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Water Sensitive Cities

Flood resilience in Water Sensitive Cities

Guidance for enhancing flood resilience in the context of an Australian water sensitive city

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Flood Resilience in Water Sensitive Cities
Guidance for enhancing flood resilience in the context of an Australian water sensitive city
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Summary

What is the issue?

Resilience has a variety of definitions, although these all share a commonality in referring to the ability of a system to recover from disturbance. Definitions vary regarding what ‘system(s)’ and as to what recovery means. Traditional considerations of ‘water sensitivity’ in the context of urban areas have often focused on the need to prevent water pollution from runoff and/or to maintain water resources, and now how water sensitive approaches can contribute to other societal needs such as alleviation of excessive heat and the liveability of urban environments. Whilst flooding has been an important consideration in the water sensitive city, the way in which resilience to flooding can best be incorporated in planning, designing and managing urban systems and services has only recently been considered.

There are a wide and diverse variety of perspectives on how best to plan and manage urban areas. Most water related perspectives focus primarily on flooding or water resources or diffuse pollution. Amongst others that include water systems, alternative perspectives start by aiming to promote biodiversity, ecosystem services or even public health. Planners and architects may focus on bringing new green spaces into cities or maximising the way in which existing green spaces are used, often with scant consideration of the related water needs and challenges. In addition to these, there are many other domain specific perspectives on the best ways of managing urban areas that include water related factors as secondary or even less important considerations.

What is this guidance about?

The issue addressed in this report is how best to ensure that flood resilience is appropriately included in planning and designing for water sensitivity. The guidance presented considers the meaning and place of flood resilience in water sensitive cities. A framework is set out to bring extremes of water management, both floods and droughts, under the same perspective and to include the wider benefit value that this can bring across urban planning and design. This perspective has been developed primarily in the Netherlands and through projects in Europe and this report considers how the ideas can be applied more broadly, especially in the context of an Australian water sensitive city. Starting from definitions of WSUD, water sensitivity and resilience, a vision and framework is developed to apply the concepts in a practical way to support water sensitivity.

What this guidance includes

The growing movement for WSUD provides inspiration for maximising the value and use of water in urban areas, together with an increasing consideration of flood and drought resilience. Dealing with flooding and droughts in a wise manner, can simultaneously optimise the use of all kinds of available resources and maximise the many benefits that may accrue due to the co-management of water and urban environments.

This report reviews various concepts: water sensitivity, water sensitive urban design, flood resilience, adaptation to changing external and internal drivers, and from this proposes four principles, emphasising the taking of opportunities as well as addressing the threats/risks:

1. Manage water to deal with both water scarcity and water excess
2. Manage and utilise the water cycle as locally as possible
3. Deal with water appropriately and synergistically within urban environments

4. Integrate water management effectively into the wider (urban) systems, services and utilities

The possibilities for and ways in which water can be used to maximise its wider value to society are also highlighted and included in the guidance.

The guidance for including flood resilience in water sensitivity planning and design is framed in a standardised way to include the following Phases:

A. Developing a vision, principles and objectives and understanding the drivers and consequences.
B. Identifying the opportunities, players and likely outcomes
C. Refinement of options under consideration and detailed analysis of these.
D. Selection of the preferred option(s), implementation and monitoring performance.

The guidance utilises a four domain perspective to classify the types of source event (e.g. rainfall magnitude; sea level) and the types of response – including utilisation; design; protection. The domains comprise the following in order of an increasing scale of disturbance events:

1. Day to day values: enhancing the value provided by options, awareness, acceptance and participation amongst stakeholders. Attention is given to the way urban space is used and perceived.
2. Technical optimisation and exceedance: where design standards apply. This considers mainly technical solutions to deal with defined design storms and river discharge events to prevent damage and meet service levels.
3. Urban resilience and spatial planning: involves dealing with extreme events, which become of necessity multi-disciplinary. Mitigating the impacts of future extreme events and allow adaptation to cope with future large events.
4. Regime change and beyond may provide opportunities to alter substantially how an urban area is laid out and how water systems are managed therein. Such a regime shift represents a loss of resilience of the system.

This approach relies on multiple use of spaces in urban areas for flood resilience and other functions. Guidance also provides the means to assess and value the wider benefits from multiple use and also multi-functional infrastructure.

Who is this guidance aimed at?

This guidance is mainly aimed at those with interests in and responsibilities for flood risk management, especially local government departments of urban planning, environmental and ecological management, urban drainage and water management. It is also relevant to the wide range of professionals working with water and those engaged in the delivery of other infrastructure, utilities and service systems that interact with water, such as highways. It is mainly of interest to those with a long-term planning agenda, who can benefit from the guidance and adopt the method set out for the realisation of projects within their respective domains.

What are the potential benefits?

The guidance presented here is intended to help decision makers and their advisers to ensure that all aspects of urban water systems and their interactions are included in any analysis and decisions made as a result of this. Recent advances in thinking and approaches to water sensitivity, flood resilience, adaptivity, ecosystem services and liveability have been brought together here in a unified approach to what was formerly disparate concepts. Using the guidance should ensure that not only are as wide a range as possible of considerations are taken into account, but also that value to society as a whole is maximised when wishing to ensure flood resilience in the water sensitive city.

Introduction

Although integrated water management (IWM) has been aspired to by many for decades, the popularity of trying to manage water as a cycle has grown rapidly since the early 1990s, despite there being no substantive examples of the delivery of IWM (e.g. Adamowicz, 2011). Such approaches are being used to maximise the quality and value of infrastructure investments and ensure legitimacy amongst the stakeholders. For example, there is a growing awareness that by using green infrastructure (Gaffin et al., 2012) many societal benefits can accrue in urban areas and at the same time ecosystem services can both be supported and also support human living. Several approaches to managing and using water more effectively and comprehensively are documented worldwide and the once contradictory vision that flood risk, water stress management and other uses of water have to be managed separately is being replaced by an integrated view that now sees the water cycle as a coherent and many faceted system to be utilised in harmony by humans and ecosystems.

Nonetheless, there is as yet no single view or model of integrated water management or any of the variants on managing the water cycle as a whole (Saeijs, 1991, USEPA, 2012) and one that provides the guidance required by practitioners or those responsible for managing aspects or the entirety of the water cycle. Various initiatives have been put forward to better manage the water cycle in an integrated way. Here, the concept of water sensitive urban design (WSUD) has been used, derived from pathfinding research and practitioner development in Australia and now in a number of countries worldwide (Wong and Ashley, 2006). Although in many cases, WSUD is being driven by the water sector, in its realisation that it cannot do things in isolation, there is an equally strong driver in the municipal sector to make cost savings and to develop synergies. This is exemplified in England where many municipalities are having to reduce their financial turnover by up to 30% over a five year period (ICLEI, 2011). In order to maintain their service to the communities that they serve, these organisations have to be more effective in the way that they work by better integration in everything that they do to manage their activities and maximise additional value. Such integration requires more effective ways of working together as well as finding new technical solutions (e.g. Dudley et al., 2013; van Herk et al., 2014).

The perspective of maximising benefits and value from any investment is developing worldwide at a rapid pace and needs to be considered when dealing with any aspect of water, as well as other systems, although the concept of 'value' is contested (e.g. Cornell, 2011). Therefore what is presented here is a framework that encompasses the vision, scale, scope and methodology for this, accompanied by specific guidance on how best to include multi-value benefits using a WSUD perspective and ensuring that flood resilience is an integral part of the approach. This framework has been adapted from Ashley et al. (2012; 2013); Rijke et al. (in press) and Salinas et al. (2014) and builds on the ideas of Fratini et al. (2012), and van Herk et al. (in press).

It is expected that the framework presented will remain usable notwithstanding advances in the way in which the wide range of benefits are included and incorporated into a benefit-cost evaluation or in the way in which water and flooding systems are analysed and managed. However, it is expected that tools and ideas for the assessment of benefits arising from using the opportunities presented by water systems will further evolve as new ideas emerge.

Water Sensitive Urban Design (WSUD)

Introduction to WSUD

Water sensitive urban design (WSUD) is a key part of the process that brings about Water Sensitive Cities as the outcome (Wong et al., 2012).

A Water Sensitive City is considered to be adaptive and resilient to broad-scale change (Wong and Brown, 2009). A Water Sensitive City would achieve this through planning for diverse and flexible water sources (e.g. dams, desalination, water grids and stormwater harvesting), incorporating Water Sensitive Urban Design for drought and flood mitigation, environmental protection and low carbon urban water services in the planning system, and enabling social and institutional capacity for sustainable water management. It would also provide attractive, comfortable, safe and liveable environments (de Haan et al., 2014).

Wong et al. (2012) state that WSUD is a term commonly used to reflect a new paradigm in the planning and design of urban environments that are “sensitive” to the issues of water sustainability and environmental protection. WSUD as a framework for sustainable urban water management is well founded and its application may result in improvement of technologies in connection to stormwater quality (Wong and Brown, 2009). However, the innovation in technologies is not sufficient by itself, and institutional capacity for advancing sustainable urban water management is also required to advance WSUD.

There is no single and common definition of WSUD amongst researchers and practitioners, mainly due to the wide variability of application of this concept. Initially defined in Australia, the term is now being revisited internationally in a number of countries (e.g. Potz & Bleuze, 2012; Ashley et al., 2013). The Australian National Water Initiative defines WSUD as “the integration of urban planning with the management, protection and conservation of the urban water cycle that ensures that urban water management is sensitive to natural hydrological and ecological processes” (COAG, 2004).

As stated by Wong and Ashley (2006), the term comprises two important parts: “water sensitive” and “urban design”. A new paradigm is defined by the words Water Sensitive by the integration of various disciplines of engineering and environmental sciences associated with the provision of water services including the protection of aquatic environments in urban areas. In already urbanised areas, being more 'water sensitive' means that residents, community organisations, businesses and land developers and governmental organisations value water as a finite and vulnerable resource that is critical the liveability of livelihoods, and that this is reflected in their behaviours related to dealing with water resources. These behaviours should, ideally, be supported and reinforced through investing in 'adaptive, multi-functional water sensitive infrastructure and urban design' incorporated into new and existing buildings, landscaping, streetscapes and open spaces. Urban Design is a well-recognised and established branch connected to planning and architectural design of urban environments working fields that traditionally have been considered peripheral to much of the water field (Digman et al., 2014).

WSUD looks for the incorporation of integrated water cycle management in which community values and aspirations of urban places govern urban design decisions and therefore water management practices (Wong et al., 2013). Within the definition of the Water Sensitive City, resilience of the systems has been incorporated and highlighted as key components for decision making (Wong et al., 2013). In Table 1 a comparison of the main attributes of traditional and water sensitive approaches are presented. The critical need for a transition towards SUWM is exacerbated considering the risks posed to cities from climate change and population growth (Keath and Brown, 2009).

Table 1. Comparison of attributes of traditional and water sensitive approaches

Attributes	Traditional approach	Water Sensitive Approach
System boundary	Water supply, sewerage and flood control for economic and population growth and public health protection	Multiple purposes for water considered over long-term timeframes including waterway health and other sectorial needs (i.e. transport, recreation/amenity, micro-climate, energy, food production, etc.)
Management approach	Compartmentalisation and optimisation of single components of the water cycle	Adaptive, integrated, sustainable management of the total water cycle designed to secure a higher level of resilience to future uncertainties in climate, water services requirements while enhancing the liveability of urban environments
Expertise	Narrow technical and economic focused disciplines	Interdisciplinary, multi-stakeholder learning across social, technical, economic, design, ecological spheres, etc.
Service delivery	Centralised, linear, and predominantly technologically and economically based	Diverse, flexible solutions at multiple scales via a suite of approaches (technical, social, economic, ecological, etc.)
Role of public	Water managed by government on behalf of communities	Co-management of water between government, business and communities
Risk	Risk regulated and controlled by government	Risk shared and diversified via private and public instruments

Source: (Keath and Brown, 2009)

Flood resilience

Like Water Sensitive, the term resilience is used in a variety of ways. Resilience has been defined in at least three major ways, from its more narrow interpretation to the broader meaning in relation to social-ecological systems (SES) (Folke, 2006). Table 2 summarises the literature review of Folke (2006) that considers some of the types of definition of resilience.

Table 2. Major definitions of resilience

Definitions	Characteristics	Focus on	Context
Engineering resilience	Return time, efficiency	Recovery	Stable equilibrium
Ecological/ecosystem resilience, robustness	Buffer capacity, maintaining function	Persistence	Multiple equilibria
Social-ecological resilience	Interplay disturbance and reorganization, sustaining and developing	Adaptive capacity, transformability	Integrated system feedback, cross-scale dynamic interactions

Source: (Folke, 2006)

Engineering resilience (Holling, 1996) refers to the dynamics of a system close to a stable equilibrium. This interpretation is concerned with the ability to recover from the response to a disturbance. It can be assessed by the speed of return to equilibrium following a disturbance. De Bruijn et al. (2004b) use engineering resilience in a study on lowland river systems, which has defined “flood resilience” as the ability of a system to recover from the flood impacts in the area.

Because of the existence of multiple equilibria, return time does not measure all of the ways in which a system may fail to maintain its functions. Ecological/ecosystem resilience (Holling, 1973) refers to the ability of a system to remain within its ‘basin of attraction’ in the face of disturbance. It can be assessed by the magnitude of disturbance that can be absorbed before the state of the system falls outside its basin of attraction (Gunderson and Holling, 2002). Ecological/ecosystem resilience often refers to the buffer capacity that allows persistence, or the capacity to absorb disturbance. Mens et al. (2011) used “robustness” in a similar way to ecological/ecosystem resilience, and have defined this term for flood risk systems as the ability to remain functioning under disturbances, where the magnitude of the disturbance is variable and uncertain. The analysis of robustness requires insight into the response curve and recovery threshold (Figure 1). This response curve shows to what extent the socio-economic system is impacted by flood events of varying magnitude. The recovery threshold indicates how likely the socio-economic system is to recover fully. It depends on social capital, which is the ability to organ repair and reconstruct and economic capital, which is the ability to finance repair and reconstruction (de Bruijn, 2004a). Comparison of the response curve with the recovery threshold provides an indication of the robustness of the system.

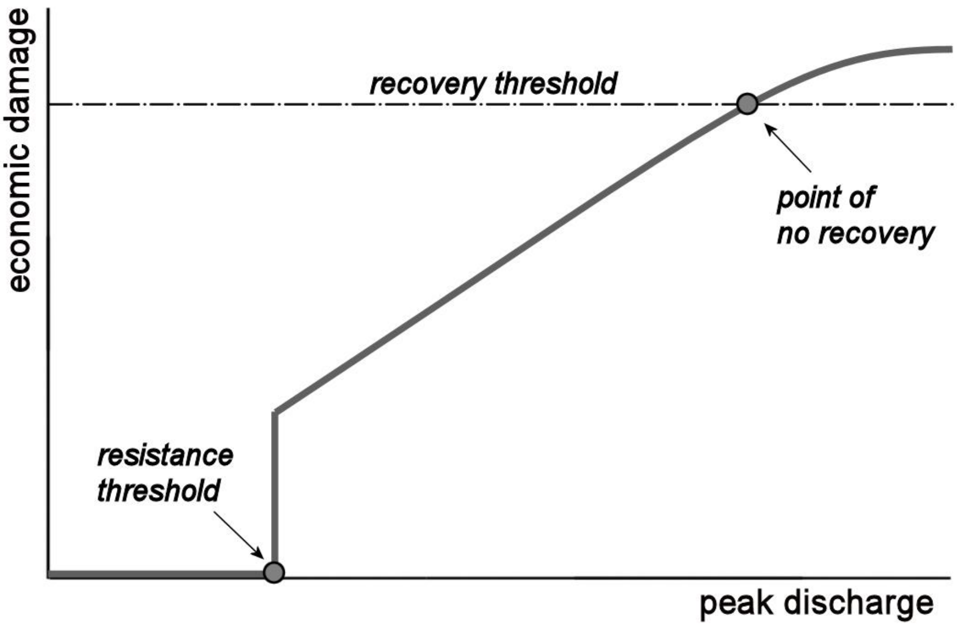

Figure 1. Theoretical response curve, showing system response as a function of disturbance magnitude, indicating resistance, the recovery threshold and the point of no recovery (Source: Mens et al., 2011)

In the recent past, resilience concepts have increasingly been applied to linked social-ecological systems (SES). The reason for extending the use of resilience to SES is that any delineation between social and ecological systems is seen as artificial and arbitrary (Berkes et al., 2000). Social-ecological resilience has been defined as the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure and feedbacks, and therefore identity, that is, the capacity to change in order to maintain the same identity (Folke et al., 2010). This definition has extended the meaning of resilience beyond (just) persistence. It incorporates the dynamic interplay of resilience as persistence, adaptability and transformability. Adaptability relates to the capacity of a system to learn, adjust its responses to changing external drivers and internal processes, and continue development along the current trajectory (Berkes et al., 2003). Adaptability has been defined inter alia as the capacity of actors in a system to manage resilience (Walker et al., 2004). The collective capacity of actors to do this, through purposeful adjustments, determines whether they can successfully avoid crossing social or ecological thresholds. Transformability, by contrast, is the capacity to cross thresholds into new development trajectories (Folke et al., 2010).

Strengthening the inclusion of flood resilience in WSUD

By considering the total water cycle, together with urban design and planning and other related goods, services, utilities and infrastructure, a multi-beneficial and productive urban environment can be created (as in New York; New York City, 2013). For this to happen it is necessary to look beyond the provision of flood resilience measures alone and consider where these fit into design processes, planning frameworks and institutional arrangements for WSUD. Traditional approaches to WSUD seek to make the interconnections and utilise water whenever and wherever it occurs in urban areas, integrating with urban planning and design (Water-by-Design, 2009). WSUD has not traditionally considered the flood resilience processes as part of this vision, only in simplistic ways, as the WSUD ideas were originally developed in water stressed regions and for environmental protection. A vision for WSUD to include flood resilience includes the 4 principles below (Ashley et al., 2013b):

1. **Manage water to deal with both water scarcity and water excess** (managing both water quantity and quality and system resilience) concurrently and in an integrated way (e.g. Rijke et al., *in press*);
2. **Manage and utilise the water cycle as locally as possible** as all aspects/occurrences of water are potential opportunities (exploit local opportunities); including source control measures and managing local topography to route flows into safe areas (e.g. Digman et al., 2014).
3. **Deal with water appropriately and synergistically within urban environments**; including ecosystems, and across urban services, design and planning processes (maximise wider value opportunities, flexibility and resilience, and more effective integration and utilisation in urban areas) (e.g. Ashley et al., 2014);
4. **Integrate water management effectively into the wider systems**, services and utilities that provide human needs in cities and other areas by taking a systems based approach and deal with the interdependencies in a planned way (e.g. Hall et al., 2013).

The principles require an emphasis on the opportunities as well as the threats/risks related to water flooding or shortages:

- When planning, designing and implementing measures to enhance flood resilience all added-value opportunities to improve urban areas, environmental and ecological systems should be considered and taken advantage of throughout the process.
- The concepts, principles and practices of water sensitive urban design (WSUD) should be considered and followed as a means to deliver both effective flood resilience and also maximise the potential opportunities to be gained from the water cycle and good urban design and management.
- The definition of WSUD should include the most up to date ideas on ecosystem services, green-blue infrastructure and best value approaches.

Scales of application of WSUD are also important, and need to encompass: Spatial scales: country, catchment, city, town, neighbourhood, plot (Bacchin, 2013); Temporal scales: longevity of scheme and robustness and flexibility to future change; System scales: water-energy, transport systems, water cycle, water resources, flood risk and drainage; Institutional, governance, regulatory boundaries and cultural scales: responsibility boundaries now and in the future. Good design and practices also need to take into account what additional values can be provided by infrastructure systems in day-to-day conditions and what happens when the limits to performance are exceeded (see e.g. Figure 4).

Traditional WSUD has often concentrated exclusively on surface water (or stormwater) management (Hoyer et al., 2011), which corresponds with the emphasis here on flood risk management. Nevertheless, opportunities from other parts of the water cycle should be sought and maximised. Emerging ideas for applications of WSUD in a European context define the terms and components in broader ways than has traditionally been applied in Australian practice (Ashley et al., 2013a).

This vision of a ‘water sensitive city’ which would also include resilience to flooding, is one way of looking at the added-value of considering water in all its’ facets in urban areas and in terms of all of the opportunities it could bring. Recent ideas go beyond the ‘water sensitive city’ and consider an integrated urban design, planning and management (IUDPM) perspective that includes, but is not restricted only to WSUD, or a water sensitive city, as it also incorporates the whole range of urban services, utilities and systems. However, ways for taking an IUDPM approach are in their infancy and in the guidance here, a WSUD approach is the focus.

The essential principles for WSUD application in the context of a water sensitive city are illustrated in Figure 2. This figure shows that all elements of the water cycle and their interconnections are considered concurrently to achieve an outcome that sustains a healthy natural environment while meeting human needs, and that planning and design processes are considered at various levels (i.e. towns, cities, places) seeking to achieve the expectations and aspirations from design.

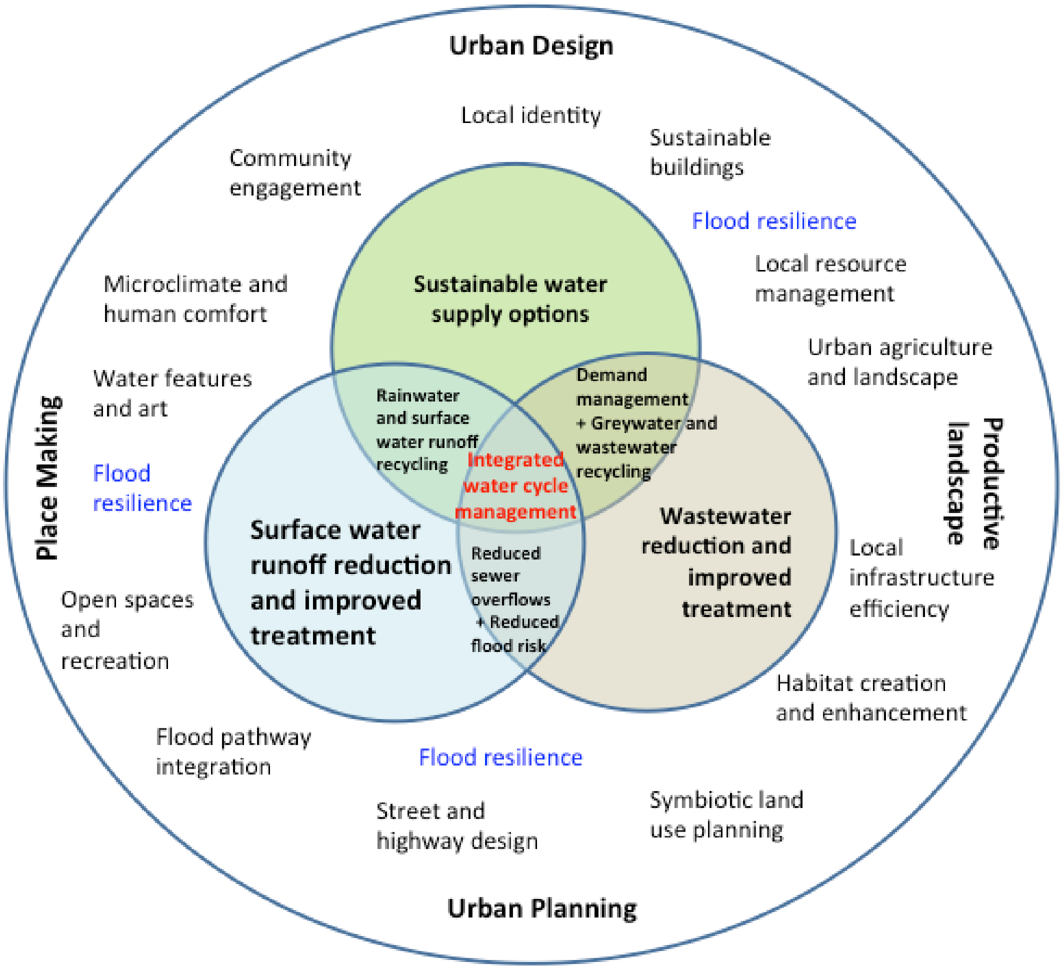

Figure 2. Components of water sensitive urban design and their interactions highlighting the place of flood resilience and other aspects of WSUD (Ashley et al., 2013a)

Managing water to enhance resilience to both floods and droughts

Multi-Level (or Layer) Safety (MLS) is a sound principle for implementing both a risk-based approach (efficiency through optimising costs and benefits) and a resilience-based approach (redundancy through diversification of strategies and measures) (van Herk et al., in press; Rijke et al., under review). It involves not only managing the probability of a flood through protection with e.g. dikes or dams, but also spatial planning and disaster mitigation, with the aim of limiting casualties and economic losses in the event of a e.g. flood. It also adopts the practice of combining different types of strategies into flood risk management (Figure 3).

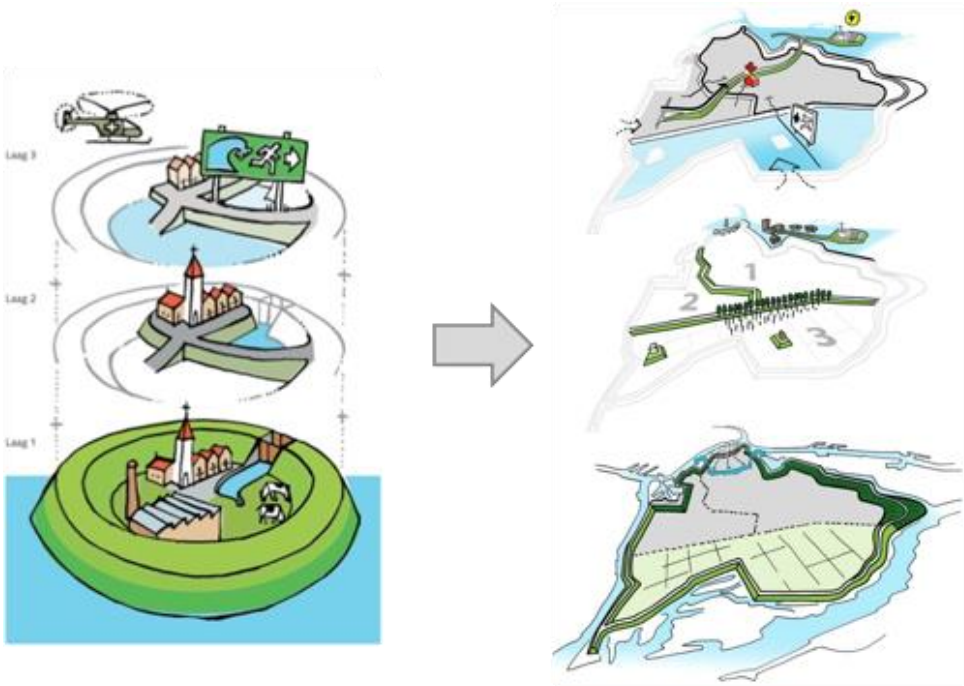

Figure 3. Dutch multi-layer safety for floods (left) and case study application for Island of Dordrecht (right); from bottom to top: protection against flooding (dikes), prevention of damage in case of flooding, preparedness for future flooding through emergency management planning (2009-2015 National Water Plan).

MLS represents an important shift in Dutch thinking about flood risk management, but has also structured policy debates around climate change adaptation in, for example, USA, Vietnam, Indonesia and Bangladesh (Zevenbergen et al., 2012). Risk-based approaches aimed at a diversification of strategies are also appearing elsewhere. The EU Flood Directive (2007/60/EC) and the Hyogo framework (UNISDR, 2007) (and the follow-on UN General Assembly, 2014 zero draft) ask for a diversification of flood risk management strategies, together with new governance arrangements to support implementation. These strategies are meant to address all phases of the risk management cycle, but focus particularly on the pre-event phase:

- **Protection (layer 1)**: taking measures to reduce the likelihood of floods, such as building flood defences;
- **Prevention (layer 2)**: using spatial planning and adaptation of buildings to reduce damages;
- **Preparedness (layer 3)**: improving organizational preparation, such as emergency plans, risk maps, and insurance;
- **Emergency relief (layer 3)**: providing emergency relief, such as evacuating communities, and providing help;
- **Recovery and lessons learned (layer 3)**: mitigating impacts on affected communities, and undertaking surveys.

The logic behind the use of the MLS concepts is to represent the relationships between the different phases or strategies as a parallel system rather than a serial system (Jongejan et al., 2012). This implies that the different layers are not as weak as the weakest link - as falsely suggested by the widely used term 'safety chain'. It also implies that it will be most efficient to invest in the layer(s) with the lowest marginal costs, and to omit or minimise the use of the other layers. However, understanding the relative balance between these investments is not straightforward. The Dutch approach to flood management, traditionally has focused largely on the protection layer of MLS, controlling hazard and exposure. As a consequence of the presumption that protection is secure, there is a certain level of false-security prevalent in Dutch society regarding a belief in 'absolute protection'; presumed provided by large-scale structural measures. This demonstrates a lack of 'mindfulness' (Aven and Krohn, 2014) on the part of not only the population but also the politicians.

Recently, first steps were made to translate the MLS approach to the context of drought risk management (Rijke et al., under review). Application of a MLS framework for drought risk management to the cities of Adelaide, Melbourne and Sydney demonstrates that MLS can also be applied to evaluate the suite of plans deployed by a city to manage future drought risks. For example, Table 3 illustrates that all three Australian cities have deployed sets of measures that span across the three layers of protection, prevention and preparedness. Protection interventions are directed at reducing the hazard source and interventions that may be classified as prevention and preparedness are directed at reducing the exposure and vulnerability to insufficient water supplies.

From close examination of the three Australian case studies, it is evident that all three, but especially Sydney, have invested a large proportion of effort in protection by reducing the hazard source (Table 3), equivalent to what the Dutch have done in flood risk control. It is interesting that Sydney has one of the largest water storage capacities per head globally. It is perhaps this 'false sense of security' that is seemingly provided by the abundance of storage capacity that has led Sydney to rely almost exclusively on only one of the three MLS layers of drought risk management. A parallel can be drawn between this and the traditional Dutch approach to flood management. In each case there is a lack of 'mindfulness' of the true nature of the hazards. In a situation where the risks are well understood/quantified, in the public mind and are not that unforeseen or sudden, this is not necessarily a risky approach. However, the reality of the constituents of drought risk is far from this. For example, it is extremely difficult to estimate the future probability of storage resources not being depleted. As demonstrated during the Australian Millennium Drought (Grant et al., 2013), the consequences of 'system failure' (i.e. immediate drinking water shortage) were extremely high; therefore, it should be unacceptable not to take all possible measures to prevent overall system failure. This is an example that demonstrates an advantage of the MLS framework which provides a structure for ensuring that a comprehensive approach is taken looking at multiple, parallel systems of risk management; improving the overall resilience of the water system. The MLS framework also provides a visual tool for planners and policy makers to evaluate the nature of drought risk management in a given city or a region. It can also help in working with communities and others to illustrate the approach.

The next step in the application of the MLS framework for drought risk management will be to attempt to quantify the contribution each group of measures can make to each of the layers of protection, prevention and preparedness in reducing or handling drought risk. However, owing to the difficulty in estimating associated probabilities, this is a challenging task. Another step will be to explore the possibility to use the MLS framework for exploring cross-connections between drought and flood risk management, to produce a comprehensive approach. In Australia, the importance of this cross-connection was highlighted during the course of events that led to the Brisbane flooding in 2011, when the flood protection functionality of the Wivenhoe Dam was temporarily ignored in favour of water storage as a consequence of the Millennium Drought that preceded the flooding. In addition, the role of groundwater may provide insights, as groundwater flooding and drought have more in common than pluvial or river flooding (e.g. slow rates of onset).

Table 3. Interventions against drought plotted in the MLS for drought framework (A=Adelaide; M = Melbourne; S = Sydney; all = all three cities)

Way of functioning	Protection	Prevention	Preparedness
Reducing hazard source (increasing available water resources)	• Desalination plant (all) • Increase storage capacity and manage reserves (all) • New pipeline to connect catchments (M)		
Reducing exposure (increasing the efficiency of available water resources)	• Wastewater recycling (all) • Storm water harvesting and reuse (all) • Household rainwater tanks (all) • Grey water recycling (S) • Sewer mining (S) • Infrastructure leak reduction (A, S) • Infrastructure upgrades (M)	• WSUD for new (residential) developments (A, M) • Water efficient design of buildings (S) • Water efficient devices (all)	• Conservation measures (all) • Conservation rebates (all) • Water restrictions (all) • Improve irrigation practices (all) • Legislative and regulatory changes (all) • Community education (all)
Reducing vulnerability (reducing the demand for and optimising allocation of water resources)		• Temporary weir (A) • Precautionary caps on rivers (M) • Environmental flow releases (S)	• Water metering (residential) (S) • Increased pricing (possibly during a drought) (A, S) • Open and competitive water markets (A) • State-wide monitoring systems (A) • Home water audits (M) • Drought tolerant home gardens (M) • Legislative and regulatory changes (all) • Community education (all)

Maximising value from water beyond flood and drought resilience

WSUD seeks to derive maximum value and benefits from water used synergistically with urban planning and design in urban areas. Water security is one of the major global threats in terms of likelihood and impacts (WEF, 2013) and the utilisation of all forms of water is therefore an essential ingredient of managing water in an integrated way and a key element of sustainable development (Griggs et al., 2013). Water offers even more opportunities for adding value especially in urban areas. Water can contribute, inter alia to ecology and green areas in cities, to aesthetic and life quality for citizens and buffer climate change extremes like heat islands. Emerging ideas about liveability seem easier to translate into practice for everyday living than ‘sustainability’. Liveability has been described as (Adamowicz and Johnstone, 2012): ‘how well the needs of a community are met’ and the definition chimes with ‘quality of life’. In applications of ‘sustainable drainage systems’ (SuDS) which are a key component of WSUD (Fletcher et al., 2014) dealing with stormwater, ‘amenity’ is a key benefit category, alongside the management of water quantity, quality and supporting biodiversity (e.g. Woods-Ballard et al., 2014). Amenity may be defined as ‘a useful or pleasant facility or service’; which includes the tangible: ‘something that can be measured in terms of use’, and the less tangible: ‘something that can be experienced as pleasure or aesthetic appreciation’ (Irwin et al., 2014). This definition is particularly relevant for describing the multi-functional opportunities associated with SuDS and WSUD, and provides a link to the concept of ‘placemaking’ now commonly used in describing the quality of a space in urban design (e.g. Ferguson, 2012).

Table 4 illustrates how managing surface water appropriately via WSUD principles and measures can contribute to liveability and add many benefits to a community. The liveability categories are taken from De Haan et al. (2014).

Table 4. Contribution of WSUD to amenity and multiple benefits

Liveability categories	**Overall group contribution to liveability**	**Specific amenity provision**	**Category description**	**Explanation and examples**
Human Existence needs [Sustenance, shelter, safety, livelihood, security]	Water resources (potable & non-potable); pollution control; health protection; flood protection; climate extreme buffering; crime reduction	Jobs & labour productivity	Employment is a key element that contributes to and impacts on all of the other human needs categories	Productivity is enhanced in attractive environments, such as business parks with green spaces, and includes a reduction in staff recruitment costs. Ponds, green and blue spaces provide job opportunities for maintenance lasting indefinitely, with additional jobs also being created by the added tourism from urban landscapes. In Philadelphia for example, it was estimated in 2009 that 170 permanent jobs would be created from 25% of the city being retrofitted with WSUD.
		Air quality	Health effects of poor air quality are important as are the aesthetic and ecological benefits	WSUD using blue and green areas, including grass and trees, provide significant air quality improvements by for example, trees 'scrubbing' fine particulates from urban streets. Toronto's urban forest comprising 10 million trees, removes >1,400 tonnes of air pollutants annually.
		Rainwater harvesting and urban agriculture opportunities	Productive landscapes are becoming more utilised in urban areas especially in horticulture and food production	Direct collection of rainwater saves water, as well as potentially providing essential irrigation resources and long-term viability for urban plants and crops.
Human Relatedness needs [Interaction and social cohesion, ecological health, knowledge and beliefs, beauty and pleasure, comfort and convenience]	Water supported public domain, productivity and comfort; healthy ecosystems; enjoyment and accessibility of water; tranquillity; quality of places and landscape	Recreational opportunities	This adds to the health and well-being of individuals and offsets medical costs.	Provided by a wide range of green and blue spaces that can be used, for example for walking, cycling, informal play or space for organised sports and games.
		Parks and other public spaces	As above and may not necessarily be for formal recreational purposes although ensure there is no overlap with aesthetics category	Provide park area opportunities that may overlap with recreation above but also provide pleasant places to be. Below-ground systems, such as infiltration basins or geocellular systems can keep spaces open, as these cannot be built over.

Human Relatedness needs (cont.)		Traffic calming/ parking opportunities	Restrictions on speeding traffic due to highway form and layout to protect public health and also discourage excess vehicular fuel consumption	SuDS, such as rain gardens and bioretention systems, can provide horizontal constraints in roads, discouraging driving at excess speeds. Spaces between SuDS components or the components themselves can also provide parking spaces for cars and bicycles.
		Noise	Quietness, peace and tranquillity are valued by many	WSUD and associated trees and grassed areas can provide noise absorbent barriers and surfaces in noisy urban areas. Green roofs can also provide sound insulation within buildings.
		Community cohesion	Green spaces increase social ties and community strength	WSUD can help bring communities together. By increasing opportunities for human interaction and creating a more enjoyable environment, people are more likely to feel they belong to the community and take a greater pride in their neighbourhood. This is especially the case if the community has been involved in the design process and residents have ownership of the on-going maintenance (even if only in part).
		Energy use	This is in the entire supply chain and life cycle: resource extraction; manufacturing, transportation, construction and usage as well as decommissioning.	WSUD requires far less energy use in all stages of the supply chain and life cycle than conventional drainage and by harvesting water at source this also save energy. For example, De Sousa et al. (2012) use Life Cycle Analysis to consider the relative merits of using porous pavements, trees and bioretention SuDS for CSO control in New York and concluded that there was a reduction of some 314 kWh/Megalitre in energy needs for the wastewater treated at the downstream plant by using WSUD compared with retaining the flows in the combined sewer network. De Sousa et al. (2012) describe how in hot climates, trees in urban areas can reduce building energy needs by some 2.5% by shading and that the reductions in energy use in New York as a result are substantial.

Human Relatedness needs (cont.)		CO2 and other greenhouse gases	Managed by sequestration and storage and also by not using grey infrastructure (avoided infrastructure).	Plants and soils take in and store CO_2 and other greenhouse gases; hence where plants are used this potential can be exploited. For example, the Ripple Effect study in Coventry (UK) stated that 1.5 tonnes of carbon dioxide is sequestered for every hectare of trees. In the example above for New York, it was estimated that the use of WSUD resulted in net greenhouse gas emissions of only around 20% of those emitted from the construction and use of the equivalent CSO storage tanks. After the first 25 years of operation, the green infrastructure would have developed sufficiently to completely mitigate all of the greenhouse gas emissions in the construction and operation of the WSUD.
		Temperature extremes	Extremes occur especially in dense urban areas and are increasing	Green and blue infrastructure buffers and moderates temperatures which will become increasingly important as the climate changes and urban areas get hotter in future. For example, the use of WSUD in Australia as part of urban planning and design has been shown to reduce urban heat island temperatures by judicious location to maximise their effectiveness.
		Aesthetics and quality of places	Green and blue infrastructure add open space to urban areas and visual quality.	Provide aesthetic value, green/blue space and contribute to biodiversity, for example in the UK, the Landscape Institute & Institute of Environmental Management and Assessment provide guidance as to how best to provide this especially for large-scale developments.
		Investment	High quality places encourage inward investment and	Using WSUD to collect surface water to irrigate green areas and creating

Human Relatedness needs (cont.)			locational establishment of vibrant businesses	attractive places encourages and supports inward investment and often attracts tourists.
		Biodiversity and ecology (ecosystem services)	Ecosystem services are the services provided by natural systems to humanity, defined as a range of benefits in four categories: Provisioning; Regulating; Habitat or supporting; and Cultural services	Green and blue WSUD help to support flora and fauna and here amenity and biodiversity value come together. See Ashley et al., 2011.
		Land and property values	A proxy measure for the relative prosperity and attractiveness of a community, neighbourhood or place and include a wide range of factors in which surface water is important	Green and blue WSUD add value to land and property nearby. For example, in a study in USA that looked at demand for local amenities, certain types of open space preservation have contributed to higher housing prices, in so doing, offsetting local demand for these natural amenities.
Human Growth needs [Culture and identity, equity and justice, purpose and expression, influence and respect, freedom and autonomy]	Water provision, culture and identity; independence, choice, freedom, autonomy and meaningful influence on water services; equity & justice; employment; education and communication	Public education	Engagement in the water cycle is important for education, public behavioural and valuing water systems and services	By using green and blue spaces as part of the management of the water cycle this provides many opportunities to support education both formally in schools and in communities as a whole.
		Tourism	Attractive and interesting places are appealing to non-residents and others	WSUD in themselves may provide interest for tourists especially where they are a novelty, as in Malmo in Sweden, but are most likely to be part of creating attractive places that will appeal to tourists.

While a developer/development may be perceived as creating an environment within the principles of sustainability as part of a process often termed ‘place making’, the experience of living in that environment may test that claim and what may be good for the future may not be ideal for current citizens, hence the need to ensure liveability as well as sustainability (Howley et al., 2009). WSUD can and does contribute to liveability as illustrated in Figure 4 in which the redeveloped area has a visually attractive appearance and also provides space and green areas for ecosystems and habitats at the same time as providing cooling during hot periods.

Figure 4. Improvement of liveability by WSUD application (above is before application of WSUD; below is after (Gersonius et al., 2012). Note that only some components of WSUD are shown in the lower images.

Notwithstanding the emerging ideas about getting more benefits for society by looking for multiple benefits from WSUD and encouraging and supporting multi-functional land use (Morgan et al., 2013), there are still many flood risk management and or water sensitive schemes that seem to ignore this, preferring to restrict their view to ‘dealing with problems’; looking at ‘environmental impacts’ rather than maximising opportunities. This may be because bringing multiple benefits and WSUD together with flood resilience is most easily done for pluvial flood risks, where added potential benefits in the urban area are readily apparent (Brouwer et al., 2010). A good-practice example of delivering both regimes (liveability and resilience) simultaneously is presented by Gersonius et al. (2012) for the management of pluvial flood risks in Dordrecht, the Netherlands (Gersonius et al., 2012). Here, the design of a park zone has been modified by lowering of the green space to allow for temporary surface storage (lower-left picture in Figure 4). For large-scale coastal flood risk and large-scale fluvial flood management, WSUD is more difficult to apply as it needs to be considered for each of the components or constituent parts of the entire development (e.g. Bacchin et al., 2014).

Interpretation of Multi-Level Safety within the context of the CRCWSC framework for flood resilience

Flood risk management has multiple goals relating to multiple time and space scales (Sayers et al., 2013). Addressing these relies on the development and implementation of appropriate sets of interventions, a process that is complicated by the changing nature of the flooding system (through climate, geomorphological and socio-economic influences). In various studies, a range of interventions have been identified to consider in enhancing flood resilience in Water Sensitive Cities (Dronkers, 1990, Hoss, 2010, Shaw et al., 2007), and these include major structural measures like dikes as well as non-structural and local flood resistance measures. Any interventions have to be tailored or matched, to ensure their applicability to the specific climate, geomorphological and socio-economic conditions before being implemented. Several overarching frameworks have been developed to identify and categorise interventions, such as the EU Flood Directive (EU, 2007) and Dutch National Water Plan (V&W et al., 2008).

This report has set out the MLS approach in the section on Water Sensitive Cities and the need to bring water management extremes of both floods and droughts, under the same perspective. Although the perspective presented in this report has been developed primarily in the Netherlands, it represents well-established (international) practice and is complementary to other frameworks. This chapter considers how the interventions derived from MLS could be interpreted within the context of the CRCWSC framework for flood resilience. It starts with an introduction of the principles underlying the CRCWSC framework for flood resilience. Then a model is developed for the alignment and comparison of both frameworks, which is based on the core components that constitute risk (e.g. WGII AR5, Merz et al., 2014), as shown in Figure 5. The chapter concludes with a discussion on the different emphases of the frameworks and guidance for appropriate priority actions - in order to support the application of the principles in an Australian water sensitive city context.

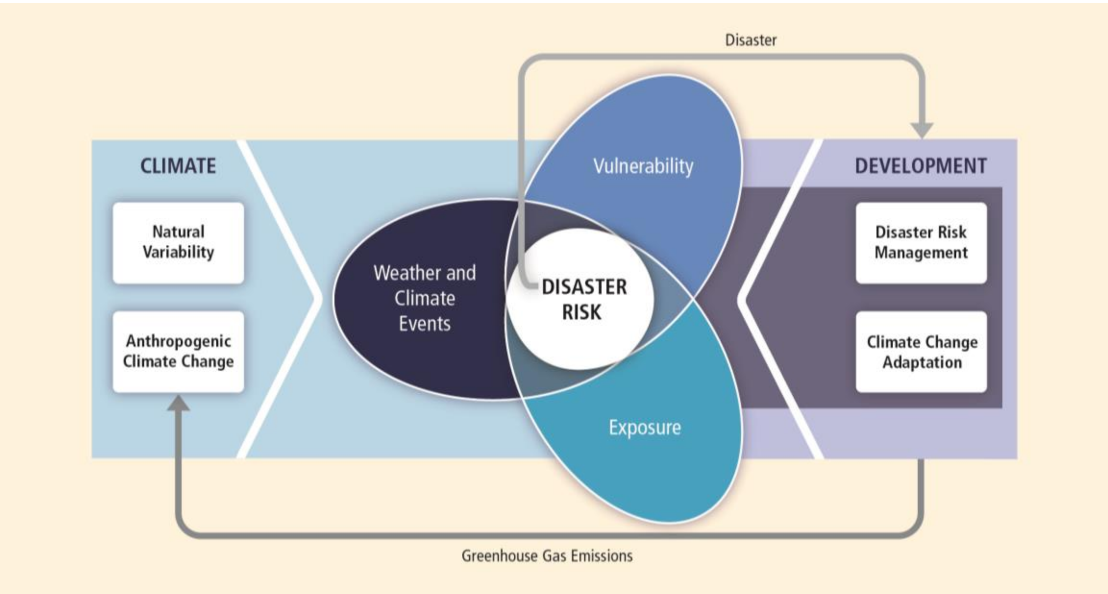

Figure 5. Framework for managing disaster risk (Merz et al., 2014)

Three-tiered approach of retreat, adapt and defend

A key objective in the Australian water sensitive city context is to develop an overarching framework to identify priority actions for building resilience, which could be equally adopted to issues beyond flooding -- e.g. to city planning and design, and city building. A tripartite model framework has been proposed for CRCWSC that categorises resilience into measures that retreat, adapt and defend against external hazards. This is one of many possible framework options to best address resilience (Wong, 2014). The approach is illustrated in Figure 6 for fluvial and pluvial flooding.

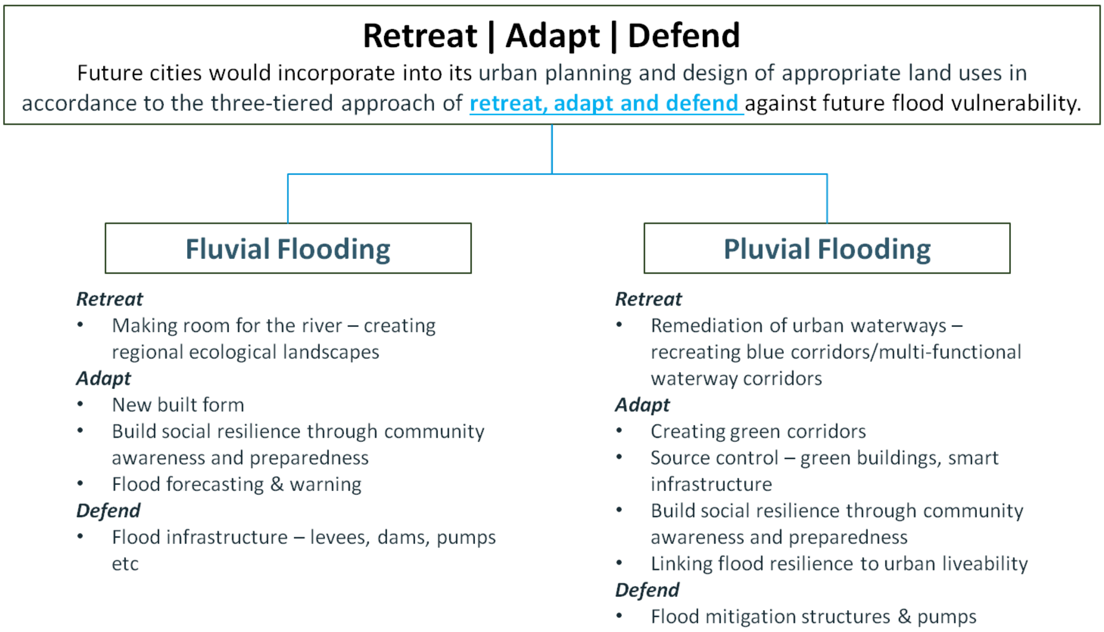

Figure 6. Framework for Flood Resilience in Towns and Cities – fluvial and pluvial (Wong, 2014)

A model for the alignment and comparison of the two frameworks

Starting from the core components that constitute risk (hazard, exposure and vulnerability), a model (4RAP) is presented in Figure 7 for alignment of MLS with the three-tiered approach of retreat, adapt and defend. The alignment of the MLS model is based on a translation to flood risk management of Haddon's 10 strategies (Haddon, 1973) to prevent a hazard from affecting objects or people, as proposed by (Hoss, 2010). By defining a sequence of interventions, Haddon illustrates possible ways as to how to prevent human and economic losses given hazardous events. The resulting classification, which does not have a preferential hierarchy with respect to the effectiveness of the specific interventions, is based on the stages that a hazard event passes through from its origin to the moment of effect on people and the economy. There are some hazards, like hurricanes, that cannot be prevented, but still there are some actions that can be taken at different moments of the hazardous event to help alleviate consequential losses.

Each individual component strategy in Haddon's categorisation has a different effect on the hazard, exposure or vulnerability. The terms hazard – exposure – vulnerability are defined by the Working Group II contribution to the IPCC's Fifth Assessment Report (WGII AR5) as:

- **Hazard**: The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. Here, the term hazard usually refers to climate-related physical events or trends or their physical impacts;
- **Exposure**: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.;
- **Vulnerability**: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

The '4 RAP' model, as adapted from Hoss (2010), is explained and illustrated in Table 5. This model has been selected for purposes of alignment and comparison, because of its comprehensive coverage of the constituents of risk and logical sequence of strategies.

Strategies to retain runoff or to relieve extreme hydraulic situations reduce the hazard source. Strategies to resist flooding by e.g. dikes or to retreat from dangerous areas focus on limiting the exposure to flooding. Strategies to accommodate flood waves or surface water flows in specific areas or to prepare for disaster relief and rescue are directed toward reducing the vulnerability of people of the economy. Further illustrative examples are given in Figure 8 (Shaw, 2007), which shows a graphic on possible interventions to enhance flood resilience at different points of application.

Figure 7. The '4 RAP' model of available strategies to enhance flood resilience

Table 5. Explanation and illustration of the '4 RAP' model

Category	Category description	Explanation and examples for river/ coastal flooding	Explanation and examples for rainfall flooding
Retain	Prevent extreme amounts of water in the system (i.e. retain runoff in the catchment so that it does not reaches a conveyance system (e.g. stream, channel, sewer pipe)	Retain run off (e.g. afforestation, upland management) (i.e. retain non-urban (rural) runoff).	Retain run off (e.g. green / vegetated roofs, SuDS) (i.e. retain urban runoff)
Relieve	Relieve extreme hydraulic situations	Redistribute water volumes over waterways (e.g. adding channels, diversion works) Capacity increase of water systems (e.g. Room for the River, deepening river bed) Relieve extreme situations (e.g. inundation polders, pumping out trapped water)	Capacity increase of water systems (e.g. detention ponds, removing obstacles) Relieve extreme situations (e.g. water plazas)
Resist	Erect a barrier between water volumes and objects/people	Flood defences (e.g. storm surge barriers, closure dams, dikes) Compartmentalisation (e.g. double wall strategy, partitioning)	Conveyance systems (e g. drains, canals) Temporary flood defences (e.g. sandbags, moveable barriers)
Retreat	Prevent objects/people from being in dangerous areas	Elevate vulnerable objects (e.g. building on stilts, raising floor levels) Relocate buildings and communities Ecosystem restoration (e.g. wetlands, managed realignment)	Elevate vulnerable objects (e.g. building on stilts, raising floor levels) Relocate buildings and communities Control water ingress (e.g. controlled flood pathways, streets as streams)
Accommodate	Prevent damage from occurring to exposed objects/people	Flood proofing (e.g. wet proof buildings, removable household items)	Flood proofing (e.g. rain proof buildings, removable household items)
Prepare	Reduce damage from occurring to those exposed and impacted	Self-reliance/ Social resilience (e.g. training, early warning systems) Disaster relief (e.g. drinking water tanks, basic supplies storage) Rescuing (e.g. preparing rescue plans)	Self-reliance/ Social resilience (e.g. training, early warning systems) Disaster relief (e.g. drinking water tanks, basic supplies storage) Rescuing (e.g. preparing rescue plans)

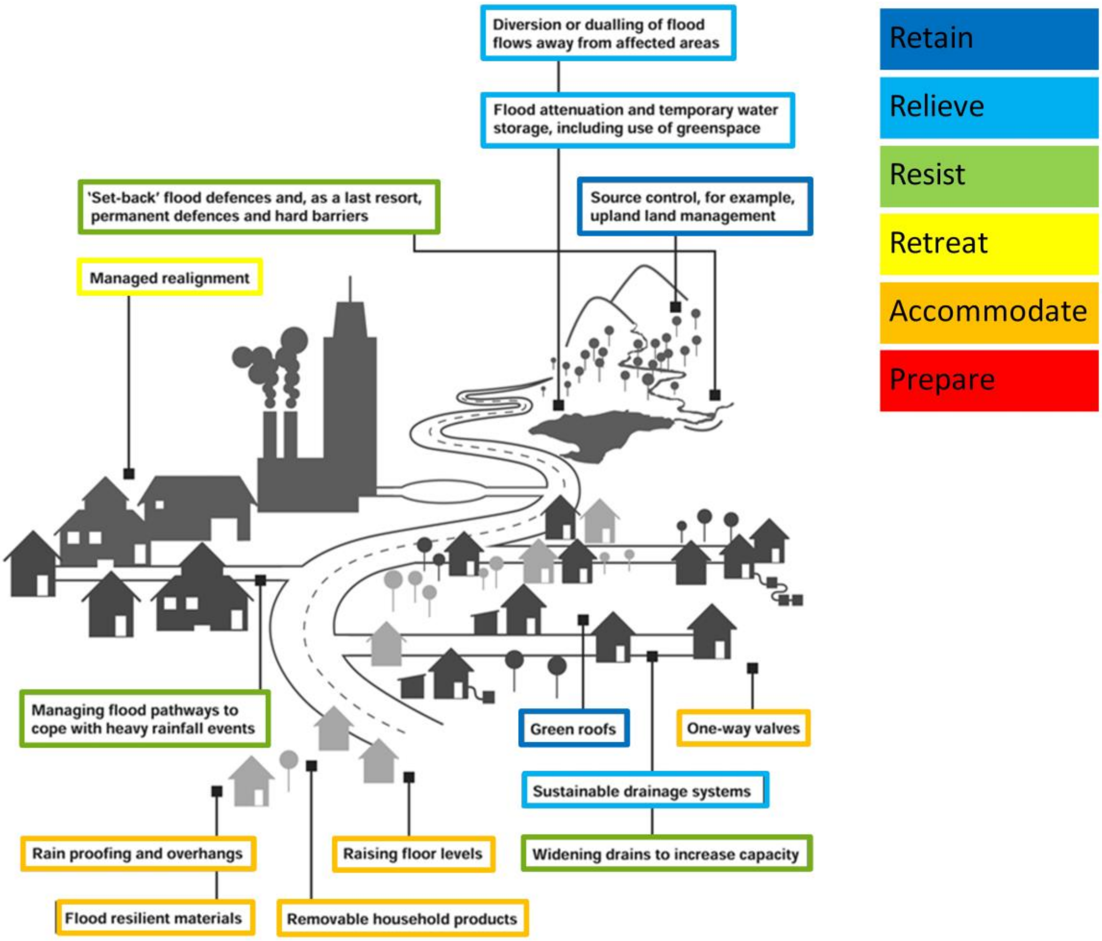

Figure 8. Mapping of interventions to enhance flood resilience using the '4 RAP' scheme (Shaw, 2007) ("Preparedness" measures are non-structural and not illustrated in the graphic)]

Alignment and comparison of CRCWSC, 4RAP and MLS

Comparisons are presented between the various model frameworks in Table 6. The following observations can be made about the alignment of MLS/4RAP and the CRCWSC framework:

- **Many commonalities**: Although the terms being used in the two frameworks are different, the principles and actions associated with these terms are very similar. When interpreting MLS within the context of the CRCWSC framework for flood resilience, it has been demonstrated that: (i) 'Protect' is a combination of 'Retreat' (e.g. Room for the River), 'Adapt' (e.g. retain runoff) and 'Defend' (e.g. flood defences); (ii) 'Prevent' is a combination of 'Retreat' (e.g. relocation) and 'Adapt' (e.g. flood proofing); and, 'Prepare' overlaps with 'Adapt' (e.g. social resilience).
- **Different emphases**: The MLS framework places greater emphasis on the sequences of strategies: 'Protect' involves strategies that reduce the probability of the risk, whereas 'Prevent' and 'Prepare' focus on consequence-reducing strategies. The emphasis of 'Retreat', 'Adapt' and 'Defend' is on the objective that these strategies are proposed for: 'Retreat' refers to the abandonment of objects in vulnerable areas, and the resettlement of people; 'Adapt' is defined for continuing the occupation and use of vulnerable areas, by modifying objects and behaviours. 'Defend' refers to the defence of vulnerable areas with (grey or green) structural approaches.
- **Typically no order of priority**: Neither MLS nor the CRCWSC framework for flood resilience suggest an order of priority. Rather, the adoption of a strategy depends critically on the physical and socio-economic characteristics of an area - as explained in the next section.

Table 6. Alignment/comparison of MLS and CRCWSC framework, using the '4 RAP' model

Constituent of risk (=H+E+V)	Constituent of risk (=P*C)	Strategy in 4RAP	Strategy in MLS	Strategy in CRCWSC framework
Hazard	Probability	Retain	Protect	Adapt
		Relieve	Protect	Retreat
Exposure		Resist	Protect	Defend
	Consequence	Retreat	Prevent	Retreat
Vulnerability		Accommodate	Prevent	Adapt
		Prepare	Prepare	Adapt

Guidance for appropriate priority actions in a Water Sensitive City

Table 6 is helpful in understanding and deciding on the trade-offs between probability-reduction actions and consequence-reduction actions in order to create cost-efficient strategies (Hoss, 2010). Probability-reduction actions in MLS fall mostly under the Protect category, whereas the majority of consequence-reduction actions fall under the Prevent and Prepare categories. The cost-efficiency of an integrated strategy to enhance flood resilience will depend on the level of interaction between probability-reduction actions and consequence-reduction actions. Probability-reduction actions make floods less likely and reduce the need for consequence-reduction actions. Consequence-reduction actions make the objects and people less susceptible to damage and lessen the need for large-scale probability-reduction actions.

It follows from the above reasoning that appropriate priority actions depend on both the physical characteristics (e.g. flood probability or magnitude) and socio-economic characteristics (e.g. current and future land use) of an area. In this respect, a matrix is presented in Table 7 that links the type of strategy with the physical and socio-economic characteristics. The physical characteristics are described in terms of hazard / exposure (i.e. flood probability and depth), while the socio-economic characteristics are described in terms of vulnerability (i.e. type of land use). With respect to land use, it is important to distinguish between built-up and non-built-up areas. This is because many of the actions identified (particularly those to reduce the consequences) cannot be implemented in existing built-up areas without demolition or major modifications.

Table 7. Matrix linking the type of strategy with the area characteristics (adapted from Pieterse et al., 2009)

Hazard / Exposure		**High probability (e.g. 2 yr)**	**Moderate probability (e.g. 100 yr)**		**Low probability (e.g. 2000 yr)**	
		All depths	Deep (e.g. >2 m)	Intermediate depth (e.g. 0.5 - 2 m)	Shallow (e.g. <0.5 m)	All depths
Vulnerability	**Built-up**	Adapt • Flood proofing • Self-reliance In MLS: Prevent & Prepare	Defend • Defences • Compartmentalisation Adapt • Self-reliance • Disaster relief • Rescuing In MLS: Protect & Prepare	Adapt • Self-reliance • Disaster relief • Rescuing In MLS: Prepare	• Normal development • Attention to cascading effects	• Normal development • Attention to cascading effects
	Not yet built-up	Retreat • Ecosystem restoration In MLS: Prevent	Retreat • No new development In MLS: Prevent	Adapt • Flood proofing • Self-reliance In MLS: Prevent & Prepare	• Normal development • Attention to cascading effects	• Normal development • Attention to cascading effects

With reference to Table 7, the appropriate priority actions for built-up areas in a Water Sensitive City are:

- **High probability**: Existing built-up areas with a high probability of flooding (e.g. river front developments) should be adapted to accommodate flooding, with concurrent impact minimisation and self-reliance, via e.g. the use of blue corridors. Because these areas flood regularly, but also are attractive for living and working, it is typically economically worthwhile to invest in consequence-reduction actions. Appropriate actions are flood-proofing buildings, and improving self-reliance through training and early warning systems.
- **Moderate probability - deep**: The casualty risk is generally high in these areas, particularly where the speed of onset of flooding (e.g. after a dike breach) is fast. Because the area is already built-up, there are limited opportunities to adapt the built form. In this case, probability-reduction actions are most appropriate, such as building or strengthening flood defences. Furthermore, the compartmentalisation of an area could enhance its flood resilience, if this reduces the speed of onset of flooding. The vulnerability of an area could be increased by improving self-reliance and preparing for disaster relief and rescue.
- **Moderate probability – intermediate depth**: The flood depths in these areas will not be more than e.g. 2 meters. This implies that the majority of people will be able to survive in their own house for a short period during flood situations. However, most people will have to be rescued, as critical services (electricity, gas, water and sewerage) will likely be disrupted. This means that the preparation of rescue plans is still essential.
- **Moderate probability - shallow flood depths/ small probability**: For these areas, the current situation is considered acceptable, and no further actions are needed to enhance flood resilience. Nonetheless, attention is required for cascading effects in and by critical infrastructure (inter)dependencies. This is to avoid flood damages extending to unaffected areas, which are linked with the affected area through infrastructure networks.

The appropriate priority actions for areas developed in a Water Sensitive City are:

- **High probability**: Not-yet built-up areas with a high probability of flooding should only be developed in a water compatible way. Appropriate priority actions include amenity, recreation and nature use (e.g. ecosystem restoration). If it is not possible to prevent new development in these areas, then spatial adaptation (e.g. flood proofing or building amphibious properties) should be considered.
- **Moderate probability - deep**: Not-yet built-up areas that will potentially inundate above e.g. 2 m of depth should preferably be kept free from development. Here, the flood proofing of buildings is impractical due to the high flood depths. If it is not possible to prevent new development, then the defence of vulnerable areas by building dikes is recommended.
- **Moderate probability – intermediate flood depth**: For these areas, spatial adaptation, i.e. changing the layout and form of the urban area and the buildings, is an effective strategy to reduce the consequences of flooding. Because of the moderate flood depths, flood proofing of buildings is an appropriate priority action.
- **Moderate probability - shallow flood depths / small probability**: These areas can be developed in a traditional way, and no further actions are needed to enhance flood resilience. Nonetheless, attention is required for cascading effects in and by critical infrastructure (inter)dependencies. This is to avoid flood damages extending to unaffected areas, which are linked with the affected area through infrastructure networks.

A framework for the assessment of water sensitivity and flood resilience

4-Domains Approach

As flood resilience is a primary component of WSUD, opportunities and threats from managing a range of rainfall or river discharges right up to extreme events need to be considered as illustrated in Figure 9. This figure is a modification from the originally proposed 3PA diagram by Fratini et al. (2012) to assist in placing urban surface water within the land use, urban design and planning processes so that maximum value can be obtained from the synergies between surface water and other urban systems. The interpretation of the diagram in considering four different domains, allows a better understanding of the continuous process in relation to resilience, sensitivity and the point at which a regime shift (irrevocable change) occurs.

Resistance has been defined as an equivalent to the external pressure needed to bring about a given amount of disturbance (e.g. flood impacts, drought impacts) in the system. Sensitivity, interpreted as the degree by which a system will respond to an external pressure (Luers, 2005), can be seen and defined as an outcome of resistance. While resistance is mainly concerned with the reduction of adverse impacts, the concept of sensitivity puts emphasis on minimising adverse impacts as well as maximising positive impacts. Therefore, the use of sensitivity instead of resistance covers a wider range of possible results, giving more freedom to practitioners in the interpretation of results.

The proposed four domains of interest to total water cycle management are shown in Figure 9: (1) day-to-day rainfall or river discharge events which are typically beneficial; (2) the 'design' events that the infrastructure and overland flow 'exceedance' pathways and measures are designed to handle; (3) extreme events that will cause substantial, but manageable damages; (4) extreme events where the resilience is compromised and the system cannot recover.

The curve in Figure 9 shows the sensitivity of the response of the system – the impact caused by the pressure (e.g. rainfall events). Sensitivity is the degree to which a system will respond to an external pressure (Luers, 2005). It is the corollary of resistance – defined as being equivalent to the external pressure needed to bring about a given impact (Carpenter et al., 2001). The assessment of sensitivity typically, but not always, requires impact modelling for a large range of flood or drought magnitudes.

The horizontal dashed line in Figure 9 represents the system recovery threshold (Mens et al. 2011). This indicates the amount of disturbance (impact) that can be tolerated before a system moves into a different regime (Carpenter et al., 2001). It shows how likely the socio-economic system is to recover fully. The recovery threshold depends on social capital, which is the ability to organ repair and reconstruction and the economic capital, which is the ability to finance repair and reconstruction (de Bruijn, 2004a).

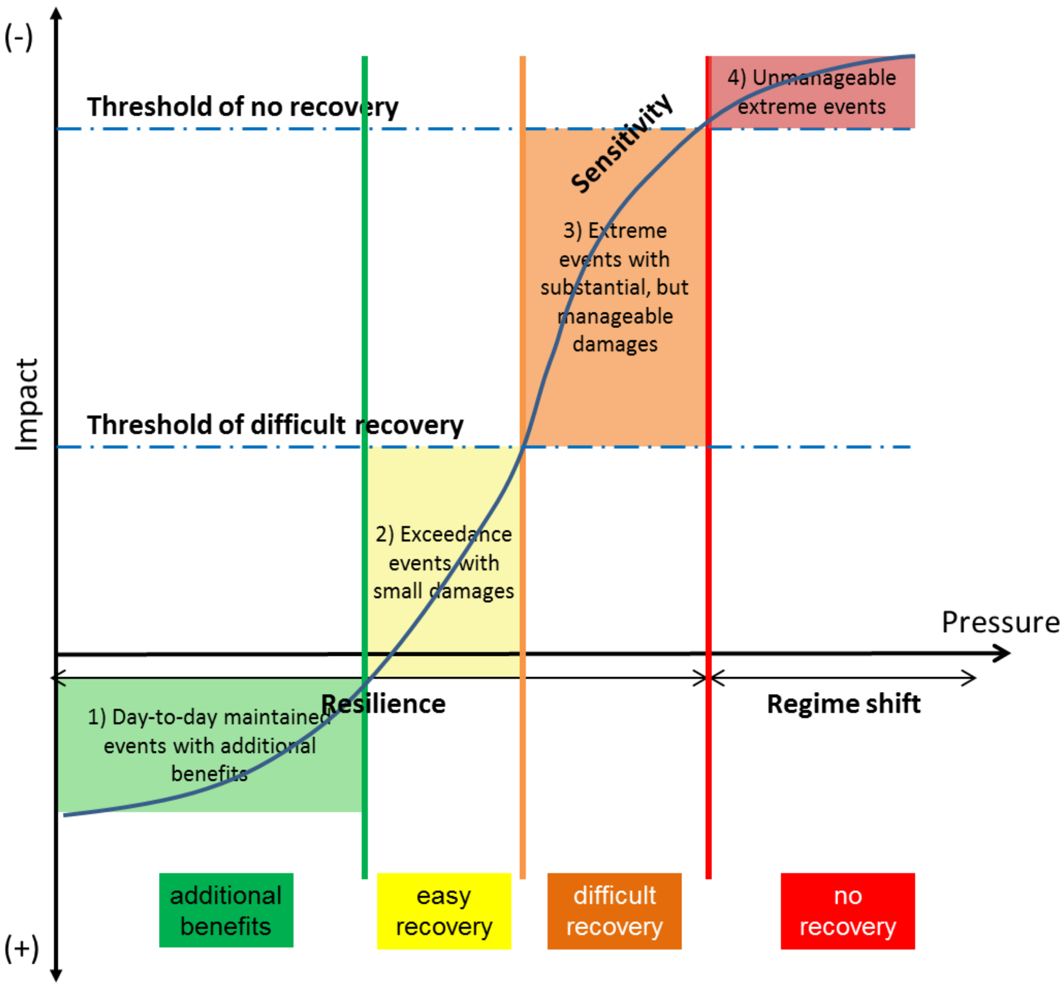

Figure 9. The '4 Domains' Approach (4DA) (modified from Fratini et al., 2012; Mens et al., 2011)

Comparison of the sensitivity (solid curve) with the recovery threshold (horizontal dashed line) provides an indication of the boundary of resilience of the system. Resilience is a term closely related to persistence (Carpenter et al., 2001), defined in terms of the magnitude of external pressure that a system can tolerate before moving to a different regime. If the response curve exceeds the recovery threshold, the system is not likely to persist and no longer be robust, shifting to another regime. Mens et al. (2011) have used "robustness" in a similar way to persistence, and have defined this term for flood risk systems as the ability to remain functioning under disturbances, where the magnitude of the disturbance is variable and uncertain.

Figure 9 is an extension of Figure 1 that reinforces the need to consider exceedance flows and also puts it into a resilience context. Note that 'exceedance' is not a concept that is relevant to droughts. The figure also highlights how events such as the 2011 Japanese tsunami (regime 4) can lead to a regime shift in society and how such events are viewed and handled.

Figure 9 can be used to help understand how water in urban areas can be seen to be both a resource/opportunity and a problem/threat in the context of what is presented in Figure 2 (WSUD perspective). The steeper the curve in Figure 9, the more likely the system is to fail suddenly. Each area is important in the way in which urban areas are laid out and managed to utilise their potential benefits and manage any adverse impacts; although only the first type of event is shown as providing positive benefits. However, the origin of the Y-axis is deliberately ambiguous, as other types of event can also provide positive benefits if managed appropriately.

The figure helps to turn the 'problem' of adapting to water stress and changing flood risks into a positive opportunity for the development and enhancement of urban areas through utilising the interactions and synergies between the surface water management system and society. The domains in Figure 9 were defined in terms of their functionality in urban areas building on Fratini et al., 2012:

Domain 1 - Day to day values: enhancing the value provided by options, awareness, acceptance and participation amongst stakeholders. Attention is given to the way urban space is used and perceived (e.g. Figure 10).

Figure 10. Example of multiple use of space - water plaza in Rotterdam

Domain 2 - Technical optimisation and exceedance: where design standards for sewers and other infrastructure like water supplies apply. This considers mainly technical solutions to deal with defined design storms and river discharge events to prevent damage and meet service levels. Alongside technical optimisation, the design for exceedance events may be considered in planning terms and in layout of urban form.

Domain 3 - Urban resilience and spatial planning: involves dealing with extreme events, which become of necessity multi-disciplinary. The aim is to mitigate the impacts of future extreme events and allow adaptation to cope with future large events while maintaining the essential identity or form of the original system.

Domain 4 – Regime change and beyond may provide opportunities to alter substantially how an urban area is laid out and how water systems are managed therein. Such a regime shift represents a loss of resilience of the system.

In designing, Domain 2 if specified appropriately, should result in no flooding and acceptable water stress – usually defined in terms of available headroom. If flooding occurs, then in Figure 9 this corresponds to Domain 3 and 4. Most of the time rainfall will provide surface water that corresponds to Domain 1, causing no problems and providing the main irrigation water source for green areas. However, in Domain 2, exceedance may occur where water appears on the surface in places it does not normally due to lack of capacity or blockage of a drainage system. Careful management of this exceedance flow can minimise impacts and often be achieved by multifunctional spaces in the urban environment (Digman et al., 2014) as illustrated in Figure 10.

Traditional approaches do not consider the water resource opportunities available for the four types of events illustrated in Figure 9. Rainfall is considered part of the urban hydrological cycle that 'discharges' to one of the following destinations: "the ground, a surface water body, a surface water sewer or a highway drain, or to a combined sewer" (Defra, 2011). It is clear, however, that day-to-day events offer water resource opportunities. Further work is still needed to develop the 4DA model in order to include droughts as well as floods.

Nowadays performance specifications usually recognise two of the domains shown in Figure 9: – 1 and 2, and for flood events, require consideration of what will happen when the designed system is no longer able to contain the flow (Domain 3). The layout and design of urban areas is usually defined in terms only of the lower magnitude rainfall and other events (Domain 1 and 2), with surface and below ground drainage systems automatically providing safe and secure environments for all events up to and including the design event (Domain 2). Typically urban planning and design sets out developments based on the use of space, land, functionality, movement of people and safety presuming that water systems can be dealt with using conventional means of supply, drainage and flood protection. Therefore, historically, the added-value of water and what it can provide within urban landscapes has been considered only in term of aesthetics and sometimes recreationally (Figure 10).

Case study application for Dutch Multi-Level Safety pilot Dordrecht

Dordrecht is an historical example of the consequences of a lack of flood resilience. Two flood events in the 15th century (1421 and 1424) changed the land use in the area from agriculture, industry and residential into an estuary. As a consequence, Dordrecht lost its position as the most powerful city in Holland to the city of Amsterdam. Later in the 17th century, parts of the estuary were reclaimed again, forming the dike ring area "Island of Dordrecht". The remaining part is a national park, "De Biesbosch". To date, Dordrecht remains at risk from flooding from high river discharges, storm surges and combinations of these. The dike ring area is identified as one of the most risky places in the Rhine-Meuse Estuary, due to its very low elevation. If flooding would occur, water depths in the urban area may rise, often quickly, up to 1.5 to 3 meters. The flood extent and impact depend on where the dike breaches. If a breach occurs in the east, then the whole city may become flooded, resulting in 5 billion euro damage, 100,000 affected persons and 500 fatalities.

A combined strategy for flood risk management has developed been that addresses the three layers of multi-layer safety, as outlined in the National Water Plan (Ven W, 2009). In the combined strategy, measures in layers 2 (spatial planning) and 3 (emergency management) are combined with protection measures in order to prevent a lack of resilience in the future

(Figure 3). The adoption of new safety standards in the Delta Programme has made it possible to invest in strengthening specific dike segments, where it is most cost-effective. By transforming the northern segment of the dike ring into an extra strong dike, Dordrecht can be safer than with an economically optimal standard for the entire dike ring -- for about the same cost. This targeted measure in layer 1 is sufficient to meet the basic safety level (chance of fatalities is not higher than 1/100,000) and reduces the risk of social disruption (large groups of fatalities) to virtually none. Economic damage and fatalities can be further reduced by optimising and using regional defences by compartmentalization (layer 2). In addition, compartmentalization of the dike ring area enables the creation of a "safe haven" for preventive evacuation on the island itself (layer 3). This also calls for thorough preparation for floods, e.g. by robust design of critical infrastructure networks, and by improved risk- and crisis communication.

The sensitivity and thresholds of no / difficult recovery have been estimated for the combined (i.e. multi-layered safety) strategy and a reference strategy (Figure 11), using a hydrological/ hydraulic model (SOBEK) and damage model (HIS-SSM). The reference strategy comprises protection by dikes and barriers (layer 1), together with a continuation of the existing safety standard (no differentiation in protection levels). Figure 11 provides insight into the effectiveness of the two alternative strategies for different return periods (or: exceedance frequencies), and into the likelihood of persistence. It can be concluded from Figure 11 that the combined strategy decreases the sensitivity of the area to extreme flood events at significantly lower cost, and therefore increases its persistence. Elsewhere, the potential for multiple benefits by regeneration using SuDS in domains 1 and 2 are outlined for an urban area in the City (Gersonius, 2012).

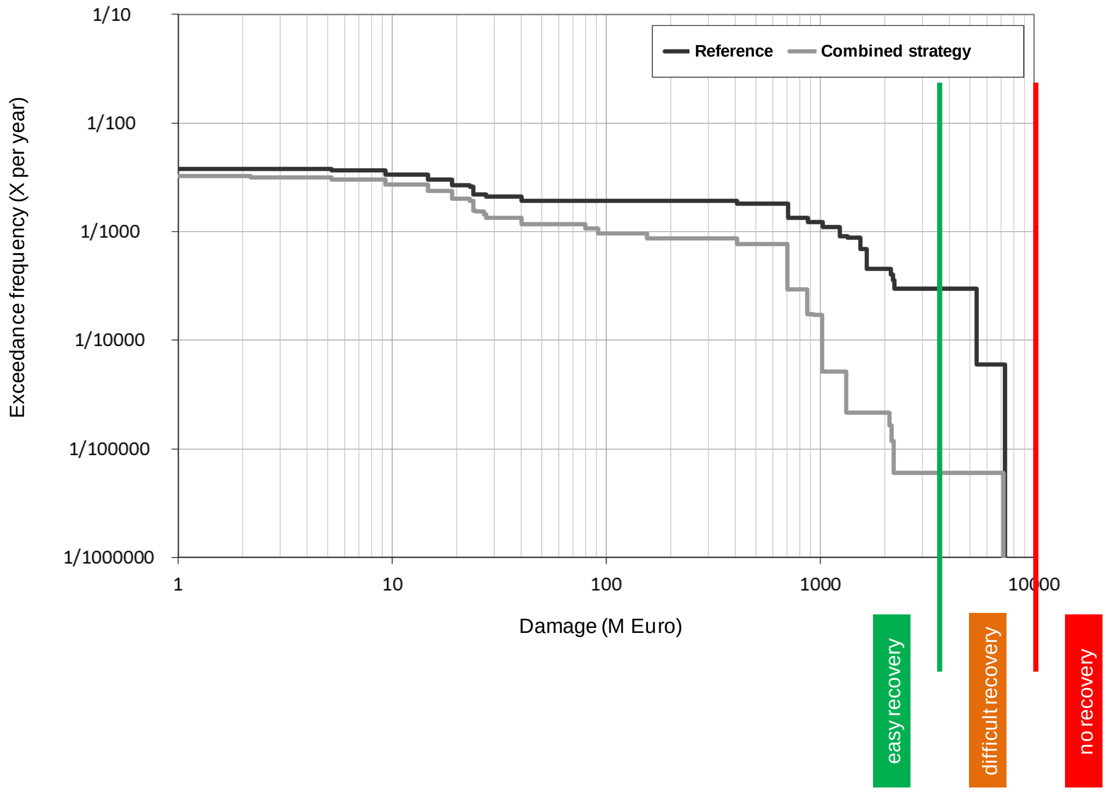

Figure 11. The 4-Domains Approach (4DA) applied for Dordrecht (Domain 1 has been omitted, but is shown in Figure 4)

A procedure for enhancing flood resilience in Water Sensitive Cities

Notwithstanding the discussion above that sets out the need to consider both flood and drought resilience in conjunction, in this section, only flood resilience is included. Further work is needed to see how best to develop the preceding ideas to properly and effectively include droughts.

Step-by-step procedure

There are a number of inter-linked research programs attempting to deliver on the vision of water sensitivity, recognising that Australian cities are placed around the 'waterways city' stage in the transition towards the water sensitive city; taking advantage of the opportunities for making the cities more aesthetic and improving urban design; with emphasis on environmental protection and providing potable supplies, public health and flood protection, among other things. Amongst such programs, the Cooperative Research Centre for Water Sensitive Cities, a AUD$120M centre led by Monash University and other research and industry participants which aims to develop strategies to transition to Water Sensitive Cities (CCRC, 2012).

The centre's research includes a project under the Water Sensitive Urbanism theme to integrate flood risk analysis and flood risk management with other management practices to enhance asset protection and help facilitate the overall objectives of the water sensitive city: *Socio-Technical Flood Resilience in Water Sensitive Cities − Adaptation across spatial and temporal scales* (Project B4.2). The latter component of the project is in collaboration with UNESCO-IHE in Delft, and builds on the tools developed in the INTERREG IVB NWE project FloodResilienCity (FRC) and the INTERREG IVB NSR projects for Managing Adaptive Responses to changing flood risk (MARE) and Skills Information and New Technologies (SKINT).

The procedure is illustrated in Figure 12 and in Table 6, a framework is shown that has been used to simultaneously deliver enhanced flood resilience and water sensitive urban design in the EU FRC project and also to maximise multiple benefits (Table 4). The procedure shown in Figure 12 is generic in that it can be applied to a wide range of responses to change, not only in the context of WSUD as shown here. Although the procedure presented suggests a linear and sequential procedure in a series of stages, revision and recursive feedback to the analysis is not only possible but also important. The feedback is possible in two defined stages in the procedure. In Step C.2, the previously defined drivers, opportunities and performance criteria are refined in light of boundaries or stakeholders' interests that might have not been considered previously. Monitoring in Step D.3 and also of the overall process, allows the evaluation of the objectives and criteria of the outcomes and also the process itself. By performing the revision activities the procedure takes into account new information and ensures that decisions have to be considered dynamic and not static. The approach is consistent with other tools and visions such as the Adaptation Compass that has been developed by the INTERREG IVB Future Cities Project (NWE, 2012).

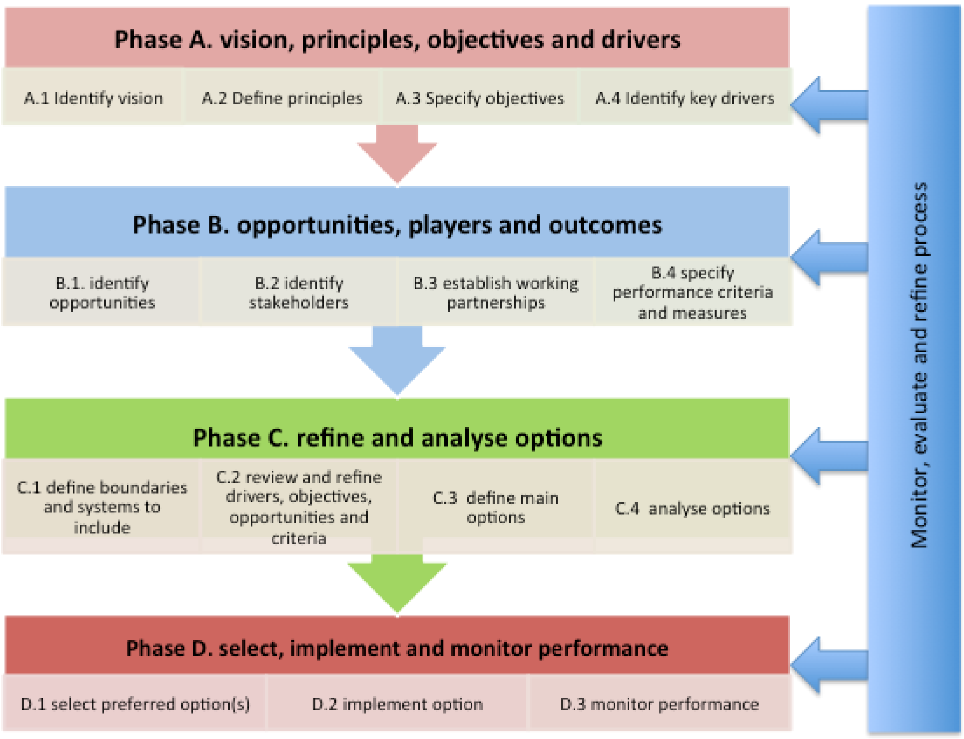

Figure 12. Analysis procedure used to incorporate flood resilience in WSUD

Table 6. Procedure for including water sensitivity and flood resilience in planning, design and delivery

Phase	Step	What it includes
A. Vision, principles, objectives and drivers	A.1 Identify vision	The vision sets your perspective and the overall way in which you wish to deliver the services provided by your organisation. This should be at a high level and not only relate to WSUD and or water sensitivity. The vision should also include scope and scale; time and space.
	A.2 Define principles	The principles derive from the vision and are overarching for the delivery of the WSUD.
	A.3 Specify objectives	The objectives are set within the above. These should include both risks and opportunities for utilisation of benefits and values beyond flood risk management in your personal context and covering the appropriate jurisdiction.
	A.4 Identify key drivers	Often the starting key driver is likely to be to enhance or provide flood resilience. However, where other key drivers take precedence, e.g. delivery of a new development, the provision or enhancement of resilience may be an added opportunity.

Phase B. Opportunities, players and outcomes	B.1 Identify opportunities	This is a first view only and will be refined later in Stage C.2 and C.3. A widely drawn list, scoping possible interventions and opportunities for changes to your systems should be created as a starting point to help in the subsequent stages. Ideally this should identify flood resilience measures and accompanying WSUD measures that go with these. Here reference needs to be made to the four Domains in Figure 9 and to the various resilience concepts to classify the opportunities and ensure that all possible eventualities are addressed.
	B.2 Identify stakeholders	These should be identified within and external to your own and other organisations and should include all those who need to be involved in the process of selecting and implementation changes/developments. Remember that it is not only flood risk stakeholders who need to be included. Rather all the potential groups and individuals who might be interested in/affected by either or both the flood resilience measures and the WSUD concepts and applications.
	B.3 Establish working partnerships	There will inevitably be a core group of prime movers, usually innovators/those who hold funds or are the most affected by the changes in urban and flood risk management systems. These can be brought together as the main participants in learning alliances, although everyone identified in Stage B.2 should have the opportunity to engage in and influence the change process. New options can emerge at this stage.
	B.4 Specify performance criteria and measures	These should be agreed in relation to outcomes and impacts in regard to objectives identified in stage A.3 and opportunities in Stage B.1 and in the context of the three external impact Domains in Figure 9. They may be statutory or guide standards, such as from WSUD guides or other practice (Domain 2, Figure 9). However, for added-value beyond flood resilience, there may not be any standardised criteria or measures other than e.g. to maximise the opportunities. It is important here to ensure that criteria and measures to evaluate performance are defined well enough to cover the boundaries (Stage C.1) will set, especially performance over time with changing external drivers.
Phase C. Refine and analyse options	C.1 Define boundaries and systems to include	This is very important to get right as it will define the scope and limits to the analysis, the range of things to include in the costs and benefits assessments and the effects of external drivers like climate change and needs to include: a. Spatial extent, geographically but could also include political jurisdiction (local, city, catchment) b. Sectors, depending upon the importance of the interactions between these (water, wastewater, stormwater, energy, transport etc.); increasingly energy is included in all such studies c. Analysis ‘layers’ – overlaps with (b) above and depends on how the analysis is carried out (benefits, costs, water quality, environmental impacts, etc.)

	C.1 Define boundaries and systems to include (cont.)	d. Time scale (annual, monthly, daily, future scenarios) is especially important for discounting costs and for considering climate and other changes. Hence some form of scenario analysis should always be undertaken and time scales agreed with all stakeholders. This should include the players over time – will they remain the same institutions? The same individuals? Politicians and policy makers will certainly change in timescales that infrastructure operates over.
	C.2 Review and refine drivers, objectives, opportunities and criteria	This Stage allows for reflection on the definitions in Phase A, Stages B.1 and B.4 and their refinement. Here some options from Stage B.1 can be readily rejected as not fitting with the boundaries (Stage C.1) and or the stakeholders' interests (Stage B.2 & B.3) or as not fulfilling aspirations for taking opportunities or performance (Stage B.4). Alternative/additional stakeholders may also be brought in at this stage and even new options if opportunities have arisen since the first assessment.
	C.3 Define main options	Here the front-running change options for maximising opportunities and benefits whilst addressing the key challenges of flood resilience should be defined, reducing the number identified in Stage B.1 and possibly B.3. A roadmapping process could be undertaken. This will reveal if changes are needed in the near, mid-term or longer term. It may also be used to assess whether or not the proposed option(s) are already emerging in your practice or if they need to be planned for in a scheduled implementation.
	C.4 Analyse selected options	Prior to this Stage, limited analysis will have been done. It is at this Stage that detailed modelling; accounting and evaluation data are generated for individual options and for options in combination with each other in portfolios. It is likely that the option performance should best be kept separate for the key aspects of resilience improvement and separately, realising WSUD opportunities and added-value benefits. The way in which the measures will be implemented (practicability) needs to be considered as well. It is likely that implementation could bring up some conflicts in delivery of both flood resilience and WSUD added value *at the same time*. Implementation of traditional structural flood resilience measures, such as increasing the elevation of a sea wall is straightforward although not necessarily easy, whereas if aesthetic quality is to be promoted as well, this will make delivery more difficult as the objectives may be contradictory and difficult to reconcile. In many instances of trying to add WSUD concepts into delivery of traditional schemes to date, at least in Europe, implementation has been deemed too difficult and the WSUD aspects have as a consequence been abandoned and traditional approaches ensue. Here also, uncertainties need to be assessed and communicated to decision makers and stakeholders. The

	C.4 Analyse selected options (cont.)	scenario analysis will help with this, especially in testing the relative robustness of the options being considered. Sensitivity analysis can also assist with understanding uncertainty. Although where the multiple benefits of using WSUD are concerned, there is no standardised approach to both evaluate and to present the results. There is a danger here that the uncertainties appear to be so great that a decision maker is put-off using WSUD or trying to maximise the benefits. When in fact, so-called traditional measures using pipes and outfalls are no less uncertain.
Phase D. Select, implement and monitor performance	D.1 Select preferred option(s)	The option(s) for change should be selected at this stage based on the pre-defined objectives and criteria (refined at Stage C.2) and the preferences of the decision maker(s) and funders. The options should also be those that are the most robust in terms of the scenario analysis; i.e. they will deliver the expected outcomes in as many of the future scenarios as possible. Due regard needs to be given to the uncertainty and sensitivity of the analysis (C.4) in making selections.
	D.2 Implement option	Timescale needs to be considered here. In any case, in an uncertain future, implementation usually needs to be staged. However, many will demand and expect a major investment as soon as possible where there are known ‘problems to be solved’. If relevant immediately, the option(s) selected should be implemented. Appropriate engagement needs to be made with local communities where these are not represented in the stakeholder group in B.3. The decision maker(s) need to be engaged effectively so that they know that this option is not a once and for all ‘solution’, but a response that will need to be monitored and reviewed for performance regularly.
	D.3 Monitor performance and adapt as needed	It is important that arrangements are made to ensure that both the implementation (construction) and the overall performance (outcomes) can be monitored over as a long a period as the option(s) is expected to perform (Stages B.4 and C.1). Also for subsequent review of the process. Here the system performance can be expected to deteriorate over time due to changes in the external drivers and also in the functionality of the system (ageing, deterioration of fabric etc.). This is why and adaptive management process is required, whereby successive interventions will be needed over time. Hence be prepared to consider short, medium and longer-term performance. In the short term, decision makers will need to be managed so that they understand the need to review and keep an eye on the performance of the system over time. It is expected that gradually all decision makers will understand this need, so longer term, they will automatically engage in this process. Here, a decision tree approach may be useful as it is readily understandable by decision makers.

The procedure in Table 6 is detailed elsewhere (Ashley et al., 2013) in the context of flood resilience and WSUD to maximise the multiple benefits that may arise in a European context. This needs to be modified to conform to the wider concepts outlined in this review report and to apply within an Australian context.

Mainstreaming the provision of flood resilience with urban renewal

In contrast with Australia, most of the opportunities to implement WSUD in European cities will often come about through redevelopment rather than Greenfield construction. ‘Mainstreaming’ looks for propitious synergies so that vulnerable areas, systems and functions in urban areas can be made resilient through adaptation as part of the ‘normal’ process of redevelopment and regeneration of existing areas (Gersonius, 2012, Veerbeek et al., 2012). Critical vulnerabilities can be identified independently of climate change projections using a tipping points method (Gersonius et al., 2013) and can be addressed using opportunistic interventions designed to maximise overall benefits by mainstreaming into normal city redevelopment and retrofitting processes.

Applications of the mainstreaming method have so far been rather simplistic and not dynamically responsive, including a wider range of tipping points for complex urban services, assets and utilities; specifically including too little and too much water, asset ageing and replacement/renovation, transportation and energy systems. Adaptation tipping points are the physical boundary conditions where acceptable technical, environmental, societal or economic standards may be compromised (Haasnoot et al., 2012). So far there are only simple economic valuation and other decision support tools that help define when, where and how best to adapt to tipping points and how best to balance between structural and non-structural measures to cultivate resilience. Collectively these emerging approaches will facilitate the adaption of environments and systems in existing urban areas (retrofit) in a way to best provide resilience to changing water management needs (too little and too much) and help influence urban development trajectories. New GIS planning tools for city growth and development projections, with a semi-automatic WSUD retrofit functionality are being developed in parallel to help with this (Bacchin, 2013). However, only limited consideration has so far been given to the barriers caused by national and local institutional arrangements that are crucial for effective delivery. For instance the private water companies in England have a duty to maximise their shareholders’ wealth and this may often be in conflict with the needs for better integration of the management of the water cycle and urban systems as a whole. It is essential therefore to identify a process that will allow the development of trust between the actors, ensures moral probity and enables effective integration (Dudley et al., 2013).

Evidence from the Netherlands has shown that it is much more efficient and effective to align urban renewal, the normal processes of property and road redevelopment that occurs every few decades, to the critical and pre-defined (but on-going re-defined) tipping points for flood risk (Gersonius, 2012). These ‘moments’ of synergy when and where this can occur have been defined as ‘mainstreaming moments’ and need to become a mainstreamed part of IUDPM processes. This is so that mainstreaming flood resilience becomes part of how a normal city functions. However, mainstreaming for flood resilience is not typically a high priority in urban planning and therefore this needs to be brought more to the attention of planners and others via Learning Alliances (Ashley et al., 2012).

The application of WSUD in countries other than Europe or Australia, is in an even more challenging task. In general, the Asian, African or South American countries lack of planning strategies on flood risk management, and their governments may find it difficult to achieve the goals proposed by WSUD, not only because of insufficient financial capacity (e.g. Dhaka in Bangladesh) but also because other constraints such as land scarcity due to urbanization rates (e.g. Shenzhen City in China).

Learning alliances for the uptake of flood resilience in practice

There are several examples of Learning Alliances that are set up to incorporate flood risk management into urban planning and design, often facilitated through European research programs, such as FRC and MARE. Although not so-called in Australia, learning in groups with a wide range of stakeholders is becoming better understood (e.g. Boss et al., 2013).

FRC, led by the Netherlands Programme Directorate 'Room for the River in the Netherlands, has enabled public authorities in 8 cities in North West Europe to better cope with floods in urban areas. The project aimed at integrating the increasing demand for more houses and other buildings in urban areas with the increasing need for more and better flood risk management measures in North West European cities along rivers. The partners included cities in France, Belgium, Netherlands, England, Germany and Ireland. The partners have many different aims and objectives, but as an example, the aim of the City of Bradford Metropolitan District Council has been to make flood risk and water management consistent with 'the Council's policy for a corporate approach to: service, strategic planning, commissioning and procurement and the delivery needs of the local area' is representative of many of the partners. In FRC, WSUD has been considered mainly from the perspective of ensuring resilience to flooding, whilst at the same time maximising the potential opportunities of getting as many benefits as possible from water systems in urban areas. The stance taken has been one in which water and urban ecosystems are seen as important components in the need to manage systems, services, utilities and infrastructure in cities by taking an integrated urban design, planning and management approach.

Another EU project, MARE, has anticipated policy developments on flood risk management in Europe (e.g. EU Floods Directive) and the Netherlands (e.g. Dutch National Water Plan) by experimenting with a multi-layer safety (MLS) approach in Dordrecht (among other North Sea Region cities). In 2010, the Island of Dordrecht gained the formal status as an MLS pilot of the Dutch Delta Program on Safety. As part of MARE, Gersonius et al. (2012) have applied the ATP method to the management of (intra-urban) flood risk in Dordrecht (the Netherlands), so as to assess its potential to maintain and/or enhance resilience to climate change (Gersonius et al., 2012). The lessons of MARE are now being extended and tested into the context of medium-sized cities in Asia in the MARE-Asia project, which was launched in 2012 and in a follow-on European project. Learning from the success of the European MARE Project, the concept of Learning and Action Alliances will be used as the vehicle to enhance liveability through a collaboratively developed vision of integrating environmental and urban ecological concerns into urban planning processes and investment planning. With the support of Asian Development Bank's `green cities' initiative, two secondary cities of Vietnam were selected to pilot MARE-Asia. The USD 250,000 pilot project will start in mid-2013 and last for two years (Gersonius et al., 2010). MARE-Asia provides the opportunity to develop evidence of the application of WSUD within a weaker urban and land use planning environment than is found in either Europe or Australia.

Financing the provision of flood resilience

WSUD is often perceived as a stand-alone intervention and consequently WSUD investments are often considered as 'additional' costs. There is a need to shift towards an overall 'resilience upgrading' approach which promotes investments that broadly improve the conditions and performance of the established urban area for investors, residents, and users (ICLEI, 2011). The resilience upgrading approach integrates WSUD with the agendas of green building, urban regeneration, and urban development.

The public sector has a leading role to play in financing flood resilience. Local governments can apply local economic instruments such as charges and taxes for emitters and polluters (waste water, solid waste, property taxes for vulnerable locations) and subsidies and tax incentives for developments contributing to flood resilience. However, there may be additional investments needed for the inclusion of WSUD in regeneration and new built development projects that are generally more than the local authorities can finance through taxes and funding. This especially holds true for local governments in many countries where austerity measures are affecting their budgets for financing (green) infrastructure, despite other national policies often promoting the use of green infrastructure.

Private investments in WSUD are often constrained by high upfront costs and long investment timelines. Other constraints to investment include lack of familiarity, limited information and knowledge, and limited expertise in WSUD (OECD, 2012).

Vanguard projects in WSUD indicate that local demand for broad-based urban investments is a prerequisite to adequately mobile resources. This can be promoted by linking cascades of interdependencies of infrastructure in ‘systems of systems’ (Hall et al., 2013). A demand-driven strategy embracing the ‘resilience upgrading’ approach, which exploits the many opportunities for mainstreaming and integrating WSUD into infrastructure renewal and urban regeneration while delivering multiple benefits, is attractive to private investors. This is because achieving multiple local development and climate adaptation objectives can create net co-benefits when considering total additional costs and total benefits. It should be noted here that Public Private Partnerships (PPP) are likely to become increasingly prominent to overcome shortage in public capital and competence in the greening of cities in the near future.

Concluding remarks

The integrated water management approach required for water sensitivity includes WSUD, which intrinsically incorporates flood resilience as well as drought resilience and ecological resilience. In this report the flood and drought resilience has been shown to comprise similar visions of resilience and potentially approachable from a common perspective. As well as for new designs, the approach may be used to identify when, where and how best to adapt and retrofit urban areas to simultaneously provide enhanced flood resilience as a component of water sensitivity. Tools to do this are now starting to emerge, dealing inter alia with costs linked with social benefits and alignment with normal regeneration or development processes so that they are more economic and incorporate a wide range of WSUD, including green infrastructure in order to provide multiple benefits. Decision makers can be supported in deciding whether or not to implement response measures or to do nothing at any point in time or space (i.e. when to adapt) based on monetised values that include the value of maintaining flexibility/resilience.

There is a need to go beyond simple Net Present Value (NPV) type approaches, which do not adequately reflect the value of flexibility, and build in headroom and flexibility into resilience of urban areas and dynamically manage adaptation via tools such as Real-in-Options (RIO). However, further tools and developments need to include the means to evaluate the interactions from WSUD and flood/drought resilience systems with other urban systems such as energy, waste and transport.

There is still some way to go to explore, test and refine the proposed framework to ensure it is fit for purpose, relevant and comprehensive. Empirical data, evidence and new supporting component tools are needed in order to prove its applicability, not only to the urban areas in the Netherlands or Australia but more generally. Additional case studies are underway in Rotterdam and Vietnam to support the universality of the approach.

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Appendix A - Review of existing frameworks to categorise interventions to enhance flood resilience

Flood risk management (FRM) has multiple goals relating to multiple time and space scales[1]. Achieving these relies on the development and implementation of appropriate sets of interventions, a process that is complicated by the changing nature of the flooding system (through climate, geomorphologic and socio-economic influences).

Hereafter, three alternative FRM frameworks are presented. Those illustrated in the following sections have been selected as they represent well-established (international) practice and complementary perspectives, though slightly differing depending on the context.

Source-Pathway-Receptor (SPR) framework

Haddon (1976) [2] introduced a comprehensive classification of interventions aiming to deal with different types of disasters that has been used extensively worldwide in planning how best to manage risks. By defining a sequence of interventions, Haddon illustrates possible ways as to how to prevent human and economic losses given extreme events. This classification, which is not hierarchical with respect to the effectiveness of the interventions, shows the stages that a disaster passes from its origin to the moment of effect and to people. There are some hazards, like hurricanes, that cannot be prevented, but still there are some actions that can be taken at different moments of the disaster to help alleviate consequential losses. In fact, Haddon suggests that some damage might be irreversible, limiting the scope of available actions.

Nonetheless, the categorization proposed by Haddon facilitates the selection of an appropriate set of interventions for the reduction of losses. Haddon states that the larger the amount of energy related to the resistance of the target, the earlier the strategies used should lie in the Sources - Pathways - Receptors sequence (e.g. [3]), as summarized below:

Sources. Sources are weather events, or sequences of events, that may result in flooding (e.g. intense rainfall and storm surges)

Pathways. Pathways are mechanisms that convey floodwaters that originate as weather events to where they may impact on receptors (e.g. flows in and out of river channels and urban overland flows)

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[1] Sayers P., Li Y., Galloway G., Penning-Rowsell E., et al. (2013). Flood Risk Management: A Strategic Approach. Paris, UNESCO.

[2] Haddon, P. (1973): Energy Damage and the Ten Countermeasure Strategies. The Journal of Trauma Vol. 13, No. 4, The Williams & Wilkins Co. USA, p. 321-331.

[3] Thorne, C R, Evans, E P and Penning-Rowsell, E Eds. (2007) Future Flooding and Coastal Erosion Risks, Thomas Telford, London, UK, ISBN 978-0-7277-3449-5.

Receptors. Receptors are the people, businesses and the built and natural environments that are affected by flooding.

The ten categories proposed by Haddon are: (1) eliminate the hazard source; (2) reduce the hazard source; (3) prevent the release of hazard; (4) modify the rate of hazard source; (5) spatial-temporal separation of hazard source from the object; (6) use a barrier between the hazard and the object; (7) modify the contact surface of hazard source; (8) strengthening of objects against hazard; (9) mitigate the damage; and (10) reparation or stabilization.

With respect to flood disasters the elimination of the hazard source, reduction of the hazard source and stabilization are usually not possible; therefore, the Haddon classification is reduced to seven categories, discarding (1), (2) and (10) above.

IPCC Coastal Zone Management (CZM)

Coastal zones have historically been highly populated because of their fertile lowlands, marine resources, water transportation facilities, aesthetic values, among other reasons.

Coastal areas are a critical part of all economies that have a sea[4] coastline. However, coastal zones are now experiencing problems as a result of inter alia climate change, development and increased population pressures and ecosystems, changing the functions and values normally associated with coastal areas. Flooding, habitat loss and modification, pollution and others have consequences on public health and economy.

In response to the above mentioned problems and consequences, the IPCC have established a framework for the management of coastal zones looking for adaptive responses that can be implemented either case-by-case, or as part of wider comprehensive and systematic coastal management programs. Although the framework is by its nature dedicated to coastal areas, the principles can be linked to other type of zones.

As mentioned in the IPCC report, coastal management has three main objectives: (1) avoid development in areas that are vulnerable to inundations; (2) ensure that critical natural systems continue to function; and (3) protect human lives, essential properties, and economic activities against the ravages of the sea. Some of these objectives are difficult to achieve depending on the characteristics of the countries where the framework is applied.

All the adaptive strategies under the IPCC CZM framework have three different categories for the interventions as a function of the objective they are proposed for: retreat; accommodate; protect.

Retreat. As defined in the IPCC report, retreat refers to the abandonment of land and structures in vulnerable areas, and resettlement of inhabitants. In general, this category of intervention needs advanced planning and acceptance and might lead to loss of some coastal zone value. This category of intervention has a direct impact on the domains of relief of extreme situations, spatial planning (i.e. multifunctional land use) and ecosystem restoration

[4] J. Dronkers, J. T. E. G., L.W. Butler, J.J. Carey, J. Campbell, E. James , C. McKenzie, R. Misdorp, N. Quin, K.L. Ries, P.C. Schroder, J.R.Spradley, J.G. Titus, L. Vallianos, J. von Dadelszen (1990). Strategies for adaption to sea level rise. Report of the IPCC Coastal Zone Management Subgroup: Intergovernmental Panel on Climate Change. Geneva, Intergovernmental Panel on Climate Change.

(i.e. urban wetlands). The need for a strong regulation system and enforcement of decisions is evident under this type of intervention.

The application of this type of intervention is most straightforward in areas that are not highly developed economically, because of the irreversible losses involved. These interventions may threaten the value of past investments, as well as limit future growth.

Retreat interventions have impacts on the socio-cultural network of the affected area. In some circumstances, relocation of inhabitants or even communities may be needed. This, for some cases, may represent the destruction of the economy and culture.

Accommodate. This category of interventions is defined for continuing the occupation and use of vulnerable areas. These types of interventions are usually linked to decrease the degree by which objects and people are affected (i.e. raising floor levels), prevent damage by flood proofing (i.e. rain proof buildings), building social resilience (i.e. early warning systems), or temporary flood proofing (i.e. sand bags).

Having multifunctional land use planning is important for this category of interventions. Inundated land, for example, can be used for new purposes, although some economic benefits and incentives may be needed.

Accommodation interventions typically have a lesser impact on the socio-cultural network than retreat.

Protect. This category represents the defence of vulnerable areas, especially those with critical importance like urban centres, main economic activities and natural resources. In general, protection in coastal zones involves measures and activities to protect areas against inundation, tidal flooding, effect of waves, salinity intrusion, etc. Successful protection interventions are those which leave options open for appropriate future responses. Dikes, levees and floodwalls have traditionally been the 'standard' intervention to protect coastal zones which over time, may become an inflexible type of intervention as they are hard to modify. Protection is most relevant for heavily populated areas where the environment has already been transformed.

Protection activities are directly related to the economic values of the protected goods. Therefore, a detailed analysis of benefits has to be conducted before implementing any intervention. In general, interventions under this category have less impact than the retreat and accommodate categories.

EU flood directive (FD)

Flood risk management aims to reduce the likelihood and/or the impact of floods. According to the EU Flood directive 'Flood risk management plans should focus on prevention, protection and preparedness. With a view to giving rivers more space, they should consider where possible the maintenance and/or restoration of floodplains, as well as measures to prevent and reduce damage to human health, the environment, cultural heritage and economic activity'[5].

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[5] EU (2007). DIRECTIVE 2007/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2007 on the assessment and management of flood risks. E. Union, European Union: L288/227- L288/234.

Prevent. Preventing damage caused by floods by avoiding construction of houses and industries in present and future flood-prone areas; by adapting future developments to the risk of flooding; and by promoting appropriate land-use, agricultural and forestry practices.

Protect. Taking measures, both structural and non-structural, to reduce the likelihood of floods and/or the impact of floods in a specific location.

Prepare. Informing the population about flood risks and what to do in the event of a flood. This framework has been applied in practice by many and various European projects. The FloodResilientCity Project involved eight different cities in the North of Europe. Using the EU FD as a general umbrella, the cities involved developed a range of activities, including the management of inland flooding caused by surface water and groundwater; streams and rivers, both small and large; and even the management of coastal flooding and its interactions with inland flooding[6]. By doing this project, the participants have move forward in the interpretation of the EU FD concepts.

Floodsite was an earlier European project based on and informing the concepts of the EU FD. With the Involvement of 9 European countries, the project also interpreted the concepts in the EU FD and also used the Source-Pathway-Receptor model[7].

Reflection

Comparing the three frameworks presented above, Source-Pathway-Receptor (SPR), IPCC for Coastal Zone Management and European Flood Directive (EU FD), most of the interventions that are key in each of the frameworks can be grouped under common categories (i.e. “protect” is an explicit category in IPCC CZM and EU FD), whereas other interventions are not considered in a specific framework (i.e. IPCC CZM has no emphasis on preparedness interventions). Also, it has to be noted that most of the measures such as ecosystem restoration, compartmentalisation and flood proofing that are mapped as ‘Retreat’ or ‘Accommodate’ measures under IPCC CZM classification fall under the ‘Prevent’ classification of EU FD.

When considering interventions leading to flood resilience, it is possible to conclude that (i) ‘Prevention’ is a combination of ‘Retreat’ and ‘Accommodation’ measures, as these measures help to manage the consequences of flooding; (ii) ‘Protection’ is a combination of Retain, ‘Relieve’ and ‘Resist’, as the measures help to manage the probability of flooding; whereas (iii) ‘Preparedness’ measures, are mostly non-structural such as evacuation plans, building social resilience, which help manage the situation in the event of flood.

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[6] FloodResilientCity Project website. http://www.floodresiliencity.eu/frc-output/93/3-the-floodresilient-actions-in-frc. Visited 14-07-2014.

[7] Floodsite Project website. http://www.floodsite.net/html/work_programme.asp. Visited 14-07-2014.

Appendix B - Details of the steps in the procedure shown in Table 6

Phase A: Identify vision, principles, objectives and key drivers

The vision, principles, objectives and drivers have been grouped together here because of their close interaction. Drivers act to put pressure on to a system that is impacted by this, such that its state is often changed (Figure A1). For example, climate change is a high level driver that leads to increased rainfall or sea level rise in many parts of the world. This results in impacts such as overloading or overtopping of existing drainage and coastal protection measures respectively. As a consequence, the state of the system changes, with e.g. more flooding and asset damage.

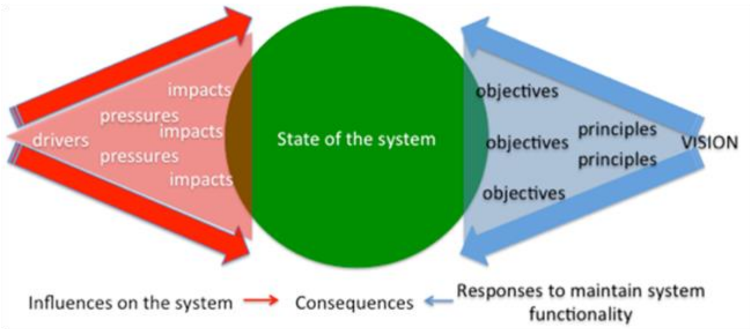

Figure A1. Illustration of the drivers acting on systems like water and their consequences, showing the need for a visionary response

Many, if not all drivers provide opportunities, not only threats for the responses to them. Increased rainfall for example, provides more water supply opportunities and higher sea levels might provide an opportunity to amend functional sea walls into multi-functional dikes as has been done in Japan's 'super-levees', where buildings are part of the dike structure. There is now even a movement for super-levee urban farms to ensure productive land use[8].

How drivers are addressed depends on the vision of those involved, the principles for addressing the drivers derived from this vision and the objectives formulated for dealing with the drivers as illustrated in Figure A1. The responses may also be applied to manage the drivers, e.g. mitigating climate change and at the pressure or impact stages. Typically responses may influence several drivers and at different points in the illustration shown in Figure A1. In urban areas for example, it is necessary to respond in a way to maintain functioning of the city or town system – this is resilience. Responses may allow or be designed to change the state of the system, provided overall functionality is maintained.

The vision relates to what you are trying to do and why you are doing it and includes the scales that you are thinking about: how long into the future; the local area for development or the entire town or city. At the least 3 timescales are needed: short, medium and long term – you need to define what these mean in the context you are working in and agree it with the others involved.

[8] http://openbuildings.comr-levee-urban-farm-profile-2756 accessed 02-09-13

The overall vision may be to enhance the health, welfare and wellbeing of people in your neighbourhood or jurisdiction. From this vision, a set of principles will emerge with which you will push forward your agenda. Everything in the process of delivering multi-value WSUD is set within the context of this vision and the principles it results in. The vision, principles and agenda may be developed within your organisation or in conjunction with others' including the general public. For example, Figure A2 shows the IWA 'cities of the future' vision and the derived principles from this vision.

Understanding and expressing a vision (which could be a mission statement) will help to identify the broad current aspirations of how an organisation wants to shape their activities in the future in the context of existing challenges. Recognised challenges and wider aspirations will help to define the principles and then the objectives for a specific initiative or project. However, there is also the vision of and for your organisation as whole. Many organisations include their own survival (sustainability) in the way they go about their activities; sometimes preferring options that support their own survival rather than those options that are best for society overall. This is because there is a culture of just looking 'at the project' and not the governance of the approach as well. Especially for large projects, which includes e.g. coping with climate change as a whole, extant governance arrangements may not be the most effective and in need of reform. Changing governance and institutional arrangements is complex and especially difficult for those in need of such reforms and will not be dealt with here, where a project-led perspective is taken[9]. It is therefore presumed from here on that the existing governance and institutional arrangements will remain in place and will be those on which resilience-led WSUD is delivered.

From an FRC perspective a starting key driver is likely to be to enhance or provide flood resilience. However, there are likely to be many drivers of which those that are water related are not likely to be of dominant consideration unless flood risks now or in the near future are significant.

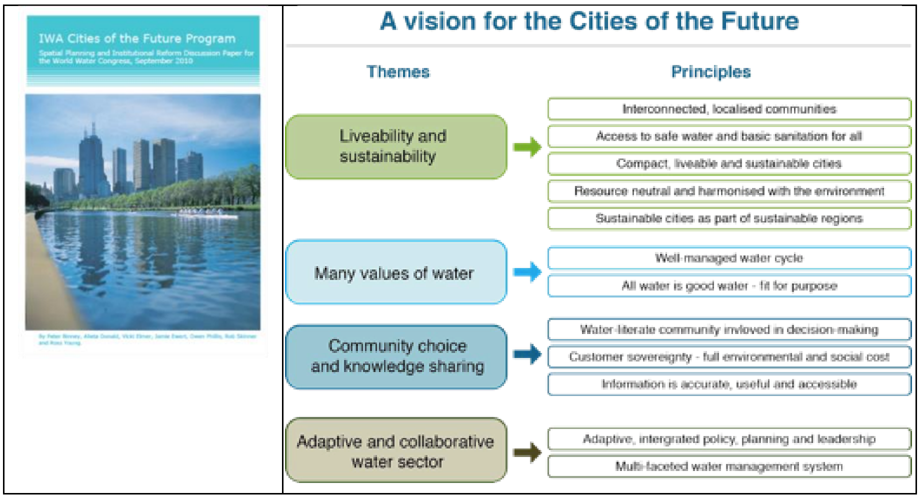

Figure A2. IWA Vision and Principles for water within a City of the Future[10]. This shared vision was created at the IWA World Water Congress which included twelve principles within four themes, as shown in Table A1.

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[9] see: changing governance

[10] Binney, P., et al. (2010) IWA Cities of the Future Program, Spatial Planning and Institutional Reform, Conclusions from the World Water Congress, Montreal, September 2010.

Table A1. Twelve principles in four themes for IWA Cities of the Future

Theme 1: cities will be liveable and sustainable
1: Cities will continue to grow in population but will be increasingly liveable. A feature of cities will be more interconnected communities.
2: cities of the future will provide access to safe drinking water and sanitation for all
3: Sustainable cities will combine a compact footprint with sustainability and liveability.
4: Cities will be resource neutral or generative, combining infrastructure and building design which will harmonise with the broader environment.
5: Sustainable cities will be part of prosperous, diverse and sustainable regions.
Theme 2: The many values of water
6: Sustainable cities will be served by a well-managed water cycle that – in addition to public health and water security – provides for healthy waterways, open spaces and a green city.
7: Sustainable cities will recognise that all water is good water – based on the concept of 'fit-for purpose' use.
Theme 3:Community choice and knowledge sharing
8: Cities will be served by informed, engaged citizenry and multi scale governance that enables local community choice.
9: Customer sovereignty with full environmental and social cost.
10: Accurate and useful information, including smart metering.
Theme 4: Adaptive and collaborative water sector
11: Sustainable cities will be served by adaptive and integrated approaches to urban development.
12: Sustainable cities will be served by a multifaceted water management system.

Within this perspective, water has an important role to play and as an example, has been defined by the State of Victoria in a 'living Melbourne' roadmap[11]:

- **Liveable Cities** – delivering safe, fit-for-purpose water supplies; attractive urban landscapes that support healthy communities and improved flood protection.
- **Sustainable Cities** – by ensuring smaller environmental footprints; healthier waterways and parklands; landscapes resilient to natural disasters and climate variability.

[11] Skinner R. (2012) Foreword.in: Howe C. & Mitchell C Eds. Water Sensitive Cities. IWA ISBN 9781843393641

- **Productive Cities** – providing water security for the future; affordable water services; a clear, transparent and contestable investment climate and economic prosperity

The translation of this into action requires:

- Preparing and being prepared for change in what is currently done as regards water management
- Getting the values of water right – i.e. water is valued appropriately in all of its' facets and uses
- Acknowledge (and account for) all of the costs
- Build a networked and smarter industry12 around water

The CRCWSC in Australia has adopted the above and is now developing the ideas and processes to deliver the vision shown in Figure A2. WSUD is a major component of the process and the water sensitive city is the outcome. The principles from this are:

- Cities as water supply catchments – access to water is through a diversity of sources at a diversity of scales
- Cities providing ecosystem services – even in the built environment it functions to supplement and support the functions of the natural environment
- Cities comprising water sensitive communities – that include inter alia, socio-political capital for sustainability and all aspects of decision making and behaviours are water sensitive

Derived objectives for managing stormwater under these principles include[13]:

- Utilise all opportunities to harvest stormwater
- Support the greening of cities
- Improve human thermal comfort to reduce heat related stress and mortality
- Decrease the total flow of stormwater runoff from urban surface and improve flow regimes for urban waterways and waterbodies
- Encourage productive vegetation and increased carbon sequestration
- Improve air quality through deposition
- Improve the amenity of the urban landscape

The UK CIRIA project that has scoped the use of WSUD[14], developed the following two principles:

1. All elements of the water cycle and their interconnections are considered concurrently to achieve a solution that sustains a healthy natural environment while meeting human needs, including:

a. Water demands and supplies

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[12] 'industry' is used in the widest sense and not to define only a private or public service provider, rather the entire industry of players that contributes to water systems and services

[13] adapted from Wong et al. (2012) Blueprint 2012 – stormwater management in a water sensitive city. Melbourne Australia: Centre for water sensitive cities. ISBN 978-1-921912-01-6. March

[14] http://www.ciria.org/service/Home/AM/ContentManagerNet/ContentDisplay.aspx?Section=Home&ContentID=25333 accessed 02-09-13

b. Wastewaters and pollution
c. Rainfall and runoff
d. Waterways and water resources
e. Flooding and water pathways

2. This consideration is made from the outset and throughout the planning and design process that creates and changes our towns, cities and places, and it seeks to achieve the expectations and aspirations for design of successful places, such as:

a. Celebrating local character, environment and community
b. Maximising synergistic cost-benefits of infrastructure and systems
c. Improving the liveability of a place for its communities
d. Providing resource security and resilience in the future.

From these principles, the CIRIA scoping document uses a number of case studies to illustrate how WSUD can align with or add to development objectives for schemes.

Phase B: Opportunities, players and outcomes

What the possible opportunities are need to be considered at this stage. This is a first assessment only and will be refined later in Stage C.2 and C.3. A widely drawn list, scoping possible interventions, however radical or unlikely they may seem and opportunities for changes to your systems should be created as a starting point to build on in the subsequent stages. This should identify the entire range of flood resilience measures and accompanying WSUD measures that are part of them together with the opportunities to deliver more than simply flood resilience. Here reference needs to be made to the four Domains in Figure 9 and to the various resilience 'A's to identify and classify the opportunities and ensure that all possible eventualities are included. In Phase C the importance of scenario considerations is described, but when scoping options it is important to try and identify some that are:

- **No-regrets** – measures that are worthwhile (i.e. they deliver net socio-economic benefit) regardless of how the future turns out
- **Low-regrets** – measures which work well in the majority of futures, have relatively low development and implementation costs and high benefits and/or can be readily modified (and avoid locking in future choices)
- **Win-win** – measures that deliver a range of benefits to a range of stakeholders – mitigating the risk that future benefits will not be achieved

'No regret' options are also defined as those that can be modified or adapted easily, hence these prevent investments in what can become 'stranded assets'; i.e. assets that are no longer fit for purpose but which have to be used because they exist and decommissioning or abandonment is too costly.

Box 1 illustrates a case example where a number of options are being considered to manage a flood risk, taken from the Environment Agency report[15]. This report suggests:

- Generating options that support a process of managed adaption
- Achieving support through reasoned argument and visuals with key stakeholders

[15] Environment Agency (2013) Promoting adaptive solutions and accounting for adaptive approaches in FCERM options appraisal – Supplementary Guide. Draft. Project Number: SC110001

- Identifying promising options for carrying forward to further development and (if appropriate) more detailed appraisal.

Each of these is included in the discussion in the rest of this report.

Box 1 illustrates a number of the steps in the overall procedure presented here and will be referred to again in the descriptions that follow. The three short-listed options of bank raising; property level protection and a bypass channel have been determined after considering a range of other options. For example, upstream measures may be a possibility with sacrificial farmland to reduce the flows locally in the town downstream. A key consideration is the need to maintain the ecosystem vitality in the future for a protected species as a result of habitat change at some time *under one possible future scenario*. This means that further flexibility and adaptation of the flood management system is possibly constrained. This in itself also limits what opportunities and options there are at the present time.

The example does not provide any commentary on the potential added-value benefits of the options and concentrates at this stage on the flood resilience aspects of the ‘problem’. i.e. this is a problem-centric rather than an opportunity-centric perspective. In practice, many added-value benefits would be revealed for the various options considered.

Box 1: example of managed adaptive approach

Town X is a small market town located in England. It has a population of around 5,000. The River C, a tributary of the River B, flows through the centre of the town. Town X has a history of flooding, the most recent notable events occurring when nearly 200 homes were flooded in both 2005 and 2009. The existing flood defences constructed in the 1980s are not able to provide the necessary standard of protection (SoP) to new properties that have since been constructed in the town. A new flood defence scheme is therefore required.

Definition of Futures

Seven futures have been identified in this example. They are a function of climate change, economic change and habitat change. It is assumed for illustration that each future can be weighted (equally in this case), but note that this is merely a basis to explore sensitivity to the weighting.

Habitat change represents the future arrival of protected species at the reach of the river with the implication that any future action involving works within the river (in this case further raising of the flood defence walls) will suffer a penalty in terms of increased costs or reduced benefits due to environmental impacts.

Future	Climate change (increased flow)	Economic Value	Other	Weighting
1	Low	None		1/7
2	High	None		1/7
3	Low	+20%		1/7
4	High	+20%		1/7
5	Low	-20%		1/7
6	High	-20%		1/7
7	High	+20%	Protected habitat moves into local area	1/7

Box 1: (continued)

Economic change is assumed to occur linearly from 2008 (the initial investment) and reaches a minimum/maximum value (-20% or +20%) by 2015. This could be caused by an increase or decrease in population (and therefore housing development) within the flood cell between 2008 and 2025 (stated regeneration period of the development plan), or a gradual increase in the affluence of this market town, for example. No further economic change is observed after this point (this is a simplification for the sake of keeping this example straightforward). Climate change projections are evaluated at three distinct climate change points: 2025, 2055 and 2085. Between these points, the climate is assumed to change linearly (starting at the initial investment in 2008). The protected species is assumed to arrive in 2025.

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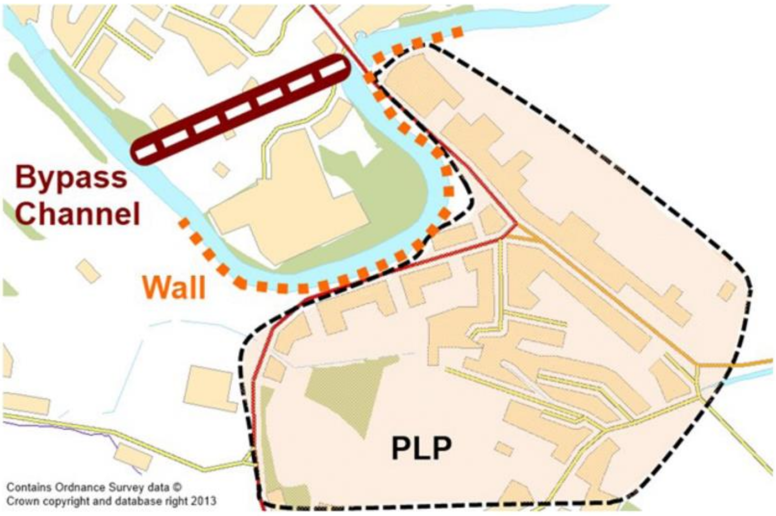
Short listed options

The aim of the flood manager is to reduce the impact of flooding in the area being considered. This area (the flood cell) is highlighted in orange in the figure below. Three principal measures have been short listed that have been anticipated to meet the desired aim over the duration of the appraisal period:

1. Raising the existing wall on the south bank of the river (both now and in the future) to protect all the properties in the flood cell
2. Installation of Property Level Protection (PLP) to provide protection up to a height of 0.5 metres at all properties in the flood cell
3. Construction of a bypass channel to remove all flooding at all properties in the flood cell

These three measures are shown spatially in the following figure:



Box 1: (continued)

A decision tree is constructed that consists of four decision pathways and six options (combinations of measures) and capital investments, maintenance costs and investment timings are also summarised.

The upper routes – replacing the wall and strengthening the foundations involve large up-front costs. These represent a precautionary (or reactive) approach where investments are "locked in" early in the appraisal period. The lower routes – installing PLP and maintaining the existing wall – involve small upfront costs and larger future costs. However the benefits are suitably lower due to the limited performance of PLP in the more extreme events. These represent a more adaptive, where larger investments are deferred until later in the appraisal period.

It is essential to identify the stakeholders within and external to your own and other organisations. This should include all those who need to be involved in the process of selecting and implementation changes/developments. Remember that it is not only flood risk stakeholders who need to be included but everyone who may be affected by or have a material influence on the proposed changes. This should include all the potential groups and individuals who might be interested in/affected by either or both the flood resilience measures and the WSUD concepts and applications. In some cases a formalised stakeholder analysis may be justified or alternatively, a 'snowballing' may be appropriate. This step should also consider whether or not to establish a learning and action alliance, defined as "*a group of individuals or organisations with a shared interest in innovation and the scaling-up of innovation, in a topic of mutual interest…LAs typically comprise a number of structured platforms, at different institutional levels (city, river basin, national, international), designed to break down barriers to both horizontal and vertical information sharing, and thus to speed up the process of identification, adaptation, and uptake of new innovation*" [16]. More information

[16] Dudley E., Ashley R M., Manojlovic N., van Herk S., Blanksby J. (2013). Learning and Action Alliances for innovation and active learning in a European context. Proc. International Conference on Flood Resilience: Experiences in Asia and Europe 5-7 September 2013, Exeter, UK.

on setting up LAAs and stakeholder analysis is provided in the EU INTERREG IVb MARE project portal[17].

LAAs are prime drivers for innovation as illustrated in Figure A3

Figure A3. Illustration of innovation in business practice from[18]

The description from the report in which Figure A4 is shown, describes the implementation of an innovation and risk management approach:

- Create a decision-making environment where it is expected that assumptions and evidence will be challenged.
- Ensure that ‘challenge’ doesn’t become a personal issue.
- Look to embed risk management in the organisation by selling the benefits rather than aspects of control.
- Ask pertinent questions about how risk assessments are carried out and ask about the relevance and status of treatments and controls.
- Clarify risk appetite in the context of the decision, rather than automatically assuming that all ‘high’ risks need to be reduced.
- Encourage people to think of the problems and find ways to solve them, and not to think how to extricate themselves if they fail, but how to ensure they succeed.

Each of these characteristics can be fostered through the workings of an effective LAA.

Establishing such working partnerships for innovation is nowadays essential. These partnerships ensure legitimacy of action and also shared responsibilities and often shared

[17] MARE portal, http://www.mare-portal.eu/mare-output/1/work-package-1-learning-and-action-alliances

[18] Cabinet office (2006) innovation and risk management: a recipe for improving performance. January. European centre for business excellence. National school of government, Ascot, England.

expenditure[19]. These can overcome reluctance to innovate and help share risks and risk perceptions, which are usually the main reasons why innovation does not happen[20][21].

There will inevitably be a core group of prime movers in any partnership, usually innovators/those who hold funds or are the most affected by the changes in urban and flood risk management systems and WSUD for e.g. place making and liveability. These can be brought together as the main participants in the learning alliances outlined above, although everyone identified in Stage B.2 should have the opportunity to engage in and influence the change process, not necessarily in formal learning alliances. New options can emerge at this stage.

Figure A4 illustrates the participatory planning process that LAAs can utilise. Due to the heterogeneity of the national and local contexts, availability of resources, as well as the priorities given to flood and climate change problems across partner countries, the LAA as an overarching concept has been found in the EU INTERREG IVb project SAWA, which set out to address both the water framework and flood Directives of the EU together, to not necessarily be the appropriate vehicle for all contexts and applications[22]. In the initial project phase of SAWA, the LAA concept was considered by many of the partners as too novel, and as such was difficult to pursue within certain rather rigid institutional structures as well as being perceived as difficult to control, i.e. a risk of loss of power on the part of decision makers. As a result of this, the SAWA LAA was exclusively constituted only to support the ‘bottom up’ FRMP process in the small urban catchment of the Wandse River in Hamburg, i.e. to support the local community, practitioner delivery and in interfacing with the ‘top’ policy and decision makers.

Figure A4. General Framework and main phases of Participatory Planning in the SAWA LAA

[19] Examples: Babbs L. (2011). Urban Flood Risk Management schemes: Case study examples of schemes with multiple funders, multiple objectives and partnership working. Maslen environmental. UK; Defra (2012) Principles for implementing flood and coastal resilience funding partnerships. GEHO0312BWDK-E-E

[20] Ashley, R., Tait, S. (2012) Use of Scenarios in PREPARED. [http://www.prepared-fp7.eu/ prepared-publications] Accessed: 05-09-2013.

[21] Rychlewski M., Westling E., Sharp E. , Tait S J., Ashley R M. (2013) Adaptation Planning Process - Key steps for implementing a strategic planning process for institutional adaptation in a water utility. http://www.prepared-fp7.eu/prepared-publications

[22] Manojlovic N., Behzadnia N., Barbarins D., Pasche (2012): Learning & Action for Flood Risk Management Planning. Proceed. Int. Hydroinformatic Conference, Hamburg, Germany.

The MARE LAAs also experience a variety of difficulties related to power sharing, legitimacy and relative willingness to innovate. Together, these various projects and FRC cover a number of European countries in both the North Sea and North West Europe regions as defined by INTERREG. Therefore the overall conclusions expressed in the reports for MARE, SAWA and summarised in[19], which suggest that LAAs are not definable as single types of entities to be established; rather they need to be formed around a specific project or scheme and with a specific goal in mind as has been done very successfully in Dordrecht I the Netherlands[23].

Importantly, a perspective of ‘learning by doing’ is needed in the group working and in the conception of project options and delivery. This also fits with an adaptive management approach[18]. Much of the knowledge held by the participants in the LAA can be defined as ‘tacit’; which is “knowledge held by virtue of experience” [24]. The approach advocated to utilise this, involves sharing narratives; empathy and even morality in regard to how schemes are conceived and delivered. Trials of the approach are underway by the Water Coalition in the Netherlands which is supported by the Ministry of Infrastructure and Environment.

In any system change it is necessary to define performance criteria and measures to assess performance. These should be agreed in relation to outcomes and impacts in regard to objectives identified in stage A.3 and opportunities in Stage B.1 and in the context of the four external impact Regions in Figure A5. They may be statutory or guide standards, such as from the urban drainage/sewerage standard EN752 or other practice. The standards will depend upon national criteria although they may share internationally agreed codes of practice. For example, EN752 is an international (ISO) standard that is interpreted in national contexts.

Within the context of over-arching standards for risk management, ISO 31000[25], provides nominal standards which may be viewed as a representation of the objectives that are affected by uncertainties in the driving forces, the expectations of communities and in the response of the flood resilience system. Alternatively, the level of risk tolerable or the costs and benefits of available risk management measures may also define the objectives that can reasonably be set or expected.

In the flooding and water resources domains a lot of progress has been made in dealing with future uncertainty in relation to climate and other changes. Much of this has focused on ensuring the flexibility and adaptability of measures. Techniques using e.g. ‘tipping point’ analysis, ‘real options’ and ‘real in options’ are being further developed from origins in the financial sector[26].

A ‘dynamic adaptation policy pathway’ approach has recently been defined as illustrated in Figure A5 for the management of water systems in relation to future climate change

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[23] van Herk S., Zevenbergen C., Ashley R M., Rijke J. (2011). Learning and Action Alliances for the integration of flood risk management into urban planning: a new framework from empirical evidence from the Netherlands. Environmental Science & Policy. 14 (2011), pp. 543-554. DOI: 10.1016/j.envsci.2011.04.006

[24] Geldof G. D., Regoort P., Bothof H. (2013). Stormwater change in existing urban areas. gwf-Wasser/Abwasser. International Issue 2013. 39-45

[25] ISO 31000:2009 Risk management – principles and guidelines. International Standards Organisation.

[26] Gersonius B., Ashley R M., Pathirana A., Zevenbergen C. (2013). Climate change uncertainty: building flexibility into water and flood risk infrastructure. Climatic Change 116:411–423. DOI 10.1007/s10584-012-0494-5

uncertainty[27]. The cyclic nature of this diagram is similar to a number of illustrative approaches to ensuring that measures planned for flood risk and water management can be modified in the future as necessary.

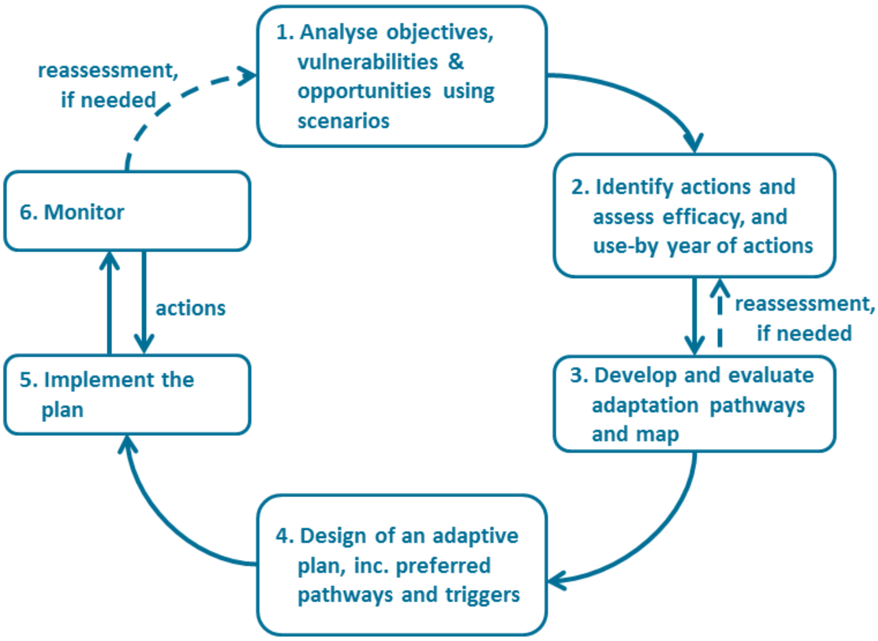

Figure A5. Dynamic Adaptive Policy Pathways for managing climate change and related uncertainties (Source: www.deltares.nl/en/adaptive-pathways)

This approach has now been taken up by the National Government in the Netherlands as the baseline for managing uncertainties in relation to flood risk management. It combines adaptation pathways with adaptation policies and provides a framework for utilising adaptation tipping points, real in options and other techniques that define where, when and how best to make system changes.

For added value beyond flood resilience for e.g. WSUD, there may not be any standardised criteria or measures other than e.g. to maximise the opportunities for uses other than for flood risk management. It is important here to ensure that criteria and measures to evaluate performance are defined well enough to cover the boundaries (Stage C.1) set, especially performance of the system over time in response to changing external drivers. Figure A6 shows a single performance line for the system which represents current conditions. Over time this line will shift due to both the deterioration in the system performance as a result of ageing of the assets and also due to changes in external drivers such as climate. Thus the definition of standards of performance and how these are evaluated in terms of outcomes from any investment needs to be as flexible and adaptable as possible.

The case study in Box 1 is illustrative of a managed adaptation approach to flood risk management that utilises a real options methodology, which is considered further in the following section.

[27] Haasnoot M. (2013) Anticipating Change - Sustainable Water Policy Pathways for an Uncertain Future. PhD thesis. Twente University, Netherlands. ISBN 978-90-365-3559-5

Phase C. Refine and analyse options

When defining the boundaries and systems to include the scope and limits to the analysis will be prescribed, for example the range of things to include in the costs and benefits assessments and the effects of external drivers like climate change and needs to include *inter alia*:

- Spatial extent, geographically but could also include political jurisdiction (local, city, catchment)
- Sectors, depending upon the importance of the interactions between these (water, wastewater, stormwater, energy, transport etc.); increasingly energy is included in all such studies
- Analysis 'layers' – overlaps with (b) above, which depends on how the analysis is carried out (benefits, costs, water quality, environmental impacts, etc.)

The water quantity aspects – flood risks and receptor vulnerabilities in terms of inundation frequency, depth, velocities etc. will be analysed using computer models of appropriate levels of complexity. The physical scale will define if this can be done simply or requires complex analysis.

Time scale (annual, monthly, daily, future scenarios) is especially important for understanding system performance now and in the future. It is also important for discounting costs and for considering climate and other changes. Hence some form of scenario analysis should always be undertaken and time scales for this agreed with all stakeholders. This should include the players and stakeholder composition over time – will they remain the same institutions? Will it be the same individuals and will they adopt the same perspective as today? Expectations of performance will change with time and this needs to be considered. Politicians and policy makers will certainly change in a democracy. Thus there will be different people making decisions in future with different point of view from today and this will influence how a managed adaptive approach is considered in the analysis.

The EU 7th Environment Framework programme project PREPARED considered scenario analysis within the context of adaptation of water assets and systems to climate change[13, 14]. The project considered both the technologies for adaptation and the capacity of decision makers and how this capacity could better be supported by a methodological approach. For dynamic and managed adaptation to work, decision makers, and or their institutions need to become 'active learners' which means they have to keep up to date with knowledge and also revisit previous decisions to ensure that these are still delivering the outcomes expected. This is different to the past when most decision makers were able to make a decision and then forget about it, as external drivers were only weakly changing. Now we know that external drivers are changing rapidly and decisions about new assets today will be challenged in the lifetime of those assets. LAAs can help decision makers in this process, but commitment is required by today's decision makers and institutions to engage in this.

The PREPARED scenarios approach has been devised to be as simple as possible and widely applicable (there were more than 12 EU Member States and beyond involved in the project). Figure A6 illustrates the scenarios.

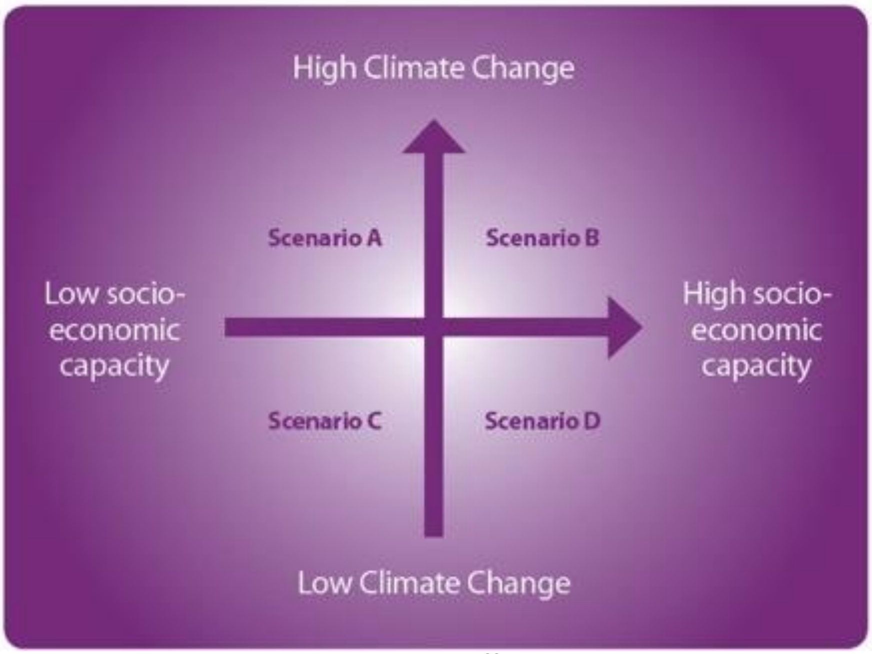

Figure A6. Scenarios used in the PREPARED Project[28]

Scenario based techniques have been used extensively to deal with issues such as flooding in the water and sanitation sector and can be applied to test the robustness of responses. Scenario planning is a method originally developed to deal with uncertainties about the future. It is not about predicting the future using descriptive futures research, but envisaging plausible and logically consistent versions of the future. Visions of the future may be termed 'scenarios' and can be used to represent how things might become at some time in the future. A minimum of four scenarios should be used in assessing the robustness of options. In the case of Figure A6, these are:

- High climate change and high socio-economic capacity
- High climate change and low socio-economic capacity
- Low climate change and high socio-economic capacity
- Low climate change and low socio-economic capacity

These are not the only scenario options in use and in most countries standardised scenario sets have been defined. Where possible these should be used instead of those above.

Socio-economic capacity (or capacity and vitality) has been selected in place of the usual governance or social structure axis as a primary indicator of adaptation potential, as this is strongly related to actually adapting. What this means is that in a societal system with significant financial reserves (disposable income or savings) or high economic turnover, there are possibilities to spend some of these on adapting. However, even where wealth is or seems high (adaptation potential is high), alternative prioritisation of investments may mean that using it to adapt water supply and sanitation systems to climate change may not actually be an option or a priority (low adaptive capacity). Associated with the scenario analysis, more than one future time horizon (epoch) needs to be used. This will depend on the purpose of the analysis but may be e.g. 2025 and 2080 if only two are being used.

[28] http://www.prepared-fp7.eu/prepared-publications accessed 30-11-13

In each application it will be necessary to define the attributes (characteristics that make up the details and context) of the 4 scenarios under each of the time epochs depending upon local circumstances. This process, together with the steps (a) – (c) below is explained in detail elsewhere.

Each option generated in the Phase B and Phase C steps should be considered in the light of:

a. if the option is feasible in each of the scenarios and epochs selected
b. if the drivers-pressures-impacts assumed in Phase A are still valid in the future(s) for each scenario and if not how should they be modified
c. the relative robustness of the response option under each of the scenarios then needs to be assessed qualitatively – i.e. how well will it work?

From the analysis above, the options that will continue to work under the various scenarios at the appropriate points in time are those that should be considered further in greater detail. A roadmapping process could be undertaken[31]. This will reveal if changes are needed in the near, mid-term or longer term. It may also be used to assess whether or not the proposed option(s) are already emerging in your practice or if they need to be planned for in a scheduled implementation.

This is the review and refinement of the drivers-pressures-impacts. At this point there is also the chance to review and refine the initial objectives, wished-for opportunities and criteria. This Stage allows for reflection on the definitions in Phase A, Stages B.1 and B.4 and their refinement. Here some options from Stage B.1 can be readily rejected as not fitting with the boundaries and the scenarios (Stage C.1) and or the stakeholders' interests (Stage B.2 & B.3) or as not fulfilling aspirations for taking opportunities or performance (Stage B.4). Alternative/additional stakeholders may also be brought in at this stage and even new options if opportunities have arisen since the first assessment.

In finally defining the main options - Here the front-running change options for maximising opportunities and benefits whilst addressing the key challenges of flood resilience should be defined, reducing the number identified in Stage B.1 and possibly B.3.

In the detailed analysis of selected options; prior to this stage, only limited detailed analysis will have been done. It is at this stage that detailed modelling; accounting and evaluation data are generated for individual options and then this should be done for options in combination with each other in portfolios of options. The option performance should be kept separate for the key aspects of resilience improvement and separately, realising WSUD opportunities and added-value benefits so that these are clearly differentiable.

The way in which the measures will be implemented and maintained (practicability) needs to be considered as well. It is likely that implementation could bring up some conflicts in delivery of both flood resilience and WSUD added value at the same time. Implementation of traditional structural flood resilience measures, such as increasing the elevation of a sea wall is straightforward although not necessarily easy, whereas if aesthetic/visual and recreational quality is to be promoted as well, this will make delivery more difficult[29]. In many instances of trying to add WSUD concepts into delivery of traditional schemes to date, implementation has been deemed too difficult or as adding unnecessary costs and the WSUD aspects have as a consequence been abandoned.

Box 1 illustrates a case example where managed adaptation was to be part of the objective of the way in which the scheme design was finalised. Box 2 follows on from Box 1.

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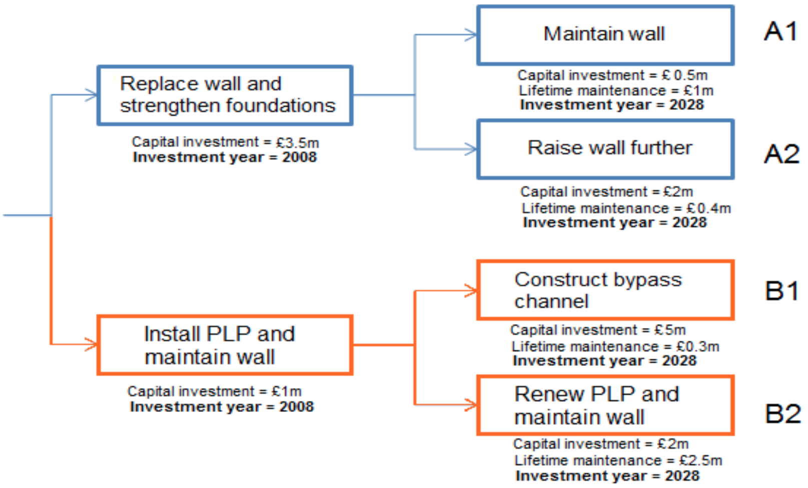
[29] for examples see the Floodprobe EU 7th framework environment project outputs: http://www.floodprobe.eu/project-outputs.asp. accessed 30-11-13

Box 2: example from Box 1 continued – decision tree and NPV estimation



Decision tree analysis for example in Box 1

Hydraulic model data were used to determine the economic damage associated with each of the proposed decision pathways, and a baseline was calculated in order to determine the benefits associated with each decision pathway.

The Net Present Value (NPV) was calculated for each of the decision pathways outlined above using standard discounted cash flow analysis.

The intention was to determine the flexibility, robustness, opportunity lost and expected performance for the tree, to help inform which decision pathway(s) should be taken forward to a fuller appraisal. The table below presents the NPV calculated for each decision pathway under each future, as well as the expected performance of each decision pathway. Values in bold represent the highest NPV that is predicted to occur under each future across all decision pathways.

Were the added-value benefits also to be considered then these figures would be considered alongside those below.

Decision pathway	Expected Performance (NPV - £millions)							
A1	14.36	13.00	17.16	15.53	11.56	10.48	14.51	13.80
A2	13.98	13.79	16.83	16.60	11.13	10.97	9.49	13.25
B1	14.43	13.88	17.22	16.56	11.64	11.19	15.37	14.33
B2	14.53	11.14	17.11	13.05	11.94	9.23	12.32	12.76

Box 3 continues the example looking at the flexibility of the options.

Box 3: continuation of example - Analysis without weighting

Flexibility. Before the practitioner has chosen to make either decision A or decision B, there are four available decision pathways, and the flexibility is therefore 4. Once either decision A or B has been taken, this flexibility will reduce to 2. In this example, flexibility does not vary between the options and therefore is not assessed. However, if an example that involved multiple decision pathways was being considered (for example, decision A might lead to 6 options becoming available, whilst decision B might lead to only 2 options becoming available) then flexibility could be used to better highlight the adaptive properties of a particular decision.

Robustness is evaluated by determining how well a given option performs under each of the 7 futures. In this case, option B produces the best performance in 6 out of the 7 possible futures. Its robustness is therefore 6/7. This value is high, and implies that option B is robust and will perform well under future uncertainties. Within option B, there are four futures under which B1 is anticipated to perform better than other decision pathways and two under which B2 would perform better. Hence the robustness of making choice B now is contingent on the optionality inherent in the choice between B1 and B2.

Lost Opportunity. The regret table for the initial options A and B is (£m):

Futures							
Options	1	2	3	4	5	6	7
A	0.17	0.09	0.06	0.00	0.38	0.22	0.86
B	0.00	0.00	0.00	0.04	0.00	0.00	0.00

Should future 4 be realised, both of the decision pathways available in B would be out-performed by decision pathway A1. The maximum lost opportunity that will result from making the initial investment choice B (and hence being able subsequently to choose any decision pathway in B but forgoing any decision pathway in A) is therefore £0.04m (derived by subtracting the maximum value in branch A under future 4, £16.60m, from the maximum value in branch B under future 4, £16.56m). This value is very small, and further implies that choosing to invest in B now is a robust decision. If, alternatively, the practitioner decided to make initial investment choice A then the maximum lost opportunity would be £0.86m (derived by subtracting the maximum value in branch B under future 7, £15.37m, from the maximum value in branch A under future 7, £14.51m). This is 20 times greater than the lost opportunity from making initial investment choice B and further demonstrates the robustness of choosing to invest in B now.

Box 4 considers the weighted assessment of the options.

Box 4: example continued - weighted assessment

Expected performance can be calculated as the average performance for each available decision pathway. In this case, the best outcome is £14.33m available in decision pathway B1 (install PLP and maintain wall now; and construct a bypass channel in the future). If the future optionality in the tree is ignored, then the expected performance of option A is £13.53m and for option B it is £13.55m. There is little difference between these two figures, and on expected value alone it would be difficult to make an informed decision. However it is clear from the consideration of robustness and opportunity loss above that option B is preferable.

Since the weightings associated with the futures are ambiguous, it is necessary to consider sensitivity to changes in those weights. For example, stakeholder beliefs might consider that the emergence of protected habitat in the reach is unlikely but may wish to check whether the analysis would change if the 3rd future (in which option A performs best) is given greater weight. The implications of this can be tested by reducing the weight on the 7th future and redistributing this onto the 3rd future. This corresponds to asserting that the combination of high climate change, +20% economic change and emergence of a protected habitat in the reach is less plausible than the other futures, whilst low climate change and +20% economic change is given more emphasis than other futures. The result of this test is that the expected performance of option A increases to £14.16m whilst option B becomes £13.96m. However, the robustness and opportunity loss analysis is not based on weighting and these metrics remain unchanged. Arguably the choice between options A and B remains finely balanced on grounds of NPV alone, but leans towards B on the basis of the non-probabilistic analysis.

If the decision maker chooses to invest now in decision B there will be 6 (out of a possible 7) futures in which the best expected performance or highest NPV will be realised. Furthermore, investing in decision pathway B will require relatively low ‘locked-in’ costs (less than a third of the costs incurred by investing in decision pathway A), and will delay making difficult decisions relating to the management of future uncertainty until a future time period. By doing so, adaptability is embedded into the decision making process and future uncertainty is managed by waiting until better information becomes available. There is only one future – future 4 (high climate change with +20% economic change) – in which neither of the options made available by investing now in decision B are predicted to result in the best expected performance. A2 (which involves a highly reactive process of raising defences multiple times) is the most economically valuable outcome under this future. However, it is not recommended that A2 is taken forward, given that option A is not robust (since it would only be preferred in 1 out of 7 futures), and generates considerable lost opportunity. These factors suggest that the adaptive capacity associated with option B is highly advantageous. It is instead suggested that decision pathways in option B are taken forward

In analysing options using techniques such as those illustrated in Boxes 1 to 4, the adaptive capacity between and across multiple decision pathways can be explored through a performance measures approach. Deferring large investments into the future and resisting reactive decision making (as happens too often in the political arena) is a policy that can be promoted through use of these performance measures. Finely balanced comparisons of economic performance can be augmented by information about robustness and opportunity loss contained within a decision tree. Expected economic performance can be sensitive to assumptions about probabilistic weights, but the non-probabilistic measures of robustness and opportunity loss can provide a useful alternative view. The approach taken here should ensure managed adaptation is properly considered and valued via appraisal, enabling informed choices about whether or not to proceed with adaptive options.

Bringing WSUD and other non-flooding related elements into this type of analysis is currently under development. Separate studies have looked at water resource planning from this adaptive perspective, but as yet not harmonised approach encompassing flood resilience and WSUD has been developed. This is the subject of a number of ongoing research studies[30].

When considering the added-value and monetary benefits of the options, there are a number of opportunities to do this using standard procedures such as ecosystems services valuation. Virtually all use the benefits transfer approach by comparing a scheme with other equivalent schemes already analysed.

Not all benefits can be monetised however. For flood and coastal erosion risk management, a UK guide provides details as to how to include environmental values[31]. An unpublished report[32] has also reviewed the various tools currently available.

Box 5 is taken as an example of application and monetisation of benefits and impacts. Box 6 shows how the monetised and non-monetised benefits can be considered together for this example. Box 7 shows the overall conclusions from the analysis.

[30] Radhakrishnan M., Pathirana A., Gersonius B., Zevenbergen C., Ashley R M (2013). Resilience approach to Urban Flood Risk Management systems using Real in Options - a review. Proc. WSUD conference Gold Coast, Australia. November.

[31] Eftec (2010) Flood and Coastal Erosion Risk Management: Economic Valuation of Environmental Effects HANDBOOK for the Environment Agency for England and Wales. Revised March.

[32] Eftec (2013a) Green Infrastructure – Valuation tools assessment (unpublished)

Box 5: example of valuing the environmental aspects of a coastal flood management scheme

FCERM Option & Environmental Effect	*Impact*	*£ value/unit (mid point value)*	*Total**
1. Do nothing (baseline)			
Carbon storage	(up to) 640 t/yr	from 50/tC02e/yr	(up to) £32,000/yr
Saltmarsh habitat	?	960/ha/yr	(up to) £24,000/yr
Mudflat habitat	?	935/ha/yr	(up to) £37,000/yr
Lagoon habitat	?	960/ha/yr	(up to) £14,000/yr
TOTAL BENEFIT (annual)			>£107,000
PVB (50 years)	n/a	n/a	>£3.1m
PVB (100 years)			>£4.4m
2. Maintain the line			
Carbon storage	decline	from 50/tC02e/yr	Negative
Saltmarsh habitat	decline	960/ha/yr	Negative
Mudflat habitat	decline	935/ha/yr	Negative
Lagoon habitat	0	960/ha/yr	£0
TOTAL BENEFIT (annual)			Negative
PVB (50 years)	n/a	n/a	Negative
PVB (100 years)			Negative
3. Partial retreat			
Carbon storage	448 t/yr	from 50/tC02e/yr	£22,400/yr
Saltmarsh habitat	>25 ha (10 ha)	960/ha/yr	£9,600/yr
Mudflat habitat	~40 ha (40 ha)	935/ha/yr	£37,400/yr
Lagoon habitat	>15 ha (6 ha)	960/ha/yr	£5,760/yr
TOTAL BENEFIT (annual)			£75,160
PVB (50 years)	n/a	n/a	£2.1m
PVB (100 years)			£2.9m
4. Full retreat			
Carbon storage	640 t/yr 25	from 50/tC02e/yr	£32,000/yr
Saltmarsh habitat	40	960/ha/yr	£24,000/yr
Mudflat habitat	15	935/ha/yr	£37,000/yr
Lagoon habitat		960/ha/yr	£14,000/yr
TOTAL BENEFIT (annual)			£107,000
PVB (50 years)	n/a	n/a	£3.1m
PVB (100 years)			£4.4m

Note: * Aggregation to present value benefit (PVB) uses hyperbolic discounting as set out by the HM Treasury Green Book for long term impacts (3.5% for years 1-30; 3% for years 31 to 70; 2.5% for years 71 to 100).

Box 6: combining monetary and non-monetary values

Option / effects	1. Maintain the line	2. Do nothing (baseline)		3. Partial retreat		4. Full retreat	
Saltmarsh lost (ha)[1]	Unknown (increasing loss)	Unknown (replaced)		Unknown (replaced)		Unknown (replaced)	
Mudflat lost (ha) [1]	Unknown (increasing loss)	Unknown (replaced)		Unknown (replaced)		Unknown (replaced)	
Saltmarsh/lagoon created (ha)[2]	0	1.11	?> or <? total 2.19	0.43	total 1.47	1.11	total 2.19
Mudflat created (ha)[2]	?	1.08		1.04		1.08	
Carbon storage (t CO2e/year)	0 (reduction)	Approx. 2.2		Approx. 1.44		Approx. 2.23	
Total	Negative	Possibly under £4.42m		Approx. £2.91m		Approx. £4.42m	

Notes: [1]Proxy for loss of supporting, provisioning and regulating services from existing intertidal habitat (water quality improvement, recreation (non-consumptive), biodiversity and aesthetic amenity benefits). ; [2]Proxy for gain of supporting, provisioning and regulating services from habitat creation Values for habitat gains and losses are a proxy for supporting, provisioning and regulating services that give rise to water quality improvement, recreation (non-consumptive), biodiversity and aesthetic amenity benefits.

Of the relevant ecosystem services identified in Steps 2 and 3, the following treatments have been possible:

- Supporting, provisioning and regulating services (except carbon storage): these have been accounted for by taking area of habitat gained or lost as a proxy and applying an estimate of the value of habitat provision. Note that the benefits of any flood or erosion regulation services should be separately estimated using the Multi-Coloured Manual. The habitat provision value accounts for specifically for water quality improvement, recreation (non-consumptive), biodiversity and aesthetic amenity benefits.
- Carbon storage: this service has been estimated separately since it is assumed to be sufficiently distinct from other regulating services to avoid double-counting issues. Current Government guidance has been followed in estimating the value of carbon storage benefits.

Box 7: Overall conclusions from the benefit analysis

The main results from the estimation of environmental costs and benefits associated with the FCERM options are as follows:

Option	Reporting Comments
1. Do nothing (baseline)	Some benefits are likely as are some losses. Overall loss of ability to optimise and control the habitat creation likely to mean gains rather less than in the MR scenarios, but there may be more habitat created overall. Net environmental values of almost £6m may arise over a 100 year horizon but this is subject to greater uncertainty than the partial and full retreat options in terms of the timing and scale of effects.
2. Maintain the line	No firm estimates. Likely environmental impacts negative and significant. Specifically these relate to ongoing habitat losses from coastal squeeze, with impacts, primarily negative effects on provisioning, regulating and supporting services.
3. Partial retreat	Substantial benefits. With a 100 year horizon our mid-point estimate is approximately £2.8m, with a low-high range of about £1.7m to a little under £4m.
4. Full retreat	Substantial benefits. With a 100 year horizon our mid-point estimate is approximately £4.5m, with a low-high range of about £3m to about £6m.

Note that reported benefits estimates are not *net* of the baseline. Inclusion of the estimated value of environmental effects within the overall appraisal framework will require subtraction of baseline benefits in order to identify gains and losses over and above the baseline. Here then, uncertainty regarding the environmental gains and losses likely to accrue in the do nothing option, makes it difficult to distinguish between the benefits of the partial and full retreat options and do nothing. Ideally reporting of these findings would reference the analysis in Step 3B where it is judged that greater uncertainty would be placed on this baseline estimate in comparison to the retreat options, given the uncontrolled and unpredictable nature of the habitat creation.

When undertaking the detailed analysis it is essential to provide some assessment of uncertainty. This can be using standard methods where the information is quantitative and may be expressed in terms of e.g. probability density. However, uncertainty as regards qualitative information is more difficult to deal with and here subjective ranges may need to be used. For example, public preferences for a particular aspect of a proposal can span a wide range from very positive to entirely against. Cascading uncertainty also needs to be considered, where the interacting uncertainties from a combination of factors and their significance for each decision stage need to be considered. Decision makers usually wish for a simple methodology for uncertainty, with subjective indications such as "we are very certain about this", "but less certain about this". Sensitivity analysis is also a useful tool, where variability in parameters can be tested simply by putting these at the limits of their possible values in the analysis. This approach has been used in the examples given in[35]. A fuller discussion and example of uncertainty methods and multi-criteria-decision-analysis for non-commensurate criteria is provided by[33].

Phase D. Select, implement and monitor preferred option

When selecting the preferred option(s) decision should be based on the pre-defined objectives and criteria (refined at Stage C.2) and the preferences of the decision maker(s) and funders, bearing in mind the need to ensure flexibility and adaptability in the future. The options should be those that are the most robust in terms of the scenario analysis (C.1); i.e. they will deliver the expected outcomes no matter what the future may be like. The selection may be collective through the LAA process and in any case the funding of implementation is likely to be from more than one funder. Each funder therefore needs to know which of the benefits accrue to them; which deliver on their regulatory responsibilities and which they are not necessarily duty-bound to provide, but are willing nonetheless to part-fund. Ideally decisions should include consideration of delivery of multiple benefit outcomes[34] and be in synergy with and cognisant of other systems, services and utilities.

Dealing with uncertainties at this point is not easy as these will prevail in both the flood resilience and the WSUD domains.

Box 8 shows an example from illustrating partnership funding.

Box 8: Example of partnership funding for flood defence scheme

The Parrett Estuary Flood Risk Management (FRM) Strategy takes a partnership approach between the Environment Agency and Sedgemoor District Council. The Parrett Estuary Strategy is aligned with the spatial development proposals in the Local Development Framework (LDF) and proposes a linked and innovative funding mechanism to pay for the preferred FRM options. This is known locally as a new development 'roof tax' through planning agreements. Expected total FRM scheme cost is £24.6 million and developer contribution is anticipated to contribute £9 million over the next 20 - 30 years

Implementation of the selected option(s) – which may be a portfolio of measures - may need to be incremental. This may be to try and see how effective it is in stages, as is planned for

[33] Sustainable decision making for the UK water industry (2003). Ashley R M., Blackwood D J., Butler D., Davies J A., Jowitt P., Smith H. ICE Journal Engineering Sustainability 156 (ES1), March. Pp41-49.

[34] e.g. Maslen (2011) Coastal Schemes with Multiple Objectives and Funders (FD2635) - Lessons Learnt and Guidance Report. Final. May.

the expansion of the Grand-Lac-du-Seine upland reservoirs that protect Greater Paris from flooding, for which a new storage wetland is to be constructed prior to full expansion of the storage facilities. It may also be that funding is not available immediately and only limited initial investment can be made. In any case, in an uncertain future implementation needs ideally to be staged in a 'learning by doing' process.

If relevant immediately, the option(s) selected should be implemented. Appropriate engagement needs to be made with local communities where these are not represented in the stakeholder group established in B.3. The decision maker(s) need to be engaged effectively so that they know that this option is a once and for all 'solution', but a response that will need to be monitored and reviewed for performance regularly. It will be important also to work with (a) those who will operate and maintain the new measures; (b) the emergency planners, so that functional operability can be assigned and guaranteed, but set within the overall process of flood and water management shown in Figure A6.

Once constructed or otherwise implemented if soft measures are used, it is essential (not optional) to monitor performance and adapt the measures as needed. It is important that arrangements are made to ensure that both the implementation (construction) and the overall performance (outcomes) can be monitored over as a long a period as the option(s) is/are expected to perform (Stages B.4 and C.1). This is also important for subsequent review of the process. The system performance can be expected to deteriorate over time due to changes in the external drivers and also in the functionality of the system (ageing, deterioration of fabric etc.). This is why a managed adaptive process is required (Phase C, whereby successive interventions will be needed over time. Hence, it is important to consider short, medium and longer-term performance. Rules for adjustment are required to ensure reliable functioning.

Figure A7 shows the policy pathways for the City of Dordrecht in the Netherlands to cope with flooding from fluvial and coastal processes. These are linked with 'mainstreaming' plans that provide opportunities for implementation of large scale regeneration of parts of the City bringing in green infrastructure at the same time as improving flood resilience.

In the short term, decision makers will need to be managed so that they understand the need to review and keep an eye on the performance of the system over time, i.e. as active learners. It is expected that gradually all decision makers will understand this need, so longer term, they will automatically engage in this process.

As the process is intended to deliver multiple benefit outcomes, it will be necessary to utilise performance assessment ideas and tools from various domains. In general the flood risk domain is well documented regarding the assessment of the effectiveness of measures. This is not the case in the WSUD domain, albeit there is a wealth of information from application in the Australian context related mainly to stormwater management. There is a need for new ideas, processes and procedures for co-evaluation of the performance of flood resilience and WSUD measures. This is the subject of ongoing research[35].

[35] Salinas Rodriguez C N A., Ashley R M., Gersonius B. et al. (2013) Incorporation and application of resilience in the context of water sensitive urban design: the Dutch and Australian perspective. WiRES journal

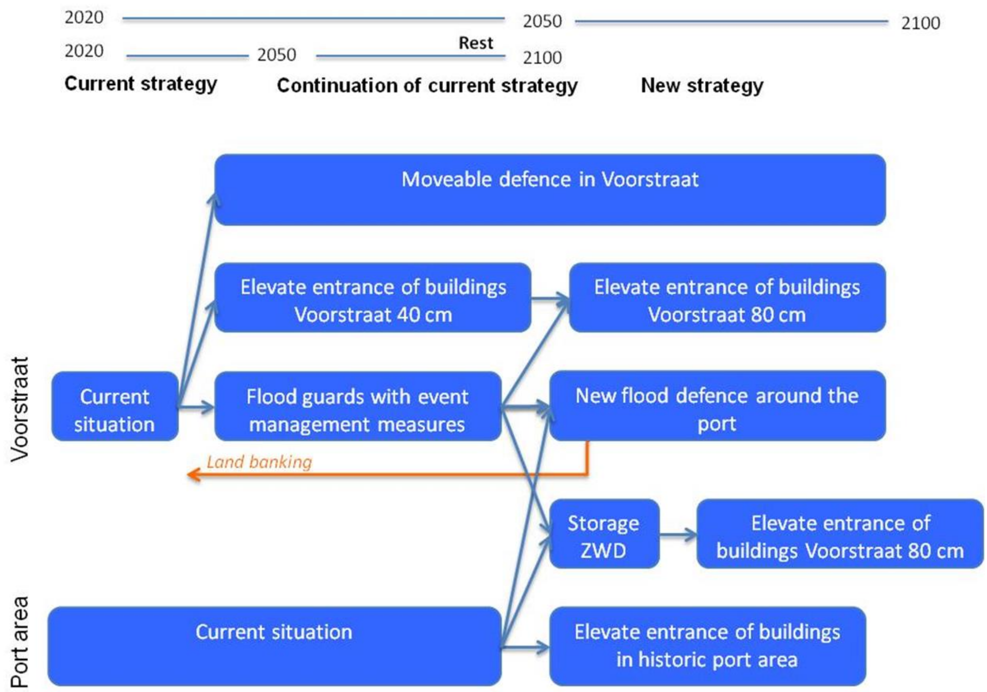


Figure A7. Adaptive policy pathways for flood risk management in Dordrecht

Monitor, evaluate and refine the processes

Any process, procedure or framework for undertaking analysis such as presented here needs to be dynamic and evolving with experience. Thus there is an overarching process of review of these procedures that needs to be operated alongside the application. From this, the value and operability of the process can be assessed and where relevant modified. In particular situations and contexts it can be abbreviated and shortened, in others it may require a deeper level of analysis and more defined guidance. This will depend on user capabilities and needs.

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