CRC for
Water Sensitive Cities

Flexibility in Adaptation planning

Guidelines for when, where & how to embed and value flexibility for urban flood resilience

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Flexibility in adaptation planning
Guidelines for when, where & how to embed and value flexibility for urban flood resilience
Socio-Technical Flood Resilience in Water Sensitive Cities − Adaptation across spatial and temporal scales - 4.2 - 4.2.5 - 2017

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Preface

This guideline provides the ingredients for embedding and valuing flexibility in adaptive planning. In contemporary adaptation planning in the urban flood risk management sector, the valuation of flexibility is about determining the expected net present value of the adaptation measures based on standardised techniques such as real options. There is little information about how flexibility can be enhanced and how to determine the most appropriate place for incorporating flexibility within a scheme plan. Hence this guideline for embedding and valuing flexibility has drawn on knowledge from the manufacturing sector (such as automobile and aerospace industries), - where flexible adaption planning is everyday practice. The selection of the water sensitive urban design (WSUD) element where flexibility is embedded is made focused on the change propagated in the urban system when the WSUD element is subject to change.

These guidelines include an Appendix where the steps detailed in the guidelines are applied in an Australian case study to help understand application. The case study is an outcome from inter-disciplinary efforts of a team comprising social scientists, engineers, architects and urban planners from various CRCWSC projects comprising A4.2, A4.3, B4.1, B4.2 and the Monash Architecture faculty. Further, these guidelines should be read in conjunction with the CRCWSC publications: (i) Flood resilience in water sensitive cities (Gersonius et al., 2016); (ii) *"Appropriate Flood Adaptation - Adapting in the right way, in the right place and at the right time"* (Veerbeek et al., 2016); (iii) *"Extended ATP approach to include the four domains of flood risk management - Manual with Prototype software tool*" (Rodriguez et al., 2016); (iv) *Adaptation mainstreaming for achieving flood resilience in cities* (Rijke et al., 2016); (v) *Flood damage assessment – Literature review and application to Elster Creek catchment* (Olesen et al., Under Review); (vi) *Towards a water sensitive Elwood: A community vision and Transition Pathways* (Gunn and Rogers, 2015) as these publications elaborate the basics of resilience, adaptation pathways, mainstreaming and the current tools that are in use for adaptation planning for flood risk management. As there is a dearth of examples from Australian practice the guidelines should only be used in an Australian context with further support from CRCWSC Project B4.2. The writers acknowledge this limitation and are currently working on a revised version of this guideline in which many of the steps are accompanied by examples from adaptation practice in Australia. The revised guideline will be supported by software that can be used for applications.

Summary

What is the issue?

Adaptation is part of an ongoing continuum of change, where there is a gradual transition from one set of objectives or drivers to another set. Whereas responses to extremes tend to be very different, in that these usually come about by sudden or rapid changes. For example, looking at the history of innovation for the wastewater and stormwater management objectives in Melbourne it can be seen that these transitioned from the protection of waterway health – drought, supply alternatives – flooding – climate change – water sensitive city, which is the present state of transition (Ferguson et al., 2013). The infrastructure systems, such as those in the water domain, whose design and use could be modified in the future in the light of new knowledge and new drivers are known as adaptive or flexible infrastructure systems (CIRIA, 2016). The value of flexibility in such infrastructure systems is usually calculated in terms of money saved or gained in speeding up or delaying the implementation of such systems depending upon the progression of one or two drivers that affect a particular objective, for example in avoiding flood damages. However, in the context of a water sensitive city, a city has to be sustainable, which means being liveable, resilient and productive. Rather than using the value of flexibility of adaptation measures as a measure of sustainability, flexibility could be proactively embedded to ensure at least one major plank of sustainability is in place in accordance with the principles of the water sensitive city.

What is this guideline about?

The aim of this guideline is to provide a step-by-step approach, termed the ‘flexible adaptation planning process’ for Water Sensitive City adaptation planning – WSCapp, for incorporating and valuing flexibility in adaptive planning with the aim to increase future resilience against climate related flood hazards and other future changes in an urban context.
The guide provides:

- Background information explaining why flexibility is important in the adaptive planning context;
- An overview of various forms of flexibility, ways of valuing flexibility and embedding flexibility;
- A step-by-step process for embedding and evaluating flexibility (WSCapp);
- A case study in Elwood, Melbourne where the WSCapp has been applied to enable the user to understand the guideline in an urban adaptation context for adapting to urban flooding.

Who is this guideline aimed at?

This guideline is mainly aimed at: (i) local councils, particularly in urban planning, environmental management, drainage and water management; (ii) regional water authorities such as Melbourne Water and planning consultants; (iii) city level and state level planning agencies; (iv) CRCWSC Board, as CRCWSC is an implementation partner in the Melbourne resilience strategy. It is also relevant to other professionals working with water and those engaged in the delivery of other infrastructure and service systems that interact directly with water, such as highways and development. It is mainly of interest to those with a long-term agenda, who can

benefit from the guideline and adopt the methodology for the realisation of projects in their respective domains.

Theory: What are the potential benefits?

Application of these guidelines helps:

- To understand the various types of flexibilities prevalent in the field of urban flood resilience and ways of valuing flexibility
- To understand the change in objectives (e.g. transitions) and drivers (e.g. rainfall) that necessitates the incorporation of flexibility
- To embed flexibility in the context of a water sensitive city using established connections between WSC elements and relationship mapping
- In making the move towards a more systematic approach to the adaptation planning process; termed the flexible adaptation planning process for water sensitive cities (WSCapp)

Introduction

"In adaptive Melbourne our institutions must be flexible and responsive to emerging information, regularly adjusting the way they deliver services as the pace of social, environmental & economic changes in our city continues to accelerate"

Page 61, Melbourne Resilience Strategy (City of Melbourne, 2016)

Climate adaptation in domains such as flood risk management can be a conundrum, as: (i) adaptation interventions are long-lived, capital intensive and largely irreversible (Gersonius et al., 2012) and; (ii) decision making in regard to adaptation is beset with uncertainties, which necessitates an approach that is flexible and in itself adaptive to the changes (Anvarifara et al., 2016). Flexibility in its' simplest form is the ability of the system to absorb change while still providing the expected service (this component is termed robustness) and also includes the ability of the system to be modified (this component is termed adaptive). Flexibility is increasingly seen as a desirable feature that enhances system capabilities and functionality in the face of uncertainty (Schulz et al., 2000) and is a property that potentially counters the effects of maladaptation throughout the entire life cycle (Gersonius et al., 2013). Melbourne`s resilience strategy considers flexibility as an important characteristic to respond to changing circumstances using a mix of strategies such as adapt, survive, thrive and embed (City of Melbourne, 2016). An earlier CRCWSC report (Gersonius et al., 2016) considers resilience and how best to ensure flexibility and adaptability in designing and planning systems for water sensitivity (Figure 1). Gersonius et al. (2016) recommends a flexible approach named 4RAP that comprises different strategies such as hazard reduction (retain, relieve), exposure reduction (resist, retreat) and vulnerability reduction (accommodate, prepare) in order to enhance flood resilience. More information on Flood resilience may also be found in e.g. UK National flood resilience review (HM Government, 2016).

Figure 1: 4RAP model – Retain, Relieve, Resist, Retreat, Accommodate, Protect strategies- of available strategies to enhance flood resilience (Gersonius et al., 2016)

The Delta programme in the Netherlands is based on adaptive delta management and recommends a flexible approach as a means for creating options in terms of implementing measures in the immediate term or somewhere down the line – i.e., speeding up or deferring implementation of adaptation measures, or implementing other measures that can prevent the risk of over or under investment (Zevenbergen et al., 2015, Deltacommissaris, 2014).

The incorporation of flexibility with respect to implementation of climate adaptation is provided in various ways: via e.g. allowing mid-term adjustments and modifications of structure (van Buuren et al., 2013, Woodward et al., 2014); keeping investment or implementation options open for future adaptation (Haasnoot et al., 2012b, Zhang and Babovic, 2012); postponing adaptation until the time when the cost of further delay would be more than the benefits (Felgenhauer and Webster, 2013). This is illustrated in CRCWSC report (Gersonius et al., 2016) Appendix B by a worked example for an application in the UK.

The traditional flexibility approaches in flood risk management systems are not as readily effective when there is a combination of drivers of change, such as rainfall, sea level rise, population increase, and where these are to be considered together. Also, these approaches do not typically consider the relationships between the adaptation measures that are being considered. Hence it is a challenge to use contemporary flexibility incorporation techniques, as the approaches towards climate adaptation and urban adaptation require a "systemic approach". A systemic approach to adaptation is where the focus is on understanding the inter-linkages of climate change impacts and adaptation measures together with socio-economic structures and regional and global trends (EEA, 2016). This is further complicated by the often inappropriate institutional systems and mechanisms that constrain systemic and interdependent acknowledging approaches (e.g. in the Murray-Darling basin, Marshall and Alexandra (2016).

A "Water Sensitive City" approach (Brown et al., 2009) considers urban water management from a perspective of intergenerational equity and resilience to climate change and aims for an adaptive, multifunctional infrastructure and urban design that provides for and reinforces water sensitive behaviours. This is also evident in the adaptation plans and actions taken by cities such as Rotterdam, Copenhagen, Dresden, London and Melbourne, where flexibility as a criterion is seen to play an important role not only in enabling adaptation against future stresses and shocks but also to enhance the present and future quality of life – expressed in terms of liveability and sustainability (City of Melbourne, 2016, EEA, 2016). The adaptation measures in these cities are termed as 'transformational adaptation measures' by EEA (2016), as these measures use behaviour and technology to change the components of urban systems fundamentally. Strategic planning for sustainable development requires a proactive planning culture which creates conditions for change to purposefully deal with future issues (Malekpour et al., 2015). This implies that a relevant flexibility embedding approach should take into account the transitions anticipated in the way climate and urban adaptation might progress in the future. Hence it becomes imperative to look through the systemic approach lens as to where, how and when to embed flexibility in a broad range of transformational adaptation measures to achieve the objectives of a water sensitive city.

This guideline sets out to explain: (i) the concept of flexibility; (ii) its relevance in adaptation planning and in a water sensitive city context; (iii) various types of flexibilities that are incorporated in a climate or urban adaptation context; (iv) methods that are used to value flexibility; (v) a suggested flexible adaptation planning process (WSCapp) for identifying a water sensitive city element or component where flexibility could be embedded and; (vi) the application of WSCapp in a flood resilience context in the Elster Creek catchment in Melbourne.

Flexibility in adaptation planning

Flexibility and its types

Flexibility is often considered as a valuable capacity to cope with uncertainty and change, whereas there is no consensus about what constitutes flexibility across the literature and in practice (Anvarifara et al., 2016) and it appears to be context and domain specific. Incorporation of flexibility to tackle uncertainty in strategic planning has its origins in managerial perspectives, which focus on increasing the flexibility of infrastructure systems to improve their capacity to accommodate change (Dominguez et al., 2011). Due to the typically large scale of civil engineering structures used in water management (dykes, dams, gates, pipes) fewer alternatives are available to provide changes in capacity, compared with the smaller scale, less costly, systems used in mechanical and electrical domains (e.g. pumps). However, it is possible to incorporate flexibility into structures that facilitates the deferral of expansion, such as the heightening of dykes and upgrading of drainage systems (Gersonius et al., 2013, Woodward et al., 2014). The Thames Estuary action plan (TE2100) for example recommends incorporating structural flexibility in the form of strong foundations constructed during the replacement of existing gates of the Thames barrier (Figure 2) so that they can take the additional load if future raising of crest levels is needed (TE2100, 2012).

Figure 2: Thames Barrier in London, its foundation will be made structurally flexible to withstand future raising of flood gate levels (TE2100, 2012). (Photo credit:)

Enhancing flood protection by means of employing demountable or temporary flood protection systems could be termed as operational flexibility. An example of operational flexibility in flood risk management is the Maeslantkering storm surge barrier in The Netherlands[1] that enables navigation as well as protection against sea surges (Figure 3); the demountable flood defences

[1] http://www.holland.com/global/tourism/article/the-maeslantkering-storm-surge-barrier.htm [accessed August 2016]

in Shrewsbury and Bewdley along the River Severn in the UK[2] (Rickard, 2009) and the 520 m long sea wall made from glass in Yorkshire[3] that minimise visual intrusion and loss of amenity.

Figure 3: Maeslantkering storm surge barrier in The Netherlands, which has operational flexibility ensuring flood protection and navigation (Photo credit: www.holland.com)

Illustrations of cases utilising the flexibility to switch from one adaptation measure to another for water management and urban flood risk management systems may be found in the literature (Haasnoot et al., 2012b, Radhakrishnan et al., Under Review). For example, the ability to incorporate diverse or decentralised small-scale modular drainage measures - from which aggregated configurations could be created - is being interpreted as a means to ensure the flexibility of wastewater treatment and storm water management systems (Spiller et al., 2015, Eckart et al., 2010). In the latter case, flexibility is defined in terms of the relative 'homogeneity' of the various functions or benefits provided by urban drainage measures (WSUD components) over time; i.e. is the value of the various functions of a similar magnitude and will this be sustained over time? This is illustrated in Figure 4 where (a) shows that in the first period 2015-2030, the benefits are dominated by amenity value, with flooding, water quality and recreation also being significant, but lesser in value. Whereas in the second period from 2030-2055, amenity benefits are negligible and flooding is the most significant under each of the four future (plausible) scenarios examined. In each case the distribution of benefits is dominated by one or other individual principal benefits. Ideally the most robust option would be one in which there is a relatively homogeneous distribution of benefits so that whatever the future, one or more of the benefits may be more or less important (as today's main benefits may no longer be those society needs). This attribute that considers long term stability (in this case of performance) in an uncertain environment can be defined as adaptive flexibility. In the CIRIA benefits of SuDS

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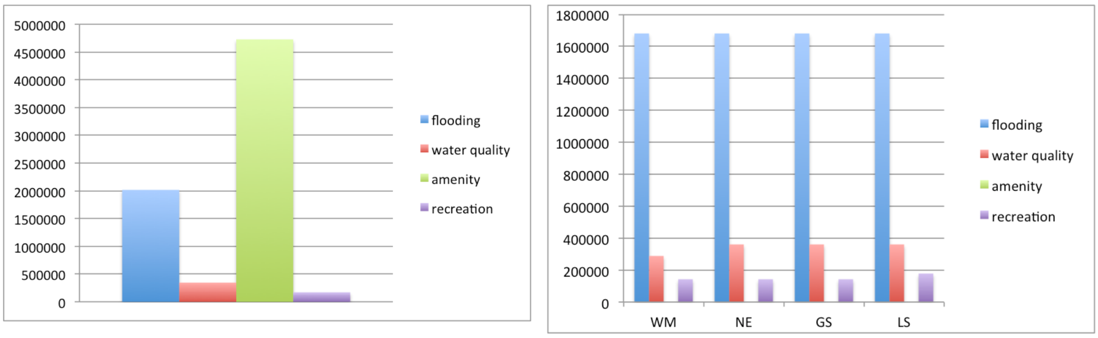
[2] http://evidence.environment-agency.gov.uk/FCERM/en/FluvialDesignGuide/Chapter9.aspx?pagenum=10 [accessed August 2016]

[3] http://www.bbc.co.uk/news/uk-england-humber-37704362

tool, BeST, this attribute is assessed using an A to E five point score, representing 20% intervals in the calculation of the relative homogeneity of the benefits provided (Horton et al., 2016).

In terms of future uncertainties, the provision of a range of functions by an item, or portfolio of measures, means that if the importance of one or more of these functions changes in the future, the portfolio has more ‘flexibility’ to adapt and remain relevant, than an option that only provides a single function. In practice, water management systems are invariably designed to address a particular primary need identified today, such as water supply or flood management. This need may, however, not come about for some time, as in planning to deal with potential water resource shortfalls in the future via ensuring the provision of headroom today. Added value or additional functionality is usually subordinate to this primary need, but may in fact be an important component in providing flexibility to deal with future uncertainties.



(a) Calculated value of individual benefits (£PV) for an SCM scheme for period 2015-2030

(b) Estimated value of individual benefits (£PV) for the SCM scheme for period 2030-2055 for 4 plausible scenarios (WM, NE, GS, LS)

Figure 4: Illustration of the way in which the relative value of individual quantified benefits provided by a SCM scheme can change over time (from Ashley et al. (2016), where scenario definitions and scheme details can be found).

Functional flexibility of a component or a system may be defined as an attribute that enables it to perform a task, which is not usually expected of it during normal operating conditions or at a particular point in time. For example a road could be designed to convey excess surface flow and a park could double up as a detention basin (Balmforth et al., 2006), whilst providing their main functions as a transport route and a recreational area. Some more recent examples of incorporation of functional flexibility in the urban environment are: (i) the creation of a “Water Plaza” in Rotterdam serving as a retention basin during high intensity rainfall events and as a play area during normal times (Box 5.22, EEA, 2016, Figure 5 as described in the CRCWSC report by Rijke et al., 2016); (ii) the pavements of Copenhagen which are designed to hold 10 cm of water between the kerbs during cloud burst events, in addition to the provision of usual street functions at other times (Box. 5.33 EEA (2016)).

Figure 5: Water Plaza in Benthemplein, Rotterdam which functions as a playground and water detention facility. (Photo credit: http://www.urbanisten.nl/wp/?portfolio=waterplein-benthemplein)

Strategic flexibility or objective flexibility may be defined as planning and executing a set of measures that are based upon a particular strategy that does not prevent or creates only minimal hindrance when switching to a completely different strategy. For example the construction of a dyke to protect the city from flooding is based on a protection strategy, whereas allowing more space for water such as in the "Room for the River (RfR)" programme through a number of component dispersed interventions in The Netherlands is based on a flexible adaptive strategy (Zevenbergen et al., 2015). Room for the River projects have inbuilt operational flexibility and flexibility to defer decisions and these characteristics have influenced policies and practices that now constitute the adaptive delta management (ADM) and the Delta programme (Deltacommissaris, 2014, Zevenbergen et al., 2015). However, it could also be argued that the Room for the River approach also has the characteristics of strategic flexibility. Although the actions in RfR are based on an adaptive delta management strategy it does not inhibit the decision makers from switching to a protection strategy in the future if the flooding situation worsens or if new knowledge comes to light. The converse is also possible, but the cost incurred would be huge as a protection strategy would lead to a lock-in to a traditional large-scale infrastructural solution, as it could not be abandoned due to the need to continue to get return from the investment.

Valuing flexibility

Real Option (RO) analysis originating in the domain of option analysis developed for finance (Myers, 1984), provides a way to value flexibility and handle uncertainty. The core principle of real options is the ability to value flexibility (Dixit and Pindyck, 1994). RO can be defined as the right but not the obligation to take action at a predetermined cost (Madhani, 2009). RO values the 'wait and watch' strategy, evaluates the scheme as it evolves and as uncertainty is revealed. RO valuation can be used to value the cost of interventions, risks and benefits in an adaptive flood risk management system, as the interventions are characterised by irreversibility, uncertainty and flexibility which are the prerequisites for RO analysis (Dixit and Pindyck, 1994).

A real options approach is a recognised procedure to handle uncertainties in infrastructure investments by providing managerial flexibility and has been used in handling uncertainties in designing urban drainage systems, coastal defence systems and water supply systems (Gersonius et al., 2012, Woodward et al., 2014, Zhang and Babovic, 2012). RO approaches could be classified as ‘on’ or ‘in’ system in infrastructure interventions depending upon their extent of application. Real options “on” projects are financial options taken on technical entities, treating technology itself as a ‘black box’ whereas, Real “in” Options (RIO) projects are options created by changing the actual design of the technical system (Wang and De Neufville, 2005). RIO is a relatively new concept for considering technical details, inter/path-dependency among options accounting for uncertainty in the cause-based framework. The RIO approach has been employed to design an optimal set of adaptive strategies of urban drainage systems and flood defence systems using climate scenarios as a main driver of impacts (Gersonius et al., 2012, Woodward et al., 2014). The approach has also been used in water resources planning (e.g. Ingham et al. (2006), Deng et al. (2013)).

Uncertainties in water sensitive city systems arise out of factors such as sea level rise, rainfall intensities, technological evolution, spatial planning, political aspirations, social aspects etc., and could potentially be modelled using multi-stage stochastic models (e.g. Dance4Water, Urich et al., 2013). For these, problems with multiple uncertainties are modelled as multi-stage stochastic models, i.e., mathematical models are constructed using the parameters which comprise the uncertainties. The constraints for each uncertainty are then determined and solved using solution algorithms based on the principle of optimisation. This is computationally intensive. This approach has been employed for real option analysis of highway development based on uncertainties such as traffic demand, land price and highway service quality (Zhao et al., 2004) and for managing uncertainties in the water supply system of Singapore based on water production capacities and costs (Zhang and Babovic, 2012).

In these studies there are various parameters used to include flexibility. Proportioning of ‘taps’ i.e. through various ways of water production such as importing water, rainwater from the urban catchment, reverse osmosis using sea water, NEWater through recycling of wastewater, based on predetermined objectives (Zhang and Babovic, 2012); widening the base, increasing height and changing the maintenance regime of defences (Woodward et al., 2014); changing pipe diameters and storage facility dimensioning (Gersonius et al., 2013) have all been used to bring flexibility into the design or plan. It can be seen that the parameters used for including or introducing the flexibility are either structural in nature, such as pipe diameters, width and height of defences etc., or technology-centric such as the production of ‘taps’. Socio-economic and political factors, although considered as objectives and uncertainties by Zhang and Babovic (2012), have not been used to consider how best to enhance flexibility. The aspect of flexibility enhancements using socioeconomic, cultural and ethical factors could, however, be better considered by adaptation planners in future RIO option problems for contextualising solutions (Radhakrishnan et al., 2017). The enhancement of flexibility is achieved through structuring the adaptation problem in the local adaptation context (Figure 6) using multiple perspectives such as engineering, social and economic perspectives; making a portfolio of all possible adaptation measures in the local context; and identifying the links between the adaptation measures themselves and with the drivers triggering the implementation of the measures (Radhakrishnan et al., 2017).

Socio-economic factors are especially important for water sensitive urban design. Zang and Babovic (2012) included financial value, socio-economic risk and political risk in the RIO analysis in the case study of Singapore’s water supply. Inclusion of the aforementioned aspects alone would not provide the entire value of flexibility in a water sensitive city context, where the systems are interconnected (e.g. Figure 6), and the functioning of systems are mutually affective. This aspect has to be taken into account in valuing flexibility and also in identifying the most appropriate place in the design, plan or part of the system where flexibility should be incorporated.

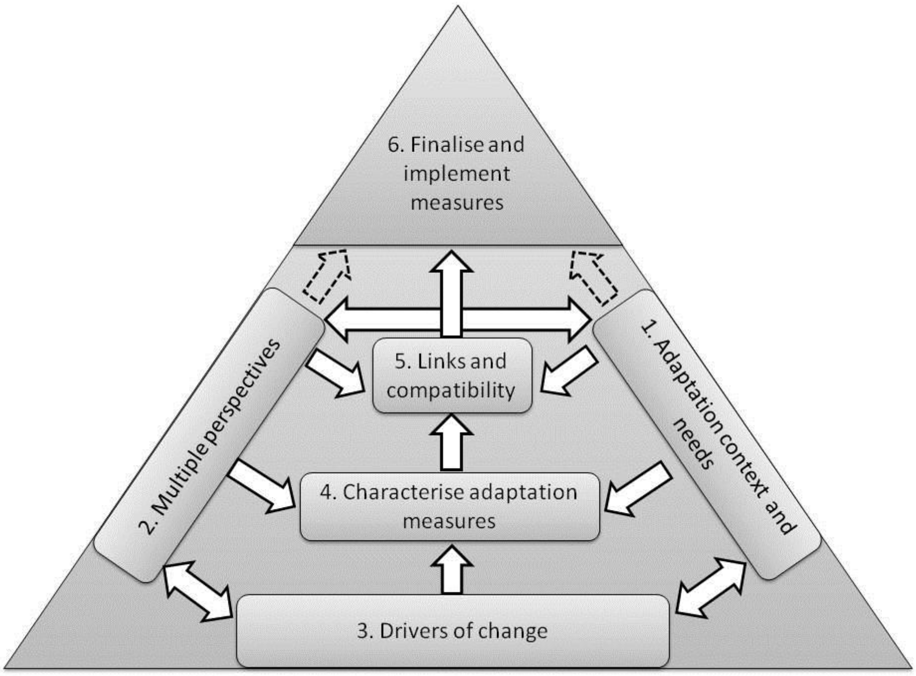


Figure 6: Framework for increasing flexibility using multiple perspectives in an adaptation context. Adapted from Radhakrishnan et al. (2017).

Embedding flexibility

The strength of current Real in Options techniques applied to the urban flood risk management (UFRM) domain lies in guiding how to specifically respond to exogenous uncertainties and value flexibility. For example Gersonius et al. (2013), Woodward et al. (2014), Zhang and Babovic (2012), do not identify where, when and how to embed flexibility but instead focus on creating flexible alternative designs, determining the cost of alternative designs and uncertainty analysis. Further, RIO techniques tend to consider UFRM systems as standalone systems and not where there is connectivity and interrelations between various urban systems such as in the context of a water sensitive city. This approach may be attributed to the reductionist way of approaching complexity from a traditional engineering perspective (Fratini et al., 2012).This shortcoming could also be attributed to the managerial approach, which is about expanding system boundaries to include various measures, but often fails to assess the breadth of future factors or uncertainties (Malekpour et al., 2015). This simplification also inhibits the possibility of bringing in additional adaptation measures in the analysis of cost and benefit. The RIO application in the UFRM domain still needs to be further customised to include the comprehensiveness of a water sensitive city (WSC) approach. This is essential as the RIO methods address resilience and sustainability to an extent, but do not look specifically at the aspect of liveability, whereas liveability is a key essence of the WSC approach. It is in this context that the identification of critical elements of flexibility and embedding flexibility becomes the most crucial and difficult step.

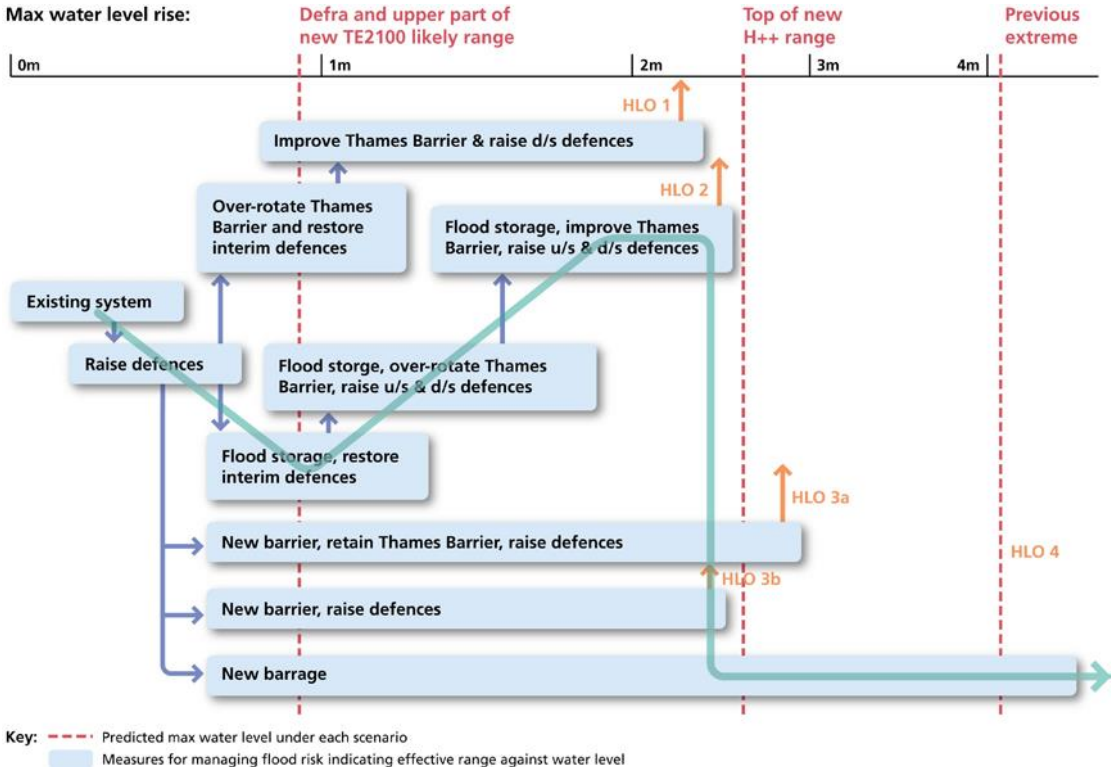


Figure 7: A high level route map for adaptation measures in Thames Estuary TE2100 project. Adapted from Reeder and Ranger (2011).

The context first approach adaptation planning process (e.g. Thames Estuary project TE2100 Reeder and Ranger (2011)) identifies the need for flexibility and to a limited extent embeds flexibility in the form of a high level route map of adaptation measures, that are useful in achieving the adaptation objectives (

Figure 7). Context first adaptation approaches (e.g. Reeder and Ranger (2011), Ranger et al. (2010), Dessai and Sluijs (2007)): (i) encourage the decision makers to begin at the level of the adaptation problem (or opportunity); (ii) specify the objectives and constraints; (iii) identify appropriate adaptation strategies; (iv) and only then apprise the desirability of adaptation measures against a set of climate change projections. The adaptation pathways approaches (Haasnoot et al., 2012a), dynamic adaptation policy pathways (Haasnoot et al., 2013) and model based adaptation pathway approach (Kwakkel et al., 2015) also fall under the category of context or policy first adaptation planning processes. Reference should be made to the CRCWSC report by Veerbeek et al. (2016) for more details on adaptation pathways. However, these context first approaches fall short of identifying the critical elements, where flexibility could be incorporated. To address this, inspiration is drawn here from the flexible platform design processes and complex change management processes (Eckert et al., 2004, Suh et al., 2007) that are prevalent in the automobile manufacturing sector in order to customise the context first approaches to the WSC context. Suh et al. (2007) claim that their ‘Flexible platform design process’ is the way to incorporate RIO in the design of chassis of cars to tackle uncertainties. Flexible platform design process ensures that an automotive component such as ‘body in white’ – a metal frame that is welded together to make the body of a car – is designed to be flexible to meet the changing demands and design attributes for various models of cars, which vary and are uncertain to due changing preference for particular models based on appearance, ergonomics and purchasing power. Suh et al. (2007) has demonstrated the design of flexible 'body in white' for three car variants whose demands as well as future dimensions. The uncertainty in dimensions is due to the evolutionary nature of attributes such as customer perceived vehicle roominess, ease of ingress/egress, fuel economy and acceleration time. We could draw parallels between the attributes in a car design to WSC concepts such as (i) roominess and ease of ingress/ egress to liveability; (ii) fuel economy to sustainability; (iii) acceleration time to resilience.

Addressing the combination of strategy transitions and uncertainty of drivers is not a challenge that is novel or specific to the domain of urban water management. In fact, similar challenges were faced during the last several decades by, amongst others, industries for manufacturing and also for software development (Koste and Malhotra, 1999, Sánchez and Pérez, 2005, Bernardes and Hanna, 2009, McGaughey, 1999). It has been recognized that businesses and organizations such as these face a volatile environment that is highly uncertain with challenges such as increased competition, globalized markets, technology obsolescence and individual customer requirements. The strategy transitions in urban water management can be compared with the evolution of new car models. For example, the uncertainty of quantity and timing of flooding due to the factors such as rainfall increase, sea level rise and impervious area in urban water management can be compared with the change in demand for cars due to a combination of varying market conditions. The automobile manufacturing sector uses strategies such as product platform strategies and flexible product platform strategies to save costs by sharing core elements among different products in a product family (Simpson et al., 2006, Suh et al., 2007). Suh et al. (2007) have developed a seven step flexible platform design process (Figure 8) to deal with uncertainty and product variants in order to ensure continuity in production and maximise profit for the automotive industry. The uniqueness of this approach is the identification of the most appropriate subset of elements where the flexibility could be embedded (step IV in Figure 8). The identification of elements or subsystems as a candidate for flexibility is based on the magnitude of change that the elements or subsystems propagate throughout the system when changed (Eckert et al., 2004).

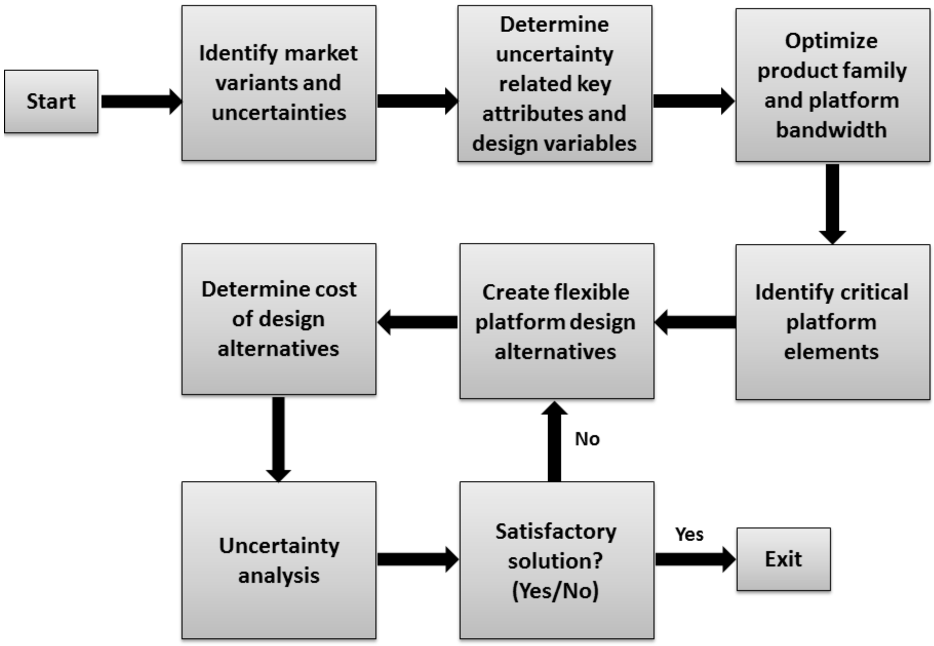


Figure 8: Flexible platform design process in the automobile manufacturing sector. Adapted from Eckert et al. (2004)

According to Eckert et al. (2004), the systems or subsystems that are capable of propagating greater change are to be assessed carefully before being selected as candidates for embedding flexibility. For example, in the design of an automobile chassis, one of the parameters that determines its dimensions, the length and breadth, is the size of the engine. The size of the engine in turn depends on the number of cylinders (Suh et al., 2007). While designing the chassis, the width is kept constant for all the variants to limit change propagation. This is because change in width has a direct bearing on the stability of the vehicle. The change propagation of chassis width is generally much higher compared with that of the chassis length. Hence the length of the chassis is a flexible design parameter that can be changed using differently sized physical components. Enabling flexibility in such design parameters requires initial investment in design, tooling and assembly equipment and is similar to using real in options (RIO) in chassis design (Suh et al., 2007). Wherever possible, change propagation is limited by means of providing sufficient margins or excess headroom (i.e. redundancy) in the design parameter to limit the change propagation within these systems. Provision of redundancy is used when the engineering cost of design changes, additional fabrication, assembly tooling and equipment investment to make these changes are higher than the cost of making a redundant design.

Flexibility in a water sensitive context

"Connections are important when it comes to resilience"

- Page 26, Melbourne Resilience Strategy (City of Melbourne, 2016)

In a water sensitive city context, various urban water systems are interconnected and change in one system will propagate to other systems. A change rarely occurs in isolation and multiple changes can have interacting effects on other systems. This change propagation becomes an important factor as it might have unintended consequences affecting the functionality of the systems such as non-compliance with design standards including flooding or increased flood damages; or a reduction in liveability aspects such as odour nuisance or mosquito problems due to water stagnation. The components or sub systems in the WSC have to be analysed from the aspect of change propagation. The systems that are capable of propagating more change in the future when modified in the future are the critical systems and thus potential candidates for incorporating flexibility. For example, the change in the type, size or number of WSUD drainage system components - such as green roofs and rain barrels - will have ramifications on downstream measures such as large scale detention systems or pumping arrangements. Increasing WSUD measures reduces runoff and could bring desirable benefits such as enhanced aesthetics, improvement in water quality, etc. or undesirable effects such as controlling odour nuisance, mosquito menace etc. Whereas if changes are made to downstream measures such as the pumps at the outfall, the change may not propagate upstream to systems such as the WSUD measures during normal operations. However, investing in the flexibility of a pumping station at a certain point in time could be economically cheaper than investments in distributed WSUD measures upstream. This crucial step of identifying the main candidate locations and measures for maintaining flexibility in future options is a balancing act between the (unwanted) physical suppression of future change propagation, where it is not wanted and investment in flexibility where this *is wanted*.

Consideration of change propagation due to the transition in vision, such as the transition of a city from a water supply city to a water sensitive city (Brown et al., 2009), is equally important as the consideration of change propagation due to change in system components. Exploring the design, implementation and maintenance of the water sensitive or flood resilient systems such as water plazas, water retaining pavements that are implemented in cities such as Copenhagen and Rotterdam (EEA, 2016), could help in understanding the change propagation in a complex urban environment. For example, such studies can help cities in Australia like Melbourne, Sydney or Brisbane to understand change propagation when the required functions of, for example, a wetland system changes as the transition happens from water quality or drought resistance to a water sensitive city perspective. Change propagation could be estimated through mapping the relationship between the systems or the adaptation measures. As an example, in order to improve the resilience of infrastructure in Victoria, the State of Victoria is pooling together various infrastructure options (Victoria, 2016a). How each option works with others, in terms of how they might enable, complement or inhibit one another in advancing one or more of the needs is referred to as relationship mapping (Victoria, 2016b). Relationship mapping between adaptation measures is a good starting point for ascertaining change propagation in urban water systems in Australia and elsewhere.

Strategy transitions and consideration of various strategies such as sustainability, liveability, resilience and mainstreaming are found in the recent urban adaptation strategies and resilience strategies such as Urban adaptation in Europe (EEA, 2016), Rotterdam resilience strategy, Melbourne resilience strategy (City of Melbourne, 2016), Infrastructure Victoria (Victoria, 2016a, Victoria, 2016b). For example the City of Melbourne considers a range of adaptation options under various sub-strategies such as adapt, survive, thrive and embed, to increase the resilience of the city as a whole (City of Melbourne, 2016).

Mainstreaming is suggested as an opportunity ‘to adapt wherever we can, instead of wherever we have to’ based on experience from cities such as Hamburg, Rotterdam, Malmo and New York (Rijke et al., 2016). However, mainstreaming is a collaborative effort where the requirements of multiple stakeholders are to be considered without compromising the interest of the asset owners. For example, a housing development project might give an opportunity to mainstream flood resilience in the form of blue-green infrastructure in the courtyard. However, if the blue-green infrastructure needs modification in the future for the sake of increasing flood resilience which might lead to restricted access to the courtyard, it may not be encouraged. Another risk is that the increase in natural ecological vitality provided by blue-green infrastructure may lead to a drainage facility becoming designated as protected against change to preserve the ecosystems; thus inhibiting the ability to adapt.

Inspiration for resolving such impasses could be found from manufacturing, for example in defence equipment such as helicopters where there is a practise called ‘offsetting’ to avoid conflicts of interest of stakeholders (Eckert et al., 2004). The latter describe situations when a client country places orders for customised defence platforms like helicopters or military jets, they also mandate the procurement of some critical components or systems from their own countries. This is done to secure access to these systems in future in case of an embargo in the main suppliers’ country or to bring back money into their economy or to support local industries. The platform manufacturer uses a practice called offsetting, where the components earmarked by clients above are left untouched (ring-fenced) even though they have the potential for flexibility. Instead they minimise the limitations in the flexibility of the system that are a consequence of the offsets by embedding flexibility or redundancy in the rest of the systems that are developed internally. This practice of offsetting is strongly context dependent and time dependent.

Water sensitive city systems or components may be categorised into the following for the purpose of incorporating flexibility:

- **Flexible resilience and sustainability components** – Common systems and flexible systems that with minor modifications can be used in multiple future scenarios. These are the best candidates for including or encouraging flexibility; e.g. rain gardens, swales and wetlands.
- **Non-flexible liveability components** – Unique systems that are customised for specific versions of current trends. These components could be kept out of the purview of flexibility as they are customised for the current trend; e.g. heritage layouts, where there is a priority for heritage and aesthetics.
- **Flexible mainstream components** – Mainstream systems or components where there is a scope as well as consensus for embedding flexibility; e.g. stormwater detention in parks, modification of street or road profiles.
- **Flexible non-mainstreamable components** – Where there is a greater degree of freedom to incorporate flexibility; e.g. mobile dewatering pumps, rainwater tanks at households.

The defined category of a component (above) might change in the future, as the means to achieve resilience, sustainability, liveability and mainstreaming are continuously evolving. For example, a non-flexible liveable component might become a flexible resilient component; such as water in the urban environment which was seen as a threat some time ago is now being accepted as an aesthetic element which also improves flood resilience. It is important therefore to bias the flexibility incorporation towards the most desired or most likely vision (in our case water sensitivity). This can be supported by scenario planning (e.g. Ashley et al. (2016).

Gersonius et al. (2016) recommends a 4 domains approach (4DA) to select flood resilience measures according to the nature of rainfall or stream discharge including: (i) day- to day events – beneficial events which cause no damage (Figure 5); (ii) design events for which the system is designed according to set standards; (iii) exceedance events – which cause no or very little damage (Figure 10); (iv) extreme events – which cause substantial damages but with the recovery range; (v) unmanageable extreme events from which recovery is not possible. Such a classification will also help in ascertaining the characteristics of the adaptation measure and help towards mainstreaming the measure or identify the flexibility with respect to speeding up or delaying the implementation of the adaptation measure.

Creativity in embedding flexibility, structural or functional or operational, is important and the best flexible designs when aligned with aspects such as mainstreaming or liveability increase the aesthetics of the urban environment. Rotterdam has incorporated functional flexibility in a very creative way to tackle localised urban flooding. The road adjoining a frequently flooded canal was modified to hold water during excessive rains. The road profile was modified by incorporating urban landscaping and street art elements that enhanced the aesthetics of the area with the flood water, adding more appeal (Figure 9). Similarly, a diversion weir to divert water to a playground during excessive rains to prevent localised flooding was added along with a local business promotion and community engagement generation programme in Stawell, Victoria (Figure 10). This programme was coordinated by Monash Architecture and Design Faculty (MADA) in 2013. The bricks manufactured by a local brick maker were used to construct a diversionary weir in the form of a series of steps, which also serves as a gallery for an open air theatre. Creatively embedding flexibility through mainstreaming may not increase upfront cost or the net cost, i.e., the cost of base elements together with the urban water element that is being mainstreamed with the base element. Refer to Rijke et al. (2016) for more details on mainstreaming.

Figure 9: Modification of road in Rotterdam which doubles up as a canal during excessive rains and is a recreation area during normal times. (Photo credit: Chris Zevenbergen, UNESCO-IHE)

Figure 10: Diversionary weir in Stawell, Victoria constructed as a part of flood mitigation and community engagement generation program. (Photo credit: Peter Benetts, Monash Architecture)

Flexibility in the context of WSC: guidance

In the previous sections various forms of flexibility, the need for flexibility, the ways in which flexibility could be evaluated and the shortcomings in the urban water sector with respect to ways to identify the most effective elements for incorporating flexibility are outlined. The shortcomings in 'context specific approaches', 'real in options', and how they could be potentially overcome using flexibility incorporation approaches that are prevalent in industrial engineering domains such as automobile and aircraft manufacturing were also highlighted. This section presents the adaptation planning process for incorporating flexibility in a WSC context using the principles from 'context specific approaches' and flexible platform design process as shown in Figure 11.

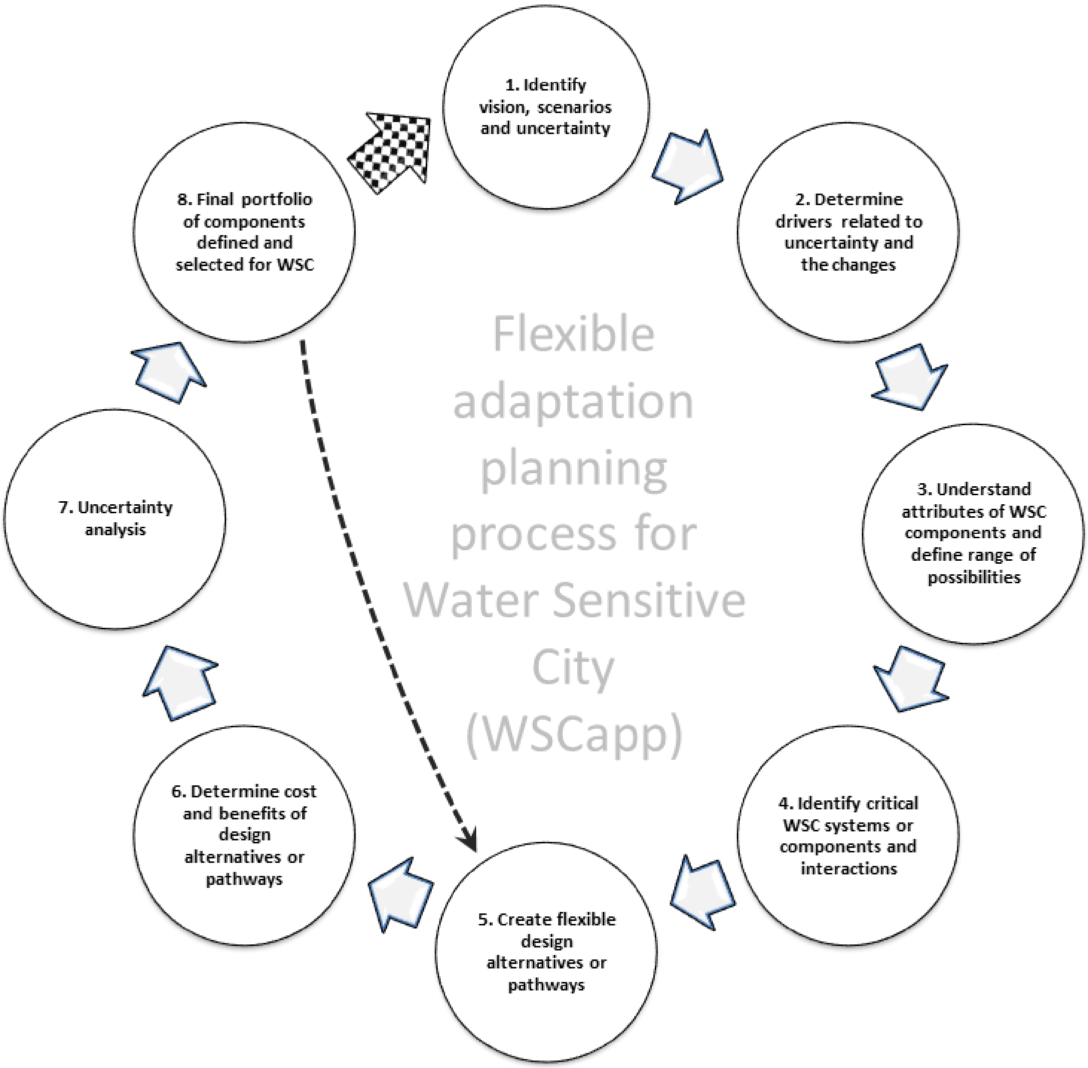


Figure 11: Flexible adaptation planning process for Water Sensitive City (WSCapp).

The application of flexible adaptation planning processes for water sensitive city (WSCapp) in an urban flooding context is presented in Table 1. Table 1 has been developed from the previous discussion and refined from applying WSCapp to adapting to urban flooding in Elwood, Melbourne. The background for application of WSCapp in Elwood and the details of the flexible adaptation planning process are provided in Appendix 1. Table 1 sets out the WSCapp step-by-step guidelines in the context of urban flooding and flood resilience.

Although the WSCapp, based on the flexible platform design process helps in selecting the flexible candidates, the role of stakeholders involved in the various steps is not clear. WSCapp needs to be applied in a diverse multi-stakeholder urban environment, whereas flexible platform design process is typically applied in a controlled factory setting, i.e. in an assembly lane where all the process are in a predetermined sequence and in clockwork precision. In contrast with WSCapp applications, the factors influencing flexible platform design process are exogenous, where stakeholders including customers are consulted through market research; inputs such as roominess, fuel economy, acceleration time (i.e. uncertain design attributes) that are obtained from research and development teams; assessment of component vendors or suppliers capacity and willingness to accommodate change in the components supplied by them. In such applications, the numbers of stakeholders and their varying degrees of influence and engagement in change propagation is evident (Eckert et al., 2004). Similarly, the varying degrees of involvement and influence could be anticipated by the many and various players in the context of WSCapp applied in a water sensitive city context.

For example in Elster Creek, the involvement of National and Regional planning agencies would predominate in identifying visions and determining the drivers (step 1 and step 2 of Figure 11); whereas the role of the Melbourne regional planning authority could be dominant in setting attributes of WSC (step 3 in Figure 11); the role of local council, City of Port Phillip, and waterway manager, Melbourne Water, could be dominant in identifying the critical WSC components, creating flexible designs, calculating the additional benefits and performing the uncertainty analysis (steps 4,5,6 in Figure 11), and each of these various agencies could play an equal role in deciding the final portfolio of options (step 8 in Figure 11). Hence in order to apply the WSCapp, an effective stakeholder consultation, engagement and partnerships are is necessary, e.g. agencies such as Municipal Association of Victoria could be engaged with for applying WSCapp.

Table 1: Flexible adaptation planning process for water sensitive city (WSCapp) steps for incorporating and assessing flexibility in an urban flooding context.

Required steps	Description	Resources for additional Guidance on individual steps	Application in Elwood, Melbourne (Refer to Appendix 1 for more details)
1. Identify vision, scenarios and uncertainty	Ascertain what the visions for the city are, such as for example a water sensitive city, resilient and climate proof city, based on ideas such as liveability, resilience and sustainability. Study of past and present visions and analysis of past transitions of a city in achieving the visions is essential for the design of adaptation measures as these measures should be of use even when visions change. Also there are possibilities for resorting to a single strategy or multiple strategies even within a single vision. Exploration of possible scenarios in the future - due to stressors (that comprise a set of drivers) such as climate change, socio-economic or global megatrends such as diversifying approach to governance, technological change; changing visions of city is essential to determine the nature of flexibility that has be incorporated in any given context.	Refer to CRC Deliverable B4.2 –3-2016 (Gersonius et al., 2016) for flood resilience in a water sensitive city context Refer to Ferguson et al. (2013) for more information on transitions in a water management context.	Melbourne now ranks highly among the most liveable cities aspires to become a resilient, water sensitive, business friendly and liveable city. The city aims to increase its resilience through strategies such as survive, adapt, thrive and embed (City of Melbourne, 2016, Victoria, 2016a). Effects of climate change and global mega trends such as urbanisation are evident in Melbourne. The change in drivers of adaptation in Melbourne such as temperature, rainfall, sea level rise and urbanisation are uncertain (CSIRO, 2015, Victoria, 2014).

Required steps	Description	Resources for additional Guidance on individual steps	Application in Elwood, Melbourne (Refer to Appendix 1 for more details)
	Ascertaining the uncertainties of drivers such as sea level rise, population increase, gross domestic product, especially the range within which they are likely to vary is a concern as they are likely to hinder or accelerate urban development and affect the quality of life. Also, it is imperative to understand the potential consequences of the interplay of drivers.		
2. Determine drivers related to uncertainty and the changes anticipated	The important drivers that affect the objectives of the adaptation should be determined using numerical models or through stakeholder consultations. Methods such as adaptation pathways based on adaptation tipping points help in determining the impact of uncertainty on meeting the required objectives based on ‘ stress tests’ in an urban area using physically based numerical models.	For more details on stress testing and adaptation tipping points refer CRC deliverable 4.2.2 (Rodriguez et al., 2016) and CRIDA (In press)	Rainfall, sea level rise and urbanisation are drivers which are related to flood damages. However, the flood damages are especially sensitive and with a wide uncertainty range for rainfall and sea level rise in Elwood.
3. Understand attributes of WSC components and define range of possibilities	Adaptation measures enable achievement of the objectives of flood management such as avoiding or minimising flood damage costs. The tangible objectives such as economic	Refer to Kreibich et al. (2015) for information on potential of adaptation measures in reducing damages	In Elwood, adaptation measures such as road elevation along the foreshore, lowering of street profiles, sea gates, foreshore

Required steps	Description	Resources for additional Guidance on individual steps	Application in Elwood, Melbourne (Refer to Appendix 1 for more details)
	losses and intangible objectives such as disruption and stress, are helpful in identifying the range of possibilities and assessing the performance of adaptation measures. The extent to which various costs of flooding that could be avoided by an adaptation measure under different scenarios depends upon the attributes of adaptation measures such as location of the adaptation measure, geometry of the measure (i.e., area, volume), repeatability of the measure, multi-functionality of the measure, flexibility aspects of the measure and robustness of performance of the measure under various scenarios. Flexibility attributes of measures pertain to time, cost and effort required to change the scale, location and function of a measure.	and Olesen et al. (Under Review) for information on estimating annual flood damage. Refer to Suh et al. (2007) for additional information on the basics of attributes related to flexible industrial design. Refer to Eckart et al. (2010) and Spiller et al. (2015) for additional information on attributes related to urban water systems. Refer to the West Garforth case study (Table 2, Gersonius et al. (2013)) for better understanding of 'range' of design variables.	mangroves, detention at parks and retrofitting existing drainage systems are being considered. These measures have characteristics of WSC components as they have secondary water sensitive functions either as a detention facility or as a conduit in addition to their primary function. The maximum and minimum range of drivers such as rainfall and sea level changes within which each of these adaptation measures or their combinations could perform optimally are determined using physically based numerical models such as Mike Urban.
4. Identify critical WSC systems or components and interactions	Carry out relationship mapping between the adaptation measures. • Are the adaptation measures interdependent?	Refer to Infrastructure Victoria (Victoria, 2016a, Victoria, 2016b),	The range of adaptation measures whose attributes have been already understood and their optimal

Required steps	**Description**	**Resources for additional Guidance on individual steps**	**Application in Elwood, Melbourne (Refer to Appendix 1 for more details)**
	• Are adaptation measures complementary or do they hinder each other's performance? • Does the change in an adaptation measure affect the functionality of another measure? Determine the change propagation in the urban system. • How does a change in attribute of an adaptation measure propagate in the urban system? • Does an adaption measure become obsolete when the vision of the City regarding urban water or other system management change? The adaption measures which propagate positive change along with those that minimise negative or undesired changes in the urban system are the potential candidates for incorporating flexibility.	Radhakrishnan et al. (2017) for mapping of relationships between adaptation measures. Refer to Eckert et al. (2004) for more information on change propagation in complex engineering systems Refer to CRC Deliverable on Flood resilience in water sensitive cities (Gersonius et al., 2016) for classification of adaptation measures based on 4 domain approach. Refer to CRC deliverable on Adaptation mainstreaming (Rijke et al., 2016).	ranges identified are the potential candidates for flexibility. These measures are further subject to detailed analysis with respect to relationships with other measures and change propagation. For example, the detention systems at household level such as rainwater harvesting tanks and at neighbourhood level such as parks are the WSC components that trigger major changes in the Elwood catchment. Increase or decrease in household detention has a direct impact on detention volume to be provided in parks or the capacity of dewatering pumps. These are also the components where flexibility could be incorporated in case of scaling up, scaling down when changes are noticed in the trend of drivers of adaptation. It is relatively simpler to implement change in detention at household

Required steps	Description	Resources for additional Guidance on individual steps	Application in Elwood, Melbourne (Refer to Appendix 1 for more details)
			level or change the floor levels of properties undergoing renewal based on the trends of sea level rise or rainfall instead of increasing dike height or making major changes to pipe network. Refer to Appendix 1 for more details.
5. Create flexible design alternatives or pathways	Adaptation pathways should be generated using the subset of adaptation measures based on relationship mapping and functionalities.	Refer to CRC deliverable 4.2.5 (Veerbeek et al., 2016) for more information on adaptation pathways. Refer to Pathway generator tool (Haasnoot and Van Deursen, 2015) For estimation of expected annual damages (EAD) refer to (Olesen et al., Under Review)	The adaptation pathways i.e. the combination of various adaptation measures for Elwood were generated using adaptation pathways and the tipping points were found to vary depending upon the pathways and climate scenario. Refer to Appendix 1 for more details.
6. Determine cost and benefit of	Calculate the cost (also non-monetary) of implementation of adaption	Refer to discounted cash flow analysis	The economic cost of individual adaptation

Required steps	Description	Resources for additional Guidance on individual steps	Application in Elwood, Melbourne (Refer to Appendix 1 for more details)
design alternatives or pathways	measures (which includes the cost of switching from one measure to another) along with each adaptation pathway for all possible scenarios. Estimation of the present economic value of pathways can be assessed based on discounted cash flow analysis. The benefits (monetary and non-monetary benefits such as ecological benefits, reduction in noise levels, etc.) that accrue over the period for all the pathways should be ascertained.	methods (e.g. Appendix B in De Neufville and Scholtes (2011). Refer to Gersonius et al. (2016) and BeST user manual (Horton et al., 2016) to assess the benefits of flood resilient adaptation measures.	measures were obtained from planning reports and from engineering firms. The present costs of adaptation pathways were obtained based on the tipping point of the measures in the pathway. The possibility of additional benefits such as ecological value, recreational value, temperature reduction are highly likely. They could be computed using tools such as BeST.
7. Uncertainty analysis	The present value or cost and benefit of pathways depends on their performance in any given scenario. As there are multiple future scenarios, the performance of pathways is likely to be different leading to differences in the tipping points. Hence scenario planning will provide a range of present values and costs for each relevant set of pathways.	Refer to standard sensitivity analysis techniques such as Monte Carlo Simulation (e.g. Appendix D in De Neufville and Scholtes (2011). Sensitivity analysis of performance may also be undertaken using results from model based performance analysis (Löwe et al., 2015).	The uncertainty analysis of present value of adaptation pathways for Elwood was performed for four climate change scenarios recommended by IPCC (IPCC, 2013), CSIRO & BoM (CSIRO, 2015). The present value of the adaptation pathways was found to be sensitive to changing climate and socio-economic scenarios.

Required steps	Description	Resources for additional Guidance on individual steps	Application in Elwood, Melbourne (Refer to Appendix 1 for more details)
8. Final portfolio of components defined and selected for WSC	Once the expected present value of adaptation pathways are identified the final portfolio of adaptation measures may be created using the adaptation pathways that have higher expected present value of benefits or the pathways that have low present value of costs. If the expected present values pertaining to the costs and / or benefits are not satisfactory then more flexible alternatives or pathways are explored (Step 5) and the steps repeated. Notwithstanding the benefits and costs outcomes, decision makers may decide to select a preferred strategy that is not optimal in financial terms but may be the best strategy for other reasons.	See Gersonius et al., (2016) where the selection of preferred options is discussed.	IPCC scenarios are plausible scenarios, are assumed to have equal probabilities for calculating the expected present cost/benefits of pathways. The portfolio of measures recommended for Elwood could be selected based on the lowest or highest expected present value of pathway options.

Conclusions

"To create the environment for communities to adapt, survive and thrive, we must innovate, be adaptive and flexible, collaborate across traditional boundaries & sectors and act for now and long term"

- Page 12, Melbourne Resilience Strategy (City of Melbourne, 2016)

It is imperative to communicate research in a way appropriate to decision makers (i.e. research translation) for informed decision making. The purpose of this guideline has been to look into the various aspects of flexibility, incorporation of flexibility and the valuation of flexibility and develop a way of applying the latest ideas and procedures in the context of the WSC. The various types of flexibilities prevalent in urban flood risk management in the cites of Europe and beyond have been documented (e.g. EEA (2016), HM Government (2016). The practices in incorporating flexibility through context first approaches, real in options and adaptation pathways have also been presented here.

As yet, there is no consensus on an agreed means of identification of potential flexibility candidates for the optional measures available for developing flood resilience. In view of this, experiences from the domain of industrial engineering processes have been reviewed and utilised to develop the flexible adaptation planning process for the water sensitive city (WSCapp) which is the topic of this guideline. At the core of the WSCapp is the identification of potential opportunities where flexibility could be incorporated. The flexibility candidate identification criteria presented are based on the connections and relationships between the adaptation measures and the system that is undergoing change in order to increase its resilience.

As decision makers often see stories and case studies as being more compelling than rigorous studies or literature synthesis (Sallis et al., In press), the guidelines formulated from synthesising the relevant literature and practice on flexibility incorporation and valuation have been demonstrated using a case example located in Elwood a suburb of Melbourne, for better understanding (Appendix 1). From this case study it is evident that each of the steps of WSCapp are relevant, needed and can be applied. It has been demonstrated that all or most of the information required for a flexible adaptation planning approach in a WSC context could be obtained from the available planning documents, information about future trends such as climate and population, which are available in the public domain. Based on these documents it is possible to identify the potential candidates for flexibility in a WSC context. The generation of adaptation pathways, assessment of the performance of adaptation pathways under different scenarios and selection of preferred pathways for the purposes of implementation have been demonstrated using examples of potential measures in Elster Creek. Not all the possible flexible components have been considered due to extensive modelling efforts required to assess their performance across scenarios and also not all the benefits have been ascertained. The next step would be to gather evidence in order to strengthen the guideline and increase the reliability of the approach further for the implementation of a resilience strategy. For example, evidence could be collected during the implementation of the Resilient Melbourne Strategy or Victoria's 30 Year Infrastructure Strategy to assess the limitations of the WSCapp presented here and address these before applying WSCapp more widely within Australia.

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Appendix 1: Flexible measures for adapting to urban floods in Elster creek, Melbourne

“Decision makers see stories and case studies as being more compelling than rigorous studies or literature synthesis.”

- Sallis et al. (In press) in The Lancet

Introduction

WSCapp has been applied to incorporate and evaluate flexible adaptation measures in Elster Creek, Melbourne, Australia, which is an urban catchment. Application of flexibility and incorporation of a valuation methodology is a part of the systematic development of flood adaptation strategies carried out in collaboration with social scientists and architect (Rogers et al., 2015). The social science, modelling and architectural perspectives provided in-depth analysis of Elster Creek’s characteristics. Elster Creek`s coastal, low-lying area (i.e. Elwood in City of Port Phillip) is at the lowest point of a 40 km^2 urban catchment and the town has been developed over drained marshland. These characteristics mean that there is a significant flood risk for the suburb (of Melbourne), which is predicted to significantly increase with climate change due to more frequent and more intense rainfall events and rising sea levels. Long-term climate models have also projected hotter and drier conditions, presenting regional water scarcity challenges. The flooded extents and the flood damages presented here for the purpose of demonstration are based on preliminary results that are subject to change and should not be considered as definitive.

Application of guidelines

1. Identify vision, scenarios and uncertainty

Melbourne ranks highly among the most liveable cities in the world and aspires to become a resilient, water sensitive, business friendly and liveable city. Melbourne aims to increase its resilience through strategies such as survive, adapt, thrive and embed (City of Melbourne, 2016, Victoria, 2016a). The effects of climate change and global mega trends such as urbanisation are evident in Melbourne. Elwood, a suburb of the City, is subject to floods and is beset with uncertainties related to increases in sea level, increases in rainfall intensity and increased urbanisation (CSIRO, 2015, Victoria, 2014).

2. Determine drivers related to uncertainty and the changes anticipated

The important drivers that affect the objectives of the adaptation may be determined using numerical models or through stakeholder consultations. Methods such as adaptation pathways based on adaptation tipping points help in determining the impact of uncertainty in meeting the required objectives based on ‘ stress tests’ in an urban area using physically based numerical models (CRIDA, In press, Rodriguez et al., 2016). The expected annual flood damages (EAD) have been assessed to determine the impact of drivers related to uncertainty and changes anticipated over time. All the three drivers: rainfall, sea level rise and urbanisation contribute to increases in expected annual flood damages. However, the effect of rainfall and sea level rise are the most pronounced. Analysis reveals that the flood damage due to a sea surge is high during return events such as 1 in 5 and 1 in 10 years, whereas the flood damage due to rainfall is high during 1 in 20, 1 in 50 and 1 in 100 year events. Hence rainfall and sea level rise are considered as the main drivers contributing to the changing challenges for Elwood.

3. Understand attributes of WSC components and define range of possibilities

The flood risk management plans for Elwood reveal a host of possible measures addressing flood risk due to sea level rise and increases in rainfall intensity. The plans have been compiled from various extant planning documents from the City of Port Phillip and Melbourne Water (e.g. Port Phillip adaptation pathways (AECOM, 2012), flood management strategy (Melbourne Water, 2015)). These have been categorized based on the Source- Pathway- Receptor concept (Sayers et al., 2013) and are presented in Figure 12.

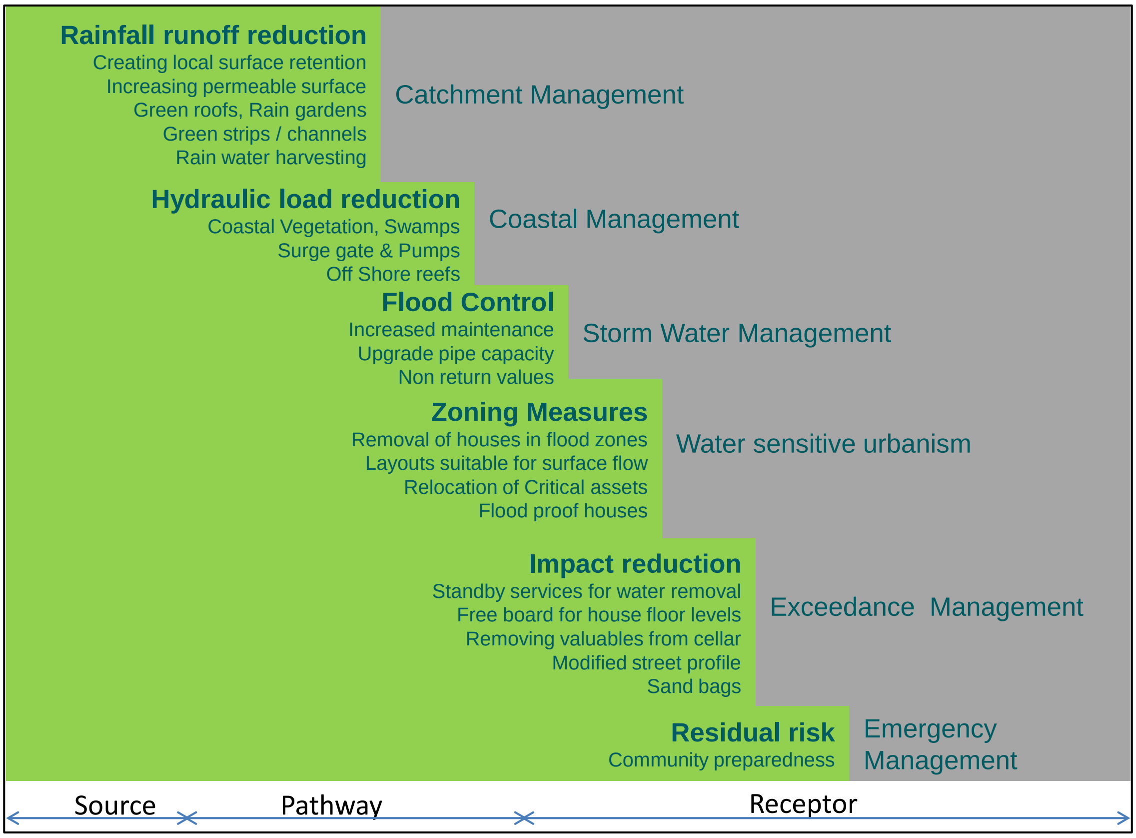

Figure 12: Flood risk management options for Elwood. Adapted from Mendoza et al. (In press).

Measures such as foreshore mangroves, lowering of street profiles and surface water detention at parks that are being considered for Elwood have characteristics of WSC components as they have secondary water sensitive functions either as a recreation facility or as a conduit in addition to their primary function. The maximum and minimum range of drivers such as rainfall and sea level changes within which each of these adaptation measures or their combinations could perform optimally were determined using physically based numerical models (i.e. Mike Urban) developed by flood modellers in the Elwood research group (Löwe et al., 2015) .

4. Identification of candidate flexibility and relationships between measures

The range of adaptation measures considered for the purpose of demonstration of flexibility incorporation and assessment in Elster Creek are: road elevation along foreshore; lowering of street profiles; sea gates with pumping stations; foreshore mangroves; stormwater detention at parks; and retrofitting of existing drainage systems. Considering the effectiveness of these adaptation measures, road elevation and sea gates with pumping gates have been found effective for flood events with higher return frequencies such as 1 in 5 and 1 in 10 years, lowering flood damage. Whereas each of the other measures have been found effective to some degree, for flood events with lower return frequencies such as 1 in 20, 1 in 50 and 1 in 100 years, damage is not as excessive as would have otherwise been. Thus there are two subsets of adaptation measures: one to tackle low frequency events (chronic stress); and the other to tackle high frequency events (acute shocks). The resilience strategy of Melbourne City (City of Melbourne, 2016) emphasises the need for adaptation measures that can withstand chronic stress and also acute shock. However, the performance of the measures are attributed to the progression of drivers such as rainfall and sea level rise, which subsequently leads to greater uncertainty as to the duration up to when in the future the measures are useful.

Structural or operational flexibility can be incorporated in all of the adaptation measures to help tackle uncertainty. It is also useful to look at the range of uncertainty of the driver in order to incorporate flexibility. Should the road elevation be a flexible measure (i.e. implemented in increments) or should it be a robust measure designed and built for the extreme sea level anticipated at the end of the planning horizon? For example the elevation of the carriageway is designed and built above the sea level anticipated for the year 2090. This depends on two factors: (i) the range of variation of sea levels between the two extreme IPCC scenarios RCP 2.6 and RCP 8.5 at 2090. Under the RCP 2.6 the change in climate drivers such as temperature, rainfall and sea level rise will be minimum whereas under RCP 8.5 it will be maximum, there two scenarios cover the entire range of variations. There is a wider acceptance amongst the scientific and political community of the range of uncertainty of climate drivers such as temperature, rainfall and sea level rise for four representative concentration pathways (RCP) - i.e., net energy emitted per m^2 as a result of mitigation actions taken by the governments - as adopted by IPCC (IPCC, 2013) and; (ii) the difference between the cost of building the foreshore road for sea level rise expected in 2090 under RCP 2.6 and upgrading it later if trends observed in case of increasing sea levels leads to RCP 8.5 scenario compared with the cost of building a higher road for sea level rise expected in 2090 under RCP 8.5. The difference between the anticipated sea level increase for RCP 2.6 and RCP 8.5 is about 0.22m at Williamstown (Table 2), which is one of the wave gauging stations for Melbourne (Page 151, CSIRO (2015)). The cost of constructing a higher road once is cheaper than doing it twice in small increments in this case (Table 3, comparison made using 2011 cost rates in Melbourne). Hence it has been concluded that a 0.22m difference in sea level increase at Williamstown between the two scenarios does not necessitate an incremental increase in dike heights and could be tackled using a robust approach. Based on this inference it has been decided that the road elevation measure is not an ideal candidate to be a flexible adaptation measure. The road elevation measure could be a robust measure with an additional allowance to tackle the uncertainty in sea level. Incorporation of additional sea level planning allowances in coastal flood defence structures is also recommended by Victorian Coastal Council (Hunter, 2014).

Table 2: Increase in Sea levels anticipated at Williamstown under various IPCC climate scenarios (CSIRO, 2015).

Climate Scenarios (IPCC, 2013)	Increase in sea level (m)			
	2030	2050	2070	2090
RCP 2.6	0.11	0.2	0.29	0.37
RCP 4.5	0.11	0.2	0.31	0.45
RCP 6.0	0.11	0.2	0.31	0.45
RCP 8.5	0.12	0.24	0.39	0.59

Table 3: Cost comparisons for foreshore road elevation to prevent coastal flooding at 2090 (Protection against 0.59 m sea level rise).

Components	Retaining wall	Carriageway	Total cost (Million AUD)
Single elevation	1 x 0.59 m	Once	9.5
Elevation in two increments	1 x 0.37 m 1 x 0.22 m	Twice	13

The events that are potentially causing maximum damage in Elster Creek are the rainfalls with lower return frequencies. The % increase in 20 year return level of maximum 1 day rainfall in 2090 is likely to be 11% or 25% respectively more than the present rainfall levels depending on the scenario (Page 118, CSIRO (2015)). The damage is spread across the catchment, which requires a catchment wide approach.

Detention at household level or at local level, using property level flood proofing measures could be effective against flooding due to high rainfall events. The detention of water or attenuation of peak discharge at household levels propagates throughout the system. Harvesting rainwater is an established practice across Australia. Hence it could be mandated through local bylaws to detain a minimum amount of rainwater at households using green infrastructure based on plot size. The quantity of detention could be revised at stipulated intervals that could reflect the increase in rainfall intensity. Similarly, there could be strict but revisable building regulations for minimum floor levels for houses that are at present under the flooding overlay levels. There is a possibility of mainstreaming flood proofing when household assets are renewed (Nilubon et al., 2016). For example, if 4% of housing stocks come up for renewal every year, all the houses would have been renewed in 25 years. This is highly likely as Melbourne is experiencing higher renewal rates due to rapid urbanisation. Twenty five years is also ample time to determine the increasing trend of rainfall intensities, based on which the regulation could be revised. Also the household adaptation measures could be complemented using functional flexibility approaches such as parks as detention facilities (Figure 10) and roads as conduits (Figure 9) during exceedance and extreme events (Gersonius et al., 2016). Such flexible approaches are relatively less complicated compared with large-scale drainage modification measures. Consideration of adaptation measures based on the 4 domains approach suggested by Gersonius et al. (2016) provides the base framework for ensuring that all types of events are appropriately considered for incorporation of flexibility wherever and whenever it is sensible to do so. However, successful implementation and integration of measures is likely to require a high level of stakeholder understanding and flexibility in the way funding is provided. However, where additional functionality is provided, over and above flood management, the multiple functions can often bring in additional stakeholders with funding (e.g. Ashley et al. (2016). The recent realisation that green and blue infrastructure is especially important for healthy populations even by the medical and public health professionals, can be a route to significant additional funding.

Although incorporating functional flexibility seems to be less complicated than changing drainage infrastructure, it might lead to implementation issues if the coordination with departments sharing the resources is difficult. For example, the roads department may not easily agree to the change in road design that facilities the flow of water on surfaces or they might have a different renewal priority list of roads than the drainage authorities list of flooded streets. In such instances mainstreaming adaptation will be complicated and the water authority could resort to operational flexibility measures. For example, the water authority could invest in high capacity dewatering pumps that could be moved anywhere in the catchment, where flooding is anticipated. The strategy to invest in movable dewatering pumps could also become a preferred option in case of a scenario where the buy in amongst the residents for a 'water sensitive city' way of living becomes less attractive and a transition towards a utility based customer – service provider relationship between the residents and city council gathers momentum.

The other aspect that has to be taken into consideration while selecting the component or subsystem for flexibility is the "mainstreamability" of the component. That there is scope for mainstreaming the adaptation measures has become evident upon assessing the current plans that are being prepared such as the Resilient Melbourne Strategy (City of Melbourne, 2016), Flood Management Strategy for Port Phillip and Westernport (Melbourne Water, 2015), and the Victoria's 30 Year Infrastructure Strategy. The resilience plan of Melbourne proposes urban forestry as a flagship programme to promote resilience that also includes lowering flood risk and improving storm water quality. The foreshore mangrove and upstream detention that has been identified as a measure for Elwood could be mainstreamed under this urban forestry initiative. The supporting actions in the resilience plan of Melbourne also call for increasing resilience through integrated solutions to reduce flood risk and increase financial safety in flood prone areas (City of Melbourne, 2016). The adaptation measures in Elwood such as street modifications and upstream detention could be mainstreamed under this or the open area management plans in Melbourne Water (2015). Improving flood resilience of Elwood College could be mainstreamed through the neighbourhood plan that aims to educate the community. After identifying the feasible mainstreamable components, a thorough assessment of operational constraints, ownership or jurisdiction issues and similar issues that involve multiple utilities have to be undertaken before selecting the possible flexibility candidates. For example the City of Port Phillip (CoPP) has the jurisdiction over Moran reserve, the large area in the foreshore, whereas Melbourne Water is in charge of drainage of open spaces which have a surface area greater than 20 hectares. Upon making the foreshore a mangrove in collaboration with Parks Victoria, it might become difficult for Melbourne Water and CoPP to make changes as the legal status of the open green land might have become a "nature reserve".

5. Creating alternative flexible pathways

The adaptation pathways i.e. the combination of various adaptation measures for Elwood were generated using the Pathways generator tool kit (Haasnoot and Van Deursen, 2015). Four options have been selected to demonstrate the adaptation pathway approach. The expected annual damage cost (EAD - economic) of AUD $5,000,000, was considered as the tipping point, upon which additional measures will need to be put in place to bring the damages below this limit, i.e. to postpone the tipping point. The EAD assumed is equivalent to 0.5% of net annual benefit in terms of revenue generated in the Elster Creek catchment or 5% of revenue generated from the vicinity of the Elwood canal below the golf course in 2011 (Table 4, AECOM (2012)). The calculated EAD for individual adaptation measures and adaptation pathways set out here are preliminary, subject to change and are presented here only to demonstrate the approach.

Table 4: Tipping points for selective adaptation pathways in Elwood.

Combined Actions or Pathways	Year of tipping point (based on EAD)			
	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Current Situation	2050	2040	2036	2025
Mangrove at Foreshore	2100	2056	2045	2035
Detention at Elwood college	2060	2045	2038	2030
Detention at upper catchments	2079	2058	2050	2038
Drainage system improvements	2100	2090	2080	2069
Detention at Elwood College + Detention in upper catchments	2085	2069	2050	2040
Mangroves at Foreshore + Detention in upper catchments	2110	2078	2062	2045
Detention in upper catchments + Drainage system improvements	2110	2100	2089	2075
Detention at Elwood College + Detention in upper catchments + Drainage system improvements	2130	2111	2095	2080
Mangroves at Foreshore + Detention in upper catchments + Drainage system improvements	2150	2124	2114	2102

The tipping points of adaptation measures and pathways for four different climate scenarios based on CSIRO(2015) for Melbourne based on IPCC (2013) are presented in Table 4, whereas the pathways and tipping points are illustrated on Figure 13 and Figure 14. From Table 4, Figure 13 and Figure 14 it can be seen that the tipping points vary depending upon the adaptation measures along the pathways and for the various climate scenarios. For example the tipping point of Elwood College occurs in the years 2030 and 2060 for the scenarios RCP 8.5 and RCP 2.6 respectively; whereas the tipping point of the Elwood College and detention in upper catchments occur in the years 2040 and 2085 for the scenarios RCP 8.5 and RCP 2.6. The inference is that the upper catchment detention measure has to be in place by 2030 after the Elwood College measure under a RCP 8.5 scenario, or in place by 2060 under RCP 2.6, in order to postpone the tipping point.

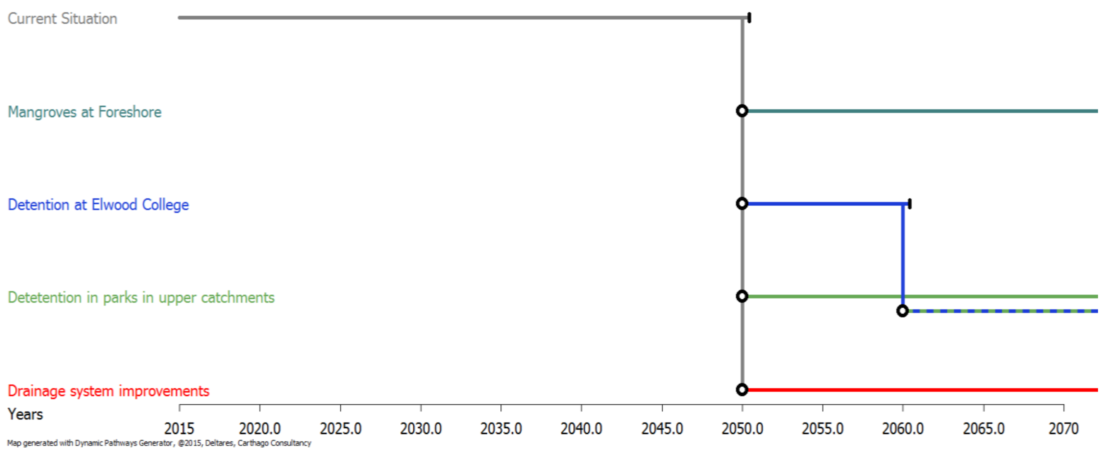

Figure 13: Adaptation pathways under Low climate scenario (RCP 2.6). (Not all the pathways are shown here.)

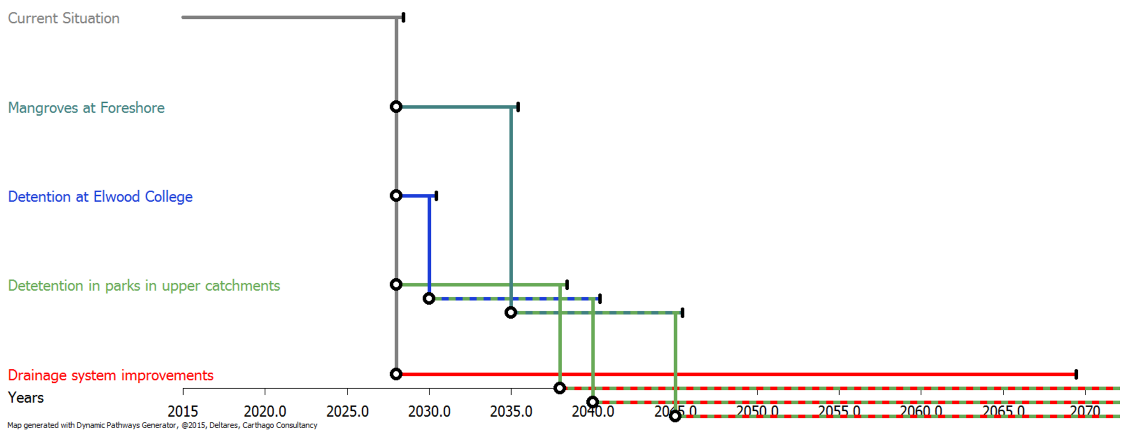

Figure 14: Adaptation pathways for extreme climate scenario (RCP 8.5). (Not all the pathways are shown here.)

It can be inferred from the adaptation pathways in Figure 13 and Figure 14, that the flexibility is realised by means of having a choice to defer the implementation of the adaptation measures depending upon the progression of sea level rise. The flexibility obtained through this step is not due the inherent nature of the measure, such as being operationally or functionally flexible. Instead, the flexibility obtained is due to compatibility of the measure with the other measures in the adaptation portfolio. This facilitates the delaying or speeding up in terms of implementation based on the increasing sea levels. For example, mangrove, upstream detention and drainage system improvements are compatible with each other when considered individually or together; they reduce the flood damages. However, the nature of each measure varies, as the mangrove and upstream detention measures have structural and functional flexibility, whereas pipe modification does not have any form of flexibility. In spite of this inflexibility, when combined with the mangrove and upstream detention and considered as a pathway, pipe modification acts to support flexibility as it defers the implementation of the subsequent measure.

6. Determine cost of design alternatives or pathways and Uncertainty analysis

The economic costs of individual adaptation measures were obtained from planning reports and from engineering consultancies. The present costs of adaptation pathways discounted using a discount rate (1.5%) were obtained based on the tipping point of the measures in the pathway (Table 5). The uncertainty analysis of present value of adaptation pathways for Elwood was evaluated for the four climate change scenarios recommended by IPCC (IPCC, 2013) and CSIRO & BoM (CSIRO, 2015) and the present value of the adaptation paths were found to be sensitive to changing climate scenarios.

Table 5: Present and expected cost of adaptation pathways based on the tipping points.

Combined Actions or Pathways	Cost of adaptation pathways (Million $AUD)	Present cost of adaptation pathways (Million $AUD)				Expected present cost (Million $AUD)
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	
Drainage system improvements	996	996	996	996	996	996
Detention in upper catchments + Drainage system improvements	1,009	164	293	367	518	335
Detention at Elwood College + Detention in upper catchments + Drainage system improvements	1,011	131	209	362	486	297
Mangroves at Foreshore + Detention in upper catchments + Drainage system improvements	1,061	113	210	305	469	274

7. Final selection of portfolio of adaptation measures

As the IPCC scenarios are plausible scenarios, they are assumed to have equal probabilities for calculating the expected present cost of the possible pathways. Selecting on the basis of lowest expected present value (costs), the portfolio of measures recommended for Elwood comprises foreshore mangroves, detention in upper catchments and retrofitting of drainage systems.

8. Other benefits due to the adaptation measures

The other benefits that accrue due to the adaptation measures such as detention of stormwater in parks in the upper catchment, detention in Elwood College and mangroves in Elster Creek have not been monetised and reported in this study. From the community consultations with the residents of Elwood it could be inferred that there is a clear preference for green measures such as rain gardens, detention in parks and mangroves. These are preferred by the residents as they believe that such measures will enhance the aesthetics of the suburb (Rogers et al., 2015). The benefits from these adaptation measures such as reduction in pollution, increase in land/property values due to presence of greenery, reduction in energy costs due to reduction in surface temperature and urban heat can be calculated using BeST or an equivalent tool (Horton et al., 2016). See also the guidance provided in the other CRCWSC deliverables including "Flood resilience in water sensitive cities"(Gersonius et al., 2016) and "Ranking projects for Water Sensitive Cities: A practical guide" (Pannell, 2015).

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