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FROM FLOOD RISK MANAGEMENT TO QUANTITATIVE FLOOD DISASTER RESILIENCE: A PARADIGM SHIFT

S. P. Simonovic[1]

1. *Professor, Department of Civil and Environmental Engineering, Director of Engineering Works: Institute for Catastrophic Loss Reduction, University of Western Ontario, London, Ontario, Canada*

ABSTRACT: There are practical links between flood risk management, climate change adaptation and sustainable development leading to reduction of flood risk and re-enforcing resilience as a new development paradigm. There has been a noticeable change in flood management approaches, moving from disaster vulnerability to disaster resilience; the latter viewed as a more proactive and positive expression of community engagement with flood risk management. As flood hazard is increasing, at the same time it erodes resilience, therefore climate change has a magnifying effect on the flood risk. In the past, standard disaster management planning emphasized the documentation of roles, responsibilities and procedures. Increasingly, these plans consider arrangements for prevention, mitigation, preparedness and recovery, as well as response. However, over the last ten years substantial progress has been made in establishing the role of resilience in sustainable development. Multiple case studies around the world reveal links between attributes of resilience and the capacity of complex systems to absorb disturbance while still being able to maintain a certain level of functioning. Building on emergency planning experience, there is a need to focus more on action-based resilience planning to strengthen local capacity and capability, with greater emphasis on community engagement and a better understanding of the diversity, needs, strengths and vulnerabilities within communities. Floods do not impact everyone in the same way. It is clear that the problems associated with sustainable human wellbeing in calls for a paradigm shift. Use of resilience as an appropriate matrix for investigation arises from the integral consideration of overlap between: (a) physical environment (built and natural); (b) social dynamics; (c) metabolic flows; and (d) governance networks. This paper provides an original systems framework for quantification of resilience. The framework is based on the definition of resilience as the ability of physical and social systems to absorb disturbance while still being able to continue functioning. The disturbance depends on spatial and temporal perspectives and direct interaction between impacts of disturbance (social, health, economic, and other) and adaptive capacity of the system to absorb disturbance.

Key Words: Flood Risk, Resilience, Climate change

1. INTRODUCTION

The terms ‘floods’, ‘flooding’, ‘flood hazard’ and ‘flood risk’ cover a very broad range of phenomena (Simonovic, 2012). Among many definitions of floods that do not incorporate only notions of *inundation* and *flood damage* for the purpose of this paper I will stay with the definition provided by Ward (1978) that a flood is a body of water which rises to overflow land which is not normally submerged. This definition explicitly includes all types of surface inundation but flood damage is addressed only implicitly in its final three words. Both, inundation and damage occur on the great range of scale.

The term such as ‘flood risk’ and ‘flood losses’ are essentially our interpretations of the negative economic and social consequences of natural events. Human judgment is subject to value systems that different groups of people may have and therefore these terms may be subject to different definitions. The flood risk, at various locations, may increase by human activity – like inappropriate land use practices. Also, the flood risk may be reduced by flood management structures and/or effective emergency planning. The real flood risk therefore, stems from the likelihood that a major hazardous event will occur unexpectedly and that it will impact negatively on people and their welfare (Smith and Ward, 1998). Flood hazards result from a combination of physical exposure and human vulnerability to flooding. Physical exposure reflects the type of flood event that can occur, and its statistical pattern, at a particular location. The human vulnerability reflects key socio-economic factors such as the number of people at risk on the floodplain, the extent of flood defense works and the ability of the population to anticipate and cope with flooding. In this paper **the formal definition of *flood risk*** is a combination of the chance of a particular event, with the impact that the event would cause if it occurred. Flood risk therefore has two components – the chance (or probability) of an event occurring and the impact (or consequence) associated with that event. The consequence of an event may be either desirable or undesirable. A convenient single measure of the importance of a flood risk is given by:

$$Risk = Probability \times Consequence \tag{1}$$

If any of the two elements in (1) increases or decreases, then risk increases or decreases respectively.

How we manage flood risk? In many countries flood risk management is evolving from traditional approaches based on design standards to the development of risk-based decision-making, which involves taking account of a range of loads, defense system responses and impacts of flooding (Sayers et al, 2002). The difference between a risk-based approach and other approaches to design or decision making, is that it deals with outcomes. The World Meteorological Organization is promoting the principal of integrated flood management - IFM - (WMO, 2009) that has been practiced at many places for decades. An Integrated Flood Management plan should address the following six key elements: (i) Manage the water cycle as a whole; (ii) Integrate land and water management; (iii) Manage risk and uncertainty; (iv) Adopt a best mix of strategies; (v) Ensure a participatory approach; and (vi) Adopt integrated hazard management approaches.

Flood risk management is a part of all social and environmental processes aimed at minimizing loss of life, injury and/or material damage. Mileti (1999) and Simonovic (2011, 2012) advocate systems view of flood risk management processes in order to address their complexities, dynamic character and interdisciplinary needs of management options. A primary emphasis of systems analysis in flood risk management is on providing an improved basis for effective decision-making. A large number of systems tools, from simulation and optimization to multi-objective analysis, are available for formulating, analyzing and solving flood risk management problems.

In order to apply a continuous improvement approach to flood risk management it is essential to have a way or thinking – a model – of what is being managed. The system in our focus is a social system. It describes the way floods affect people. The purpose of describing the system is to help clarify the understanding and determine best points of systems intervention.

The flood risk management system comprises four linked subsystems: individuals, organizations and society, nested within the environment. Individuals are the actors that drive organizations and society to behave in the way they do. They are decision makers in their own right, with a direct role in mitigation, preparedness, response and recovery from flooding. Organizations are the mechanism people use to produce outcomes that individuals cannot produce. Organizations are structured to achieve goals. Structure defines information and/or resource flows and determines the behavior of the organization. The concept of society is different from those of individuals and organizations, being more difficult to put boundaries around. In general, society itself is a system of which individuals and organizations are subsets and contains the relationships people have with one another, the norms of behavior and the mechanisms that are used to regulate behavior. The environment includes concrete elements such as water and air, raw materials, natural systems, etc. It also encompasses the universe of ideas, including the concept of 'future'. This concept is important in considering flood risk management - it is the expectation of future damages and future impacts that drives concern for sustainable management of flood disasters. Six management principles are presented by Simonovic (2012).

A change to proactive flood risk management requires an identification of the risk, the development of strategies to reduce that risk, and the creation of policies and programs to put these strategies into effect. Flood risk management is a part of all social and environmental processes aimed at minimizing loss of life, injury and/or material damage. A systems view of flood risk management is recommended in order to address the complexity, dynamic character and interdisciplinary needs of management options. A primary emphasis of systems analysis in flood risk management is on providing an improved basis for effective decision-making. A large number of systems tools, from simulation and optimization to multi-objective analysis, are available for formulating, analyzing and solving flood risk management problems. The main objective of this book is to present a variety of systems tools for flood risk management.

Recognizing the progress in flood risk management and recognizing the needs of vulnerable communities, the United Nations and its partners at the World Conference on Disaster Reduction (WCDR) in Kobe City in January 2005, came up the "Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters". This was the introduction of resilience thinking as a replacement for flood risk management. Governments around the world have traditionally planned large-scale, centralized infrastructure flood protection systems that aim to control variables and reduce uncertainties. There is growing awareness that a transition toward sustainable alternatives is necessary if systems are to meet society's future water needs in the context of drivers such as climate change and variability, demographic changes, environmental degradation, and resource scarcity. However, there is minimal understanding of how to transition from flood risk management to building flood resilience and how to operationalize resilience thinking as one component of strategic planning for such change to facilitate the transition to a sustainable water future (Ferguson et al, 2013).

1.1 **Resilience quantification framework**

There are many definitions of resilience (Simonovic and Peck, 2013), from general: (i) The ability to recover quickly from illness, change or misfortune; (ii) Buoyancy; (iii) The property of material to assume its original shape after deformation; (iv) Elasticity; to ecology–based (Gunderson and Holling, 2001): (i) The ability of a system to withstand stresses of 'environmental loading'; to hazard–based (UNISDR, 2014): (i) Capacity for collective action in response to extreme events; (ii) The capacity of a system, community, or society potentially exposed to hazards to adapt, by resisting or changing, in order to reach and maintain an acceptable level of functioning and structure; (iii) The capacity to absorb shocks while maintaining function; (iv) The capacity to adapt existing resources and skills to new situations and operating conditions. The common elements of these definitions include: (i) minimization of losses, damages and community disruption; (ii) maximization of the ability and capacity to adapt and adjust when there are shocks to systems; (iii) returning systems to a functioning state as quickly as possible; (iv) recognition that resilient systems are dynamic in time and space; and (v) acknowledgements that post-shock functioning levels may not be the same as pre-shock levels.

Resilience is a dynamic process, but for measurement purposes is often viewed as static phenomena (Cutter et al, 2008). In this paper a *flood resilient community* is a sustainable network of physical (constructed and natural) systems and human communities (social and institutional) that possess the capacity to survive, cope, recover, learn and transform from flood events by: (i) reducing failure probabilities; (ii) reducing failure consequences (for example material damage); (iii) reducing time to recovery; and (iv) creating opportunity for development and innovation from adverse impacts. Numerous institutions, organizations, and elements in the urban environment contribute to community flood resilience, for example water and power lifelines, acute-care hospitals, and organizations that have the responsibility for emergency management. Improving the resilience of critical lifelines is critical for overall community resilience. These organizations are essential for community functioning; they enable communities to respond, provide for the well-being of their residents, and initiate recovery activities when disasters strike (Bruneau et al, 2003). For example, since no community can cope adequately with a flood disaster without being able to provide emergency care for injured victims, hospital functionality is crucial for community resilience. Water is another essential lifeline service that must be provided to sustain disaster victims.

The quantification framework recommended by Simonovic and Peck (2013) following Cutter et al (2008) has two qualities: inherent (functions well during non-flooding periods); and adaptive (flexibility in response during flood events) and can be applied to physical environment (built and natural), social systems, governance network (institutions and organizations), and economic systems (metabolic flows). An original space-time dynamic resilience measure (STDRM) of Simonovic and Peck is designed to capture the relationships between the main components of resilience; one that is theoretically grounded in systems approach, open to empirical testing, and one that can be applied to address real-world problems in various communities.

STDRM is based on two basic concepts: level of system performance and adaptive capacity. They together define resilience. The level of system performance integrates various impacts (*i*) of flood on a community. The following impacts (units of resilience (ρ^i)) can be considered: physical, health, economic, social and organizational, but the general measure is not limited to them. Measure of system performance $P^i(t,s)$ for each impact (*i*) is expressed in the impact units (physical impact may include for example length [*km*] of road being inundated; health impact may be measured using an integral index like disability adjusted life year (DALY); and so on). This approach is based on the notion that an impact, $P^i(t,s)$, which varies with time and location in space, defines a particular resilience component of a community, see Figure 1 adapted from Simonovic and Peck (2013). The area between the initial performance line $P_0^i(t,s)$ and performance line $P^i(t,s)$ represents the loss of system resilience, and the area under the performance line $P^i(t,s)$ represent the system resilience ($\rho^i(t,s)$). In Figure 1, t_0 denotes the beginning of the flood event, t_1 the end, and t_r the end of the flood recovery period.

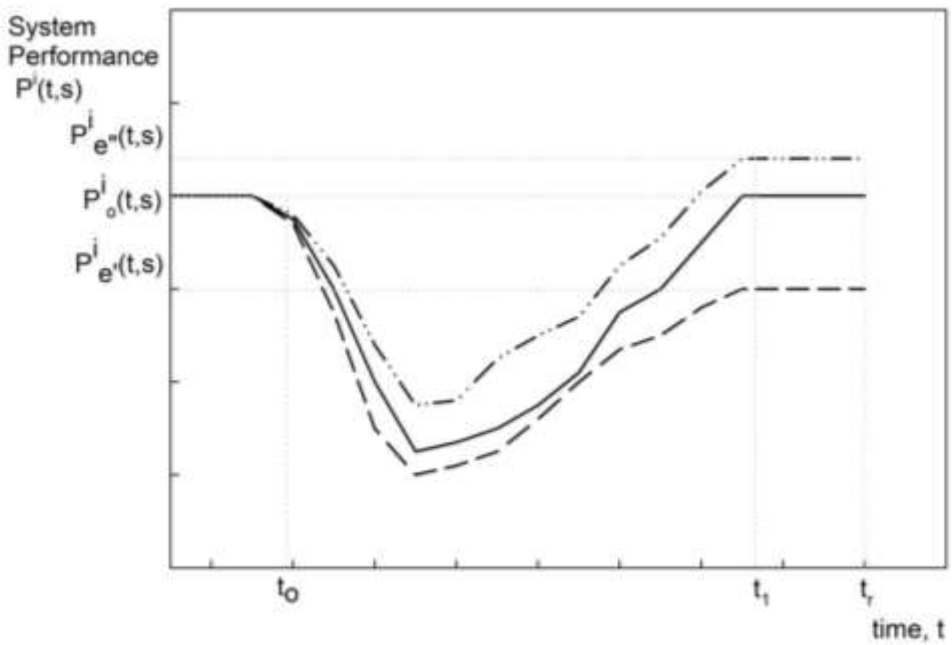

Figure 1 System performance

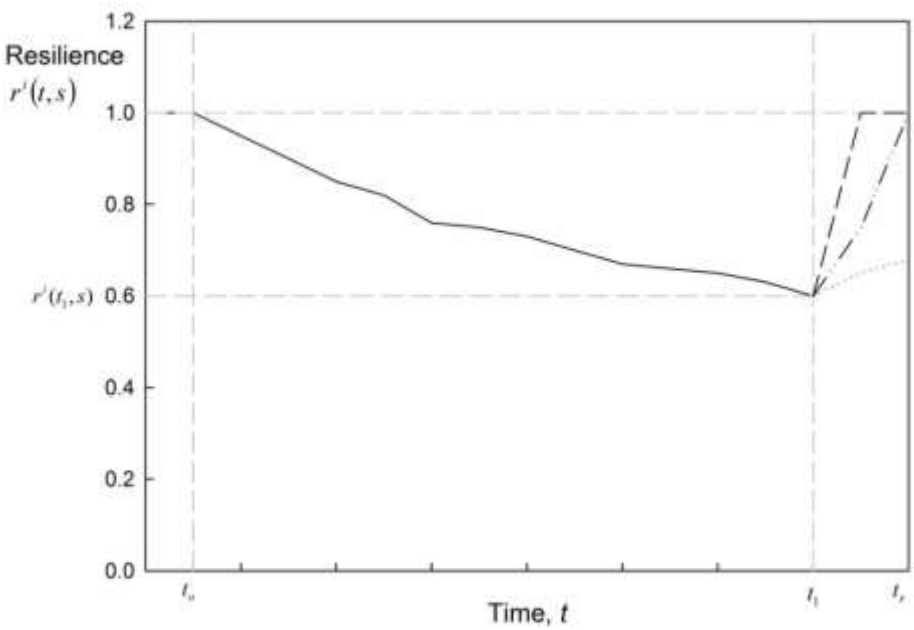

Figure 2 System resilience

In mathematical form the loss of resilience for impacts (i) represents the area under the performance graph between the beginning of the system disruption event at time (t_0) and the end of the disruption recovery process at time (t_r). Changes in system performance can be represented mathematically as:

$$\rho^i(t,s) = \int_{t_0}^{t} \left[P_0^i - P^i(\tau,s)\right] d\tau \quad where \;\; t \in [t_0, t_r] \tag{2}$$

When performance does not deteriorate due to disruption, $P_o^i(t,s) = P^i(t,s)$ the loss of resilience is 0 (i.e. the system is in the same state as at the beginning of disruption). When all of system performance is lost, $P^i(t,s) = 0$, the loss of resilience is at the maximum value. The system resilience, $r^i\ (t,s)$ is calculated as follows:

$$r^i(t,s) = 1 - \left(\frac{\rho^i(t,s)}{P_o^i \times (t - t_o)}\right) \tag{3}$$

As illustrated in Figure 1, performance of a system which is subject to a flood (disaster event) drops below the initial value and time is required to recover the loss of system performance. Disturbance to a system causes a drop in system resilience from value of 1 at t_o to some value $r^i(t_1,s)$ at time t_1, see Figure 2. Recovery usually requires longer time than the duration of disturbance. Ideally resilience value should return to a value of 1 at the end of the recovery period, t_r (dashed line in Figure 2); and the faster the recovery, the better. The integral STDRM (over all impacts (*i*)) is calculated using:

$$R(t,s) = \left\{\prod_{i=1}^{M} r^i(t,s)\right\}^{\frac{1}{M}} \tag{4}$$

$$where\ M\ is\ the\ total\ number\ of\ impacts$$

The calculation of STDRM for each impact (i) is done at each location (s) by solving the following differential equation:

$$\frac{\partial \rho^i(t)}{\partial t} = AC^i(t) - P^i(t) \tag{5}$$

$$where\ AC^i\ represents\ adaptive\ capacity\ with\ respect\ to\ impact, i$$

The STDRM integrates resilience types, dimensions and properties by solving for each point in space (*s*):

$$\frac{\partial R(t)}{\partial t} = AC(t) - \prod_i P^i(t) \tag{6}$$

The implementation of the presented framework is proceeding by using system dynamics simulation approach together with spatial analysis software (Srivastav and Simonovic, 2014; Peck and Simonovic, 2014) in the form of Coastal Megacity Resilience Simulator (CMRS).

2. APPLICATION

The presented resilience framework is being implemented on large cities in low-lying deltaic environments (Vancouver, Canada; Manila, Philippines; Lagos, Nigeria; and Bangkok, Thailand) selected for consideration under the project "Coastal Cities at Risk: Building Adaptive Capacity for Managing Climate Change in Coastal Megacities" supported by the International Research Initiative on Adaptation to Climate Change of the Canadian International Development Research Centre (IDRC, 2014).

In this paper some basic information is provided for the implementation in Vancouver, Canada. Vancouver is a coastal megacity and can be considered as a network of three interdependent subsystems: (i) the natural subsystem; (ii) the socio-economic subsystem; and (iii) the administrative and institutional subsystem. Each of the three subsystems is characterized by its own elements and is surrounded by its own environment. For the purpose of the project, coastal megacity resilience is caused by the interaction between society and climate change caused hazards (project focus is on precipitation, floods and seal level rise).

The five major impacts that are being considered in the STDRM include: physical impacts, economic impacts, social impacts, health impacts and organizational impacts. They are being individually modeled for Vancouver in order to describe the local conditions.

The Coastal Megacity Resilience Simulator (CMRS) is data intensive. A very detailed description of each of the five impacts considered within the tool and detailed temporal and spatial scales require serious data support (Simonovic and Peck, 2013).

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