AN INTERPRETATION OF 'WATER SENSITIVITY'AND 'RESILIENCE' BRINGING TOGETHER FLOOD AND DROUGHT RISK MANAGEMENT

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ABSTRACT: Water Sensitive Urban Design (WSUD) defines a new paradigm in total water cycle management that integrates both the engineering and ecological professions associated with protection of urban water resources and also the built environment professions. Synergistic integration between the extant knowledge on WSUD together with resilience concepts, can lead to the establishment of a new model for Water Sensitive Cities, which are also resilient to floods and droughts.

Sensitivity and resilience are concepts frequently defined independently from one another. Having a myriad of concepts for sensitivity and resilience, it is important to establish the provenance of these; what is their current status, and where are they heading to, in such a way that the ‘grey zones’ of vagueness are covered and the definitions made clear for both researchers and practitioners in the field of water cycle management. Moreover, it is necessary to show how to assess the sensitivity and resilience of urban areas as an outcome.

Bringing together both concepts can advance their application with respect to flood and drought risk management. The interaction between sensitivity and resilience can best be considered by identifying the system response curve and recovery threshold. Comparison of the response curve with the recovery threshold provides an indication of the boundary of resilience of the system. If the response curve exceeds the recovery threshold, the system is not likely to persist and no longer be robust, shifting to another regime.

This paper updates the 3 Points Approach (3PA) to assist in placing urban surface water within the land use, urban design and planning process so that maximum value can be obtained from the synergies between surface water and other urban systems. The updated interpretation of the approach considering four different domains, allows a better understanding of the continuous process in relation to resilience, sensitivity and the point at which a regime shift occurs.

Key Words: drought, flood risk, resilience, water sensitivity

1. INTRODUCTION

There is no common definition of Water Sensitive Urban Design (WSUD) amongst professionals and researchers, mainly due to its amplitude of application in different fields of endeavour. The Australian National Water Initiative defines WSUD as “the integration of urban planning with the management, protection and conservation of the urban water cycle that ensures that urban water management is sensitive to natural hydrological and ecological processes” (COAG, 2004).The concept is now being reinterpreted by international researchers to make it available for specific purposes in urban water management while adding some other facets that may have not been considered originally, especially with respect to its assessment.

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

As stated by Wong and Ashley (2006), WSUD comprises two important parts: “water sensitive” and “urban design”. A new paradigm is defined by the words Water Sensitive by the integration of various disciplines of engineering and environmental sciences associated with the provision of water services including the protection of aquatic environments in urban areas. Urban Design is a well-recognised and established branch of practice connected to planning and architectural design of urban environments that traditionally has been considered peripheral to much of the water field (Bacchin et al, 2014).

WSUD looks for the incorporation of integrated water cycle management in which community values and aspirations of urban places govern urban design decisions and therefore water management practices (Wong et al., 2013). Within the definition of the Water Sensitive City, resilience of the systems has been incorporated and highlighted as key components for decision making (Wong et al., 2013).

For the purpose of this paper, resilience is considered as the magnitude of external pressure that a system can tolerate before moving to a different regime. Resilience and sensitivity interact in such a way that the response curve is defined and recovery threshold is identified. Comparison of the response curve with the recovery threshold provides an indication of the boundary of resilience of the system. If the response curve exceeds the recovery threshold, the system is not likely to persist and no longer be robust, shifting to another regime.

There is an opportunity for synergistic integration between the extant knowledge on WSUD together with resilience, can lead to the establishment of a new model for Water Sensitive Cities which are simultaneously resilient to floods and droughts. In this sense, the work by Brown et al. (2007) highlights how the hydrosocial contract for a Water Sensitive City under the WSUD concept would integrate the normative values of environmental repair and protection, supply security, flood control, public health, amenity, liveability and economic sustainability, amongst others (Brown et al., 2009). Moreover, the importance of the Water Sensitive City is highlighted as a conceptual representation for urban water systems, building on sustainable urban water planning and management practices and prioritizing liveability, sustainability and resilience in the design of its institutions and infrastructure (Ferguson et al., 2013).

There is still the need to incorporate the various and often disparate concepts that at the moment are considered in isolation with respect to one another in relation to water sensitivity. To address this, a novel conceptualisation and assessment method for urban water management is presented here.

2. THE 4 DOMAINS APPROACH (4DA)

As flood resilience is a primary component of WSUD, opportunities and threats from managing a range of rainfall or river discharges right up to extreme events need to be considered as illustrated in Figure 1. This figure is an adaptation from the originally proposed 3PA diagram by Fratini et al. (2012) to assist in placing urban surface water within the land use, urban design and planning process so that maximum value can be obtained from the synergies between surface water and other urban systems. The interpretation of the diagram considering four different domains, allows a better understanding of the continuous process in relation to resilience, sensitivity and the point at which a regime shift occurs.

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

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

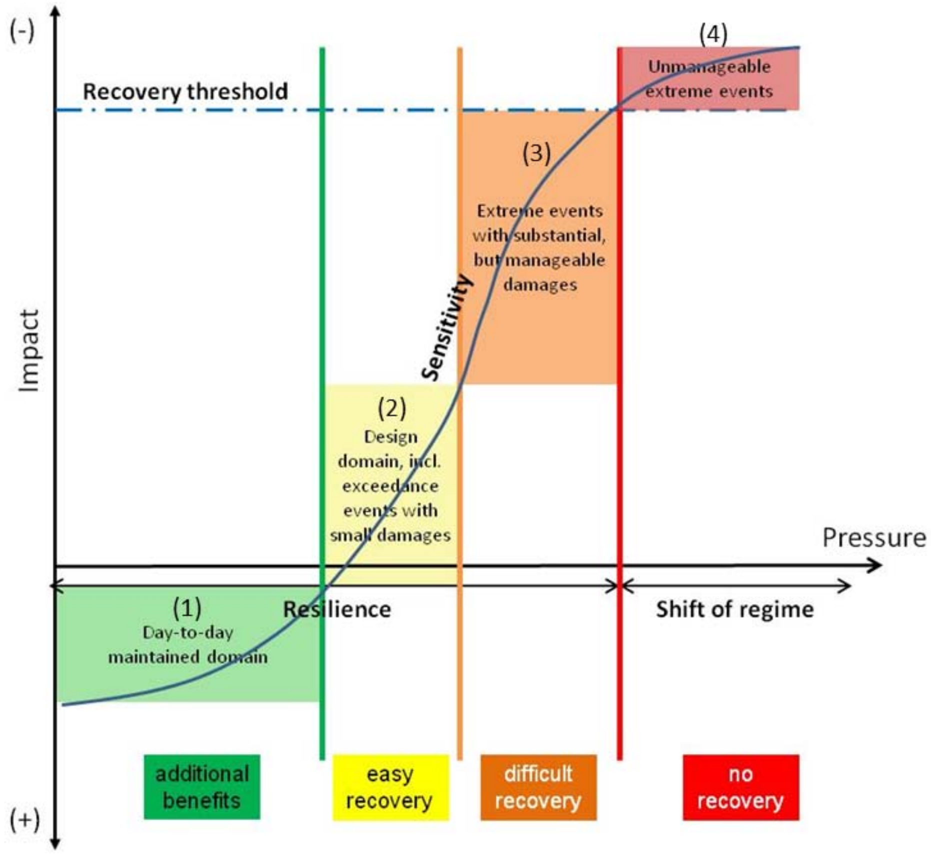

Figure 1: The '4 Domains' approach (4DA) (adapted from Fratini et al. 2012; Mens et al, 2011)

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

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

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

Figure 1 can be used to help understand how water in urban areas can be seen to be both a resource/opportunity and a problem/threat. The steeper the curve, the more likely the system is to fail suddenly. Each area is important in the way in which urban areas are laid out and managed to utilise their potential benefits and manage any adverse impacts; although only the first type of event is shown as providing positive benefits. However, the origin of the Y-axis is deliberately ambiguous, as other types of event can also provide positive benefits if managed appropriately.

The figure helps to turn the ‘problem’ of adapting to water stress and changing flood risks into a positive opportunity for the development and enhancement of urban areas through utilising the interactions and synergies between the surface water management system and society. The domains in Figure 1 were defined in terms of their functionality in urban areas (adapted from (Fratini et al., 2012):

Domain 1 - Day to day values: enhancing the value provided by options, awareness, acceptance and participation amongst stakeholders. Attention is given to the way urban space is used and perceived (Figure 2).

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

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

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

Figure 2: Example of multiple use of space - water plaza in Rotterdam

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

Traditional approaches do not consider the water resource opportunities available for the four types of events illustrated in Figure 1. Rainfall is considered part of the urban hydrological cycle that ‘discharges’ to one of the following destinations: “the ground, a surface water body, a surface water sewer or a highway drain, or to a combined sewer” (Defra, 2011).

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

3. APPLICATION FOR FLOOD RISK IN DORDRECHT

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

A combined strategy for flood risk management has developed been that addresses the three layers of multi-layer safety, as outlined in the National Water Plan (Ven W, 2009):

☐ Layer 1: Protection from floods through dikes;

☐ Layer 2: Limiting the consequences of floods through spatial planning;

☐ Layer 3: Limiting the consequences of floods through emergency management.

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

The sensitivity and thresholds of no / difficult recovery have been estimated for the combined (i.e. multi-layered safety) strategy and a reference strategy (Figure 4), using a hydrological/ hydraulic model (SOBEK) and damage model (HIS-SSM). The reference strategy comprises protection by dikes and barriers (layer 1), together with a continuation of the existing safety standard (no differentiation in protection levels). Figure 4 provides insight into the effectiveness of the two alternative strategies for different return periods (or: exceedance frequencies), and into the likelihood of persistence. It can be concluded from Figure 4 that the combined strategy decreases the sensitivity of the area to extreme flood events, and therefore increases its persistence.

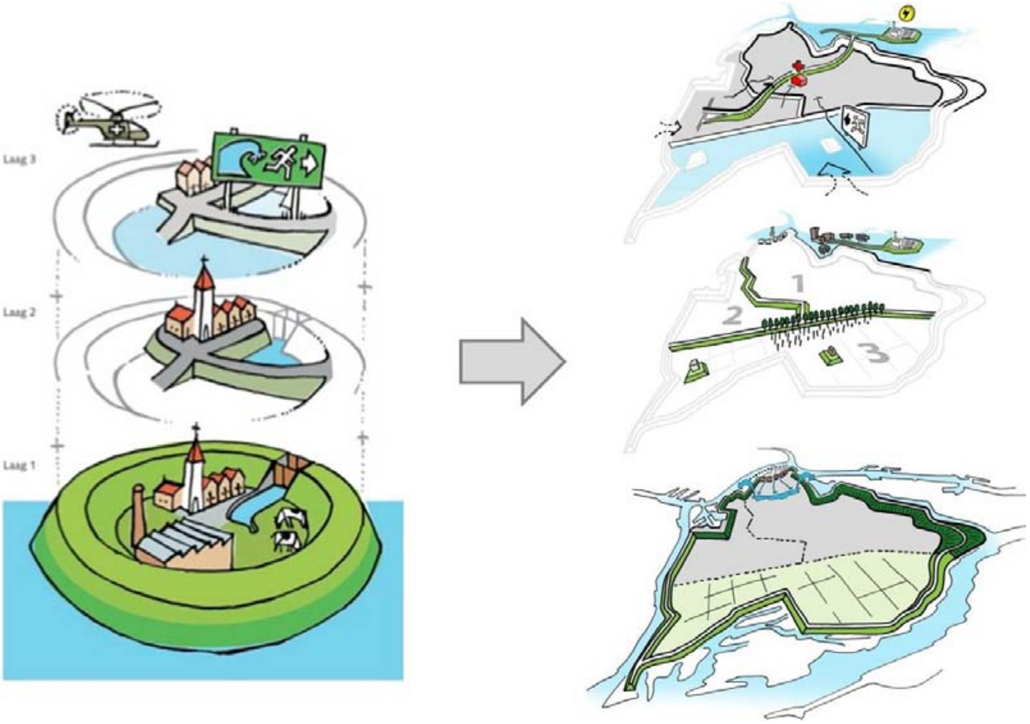

Figure 3: Multi-layered safety for the Island of Dordrecht

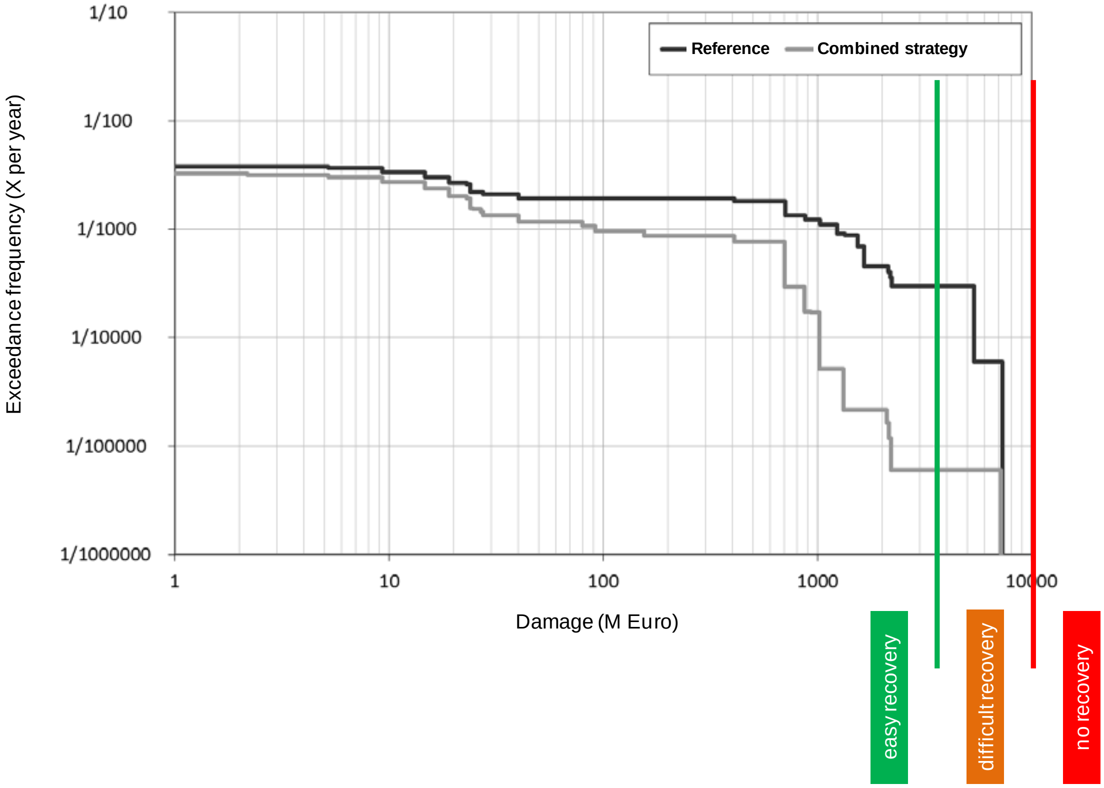

Figure 4: The 4 Domains Approach (4DA) applied for Dordrecht (Domain 1 has been omitted)

4. CONCLUSION

This paper has provided insight into the mutual relation of sensitivity and resilience. This improved understanding provides a way forward for bringing together flood and drought risk management. For this purpose, the 3 Points Approach of Fratini et al. (2012) has been updated to include four different domains: (1) day-to-day rainfall or river discharge events which are typically beneficial; (2) the 'design' events that the infrastructure and overland flow 'exceedance' pathways and measures are designed to handle; (3) extreme events that will cause substantial, but manageable damages; (4) extreme events where the resilience is compromised and the system cannot recover.

The 4 Domains Approach can be used to identify when, where, and how best to adapt and retrofit urban areas to simultaneously provide enhanced sensitivity and resilience to floods and drought. Tools to do this are now starting to emerge, dealing amongst others, with costs linked with social benefits and alignment with normal regeneration or development processes so that they are more economic and incorporate a wide range of WSUD including GI to provide multiple benefits.

There are still many paths to explore and for the proposed approach to become relevant, some empirical data, evidence, and new tools are necessary in order to prove its applicability in most urbanized cities, not only those in the Netherlands or Australia.

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6. REFERENCES

Bacchin T., Ashley R M., et al (2014). Green-blue multifunctional infrastructure: an urban landscape system design paradigm. 12th International Conf. on Urban Drainage. Malaysia. Sept.

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N., 2001: "From Metaphor to Measurement: Resilience of What to What?". *Ecosystems, 4:*8, 765-781

COAG, 2004: *Intergovernmental agreement on a national water initiative*. Sydney, Australia.

Digman C J., Ashley R M., Hargreaves P., Gill E. (2014). Managing urban flooding from heavy rainfall - Encouraging the uptake of designing for exceedance. CIRIA report C738a. Construction Industary Research and Information Association, London.

Fratini, C. F., Geldof, G. D., Kluck, J., & Mikkelsen, P. S., 2012: "Three Points Approach (3PA) for urban flood risk management: A tool to support climate change adaptation through transdisciplinarity and multifunctionality". *Urban Water Journal, 9:*5, 317-331

Luers, A. L., 2005: "The surface of vulnerability: an analytical framework for examining environmental change". *Global Environmental Change, 15:*3, 214-223

Wong, T., Allen, R., Brown, R. R., Deletic, A., Gangadharan, L., Gernjak, W., . . . Walsh, C. (2013). blueprint2013 - Stormwater Management in a Water Sensitive City. Melbourne, Australia: Cooperative Research Centre for Water Sensitive Cities.

Wong, T., & Brown, R., 2009: "The water sensitive city: principles for practice".