Flexible adaptation planning process for urban adaptation in Melbourne

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Published in:
Proceedings of the Institution of Civil Engineers - Engineering Sustainability

Link to article, DOI:
10.1680/jensu.17.00033

Publication date:
2019

Document Version
Peer reviewed version

Citation (APA):
Radhakrishnan, M., Löwe, R., Ashley, R. M., Gersonius, B., Arnbjerg-Nielsen, K., Pathirana, A., & Zevenbergen, C. (2019). Flexible adaptation planning process for urban adaptation in Melbourne. *Proceedings of the Institution of Civil Engineers - Engineering Sustainability*, *172*(7), 393-403. https://doi.org/10.1680/jensu.17.00033

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01 May 2017

Paper for ICE Proceedings on Engineering Sustainability

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No. of words (all): 7885

No. of words excluding abstract and references: (Including Tables and figures) 6484

No. of words in main section excluding abstract, tables and references: 5631

Word limit of main section - 5000

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Abstract

Resilience towards climate and socio-economic change can be increased by means of flexible adaptation. In contemporary adaptation planning, building resilience is considered together with objectives such as sustainability, productivity and transformations. An adaptation planning process (termed WSCapp) may be used to incorporate flexibility or incremental flexible adaptation measures in a comprehensive adaptation strategy, such as when planning water sensitive cities. This paper has applied WSCapp in the context of adapting to urban flooding in Melbourne, which aspires to become a water sensitive city. Application of WSCapp – through nine steps of analysis - has helped to identify appropriate adaptation measures; and economic adaptation pathways. In the case of Melbourne, of the three adaptation measures considered, the combination of rain water tanks at household level and the flood proofing of households was found to be most effective. WSCapp is fundamental for future work with urban planning and infrastructure consultants and can greatly benefit them at obtaining more flexible and sustainable flood management response.

Keywords: Climate Change, Floods & floodworks, Infrastructure planning, Sustainability, Urban Regeneration.

1. Introduction

The concept of a “*Water Sensitive City*” (WSC), i.e. a city being liveable, resilient, sustainable and productive whilst managing all aspects of the water cycle, is gaining popularity especially in developed economies (Howe and Mitchell, 2011;Wong, 2006). The WSC concept is being adopted by cities in Australia, whereas similar adaptation concepts such as transformative urban adaptation and resilient cities are gaining traction elsewhere in the world (Spaans and Waterhout, In Press;EEA, 2016;Revi et al., 2014). WSC and transformative urban adaptation concepts promote flexibility as an essential attribute to take advantage of opportunities from uncertainties. Flexibility in this context can be defined as there being opportunities arising from the number of alternative ways to provide services required when responding to changing circumstances (City of Melbourne, 2016). Flexibility can also result as a consequence of compatibility of the adaptation measure with the other measures in the adaptation portfolio (Radhakrishnan et al., 2016). Flexibility may also be seen as an essential characteristic of urban planning and infrastructure planning to deal with transformation in objectives such as becoming a water sensitive city (Ashley et al., 2013).

Adaptation and transformation in urban water management can be compared with the evolution of new car models in response to changing customer preferences and also technological advancements. For example, the consideration of aesthetics benefits of water in an urban landscape along with flood resilience in cities can be considered in a similar way to the preference for car engines with reduced emissions without compromising on the engine power and fuel efficiency. Cars not only provide transportation, but also offer the freedom to move and social status, which is similar to the concept of WSC, where water services, in addition to catering for basic needs, contributes towards enhancing the livability and productivity in the city. Although the objectives of automobile industry and flood risk management are not comparable, the processes used in both these sectors are comparable.

The automobile manufacturing sector uses product platform strategies, such as the flexible platform design process (Suh et al., 2007), to save costs by sharing core elements among different products in a product family. The uniqueness of this process is the identification of flexible components upfront to create an integrated platform, such as a car chassis, where the individual components can be changed easily in the future due to changing requirements (Suh et al., 2007). The incorporation of flexibility is based on the concept of change propagation, i.e., the components that are capable of propagating greatest change need to be assessed carefully before being selected as candidates for embedding flexibility (Eckert et al., 2004). According to the concept of change propagation, flexibility is incorporated in a location or in a component of the system that could minimise negative impacts and/ or maximise positive impacts when the system is subject to changing conditions (Eckert et al., 2004;Suh et al., 2007). Similarly consideration of change propagation through systems such as rain gardens, rainwater harvesting tanks, mangroves – either due to the change in climate drivers such as rainfall, sea level rise and/ or change in vision or strategy such as from a water supply city to a water sensitive city – in an urban water context is essential to adapt in a flexible manner to changing circumstances.

Transitioning to a WSC needs a process, or processes that incorporate flexibility into planning, implementation and operation. An adaptation planning process for water sensitive cities is utilised here, known as WSCapp, to identify where flexibility can be incorporated into subsystems of a WSC, such as urban flood risk management systems (Radhakrishnan et al., 2018). WSCapp (Figure 1) has been developed drawing on knowledge and practices that are prevalent in the automobile and aerospace sectors, where adaptation – such as to changing customer requirements, technological advancements and market variations – is facilitated using flexible designs (Radhakrishnan et al., 2018).

This paper applies WSCapp to incorporate and evaluate flexibility into adaptation measures for managing flood risk in the Elster Creek catchment in Melbourne, Australia. The City of Melbourne was selected as a case study because, together with the State of Victoria it has begun to include flexibility explicitly in adaptation planning (Victoria, 2016a;Victoria, 2016b;City of Melbourne, 2016).

2. Methodology

The application of WSCapp follows steps 1 to 9 Figure 1 indicated by the black arrow. The dashed line from step 8 and 9to step 1 illustrates feedback, whereas the white arrow enclosed in a black line represents the repeating nature of the analysis for each iteration where the decision makers do not favour the outcomes.

Figure 1: Flexible adaptation planning process for water sensitive cities – WSCapp : The black arrows represent the sequence of steps in the WSCapp (clockwise). The dashed line from step 8 and step 9 to step 1 represents the feedback to the vision cycle (Radhakrishnan et al., 2018)

Most of the steps in WSCapp are similar to the processes followed in the recent adaptation planning methods that are used in urban water management, such as real options, real-in-options, adaptation pathways and robust decision making (e.g. Gersonius et al. (2013), Haasnoot et al. (2012), Zhang and Babovic (2012), Hall et al. (2012)). This similarity should help to facilitate the understanding and application of WSCapp. These methods make the overall planning and implementation process flexible. WSCapp focusses on the identification of effective adaptation measures where flexibility can be incorporated (Step 4 in Figure 1). In a water sensitive city context (WSC) adaptation measures such as flood resilience measures are not only selected based on their ability to increase flood resilience, but also on the ability to enhance the livability and productivity. The identification of effective adaptation measures should be based on the following attributes:

- Flexible or robust nature of the measure
- Secondary function of the measure
- Compatibility of the measures with other measures
- Change propagation in terms of resilience, livability and productivity
- Inter-relationships between measures.

For example, a conventional drainage system, though effective in reducing flooding, does not contribute to the livability aspect of WSC, hence it is not an ideal candidate for incorporating flexibility. However, a rainwater harvesting system can also contribute to productivity in terms of reduced water consumption from the city network. Similarly, a rain garden can also enhance the aesthetics of the neighbourhood in addition to reducing the risk of pluvial flooding. Hence the change propagation aspect in a WSC context considers the change and the degree of change due to adaptation measures in terms of flood resilience, livability, and productivity.

3. Application of WSCapp in Elster Creek, Melbourne

WSCapp has been applied in the context of adapting to flooding in the catchment of Elster Creek in Melbourne. WSCapp can be applied to all the adaptation measures in Elster Creek but it was applied to fewer measures to a cover a space that is sufficient to be illustrative. Elster Creek`s coastal, low-lying area (i.e. Elwood in City of Port Phillip) is at the lowest point of a 45 km^2 urban river catchment and has been developed over drained marshland (Figure 2). Refer to Gunn and Rogers (2015) and

Rogers et al. (2015) for background information on Elster Creek. These characteristics mean that there is a significant flood risk which is predicted to increase with climate change due to frequent and intense rainfall events and rising sea levels (CSIRO, 2015). A combined 1D-2D hydraulic simulation in MIKE URBAN (Davidsen et al., 2017) for the different adaptation measures for various rain depths, sea levels and urban development states was undertaken to assess the flood risk (Figure 2). Simulated flood areas were intersected with land-use layers to compute flood damages using depth-damage functions(Olesen et al., 2017). The damages obtained from the different simulations were interpolated using a kriging approach to compute expected damages in different scenarios (Löwe et al., 2018). For further details on computed damages in Elster creek catchment refer to Löwe et al. (2018). These issues have prompted reconsideration of water management at the local and metropolitan planning levels. For example, planning controls across the City of Port Phillip were recently reviewed to minimise the impact of 100-year ARI flood events on new development (CoPP, 2016).

Figure 2: Flood map of Elster Creek with Sea level of 1.9 m at outfall and 69 mm rainfall in 4.5 hours. Both these events correspond to 1 in 100 year return period under RCP 4.5 IPCC scenario in Year 2090

3.1. Identify vision

Melbourne ranks highly among the most liveable cities in the world and aspires to become a resilient, water sensitive and business friendly city (Step 1 in Figure 1) By considering the history of the changing visions and adaptation objectives in Melbourne, it is apparent that these have changed from the protection of waterway health to that of a resilient water sensitive city (Ferguson et al., 2013). The Urban resilience in the context of Melbourne is defined as the capacity of individuals, institutions and systems to survive and grow when exposed to chronic stresses and acute shocks. Effects of climate change and global trends such as urbanisation are evident in Melbourne and the City aims to increase its resilience (City of Melbourne, 2016;Victoria, 2016a;Victoria, 2014).

3.2. Determine drivers and associated uncertainty

Elwood, a suburb of Melbourne, is subject to flooding and uncertainties related to likely increases in sea level, rainfall intensity and urbanisation (CSIRO, 2015;Victoria, 2014). The key drivers that affect the adaptation objectives were studied with the aid of numerical models and through stakeholder consultations (Rogers et al., 2015) (Step 2, Figure 1). The adaptation tipping point method helped in determining the impact of uncertainty in meeting the required objectives based on ‘stress tests’ by using numerical models (Rodriguez et al., 2016). Tipping points are the points in the future, or predetermined values of variables such as sea level rise or rainfall, at which the objective of an adaptation strategy is no longer met or the required performance of an adaptation measure is compromised (Kwadijk et al., 2010). The range of uncertainty of climate drivers – rainfall and sea level rise for four representative concentration pathways (RCP) (i.e., as a result of possible mitigation actions taken by governments) – is as defined by the Intergovernmental Panel on Climatic Change (IPCC) (IPCC, 2013).

Under the RCP 2.6 the change in climate drivers such as temperature, rainfall and sea level rise will be the minimum, whereas under RCP 8.5, it will be the maximum. These two scenarios cover the entire range of variations. For example in Melbourne region, the % increase in 20 year return level of maximum 1 day rain fall in Year 2090 is likely to be 11% and 25% more than the present rainfall for RCP 2.6 and RCP 8.5 scenarios respectively (Page 18, CSIRO (2015)). Further the increase in Sea levels in Melbourne region in Year 2090 for the aforementioned scenarios is likely to be between 0.37m and 0.59m (Page 151, CSIRO (2015)). Also the population of Melbourne is likely to be between 5.85 million and 6.15 million in the Year 2031, which will lead to the establishment of about 310,000 new dwellings in Central Melbourne and its immediate surroundings (Victoria, 2014). This will lead to uncertainty in determining the extent of pluvial flooding, number of residents affected and total flood damages in Elster Creek Catchment.

3.3. Understand attributes of adaptation measures and define the range of possibilities

Existing flood risk management plans for Elwood revealed a host of possible measures for addressing increasing flood risk due to sea level rise and higher rainfall intensities (Step 3, Figure 1). The adaptation measures (Figure 3) 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), GHD (2014), Gunn and Rogers (2015)). 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 in all the IPCC scenarios.

Figure 3: Possible adaptation measures in Elster Creek

Flexibility is the ability of the system to respond in an efficient way in terms of performance, cost and time when the system is confronted with uncertainties, negative consequences and opportunities (Radhakrishnan et al., 2018). The flexibility analysis of measure in Elster creek, based on the cost and inconvenience incurred in making changes to the measures in future, shows that the foreshore mangrove, rainwater harvesting, flood proofing of households, detention in parks and retrofitting can be the suitable candidates for incorporating flexibility. The road considered for elevation to prevent coastal flooding in this study is Marine Parade in Melbourne. The net cost, across the scenarios, of elevating the road once using a robust design is less than (9.5 million Australian dollars) elevating the road twice using a flexible design (about 13 million Australian dollars), as the flexible design requires road formation twice that makes the design expensive. The cost for road elevation was estimated based on the prevailing market rates in Melbourne. Hence, the road elevation measure can be a robust measure and is not suitable to be a flexible measure. Also with the exception of road elevation, all adaptation measures have a secondary function as an amenity in addition to their primary function. The adaptation measures in Elster Creek are independent of each other, i.e., presence or absence of a measure does not hinder the performance of another measure or hinder the function of measure. Hence these measures are compatible with each other and can complement the functioning of each other. The attributes of adaptation measure are summarised in Table 1.

Table 1 Attributes of adaptation measures in a water sensitive Melbourne

Adaptation measure	**Nature of the adaptation measure**			**Change propagation**			**Mainstreaming possibilities**	**Offsetting complications**
	Robust / Flexible	**Secondary function**	**Compatibility**	**Flood risk**	**Livability**	**Productivity**		
Road elevation	Robust	Yes	Yes	Yes	No	No	Yes	Yes
Foreshore mangrove	Flexible	Yes	Yes	Yes	Yes	No	Yes	Yes
Rainwater harvesting	Flexible	Yes	Yes	Yes	Yes	Yes	Yes	No
Wet proofing houses	Flexible	No	Yes	Yes	Yes	No	Yes	No
Drainage retrofitting	Flexible	No	Yes	Yes	No	No	Yes	Yes
Detention in parks	Flexible	Yes	Yes	Yes	Yes	No	Yes	No

Notes:

1. The nature of the adaptation measure, which is either robust or flexible is based on the cost and inconvenience incurred in making the design and implementation amenable to changes in future requirements
2. The primary function of all the measures is the reduction in flood risk, except road elevation where the primary function is connectivity and secondary function is reduction in flood risk. The secondary functions for other adaptation measure considered are ecological benefits, recreational benefits and economic benefits due to reduced water consumption.
3. The flood risk and change in flood risk, i.e., estimated annual damages is based on simulations whereas change in livability and productivity are qualitative but can be computed.
4. Offsetting is the practice of avoiding incorporation of flexibility in adaptation measures where there is a likelihood of operational constraints, ownership or jurisdiction issues and similar issues that involve multiple utilities (Eckert et al., 2004). In contrast, mainstreaming is actively looking for opportunities to implement adaptation measures together with other urban infrastructure components (Rijke et al., 2016).

5. The assessment of mainstreaming possibilities and offsetting complications are based on the present utility management practices prevalent in City of Port Phillip and Melbourne Water.

3.4. Identify effective adaptation measures and interactions

The range of adaptation measures whose attributes have been already understood by the planners or city managers and their performance ranges identified are the potential candidates for embedding flexibility. These measures are further subject to detailed analysis with respect to relationships with other measures change propagation, mainstreaming and offsetting. For example, the detention systems at household level such as rainwater harvesting tanks and at neighbourhood level such as parks, are measures 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 can 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 level or change the floor levels of properties undergoing renewal in response to the trends of sea level rise or rainfall instead of increasing dike height or making major changes to the pipe network.

After determining the set of adaptation measures that are flexible, the change propagation aspects of those measures were determined (Step 4, Figure 1). The changes that propagate though the adaptation measures in the catchment pertains to flood resilience, livability and productivity. The change in productivity was assessed based on the water saved due to the presence of rainwater tanks as about 88 AUD per annum can be saved due to the savings in water (Moglia et al., 2014). The extent of foreshore mangrove and its seasonality, i.e., presence, absence and the duration of the same is a subjective indicator of livability (qualitative). Similarly, the degree of change for individual measures and combinations of measures in varying proportions can also be determined for all scenarios.

3.4.1. Identification of effective adaptation measures based on change propagation

Detention at household or local level, using property level flood proofing measures, is effective against flooding by attenuating peak discharges of extreme rainfall events. Hence, it was considered worthwhile to investigate, in detail, the changes propagated by these measures at household levels in the catchment. For example, rainwater harvesting can be mandated through local byelaws to detain a minimum amount of rainwater at households based on plot size. Although most of the households in Elster Creek have a standard 2m^3 rainwater tank, a larger 5m^3 rainwater tank was found to be effective in reducing downstream flood damages. The volume of detention can be revised in the future at stipulated intervals to reflect the changes in rainfall intensity over time.

Any change in the regulation regarding special building overlay or the preference for rainwater harvesting tanks is likely to have an effect on the livability, productivity and flood resilient aspects of the catchment. This propagated change can be regulated using appropriate adaptation measures. Hence, there can be strict but revisable building regulations for minimum floor levels for houses that are at present under the flooding overlay levels; i.e., the special building overlay (SBO) of City of Port Phillip (CoPP, 2016;Victoria State Government, 2018). There is a possibility of 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 (Victoria, 2014). Instead of a blanket enforcement, CoPP can enforce flood proofing of houses that apply for renewal permits and a public consultation on the same, a standard practice in CoPP while revising its building overlays (CoPP, 2016). During this

25 year period the increasing trend in rainfall intensity will be continuously be reviewed, supporting the revision of local regulation.

3.4.2. Identification of effective adaptation measures based on interrelationships

The other aspect that should be taken into consideration while selecting the component or subsystem for flexibility is the inter-relationships, i.e. the link between the adaptation measure with other measures or with stakeholders. These relationships may help in deciding where, how and when to implement the adaptation measures. The resilience plan for Melbourne proposes urban forestry as a flagship programme to promote resilience that also includes lowering flood risk and improving storm water quality (City of Melbourne, 2016). The foreshore mangrove and upstream detention that has been identified as a measure for Elwood can be implemented under this urban forestry initiative. Improving the flood resilience of Elwood College can also be implemented through the neighbourhood plan that aims at training and building the community (City of Melbourne, 2016). Similarly, the road elevation or street profile modifications are related to the drainage improvement as these measures are taken up in the same "right of way" of the streets and can benefit from each other.

Aligning adaptation measures together when there is an opportunity is also known as mainstreaming (Rijke et al., 2016). However, after identifying the effective adaptation measures, a thorough assessment of operational constraints, ownership or jurisdiction issues and similar issues that involve multiple utilities has to be undertaken before finalising the adaptation measures. This assessment process and finalisation of effective adaptation measures is known as offsetting, which is prevalent in the defence equipment manufacturing industry (Eckert et al., 2004). For example, the City of Port Phillip (CoPP) has the jurisdiction over the Moran reserve, a large area on the foreshore, whereas Melbourne Water is responsible for drainage of open spaces which have a surface area greater than 20 hectares. After converting the open space on the foreshore into a mangrove forest in collaboration with the Forestry department, it may subsequently be difficult for Melbourne Water and CoPP to intervene in the future or to make other changes, as the legal status of the open green land will have become a “nature reserve” . Similarly, 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 coordinating adaptation actions will be complicated and the water authority could resort to offsetting.

3.5. Create flexible design alternatives or pathways

After identifying the individual flexible adaptation measures, the overall flexibility of the flood risk management system can also be increased by means of sequencing the adaptation measures in such a way that they complement each other (Step 5, Figure 1). An adaptation pathways approach can be used to generate the flexible adaptation pathways (Haasnoot et al., 2012;Haasnoot and Van Deursen, 2015). An adaptation pathway approach builds flexibility into decision making processes by sequencing a set of adaptation measures based on a ‘tipping point’ to changing circumstances in a range of plausible future conditions (Haasnoot et al., 2012). The performance of the measures used or existing systems along the adaptation pathways and the tipping points – i.e., switching to another adaptation measure as there is a very high likelihood that adaptation objectives will be no longer met – were determined based on the expected annual damages. Out of the five flexible adaptation measures discussed in the previous section, three adaptation measures – (A) drainage improvements; (B) rainwater harvesting; and (C) flood proofing – have been considered to demonstrate the application of adaptation pathways.

Rainwater harvesting and flood proofing at a household scale were selected as potential adaptation measures to support and manage change propagation (Table 1). Conventional drainage retrofitting measures were also considered as the base case; i.e. storage tanks and enlarged stormwater drains (Melbourne Water, 2015). Kindly refer to Melbourne Water (2015) for specific details on drainage systems. The estimated annual damages for each of these measures and for the combination of the measures has been calculated based on the year from which these measures were to be implemented. The expected annual damage cost (EAD) of AUD 5,500,000 was considered as the tipping point, which is equivalent to 0.5% of the net revenue generated in the Elster Creek catchment annually (Table 4, AECOM (2012)). A small EAD, i.e., tipping point, was selected with the intention to simulate the frequent tipping in order to demonstrate the performance of pathways with multiple adaptations measures within the planning horizon. From Figure 4 it can be seen that the tipping point for the rainwater harvesting measure occurs at the year 2015 from a start date of 2010. However, when this measure is combined with flood proofing the tipping point is delayed and it does not occur until the year 2057.

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 2, whereas the pathways and tipping points are illustrated on Figure 4 (RCP 2.6) and Figure 5 (RCP 8.5).

Figure 4 Adaptation pathways, based on estimated annual damages (EAD), under Low climate scenario (RCP 2.6).Tipping point is reached when EAD increase to AUD 5.5million, i.e., 0.5 % of net annual revenue generated in Elster Creek. The think black ring represents the transfer point at which the next adaptation measure is implemented. For example in year 2044 flood proofing measure reaches the tipping point leading to implementation of rainwater harvesting (top) or drainage retrofitting (bottom). The black vertical line at the end of each pathway denotes the year (median value) at which the tipping point occurs. The range of tipping point is represented by the grey dimension lines shown above the pathways. Not all the pathways are shown here.

Figure 5 Adaptation pathways based on estimated annual damages (EAD), for extreme climate scenario (RCP 8.5). Tipping point is reached when EAD increases to AUD 5.5million, i.e., 0.5 % of net annual revenue generated in Elster Creek. The black vertical line at the end of each pathway denotes the year (median value) at which the tipping point occurs. The range of tipping point is represented by the grey dimension lines shown above the pathways. Not all the pathways are shown here.

From Table 2, Figure 4 and Figure 5 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 rainwater harvesting in households and drainage retrofitting occurs in the year 2015; whereas the tipping point of the flood proofing of households occurs between 2032 and 2044 dependent on the climate scenario. The rainwater harvesting measures and drainage retrofit are not as effective as the flood proofing measures in delaying the tipping point across the scenario. However, the combination of these measures with other measures such as flood proofing postpones the tipping point. For example, when rain water harvesting or drainage retrofitting measure is combined along the pathway with flood proofing the tipping point of this pathway is likely to occur between the years 2038 and 2055 (Figure 4 and Figure 5)

Hence, these combinations of measures are effective in delaying the tipping points at which service is no longer adequate. Adaptation pathways approach does not fix a pathway which has to be followed for four decades, rather it ascertains pathways with corresponding investments at certain point in future to postpone the tipping points. This will enable the decision makers to reassess the situation and prioritise investments at that time.

3.6. Determine cost and benefits

The identification of preferred pathways can be based on an assessment of the cost and benefits that accrue along the pathways or the risks anticipated (Step 6, Figure 1). The economic costs of individual adaptation measures were obtained from planning reports and from engineering consultancies (AECOM, 2012;Melbourne Water, 2015;Gunn and Rogers, 2015;GHD, 2014). The present costs of adaptation pathways discounted at 1.5% were obtained for the tipping point of the measures in the pathway (Table 2). The present value of the adaptation cost can also be calculated using a risk based approach (e.g. Kind (2014)), which can lead to a different set of adaptation measures, as the timing of implementation of adaptation measures are determined based on the reduction of overall risk during the entire planning horizon. Table 2 comprise the present value of accumulated total cost of flood damages and implementation cost of adaptation measures accumulated over 75 years. The uncertainty in the present value of the adaptation pathways for Elwood has been represented as a range, which comprises the present value of adaptation costs for the four climate change scenarios recommended by IPCC (IPCC, 2013) and CSIRO & BoM (CSIRO, 2015). The present value of the adaptation pathways and combinations was found to be sensitive to changing climate scenarios. Also, from the cost - benefit ratio of adaptation measures (Table 2), it can be seen that a combination of measures, especially rainwater harvesting and flood proofing, yields a better cost – benefit ratio across all the scenarios.

Table 2 Tipping points and present value of adaptation costs for selective adaptation pathways in Elwood based on IPCC scenarios

Adaptation Measures	**Tipping Point (median Year)**				**Present value of total cost of flood damages accumulated over 75 years (in Million AUD)**				**Expected Value across scenarios (in Million AUD)**	**Investment Cost of adaptation measures (in Million AUD)**	**Cost – benefit ratio , i.e Benefit / Cost (Range , i.e., From RCP 2.6 to RCP 8.5)**
	RCP 2.6	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**	**RCP 2.6**	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**			
No measure	*2015*	*2015*	*2015*	*2015*	*5,444*	*7,984*	*8,119*	*15,872*	*9,355*	-	-

A	2015	2015	2015	2015	2,042	2,506	2,538	4,103	2,797	996	3.4 to 11.8
B	2015	2015	2015	2015	1,413	1,944	1,980	3,742	2,270	196	20.6 to 61.9
C	2044	2038	2037	2032	655	986	992	2,242	1,219	180	26.6to 75.7
A & C	2055	2047	2047	2038	1,471	1,802	1,808	3,508	2,305	1176	3.4 to 10.5
C & A	2055	2047	2047	2038	1,456	1,686	1,694	2,586	1,856	1176	3.4 to 11.3
C & B	2057	2048	2048	2039	644	857	866	1707	1018	376	12.8 to 37.7
B & C	2057	2048	2048	2039	671	1,002	1,008	2,258	1,235	376	12.7 to 36.2

Adaptation Measures: A – Drainage retrofitting; B – Rainwater harvesting; C– Flood proofing households

The rainwater harvesting measure has a bigger cost - benefit ratio under RCP 2.6 as this measure is effective in reducing the flood damages only up to a certain increase in intensity of rainfall. When the increase in intensity of rainfall is higher, such as in scenarios RCP 4.5 to 8.5 there is no significant reduction in flood damages, consequently there is a low cost - benefit ratio in these scenarios. The other reason for the higher cost - benefit ratio, in general, for the rainwater harvesting measure is the low cost of rainwater harvesting compared with the flood proofing or drainage retrofitting measures. The rain water harvesting measure costs about 2300 AUD per household and the total cost of the measure is also offset by about 88 AUD due to the savings of about 40 m3 of water annually (Moglia et al., 2014). There are about 10,000 properties in Elster Creek. The total cost of implementing rainwater harvesting is about 21 million AUD, cost of implementing flood proofing is 180 million AUD, whereas the cost of drainage retrofitting is about 996 million AUD.

3.7. Final portfolio of adaptation measures

The adaptation pathways can be assessed based on the present value cost across all plausible scenarios in order to select a preferred pathway (Step 8, Figure 1). As the IPCC scenarios are all equally plausible, they were assumed to have equal probabilities when calculating the expected present cost of the possible pathways or combinations thereof. Based on the lowest expected present value of adaptation costs and the highest cost - benefit ratio among the three selected example pathways, the portfolio of flexible adaptation measures recommended for Elster Creek comprises rain water harvesting and flood proofing through the elevation of floor levels for households.

4. Discussion

Flexibility obtained through adaptation pathways is not due to the inherent flexible nature of the measure - such as structural or operational or functional flexibility of specific adaptation measure - , flexibility is realised by means of having a choice to implement or defer the adaptation measures (Radhakrishnan et al., 2016). Here, the flexibility is a consequence of 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 rainfall intensities.

WSCapp applied in the context of adapting to urban flooding in Elster Creek compliments the contemporary adaptation planning approaches. The significant outcome is that WSCapp has provided a structured approach to the identification of adaptation measures, such as rainwater harvesting and flood proofing in households based on the nature of the adaptation measures and the change propagated through these measures (Section 3.4.1). The WSCapp also identifies the potential conflicts between the adaptation measures that might arise during the implementation and identification of measures that can be offset, such as drainage improvements and street profile changes (Section 3.4.2). For example, the Melbourne water authority can invest in high capacity dewatering pumps that can be moved anywhere in the catchment where flooding is anticipated. The strategy to invest in moveable dewatering pumps can become a preferred option where the buy-in amongst the residents for a 'water sensitive city' way of living becomes less attractive and the City moves towards a utility based customer – service provider relationship between the residents and city council instead of the current position.

Although the WSCapp, based on the flexible platform design process, helps to select the flexible adaptation measures, the role of the various stakeholders involved in the many process steps needs to be included. Also, the planning of adaptation actions must be considered in relation to the powerful and often ubiquitous political- economic interests in urban areas (Chu et al., 2017). The varying degrees of involvement and influence may be anticipated by the many and various players in the context of WSCapp applied in the Melbourne WSC context. For example in Elster Creek, the involvement of the National and Regional planning agencies would predominate in identifying visions and determining the drivers (step 1 and step 2 of Figure 1), whereas the role of the Melbourne regional planning authority would be predominant in setting the attributes of the WSC (step 3 in Figure 1). The role of the local council - City of Port Phillip - and waterway manager - Melbourne water - would be to lead in identifying the critical WSC components, creating flexible designs, calculating the additional benefits and undertaking the uncertainty analysis (steps 4,5,6 in Figure 1). Each of these various agencies can play an equal role in deciding the final portfolio of options (step 8 in Figure 1) as the final selection of adaptation measures are based on the yearly investment budget across the various agencies for implementing adaptation measures. Hence in order to apply the WSCapp, effective stakeholder consultation, engagement and partnerships are necessary (e.g., agencies such as Municipal Association of Victoria can be engaged in the process of applying WSCapp in Elster Creek).

Also, the application of WSCapp and identification of flexible adaptation measures early in the planning processes can improve the agility of the system; i.e., by establishing a system that can respond with ease to uncertainty, threats and opportunities in a medium and long term (Pathirana et al., 2017). WSCapp assesses the compatibility and interrelationship between the adaptation measures to arrive at the final portfolio of measures over a range of uncertainties; possible threats and opportunities. This enables the decision maker to act quickly by selecting the adaptation measure(s) suitable for the situation from the pre-assessed set of adaptation measures. The agility of the system increases as WSCapp enables changing the individual adaptation measures without or minimal negative impact on the systems, which is based on the platform designs from automobile industry.

Although the change propagation can be quantified in terms of livability, resilience and productivity, this paper has focused more on the aspect of flood resilience in order to demonstrate the application of WSCapp in Elster Creek based on change propagation. This is a limitation of this paper and can be overcome with a comprehensive study which covers all the adaptation measures addressing the objectives of resilience, livability and productivity. Further, monitoring the performance of the implemented adaptive measures will inform how effective these measures are and, hence, promote future incorporation of the most effective measures and review on improving the less effective measures.

The next step would be to gather evidence during implementation– such as type of adaptation measures implemented, time of implementation of the measure, reasoning behind the selection – in order to strengthen the flexible adaptation planning process and increase the reliability of the approach further for the implementation of a resilience strategy. For example, evidence can be collected during the implementation of the City of Melbourne's overall resilience strategy or the State of Victoria`s infrastructure strategy to assess the limitations of the results presented here and address these before applying WSCapp approach more widely in Australia and elsewhere.

It can be summarised that if adaptation measures are comprehensively incorporated in Elster creek catchment using the WSCapp process the benefit to the this generation would be (i) maximised benefits from adaptation measures; (ii) efficient use of investments in form of flexible adaptation measures; (iii) reduced maladaptation potential; (iv) minimisation of implementation bottlenecks due to prior assessment of offsetting and mainstreaming. The future generation will benefit from the flexibility of making their own choice of choosing and implementing adaptation measures at that point in time, as their choices will not be bound or restricted by large scale infrastructure measures that were carried out in the past.

5. Conclusions

In the context of enhancing urban resilience, flexibility is seen as being open to opportunities arising from the number of alternative ways to provide services required when responding to changing circumstances. Cities such as Melbourne are already incorporating flexibility to enhance the overall resilience of the city (City of Melbourne, 2016). Decision makers see stories and case studies as more compelling rigorous studies (Sallis et al.). Hence flexible adaptation planning process formulated from synthesising the relevant literature and practice on flexibility incorporation and valuation has been demonstrated using the case study example of Elster Creek catchment of Melbourne. It has been demonstrated that it is possible to identify the potential candidates for embedding flexibility in a WSC context. If adaptation measures are comprehensively incorporated into the Elster Creek catchment using the WSCapp process the present and future benefit would be reduced flood damages, increased productivity, enhanced flood resilience and livability. In our view Melbourne water or City of Port Phillip has to commission a detailed study though a consultant to do an in depth assessment of a broad range of adaptation measures (including measures such as rain gardens) and combinations using WSCapp. WSCapp is fundamental for future work with urban planning and infrastructure consultants and can greatly benefit them at obtaining more flexible and sustainable flood management response.

6. Acknowledgement

This technical paper is an outcome of ongoing research funded by the Cooperative Research Centre for Water Sensitive Cities (CRC), an initiative of the Australian government. This paper is based on collaborative inputs from CRC projects A4.2, A4.3, B4.1, B4.2, MADA (Monash art, design and architecture faculty) and City of Port Phillip.

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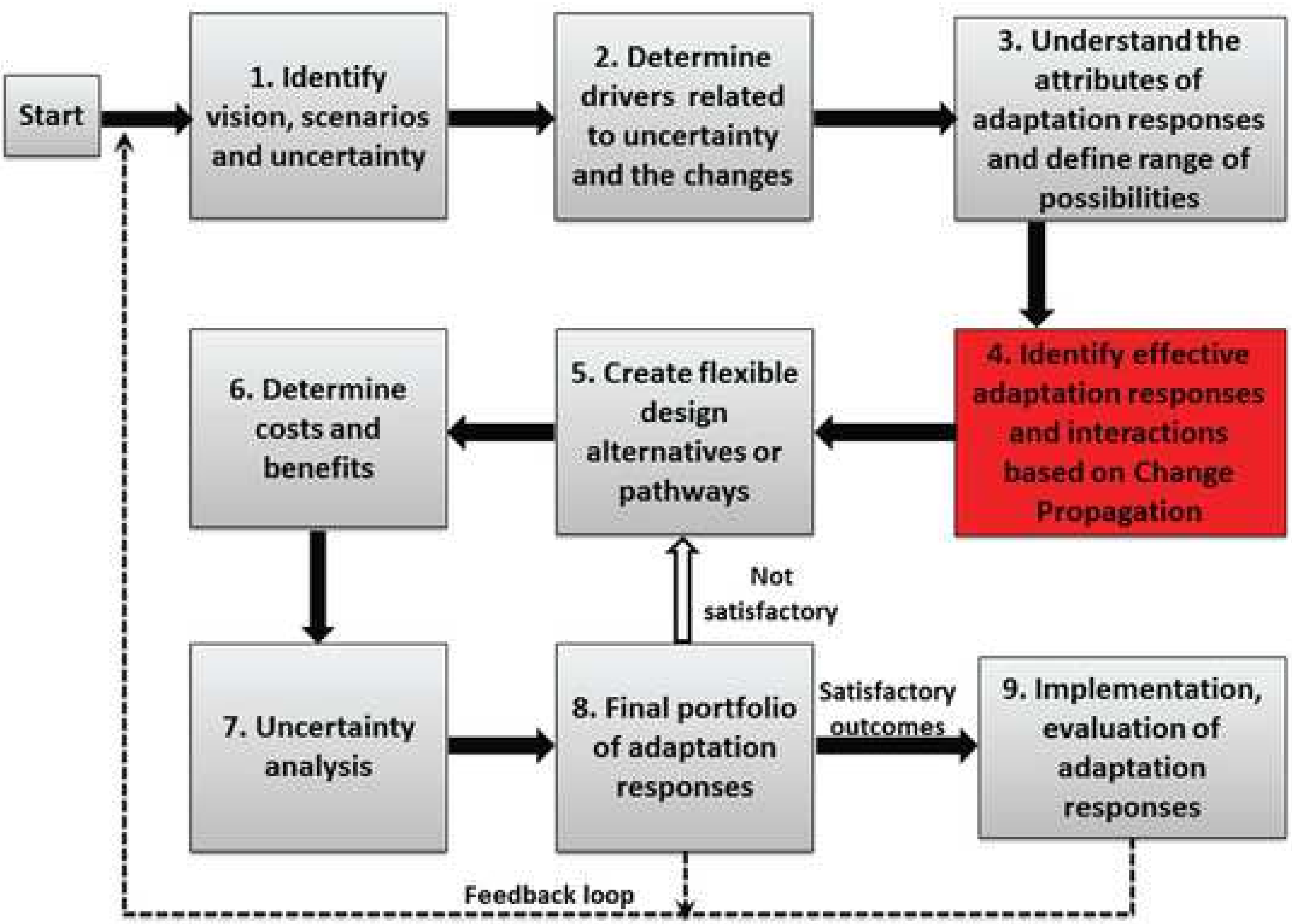
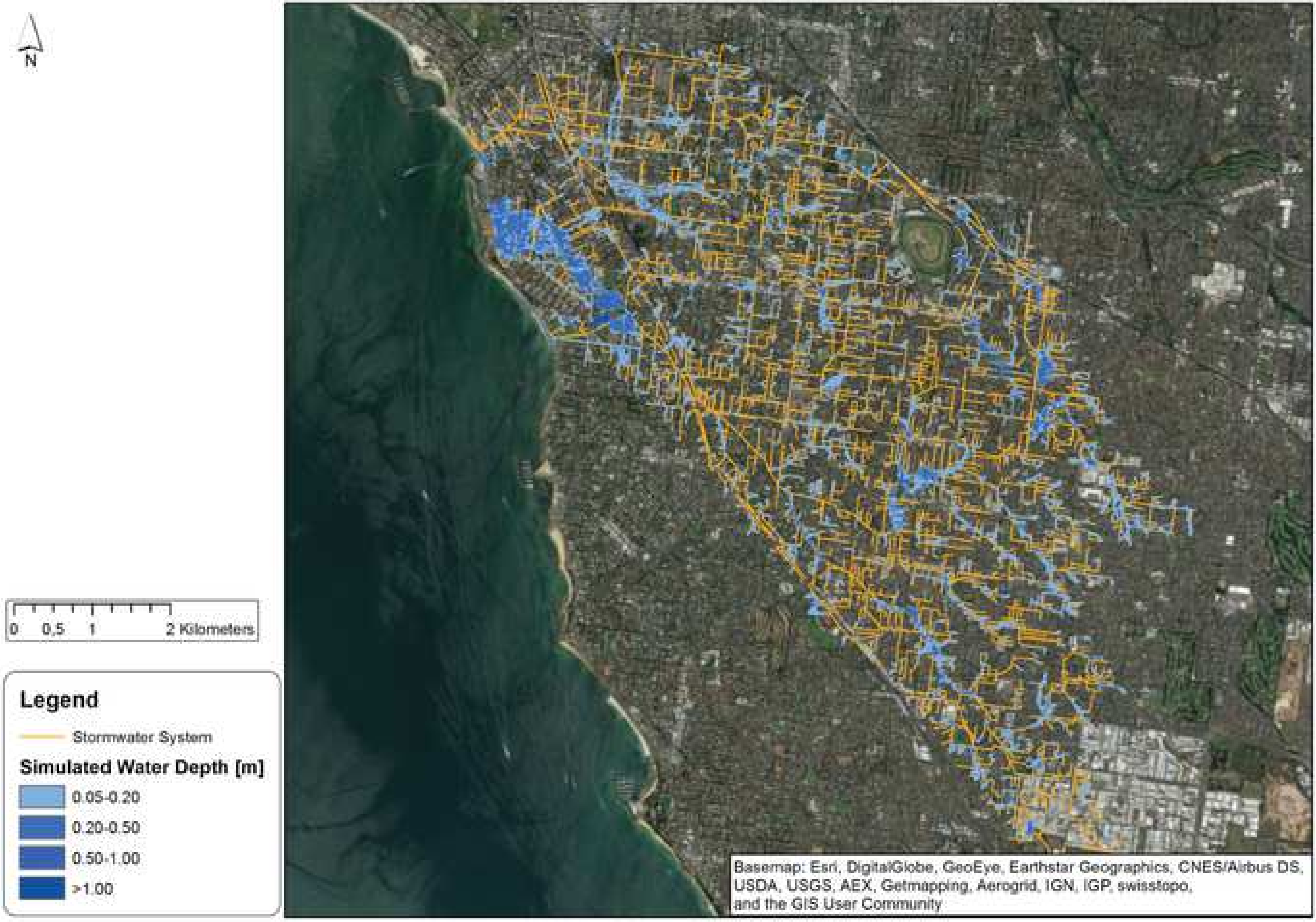
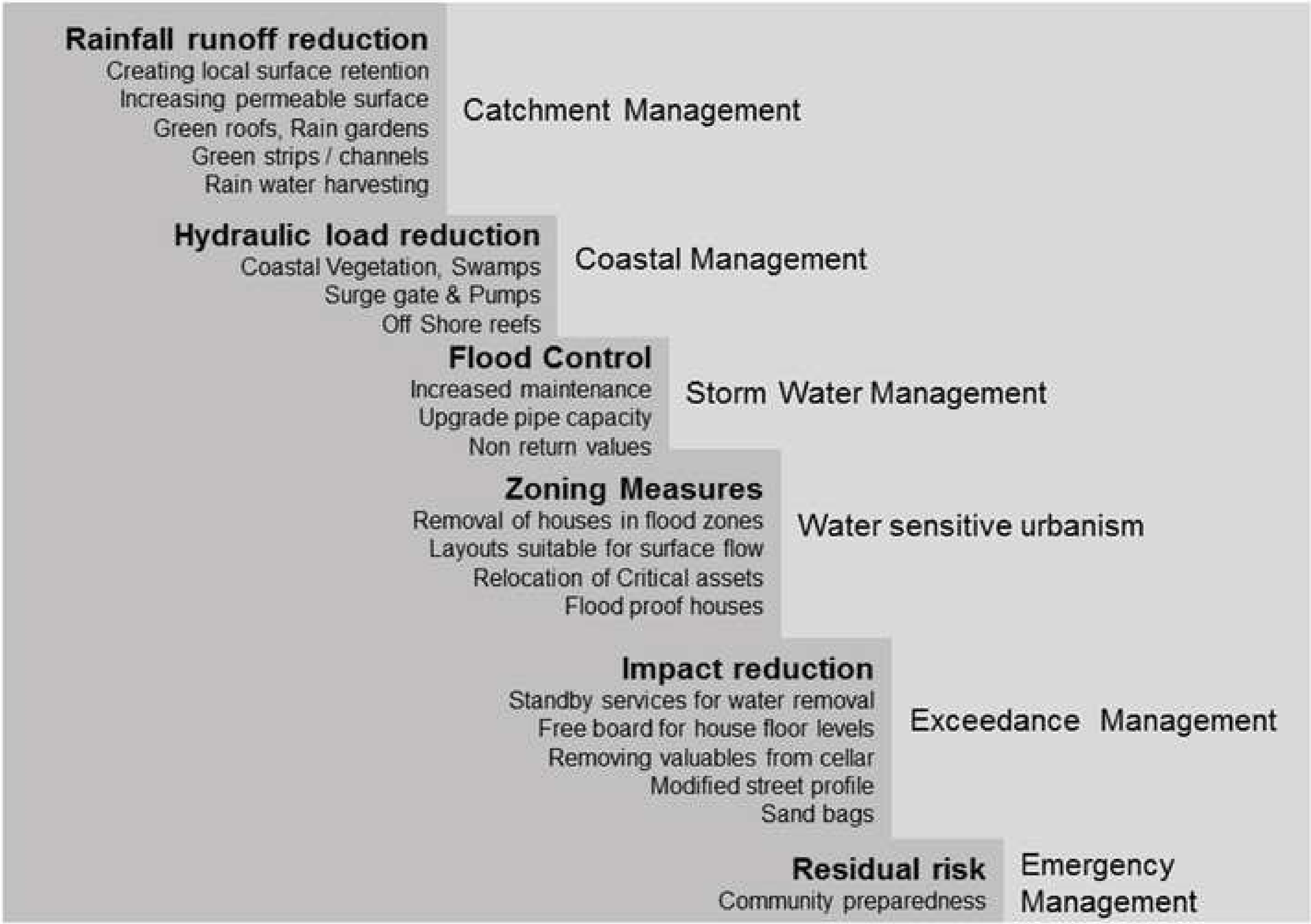
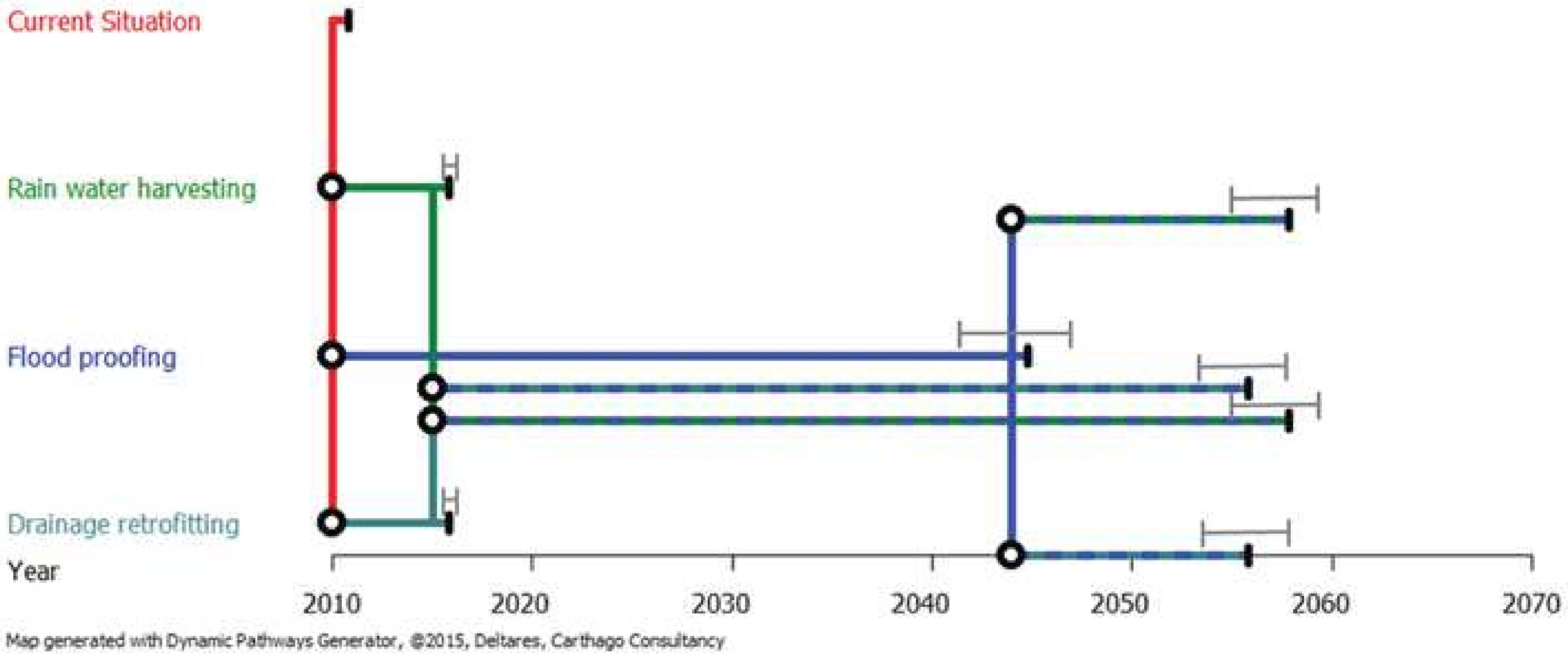

Start
1. Identify vision, scenarios and uncertainty
2. Determine drivers related to uncertainty and the changes
3. Understand the attributes of adaptation responses and define range of possibilities
4. Identify effective adaptation responses and interactions based on Change Propagation
5. Create flexible design alternatives or pathways
6. Determine costs and benefits
7. Uncertainty analysis
8. Final portfolio of adaptation responses
Not satisfactory
Satisfactory outcomes
9. Implementation, evaluation of adaptation responses
Feedback loop



Basemap: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Rainfall runoff reduction
Creating local surface retention
Increasing permeable surface
Green roofs, Rain gardens
Green strips / channels
Rain water harvesting
Catchment Management
Hydraulic load reduction
Coastal Vegetation, Swamps
Surge gate & Pumps
Off Shore reefs
Coastal Management
Flood Control
Increased maintenance
Upgrade pipe capacity
Non return values
Storm Water Management
Zoning Measures
Removal of houses in flood zones
Layouts suitable for surface flow
Relocation of Critical assets
Flood proof houses
Water sensitive urbanism
Impact reduction
Standby services for water removal
Free board for house floor levels
Removing valuables from cellar
Modified street profile
Sand bags
Exceedance Management
Residual risk
Community preparedness
Emergency
Management


Current Situation
Rain water harvesting
Flood proofing
Drainage retrofitting
Year
2010
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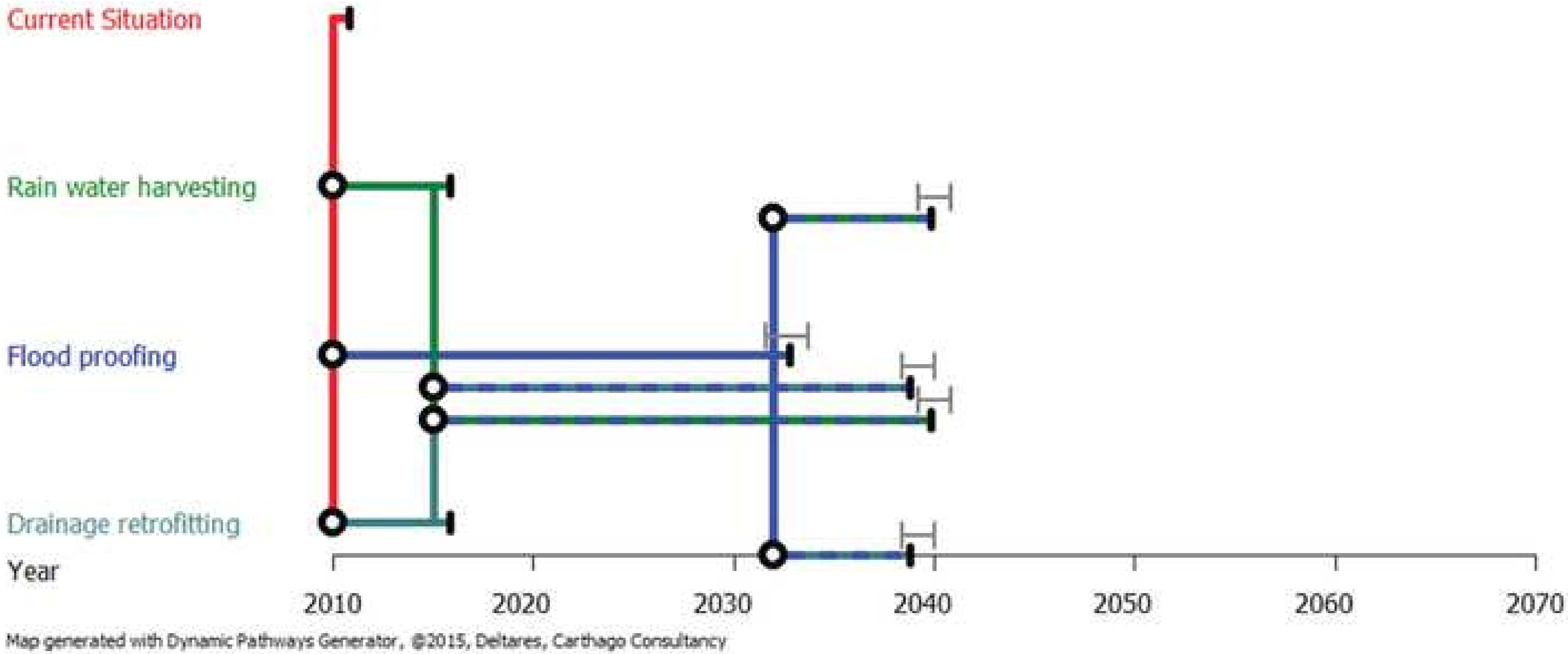
Map generated with Dynamic Pathways Generator, ©2015, Deltares, Carthago Consultancy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