sense: why water management by current regimes is not sustainable and what we can do about it. Proceedings of the 9th Nordic Environmental Social Science (NESS): *Knowledge, learning and action for sustainability*. London, UK, 10-12 June 2009.

Bahadur, A.V., Ibrahim, M., & Tanner, T. (2010). *The resilience renaissance? Unpacking of resilience for tackling climate change and disasters.* [pdf] Brighton: Institute of Development Studies. Available at:<http://community.eldis.org/.59e0d267/resilience-renaissance.pdf>[Accessed 17 July 2014].

Brown, J. D., & Damery, S. L. (2002). Managing flood risk in the UK: towards an integration of social and technical perspectives. *Transactions of the Institute of British Geographers* 27(4): 412-426.

Bruneau, M., Chang, S., Eguchi, R., Lee, G., O'Rourke, T., Reinhorn, A., Shinozuka, M., Tierney, K., Wallace, W., & von Winterfelt, D., (2003). *A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities*, EERI Spectra Journal, Vol.19, No.4, pp.733- 752.

Cutter, S. L., Burton, C. J., & Emrich. C.T. (2010). Disaster resilience indicators for benchmarking baseline conditions. *Journal of Homeland Security and Emergency Management* 7(1).

Dawson, R. J., Ball, T., Werritty, J., Werritty, A., Hall, J. W., & Roche, N. (2011). Assessing the effectiveness of non-structural flood management measures in the Thames estuary under conditions of socio-economic and environmental change*. Global Environmental Change,* 21(2): 628–646.

De Bruijn, K. M. (2004). Resilience and flood risk management. *Water Policy* 6(1): 53-66.

Folke, C. (2006). Resilience: the emergence of a perspective for social- ecological systems analyses.*Global Environmental Change*, 16, 253–267.

Garvin, S. (2012). *Flood Resilient Building – Part 2: Building in flood-risk areas and designing flood-resilient buildings*. Watford: BRE Press.

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

Gersonius, B., Ashley, R., Pathirana, A., & Zevenbergen, C. (2010). Managing the flooding system's resiliency to climate change. *Proceedings of the ICE-Engineering Sustainability* 163(1): 15-23

Holling, C. S. (1973). Resilience and stability of ecological *systems. Annual Review of Ecology and Systematics*, 4, 1–23.

Huntjens, P., Pahl-Wostl, C., Rihoux, B., Schlüter, M., Flachner, Z., Neto, S., & Nabide Kiti, I. (2011). Adaptive water management and policy learning in a changing climate: a formal comparative analysis of eight water management regimes in Europe, Africa and Asia. *Environmental Policy and Governance* 21(3), 145-163.

Linkov, I., Kröger, W., Levermann, A., Renn, O. et al. (2014). Changing the Resilience Paradigm. *Nature Climate Change*. 4, 407–409. doi:10.1038/nclimate2227

Liao, K. (2012). A theory on urban resilience to floods—a basis for alternative planning practices. *Ecology and Society* 17 (4), 48. http://dx.doi.org/10.5751/ES-05231-17044

Mayunga, J. S. (2007). Understanding and applying the concept of community disaster resilience: a capital-based approach. *Summer Academy for Social Vulnerability and Resilience Building* 1-16.

Mens, M. J. P., Klijn, F., De Bruijn, K. M., & Van Beek, E. (2011). *The meaning of system robustness for flood risk management*, Environ. Sci. Policy, 14, 1121–1131, doi:10.1016/j.envsci.2011.08.003.

Sayers, P., Galloway, G., Penning-Rowsell, E., Yuanyuan, L., Fuxin, S., Yiwei, C., Kang, W., Le Quesne, T., Wang, L., & Guan, Y. (2014). Strategic flood management: ten 'golden rules' to guide a sound approach. *International Journal of River Basin Management*, 13(2), 137-151.

Wardekker, J. A., de Jong, A., Knoop, J. M., van der Sluijs, J. P. (2010). "Operationalising a resilience approach to adapting an urban delta to uncertain climate changes". *Technological Forecasting and Social Change*, 77 (6), pp. 987-998.

Zevenbergen, C. (2007). *Adapting to change: towards flood resilient cities.* UNESCO-IHE, Delft, The Netherlands. ISBN 978-90-73445-18-5

Zevenbergen, C., Veerbeek, W., Gersonius, B., & van Herk, S. (2008). Challenges in urban flood management: travelling across spatial and temporal scales. *Journal of Flood Risk Management* 1(2), 81–88.

Zevenbergen, C., van Herk, S., Rijke, J., Kabat, P., Bloemen, P., Ashley, R., & Veerbeek, W. (2013). Taming global flood disasters: lessons learned from Dutch experience. *Natural Hazards* 65(3), 1217–1225.