FLOOD RESILIENT COMMUNITIES: A FRAMEWORK AND CASE STUDIES

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ABSTRACT

Internationally there is a growing call for building more resilient cities and for improving the resilience of our communities and critical infrastructure. This is in response to a realisation that the services we take for granted may be robust in the face of predictable hazards, but are actually extremely fragile in the face of unanticipated shocks. But what does building resilience actually mean and entail?

Flooding is a relatively predictable hazard that has the potential to affect all New Zealand towns and cities, and with the impacts of climate change becoming increasingly clear, the likelihood of major flood events (both land based, and coastal) affecting our communities and critical infrastructure is increasing.

This paper looks in detail at the concept of resilience, and draws on related research to propose a framework for assessing and improving resilience to flood hazards. The framework divides resilience into a number of broad dimensions: namely community, technical and organisational, and develops a series of specific principles within each of these dimensions.

The authors also discuss a range of terms related to resilience - such as risk management, vulnerability and sustainability and how they inter-relate. They also emphasise how the various fields of land use planning, infrastructure planning and natural hazard planning must work more closely together to, ultimately, make our communities more resilient to flooding.

A number of case studies are presented, which provide learnings from both successes and failures, in planning for and recovering from large flood events.

KEYWORDS

Flooding, flood management, resilience, adaptation, climate change, sustainability.

PRESENTER PROFILE

James Hughes: James is a chartered professional engineer with wide experience across the areas of urban resilience, urban planning, climate change adaptation, sustainability and civil engineering. He has specific interest in the integration of disciplines and understands the need to consider the relationships between our built environment and the, often unpredictable, natural environments in which we live.

Brian Sharman: Brian is a chartered professional engineer with over 40 years of experience in the water industry; including 15 years at Executive and Senior Management level in water supply, wastewater and stormwater based organisations in the UK and New Zealand. Brian is experienced in all aspects of network related infrastructure and business management, covering the asset lifecycle.

1 INTRODUCTION

Efforts to improve resilience to natural hazards have taken centre stage over recent years. Policy makers, planners, engineers, sociologists, and communities must all play a part, however to do this – further clarity is required on what actions to take, who is responsible, what is an appropriate approach, and where to invest limited resources.

This paper focuses on resilience to flood hazards, and looks in detail at the concept of resilience, drawing on related research to propose a framework for assessing the resilience of our critical infrastructure and communities to flood hazards.

We begin by clarifying the need for an improved focus on resilience, discuss challenges in delivering resilient outcomes, and present a range of resilience definitions and concepts. In Section 5 we discuss linkages to related fields and suggest there is a need to unify some concepts across multiple areas of practice.

Section 6 of the paper discusses hazards, failure and uncertainty, with a particular focus on flooding.

Section 7 presents some frameworks developed by a range of authors which allow a structured assessment of resilience. These are discussed and compared and a draft consolidated framework for flood hazards proposed.

Finally some case studies and recommendations for next steps are presented in the final sections of the paper.

2 THE NEED FOR RESILIENCE

We live in a world in which the known and unknown hazards we face are becoming increasingly frequent, one where the costs of rebuilding from major shock events are placing massive pressure on governments, infrastructure owners and societies alike. Globally, while losses of life have been shown to have decreased from natural disasters, capital losses have exceeded US$2.5T since 2000 (United Nations, 2013). A focus on building resilient societies, and ensuring our critical infrastructure is resilient is of increasing importance.

Critical infrastructure not only responds to the needs of society for the smooth daily continuation of activities, but also provides the basis on which society exists and relies (Croope, 2010).

Godshalk (2002) lists two reasons behind the importance of resilience:

1) Because the vulnerability of technological, natural and social systems cannot be predicted, the ability to accommodate change without catastrophic failure in times of disaster is critical.
2) People and property fare better in resilient cities when struck by disasters. Fewer buildings collapse, fewer power outages occur, fewer businesses are put at risk, and fewer deaths and injuries occur.

In addition to the often unforeseen shock events, we are also faced with longer term, ‘corrosive’ stress events, such as coastal erosion due to sea level rise, or pervasive infrastructure degradation.

Further still, we face more holistic challenges such as urban sprawl, resource depletion and over-exploitation that raises fundamental questions in regard to our approach to sustainable development within cities and societies.

With our increasing reliance on interdependent infrastructure and technologies, and our unwavering expectation for 24/7 service delivery, there is a growing awareness of the need to:

a) Provide meaningful, integrated solutions to these complex problems, and;

b) Provide means to justify any interventions and the expenditure required.

In recent years, flood-related disasters have had tremendous social and economic impact around the world—from the Philippines, Thailand, China to the UK, Australia, the United States, and New Zealand (to name a few). Floods affect more people globally than any other type of disaster (Keating et al, 2014).

In New Zealand, flooding is a relatively regular occurrence – with significant impacts to property and infrastructure. The impacts of climate change mean that the heavy rainfall events will likely become more frequent (MfE, 2008).

Flooding (like any other natural hazard) has the consequential effects of impeding development and diverting resources away from more productive uses. Given the high concentrations of population in urban centres, flooding can have huge impacts on communities, livelihoods, families and individuals. As a result, building resilience to flooding is crucial.

3 CHALLENGES IN IMPROVING RESILIENCE

Improving resilience requires dealing with complexity. Uncertainty around hazards, competing priorities in both the long and short term, constrained resources, and the need to consider views from a wide range of stakeholders mean that decision-making can become protracted.

The requirements for robust financial business case analyses and discounting of future benefits, puts pressure on organisations to ‘optimise’ all expenditure and ultimately deliver a ‘return on investment’. Investments which mitigate the risk of future and uncertain hazard events, require a common understanding of risk, and consensus needs to be reached among decision-makers and stakeholders. Understandably, this can be difficult to achieve. Consequently the development of a method/framework to assist in the assessment of resilience and prioritization of investments is necessary, and is a key focus of this paper.

Additionally, many of the principles commonly associated with resilience are apparent opposites. These include redundancy and efficiency, diversity and interdependence, robustness and safe-to-fail, autonomy and collaboration, planning and adaptability (refer Figure 1 below). It is evident that establishing careful definitions and delineation between these possible outcomes is important.

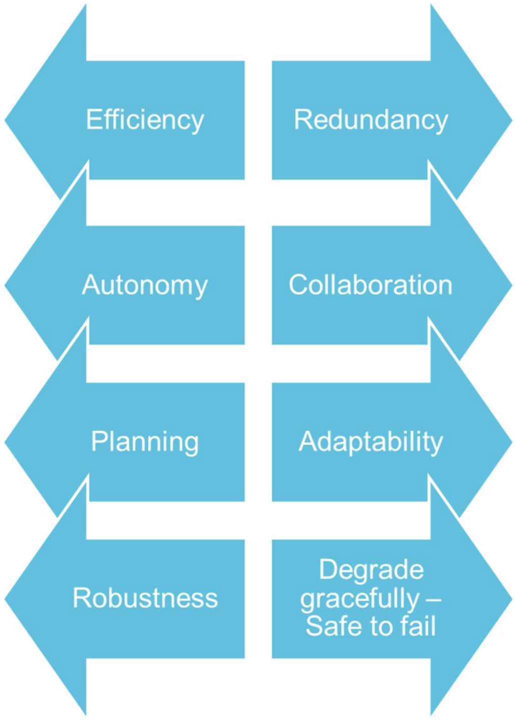

Figure 1: Apparent opposites when considering resilience

A range of other challenges are listed below:

1) Behavioral drivers within organisations and communities leading to an emphasis on response and recovery rather than risk reduction and preparedness.

2) Uncertain future conditions: the inherent (and deep) uncertainty with the likelihood and magnitude of hazard events, along with their associated consequences means planning and decision making is difficult. Risk analysis and resilience-based approaches are possible, however, the presence of deep uncertainty gives extra weight to "soft" options that increase the flexibility of a system and enhance its adaptive capacity, also known as "low-regret strategies" (Fankhauser et al., 1999; IPCC, 2012).

3) A holistic understanding of both disaster risk and community wellbeing. Keating et al (2014) recommend a much stronger focus on closing the gaps between centrally planned disaster risk management and community-led responses. Too often, planned responses fail or are not implemented.

4) Identifying linkages between resilience to natural hazards, and longer term sustainability, ensuring co-benefits are identified, and systemic actions are considered. This is discussed further in Section 5 below.

4 DEFINITIONS

There are a wide variety of definitions of resilience, most of which cover concepts such as the ability of a system to withstand and/or cope with disruption, disturbance or hazardous events. Many definitions also cover ideas such as adaptability and flexibility, as well as, early discovery and rapid recovery from failure. Some distinguish between bouncing 'back' and bouncing 'forward' from an event (Manyena et al, 2011).

A useful definition provided by NIU (2011) is as follows: *Resilience is defined as the ability to withstand disruption, absorb disturbance, act effectively in a crisis, adapt to changing conditions, including climate change, and grow over time*.

The concept of resilience has evolved over recent years, from an early ecosystem focus (Holling, 1973) to a focus on socio-ecological systems and disaster risk reduction (Gunderson, 2000; Walker et al., 2004), through to a more recent focus on resilience of infrastructure and the built environment (Bruneau, 2003; NIU, 2011; NIAC, 2010).

A holistic approach to *urban* resilience would necessarily cover all facets relating to the urban environment, as summarised by the diagram below. Each specific area is its own area of specialism, with a wide range of attributes / indicators having been proposed by different authors.

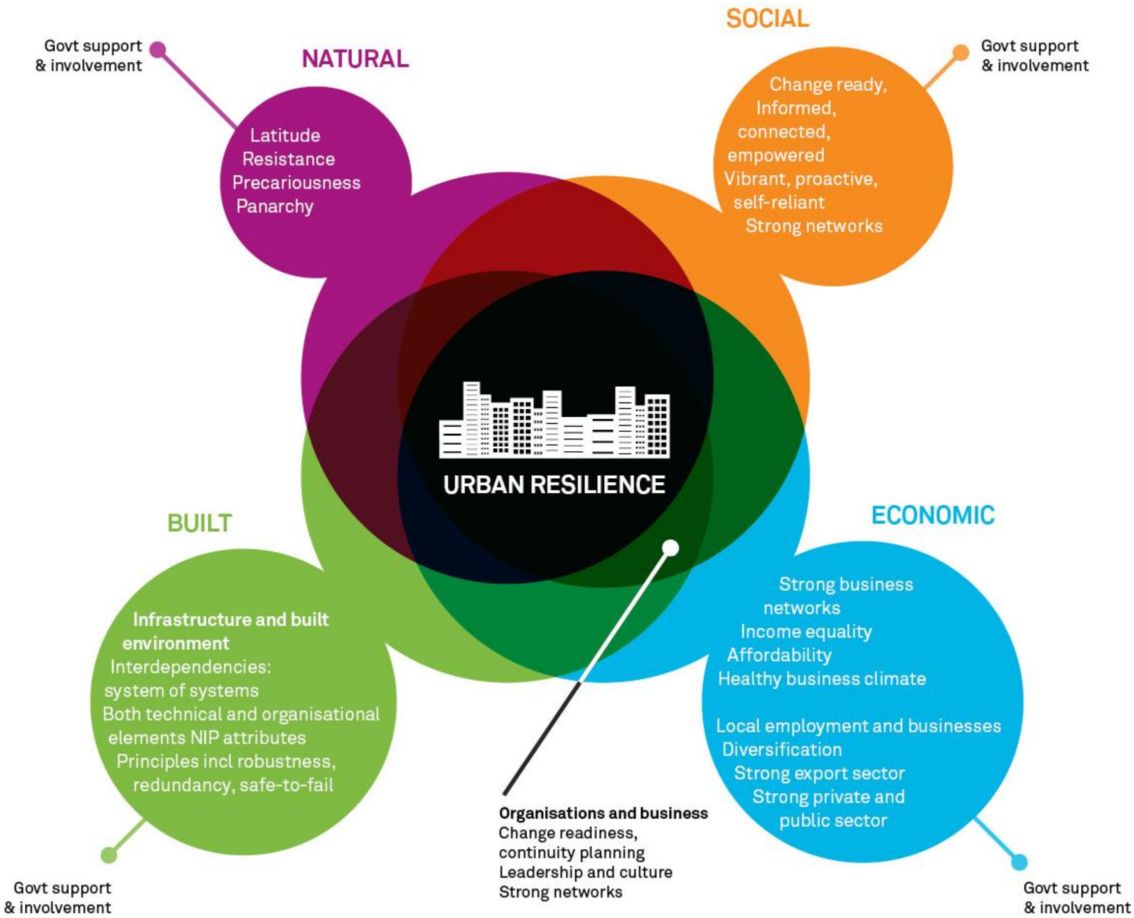

Figure 2: Urban resilience schematic (author adapted from Chelleri et al, 2012)

Recent studies relating to resilience measurement / assessment have led to improvements in the understanding of which factors enhance resilience in societies and within the built environment and infrastructure. While there are a wide range of views on this, some common factors are emerging:

- Infrastructure resilience: Principles include: robustness, redundancy, modularisation, safe-to-fail, diversity and flexibility (Hughes & Healy, 2014; da Silva et al.,2012).
- Community and organisational resilience: Principles include: change readiness, strong networks, leadership and culture, situational awareness and responsiveness (Resilient Organisations, 2012; Lee et al, 2013).

These principles of resilience are discussed further in Section 7, specifically in the context of flood hazards.

5 LINKAGES TO OTHER FIELDS

With the increasing reliance on interdependent infrastructure and technologies that can be impacted by hazards such as flooding, there is a growing need to develop clear, integrated solutions to mitigate infrastructure and system failure, and the broader effects of hazards.

Efforts to address these complex problems originate from a wide range of institutions and agencies, and touch on an equally wide range of disciplines. These include: disaster risk management (DRM), asset management, civil defence and emergency management (CDEM), climate change adaptation, policy development, social sciences, economics, sustainable development, risk management, and resilience – among others.

Practitioners and researchers from each of these fields have developed their own conceptual models and unique sets of terms, parameters and definitions, and while efforts have been made to bring many of these disciplines together, the terms used are often confusing and overlapping.

These terms include: resilience, robustness, redundancy, sustainability, risk, hazard, vulnerability, sensitivity, exposure, likelihood, consequence and adaptive capacity, to name but a few. The definitions of some of these terms are often unclear, as are the relationships between many of them. In fact, terms may have different meanings when used within different fields of study.

A detailed analysis of each term and their inter-relationships was undertaken by Hughes and Sharman (2014). Of particular interest to the context of this paper are the linkages between the concepts of *sustainability* and *resilience*. This is discussed further below.

5.1 SUSTAINABILITY AND RESILIENCE

The sustainability of a system is a measure of its lifespan. Resilience is one measure of the potential sustainability of a system; so, resilience is to sustainability what, say, blood pressure is to health. Since resilience is a component of sustainability, the opportunity should exist to do both things simultaneously (McRoberts 2010).

Much research has been undertaken regarding the linkages between sustainability and resilience, and in a variety of different contexts – such as green growth, urban design and land-use planning. Beatley (1998) suggests 'a sustainable community is a resilient one; it is a community that seeks to understand and live with the physical and environmental forces present at its location'. Saunders (2010) highlights the importance of sustainable urban design, land-use planning and building codes in delivering resilient communities.

Godschalk (1999) proposes: 'To sustainability's economic, environmental protection and social criteria is added a fourth criterion – sustainable development which must be resilient to the natural variability of the earth'.

Given the large and arguably incontrovertible weight of evidence pointing to humanity's influence on global warming and climate patterns, and our on-going modification and destruction of ecosystems and landscapes, it is clear that unsustainable practices have resulted in many communities becoming non-resilient and vulnerable.

Mitigation, by way of halting or reversing these unsustainable practices, is an obvious approach that is advocated by many, however for a variety of reasons has, to date, been largely unsuccessful.

Adaptation, therefore, has risen to prominence, which perhaps has, at its core, a belief that our unsustainable practices can continue, meaning communities will remain vulnerable; however; we can adapt and 'engineer' to build resilience nonetheless.

A third approach suggested, could be called 'transformation' (which perhaps is more challenging than mitigation), and involves re-imagining and transforming our communities around a new functional regime.

The following diagram (Figure 3) aims to integrate these concepts over the short term (shock event), through to the longer term (new shock or stress event). This diagram utilises the 'ball-in-cup' model (Holling, C.S. et al. 1995) and incorporates the 'bounce forward' idea of resilience (Manyena et al, 2011). A typical resilience response to a short term shock event, would be to focus on 'robustness' and bounce *back* to the status quo. This can raise the risk of locking in dependency on poor, non-resilient or perhaps unsustainable approaches. Instead, it is suggested that by planning and providing adaptable/flexible solutions, a community or system could bounce *forward* from a shock event and into a new state/paradigm. This new paradigm would be more adaptable and more resilient to both new shock events and stress events. It is suggested, this *transformation,* over the long term, approaches the concept of sustainability.

In the context of flood prevention, evidence points to the multiple benefits that green infrastructure (water sensitive urban design) can achieve both in buffering flood events (increasing resilience), and providing long term stormwater quality/quantity improvement, urban heat island reduction, biodiversity and amenity etc – that is a more *sustainable* outcome.

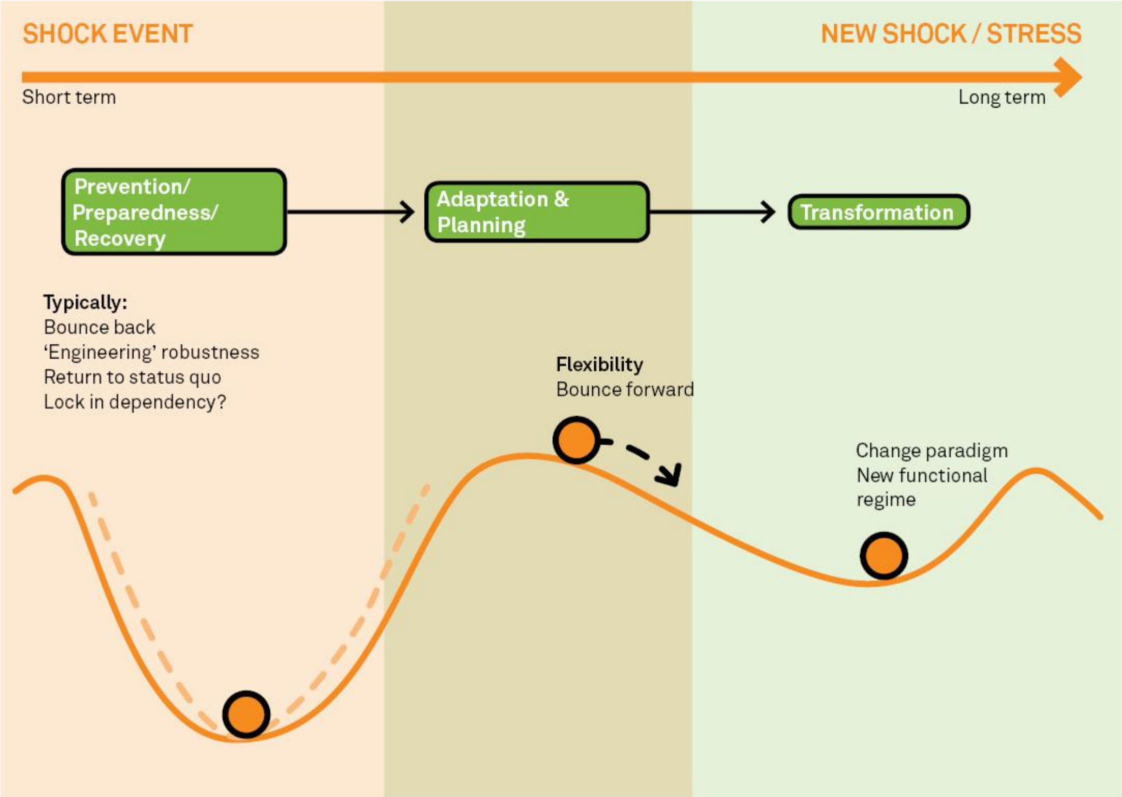

Figure 3: Temporal aspects of resilience

In summary, sustainability and resilience are clearly related topics. There are growing numbers of examples where resilience improvements have also led to gains in terms of sustainability. This is evident, for example, in the fields of green infrastructure design (Ahern, 2010; Hawkins and Prickett, 2014), decentralised infrastructure provision, and climate change mitigation.

6 FLOOD HAZARDS AND IMPACTS

6.1 FLOOD HAZARDS AND UNCERTAINTY

Recent events globally have highlighted:

a) a failure to predict extreme events (including floods), and their consequences, and;

b) an inability to understand the complex systems impacted by hazards and the potential range of failure possibilities.

Flood hazards are relatively unique in the sense that there exist relatively sophisticated methods for forecasting their occurrence (albeit with short periods of warning), and modelling potential flooding extents (computer modelling).

However the methods and models used only provide *estimates* of flood magnitudes and extents. There are a vast range of assumptions, limitations and unknowns, both in terms of the rainfall data used and how rainfall intensities may vary due to climate change, the way it transforms to runoff, and is conveyed via drainage systems to an outfall.

As pointed out by Reece (2006) *"Urban hydrology is a compromise between accuracy and data availability. And as Murphy would have it, a densely populated urban setting is the one place a designer would most want to be accurate in flooding predictions, and is also the one place where accuracy is often least possible to attain."*

Schnoor (2008) explains how large uncertainties in river management arise from: (1) the inherent stochastic nature of hydro-climatic forcing, (2) nonstationarity in such forcing (e.g., land use and land cover changes, precipitation changes, and climate change; additional infrastructure changes), and (3) absence of adequate long-term records to reliably predict the occurrence of extreme flood events, such as 100-year or 500-year events.

In saying this, designers and engineers who understand both the sensitivity of: a) modelling outputs to inputs and assumptions, and; b) on-the-ground flood levels/extents to changes in those inputs and assumptions, will be able to quantify risk more meaningfully and in a way which enables sound decision-making.

6.2 IMPACTS ON INFRASTRUCTURE AND PROPERTY

Flooding can have wide ranging impacts on property and critical infrastructure. Impacts can either be direct (e.g. flooded properties), or indirect (failure through interdependent infrastructure linkages).

In general, we have a poor understanding of how failures can propagate and amplify within and across complex systems. Risks can emerge through both linear (cascade) and non-linear interactions among internal system components and external factors/events. In the latter case, failures generally only become observable after they occur.

When assessing the resilience of assets to hazards such as flooding, it is important to consider the relevant interdependencies with, for example, other utility services and the range of possible failure modes.

7 FRAMEWORKS FOR UNDERSTANDING FLOOD RESILIENCE

This section presents a number of frameworks developed by various authors which seek to clarify and conceptualise resilience in the context of flood hazards. It is noted there are a large number of frameworks which have been published. The ones presented below have been chosen for their diversity in representing alternative approaches to this complex issue.

Broadly speaking, all the frameworks include high level 'dimensions' for resilience, followed by more detailed 'principles'. It is anticipated that strategies or even measures could be developed that sit below these principles. Refer Figure 4 below.

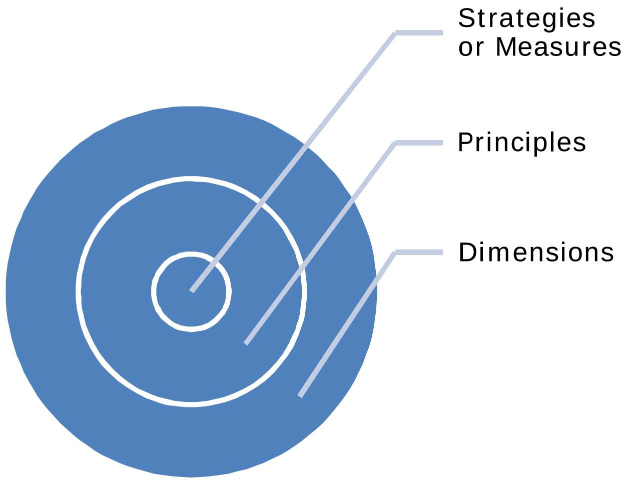

Figure 4: Dimensions, principles and strategies/measures

It is noted that a number of frameworks divide resilience dimensions into the equivalent of 'hard' and 'soft' systems, hard systems pertaining to the technical and mechanical capabilities of infrastructure and organisations, and soft relating to the human needs, behaviours and psychology within organisations and communities.

A number of detailed examples are presented below.

7.1 T.O.S.E. AND THE FOUR 'R'S

Bruneau et al (2003) developed four dimensions of resilience: technical, organisational, social and economic (TOSE). They note that these four TOSE dimensions cannot be measured by any single performance measure; instead they require different measures for each system under analysis. Related to these dimensions they also developed four 'R' principles which are: robustness, redundancy, resourcefulness and rapidity.

Robustness relates to the strength, or the ability of elements, systems and other units of analysis, to withstand a given level of stress or demand without suffering degradation or loss of function.

Redundancy relates to the extent to which elements, systems, or other infrastructure units exist that are substitutable, i.e. capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality (Bruneau et al 2003).

Resourcefulness relates to the capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis.

Rapidity relates to the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption.

This framework was developed initially in relation to earthquake hazards, however is considered broadly applicable across other hazard types including flooding.

7.2 THE RESILIENCE ACTION INITIATIVE FRAMEWORK

The Resilience Action Initiative (Albani and Kupers, 2014) have developed a framework that covers the areas as detailed below.

Table 1: Resilience Action Initiative Framework

Structural resilience	Integrative resilience	Transformative resilience
Redundancy	Multi-scalar interactions	Distributed governance
Modularity	Thresholds	Foresight capacity
Requisite diversity	Social capital	Innovation and experimentation

Structural resilience focuses on the structural elements which build resilience of the system itself, with a view to improve system performance continuity: This includes redundancy or putting buffers or spares in the system, modularity to separate components and avoid a cascade of failures and requisite diversity in those dimensions that are relevant for this particular system at this particular time.

Integrative resilience emphasises the complex interconnections within and between 'hard' and 'soft' systems and across scales. This includes multi-scale interaction, feedback loops between scales, thresholds or discontinuities at which point the system goes through a step change and social capital describing the accumulated capacity for bottom-up self organization of a society to respond to stress.

Transformative resilience adds a longer time scale and thus opens the range even more, to ensure and enhance a system's transformability. This includes distributed governance in order to tap into the self-organising capacity beyond straightforward top-down interventions, the foresight capacity to have a process to include irreducible uncertainties into the envisaged solutions, as well as innovation and experimentation as enablers through learning-by-doing.

7.3 ZURICH FLOOD RESILIENCE ALLIANCE

Keating et al (2014) have done extensive research into flood resilience, and have developed an holistic framework based on five community 'Capitals' as illustrated in Figure 5 below.

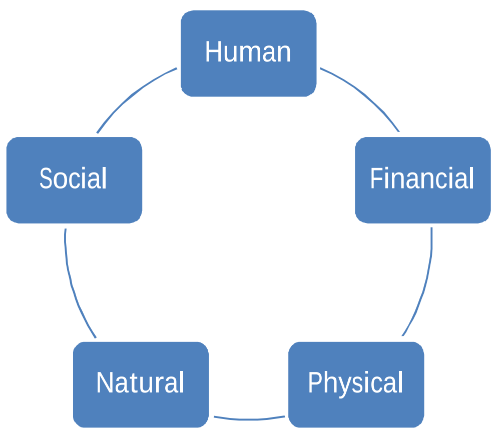

Figure 5: The 5 capitals for community flood resilience

The 5 capitals can provide significant data about a community's resilience providing a holistic picture of a community's resilience level. The capitals include:

- Physical (things produced by economic activity from 'other' capital, such as infrastructure, equipment, improvements in crops, livestock, etc.)
- Financial (level, variability, diversity of income sources and access to other financial resources that contribute to wealth)
- Human (education, skills, health of people)
- Social (social relationships and networks, bonds that aid cooperative action, links to exchange and access ideas and resources)
- Natural (natural resource base, including land productivity and actions to sustain it, as well as water and other resources that sustain livelihoods)

This framework provides a system and a type of matrix to measure the sources of community flood resilience. It can allow comparisons within and across communities to assess resilience in relation to floods.

7.4 NZTA RESILIENCE FRAMEWORK

In 2013 the New Zealand Transport Agency commissioned a research study to develop a resilience framework for the transport network (Hughes and Healy, 2014). The framework included the two specific dimensions (technical and organisational) and a range of principles as illustrated in Table 2 below, as well as a series of around 90 specific qualitative measures categorised across the various principles.

The two resilence dimensions can be further described as follows:

Technical resilience: the resilience of assets or physical infrastructure system elements to shocks or stresses.

Organisational resilience: the resilience of the organisation(s) responsible fo the planning, design, operation and maintenance of the infrastructure system.

The framework was developed to be applicable at an individual asset scale, or at a broader network scale, and enabled scores to be applied for each measure, and then aggregated and weighted as required. The intent of the measurement tool was to enable a clear view of deficiencies and to allow prioritisation of improvements or areas of focus.

Table 2: Resilience assessment framework (Hughes and Healy, 2014)

Dimension	Principle	Comment
Technical / Asset	Robustness	Strength, or the ability of elements, systems, and other units of analysis, to withstand a given level of stress or demand without suffering degradation or loss of function.
	Redundancy	The extent to which elements, systems, or other infrastructure units exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality.

	Safe-to-fail	The extent to which innovative design approaches are developed, allowing (where relevant) controlled, planned failure during unpredictable conditions, recognising that the possibility of failure can never be eliminated.
Organisational*	Change readiness	The ability to sense and anticipate hazards, identify problems and failures, and to develop a forewarning of disruptive threats and their effects through sourcing a diversity of views, increasing alertness, and understanding social vulnerability. Also involves the ability to adapt (either via redesign or planning) and learn from the success or failure of previous adaptive strategies.
	Networks	The ability to establish relationships, mutual aid arrangements and regulatory partnerships, understand community interconnectedness and vulnerabilities across all aspects of supply chains and distribution networks, and; promotes open communication and mitigation of internal / external silos.
	Leadership and culture	The ability to develop an organisational mind-set/culture of enthusiasm for challenges, agility, flexibility, adaptive capacity, innovation and taking opportunity.

* Resilient Organisations (2012)

7.5 STRATEGIES FOR RESILIENCE BY JACK AHERN

Ahern (2010) published a detailed approach to planning and design for both sustainability and resilience within cities – with a particular focus on water and water sensitive design. He emphasises the importance of ecosystem services in delivering both these outcomes, and stresses that resilience is a strategic way of thinking about sustainability, and by definition, must be: a) informed by the environmental, ecological, social and economic drivers and dynamics of any particular place, and; b) must be integrated across a range of linked scales.

In a subsequent paper (Ahern, 2011) he adds the concept of 'safe-to-fail' to his recommended approach (refer also Section 4 above). He uses this term in two contexts:

1) Systems design: 'Safe to fail' involves anticipating failure and requires strategic systems design so that failure is contained and minimized.
2) Innovation: For urban planning and design to be truly innovative and adaptive in its pursuit of sustainability and resilience, it has an inherent potential to fail. To reduce the risk of failure, innovations can be "piloted" at a small scale, as 'safe-to-fail' design experiments.

The following table summarises Ahern's 'strategies for resilience'.

Table 3: Strategies for resilience (Ahern, 2011)

Strategies	Attributes	Examples
Multifunctionality	Multiple 'intertwined' benefits - for example flood management, water quality, bio-diversity. Spatially efficient to work with	Green streets programmes. Multi-functional wetlands. Flood plain parks.

	constrained urban areas. Economically efficient. Builds a constituency of social / political support associated with the multiple functions.	
Redundancy and modularisation	Risk-spreading across time, geographical areas and across multiple systems. Allows for back-up functionality. Metasystems (system of subsystems) which are decentralised, flexible and adaptable. Able to 'contain' disturbance.	Site or precinct based stormwater, waste water and grey water systems. These can result in reduced piped flows and potentially reduced combined sewer overflows. Other forms of decentralised infrastructure.
Bio (and social) diversity	Differential response to disturbance and stress. Bio-library of knowledge and memory. Complementarity of resource requirements.	Low impact development practices such as permeable pavement and bioswales, and urban tree canopy to intercept rainfall before it reaches the ground. Each feature adds to the response diversity of the urban stormwater system, reducing the amount of storm drainage infrastructure that a city needs to build and maintain, and enhancing the overall resilience capacity of that system. Similarly, an economically and socially diverse city can support social services and cultural programs that keep it economically vibrant, equitable, and attractive place for people to live and work.
Multi-scale networks and connectivity	Redundant 'circuitry' that maintains functional connectivity after network disturbance. Blue-green networks that support biodiversity, hydrological processes, pedestrian transportation, climatic modification, neighborhood identity and aesthetic enhancements.	Walking trails that link with bus routes, or urban drainageswales that connect to non-channelized low-order streams, that, in turn, link with higher-order streams. Can also apply to social and organisational networks.
Adaptive planning and design	Actions as opportunities for experimentation, prototyping, innovation. 'Learning by doing', 'safe-to-fail' design experiments.	New planning processes (for example the 'Kamo Place Race' in New Zealand.

7.6 DISCUSSION

In the previous sections we have identified a range of resilience frameworks that have been developed by various authors, each of which are slightly different in their focus and application.

Below we summarise a range of broad considerations and commonalities across the frameworks and consider how these may be integrated in the context of flood mitigation:

Resilience of what? It is important to consider what the focus of flood resilience activities are. For example a focus could be on resilience of communities, property, or critical infrastructure to flood hazards. Critical infrastructure could include lifelines utilities (e.g. power, water, transportation routes) or key flood protection infrastructure itself (culverts, drainage systems, channels, levees etc).

Resilience to what? To answer this question in the context of flood hazards, planners and decision makers need to critically assess their understanding of and approach to modelling flood hazards, and which magnitude events they plan for. This needs to be done with both an understanding of climate risk, and those geographical, environmental or social factors which may amplify the consequences of extreme flood events. For example, in areas of particularly social vulnerability, within narrow flood plains, perhaps a more conservative (and extreme) storm event needs to be planned for.

Resilience dimensions and principles: At a broad level, resilience dimensions should include a focus on both technical / or design factors, community and organisational resilience. The technical aspects should be considered in the broadest context, including both 'hard' and 'soft' approaches to design of infrastructure and property.

A broad range of principles have been developed by various authors, as described in previous sections. Many overlap, and we suggest below a consolidated number of principles as being representative within the context of flood hazards, and which link to the dimensions above.

Governance and integration of approaches: At a high level, it is vital that appropriate leadership and governance is provided to enable resilience improvements. This includes appropriate 'top-down' decision-making, yet also allowing community-led approaches that are tailored and specific to individual locations and risks faced by these communities. The integration of public, private and community sectors and well as the various relevant disciplines including; urban planning, flood management, disaster risk management is key.

Figure 6 below offers a draft framework for flood resilience that brings together many of the key ideas developed above.

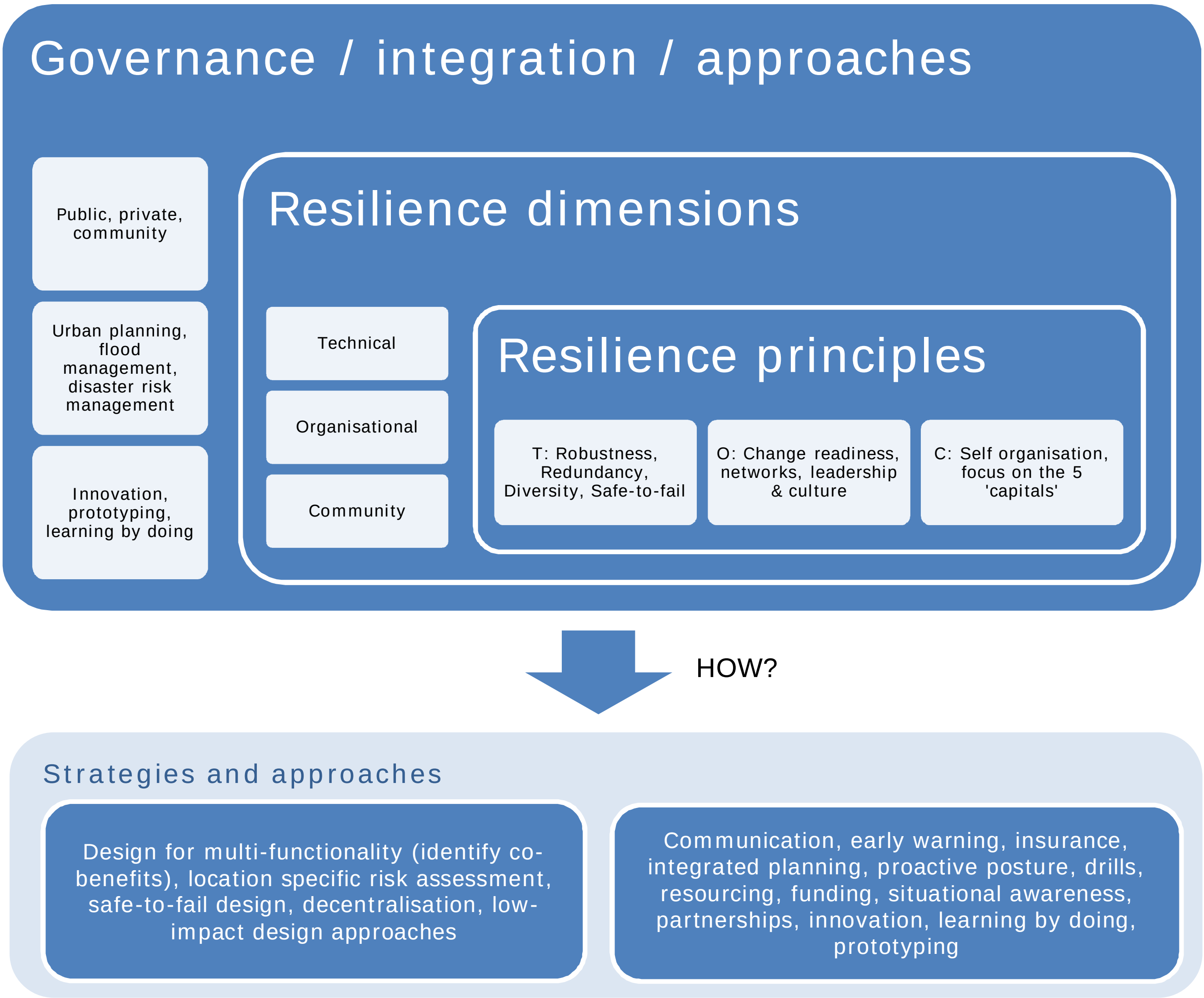

Figure 6: Draft framework for flood resilience

Linkages with long term sustainability: It is important that planners and decision-makers take a long-term view and consider broader environmental sustainability when developing solutions for flood management. If these are co-designed with communities, and are integrated with land-use planning processes, then urban areas have the potential to be both resilient to extreme flood events, and also provide for long term social and environmental well-being. Low impact (green) design, and decentralised infrastructure are potential avenues to achieving these multiple objectives. Essentially, approaches which instead of 'fighting against the water' look to provide 'room for the water' are what are called for.

Adaptability, learning by doing, prototyping: In order to achieve meaningful change in what is a complex area, a shift needs to occur from a traditional, centralised approach to flood management and planning, to a more experimental and open approach. This would combine the scientific, historical and institutional knowledge within government agencies with the location-specific challenges faced by communities and the unique settings (environmental, social, cultural) in which each community exists. A new approach would be adaptable and flexible, and would embrace innovation - with a focus on “soft” options that increase the flexibility of a system and enhance its adaptive capacity, also known as “low-regret strategies” (Fankhauser et al., 1999; IPCC, 2012).

Scale: When it comes to implementing *technical* flood resilience improvements, it is important to be aware of different scales of action and the relevant challenges associated with each. Simplistically, scale could be categorised as follows:

a) Catchment or sub-catchment scale: Approaches at this scale may involve large scale flood defences or stream works/improvements.

b) Neighbourhood scale: Approaches may include overland flow path improvements, stream works, flood defences, property raising etc.

c) Property scale: Approaches at this scale can involve a variety of interventions – including: property raising, local permanent flood diversions / defences, temporary, flood exclusion means (eg barriers).

8 CASE STUDIES

As illustrated in preceding sections, building resilience to floods is complex and requires consideration and integration of a vast range of different elements. Worldwide, there are countless numbers of individual projects and actions which demonstrate how improvements can be made in both a technical and societal sense. Some are discussed further below.

8.1 BOULDER COLORADO

Due to the foresight of Gilbert White, known as ‘the father of floodplain management’, Boulder has been holistically planning for floods for decades. Boulder is prone to flash flooding and has had a number of catastrophic events in the past – including the ‘Big Thompson Flood’ of 1976 and the recent 2013 floods, estimated to be a 1 in 1000 year event.

Boulder has progressively taken an approach expounded by White – in which the central philosophy is that cities should *accommodate* floods and allow the water to pass through as easily as possible, rather than trying to hold them back with dams and levees.

Some examples of strategies include:

- Focus on good land-use planning and stewardship, rather than large engineered solutions. Buildings relocated from the flood plain (or above the flood plain), and rip rap, planting and cascades used to control and manage peak flows.
- ‘Breakaway bridges’ over major creeks. These have large hinges that allow the bridge to swing parallel to the creek and avoid the impact of major floods and associated debris. This benefits not only the conveyance capacity of the waterway, but also prevents costly damage to the bridge.
- Cycle paths constructed beneath bridges and within flood plains. In spring, when flows are high, most of the paths are submerged during relatively regular flood events.

Figure 7: Boulder cycle path and flood plain

Refer: http://nextcity.org/features/view/you-cant-stop-urban-flooding

8.2 COPENHAGEN CLOUDBURST MANAGEMENT PLAN

As a result of floods in 2011, and an acute awareness of climate risk, Copenhagen and the neighboring municipality of Frederiksberg are investing heavily in protecting the city against future extreme weather. They are also on the leading edge of urban innovation with a vision of transforming their city into a sustainable, $C0_2$ neutral city by 2025.

The 2011 floods were a ‘game-changer’ for Copenhagen, resulting in significant national attention, and fast implementation of new approaches, including financing.

Figure 8: Copenhagen floods 2011

The city and its partners have since developed a comprehensive *Cloudburst Management Plan* based on detailed catchment modelling and planning. This approach recommends a new generation of blue-green infrastructure to enhance essential city services such as mobility, recreation, safety and biodiversity, creating a feasible strategy to ensure long-term resilience and economic buoyancy.

Key features of the plan include:

- A focus on overland flow, rather than bigger pipes. Overland flow designed down the centre of roads, rather than within a kerb and channel on the edges.
- Focus on green streets, retention and low impact (water sensitive) design.
- Integration of overland flow with parks, open space, streets and shared spaces.
- Retaining as much water as possible in the highest elevation areas
- Create robust and flexible drainage for the main depressions
- Create value for the city by blue/green solutions on the surface
- Added value through multifunctionality: improved recreational value and biodiversity, meeting places, improved microclimate, synergy with traffic planning, accessibility.

Some images from the management plan are shown in Figure 9 below.

Figure 9: Conceptual flood adaptation ideas

Source: http://www.ramboll.com/media/rgr/copenhagen-cloudburst-solutions

8.3 QUEENSLAND FLOODS 2008, 2011, 2013

Queensland has been subject to a number of major floods in recent times – in 2008, 2011, 2013. These impacted (often repeatedly) on a number of specific settlements, causing significant damage – including property and infrastructure damage, and loss of life.

The ongoing flooding has caused residents and media to openly criticise local government for being largely reactive to the flood events, and not adapting or changing the way that the settlements are planned, or the events managed.

Figure 10:   Queensland floods

Below are some findings summarised from a number of studies and surveys into the flood responses over the years (Bird et al, 2013; NCCARF, 2008):

- Risk: Many residents were aware that their home was vulnerable to flood yet very few tried to protect their house with sandbags. There was a widely held complacency that dams and protection works had had 'flood proofed' areas, and that the risk should have been minimal.
- Insurance: Many residents were renting flood-affected houses with no flood insurance, as there were no other options available to them. During the rebuild, many insurance companies did not support or encourage improvements to reduce flood impact.
- Areas with long-established residents, with strong connections within the community, and possibly prior experience of flood events, generally display greater resilience in a flood event.
- When re-building after the floods, many residents opted to rebuild 'better' (i.e. upgrade old with more desirable) instead of rebuilding with the aim of becoming more resilient to floods. Few people understood that building a more flood resilient home may possibly increase value of those located in flood hazard zones (by, e.g., replacing carpet with tiles, raising air conditioning units and power points).
- Despite many people believing in the likelihood of a flood in the next 10 years, many do not intend to make changes to reduce their risk. Of those who indicated they would consider changes, the most popular methods were to modify insurance policies, improve garden drainage and build permanent barriers around properties, which could prove difficult due to local government restrictions. Respondents whose wellbeing suffered after the flood perceive that they are less able to make changes to reduce flood risk compared to others in their community.
- There was widespread dissatisfaction of how the flood responses had been handled; a number believed that other unaffected parts of affected areas had 'moved on' while they continued to deal with the flood's aftermath. The emotional stress of the flood event and recovery process has had an impact on wellbeing, with large proportions of men reporting that the flood had negatively affected their wellbeing, in terms of at least one of the following factors: relationships with family / friends, financial status, physical health, mental health, and general happiness.

- While cynicism towards insurance and the local council were very common, there was a strong feeling of resilience in the community. Many respondents talked of how much closer they felt to their neighbours and wider community, expressing that, while the flood was a negative experience, it had produced some positive outcomes.
- A dominant finding from studies was that a greater number of constraints inhibit adaptation than factors that enable adaptive change and behaviour. Balanced against the criticisms and fault identification the study showed that resilient communities do get on with their lives and largely drive recovery themselves. The extensive qualitative comments and opinions garnered from interviews and questionnaires reflect high levels of acceptance of catastrophe and stoic endurance. This does not necessarily translate to adaptation to future events and a changed hazard landscape, but it does reflect strong resilience in the community.
- There was a recognised need to facilitate community involvement in volunteer organisations and identify vulnerable community members. Education, information and communication campaigns are required to address community inexperience and indifference.

9 SUMMARY AND CONCLUSIONS

Climate change and continuous urbanisation contribute to an increased risk associated with flooding. Relying solely on traditional flood control measures is largely considered inadequate, as the damage can be catastrophic if flood controls fail.

Approaches to improving flood-resilience are emerging and there are a vast number of case studies worldwide – which demonstrate successes and failures. What is clear however, is that a completely ‘flood-proof’ city is an impossibility. The uncertainty around our understanding of rainfall, and the consequential flooding in our evolving urban environments, means that risk will always be present.

We need to accept, and ‘live with’ the water, instead of ‘fighting against’ floods through the construction barriers and defences.

Admittedly, realizing these changes is an extremely long-term and difficult prospect, given our history and attachment to development in flood prone areas adjacent to rivers and coastlines.

Based on the research presented within this paper, it is evident that a multi-pronged approach is needed, over the long term. This approach needs to address the technical, organisational and community dimensions of building resilience in an integrated manner. It needs to be forward-looking and experimental in trialing new ways of working with community to develop location-specific interventions. It needs to embrace multi-functionality and diversity to deliver long term sustainability outcomes as well as resilience outcomes.

A new model of working together is clearly required, across governments, councils, communities and the private sector if we are to effectively deal with our most pressing resilience challenges – of which flooding is most definitely one.

REFERENCES

Ahern, J. (2011). From fail-safe to safe-to-fail: sustainability and resilience in the new urban world. Landscape Architecture & Regional Planning.

Ahern, J. (2010). Planning and design for sustainable and resilient cities: theories, strategies and best practices for green infrastructure. In: Novotny, V., Ahern, J., Brown, P. (Eds.), Water-centric Sustainable Communities. John Wiley and Sons, Hoboken, pp. 135–176.

Albani, M and Kupers, R (2014). A pragmatic frame to explore resilience. In Turbulence, A Corporate Perspective on Collaborating for Resilience. Amsterdam University Press, pp 87-100

Beatley, T (1998) The vision of sustainable communities. Chapter 8 in Cooperating with nature. R Burby (Ed). Washington, DC: National Academy Press, Joseph Henry Press.

Bird, Deanne, Box, Pamela, Okada, Tetsuya, Haynes, Katharine, and King, David (2013). Response, recovery and adaptation in flood-affected communities in Queensland and Victoria. Australian Journal of Emergency Management, 28 (4). pp. 36-43.

Bruneau, M, S Chang, R Eguchi, G Lee, T O'Rourke, A Reinhorn, M Shinozuka, K Tierney, W Wallace and D von Winterfelt (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. EERI Spectra Journal 19, no.4: 733–752.

Chelleri, L (2012). Lessons for Urban resilience from Delta Urbanism. The Dutch Polders Case. Multidisciplinary perspectives on urban resilience. Basque Centre for Climate Change

Croope, S (2010). Managing critical civil infrastructure systems: improving resilience to disasters. PhD dissertation, University of Delaware.

da Silva, J., Kernaghan, S., Luque, A (2012). A systems approach to meeting the challenges of urban climate change

Fankhauser, S., Smith, J.B. and Tol, R.S.J. (1999). 'Weathering Climate Change: Some Simple Rules to Guide Adaptation Decisions', Ecological Economics 30, 67-78

Godschalk, DR (2002). Urban hazard mitigation: creating resilient cities. Urban Hazards Forum, John Jay College, City University of New York, January 2002.

Godschalk, DR, T Beatley, P Berke, DJ Brower and EJ Kaiser (1999). Natural hazard mitigation: recasting disaster policy and planning. Washington, DC: Island Press.

Gunderson, L.H. (2000). Resilience in theory and practice. Annual Review of Ecology and Systematics 31, 425–439.

Hawkins, N and Prickett, G (2014). The case for green infrastructure. In Turbulence, A Corporate Perspective on Collaborating for Resilience. Amsterdam University Press, pp 87-100

Holling, C. (1973). Resilience and Stability in Ecological Systems, Annual Review of Ecology and Systematics 4: 1-23.

Holling, C.S. et al. (1995). Biodiversity in the functioning of ecosystems: an ecological synthesis. In Biodiversity Loss, Ecological and Economical Issues (Perrings, C.A. et al., eds), pp. 44–83, Cambridge University Press

Hughes, JF and K Healy (2014). Measuring the resilience of transport infrastructure. NZ Transport Agency research report 546, 82pp.

IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

Keating, A., Campbell, K., Mechler, R., Michel-Kerjan,E., Mochizuki, J., Kunreuther, H., Bayer, J., Hanger, S., McCallum, I., See, L., Williges, K., Atreya, A., Botzen, W., Collier, B., Czajkowski, J., Hochrainer, S., Egan, C. Operationalizing Resilience against Natural Disaster Risk: Opportunities, Barriers, and a Way Forward for Zurich Flood Resilience Alliance

Lee, A, J Vargo and E Seville (2013). Developing a tool to measure and compare organisations' resilience. Natural Hazards Review 14, no.1: 29–41.

Manyena, S, G O'Brien, P O'Keefe and J Rose (2011). Disaster resilience: a bounce back or bounce forward ability? Local Environment 16, no.5: 417–424.

McRoberts, N (2010). Sustainability and resilience demystified. Accessed February 2013, www.knowledgescotland.org/briefings.php?id=116

Ministry for the Environment (2008). Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand. 2nd Edition. Mullan B; Wratt D; Dean S; Hollis M; Allan S; Williams T, Kenny G and MfE. Ministry for the Environment, Wellington. xviii + 149 p.

National Climate Change Adaptation Research Facility (2008). Historical case studies of extreme events. The 2008 Floods in Queensland: Charleville and Mackay

National Infrastructure Advisory Council (NIAC) (2010). A framework for establishing critical infrastructure resilience goals. Final report and recommendations by the council. Washington DC.

National Infrastructure Unit (NIU) (2011). National infrastructure plan 2011. Wellington: National Infrastructure Unit, The Treasury.

Reese, Andrew J. Voodoo Hydrology. Stormwater (July-August 2006) http://www.stormh2o.com/july-august-2006/urban-hydrology-methods.aspx

Resilient Organisations (2012). What is organisational resilience? Accessed 15 February 2013. www.resorgs.org.nz/Content/what-is-organisational-resilience.html

Schnoor JL. (2008). Lessons from the flood. Environmental Science & Technology, 42(15):5379–5379

Walker, B.H., Holling, C.S., Carpenter, S.R., Kinzig, A.P. (2004). Resilience, adaptability and transformability in social–ecological systems. Ecology and Society 9 (2), 5 [online] URL http://www.ecologyandsociety.org/vol9/iss2/art5/.