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Development and valuation of adaptation pathways for storm water management infrastructure

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ABSTRACT

Policymakers today are faced with a difficult task of planning for large scale infrastructure that can cater to the climatic and socio-economic changes that the future will bring. To address the deeply uncertain nature resulting from long-term changes, it is becoming necessary to develop strategies that support flexibility and react more strategically than traditional planning approaches. This paper applies the concept of adaptation tipping points and adaptation pathways to a case study in Singapore for the planning of long-term urban drainage infrastructure. Using conventional grey and sustainable green solutions in isolation and in combination, adaptation pathway maps are developed and compared across outlined climatic and landuse scenarios. To understand and justify if the imparted flexibility is worth its cost, economic assessments are performed. This is a valuable extension of the existing framework, helps to identify the preferred configuration of land use and sub-select adaptation actions that should be implemented at the current time frame. The main finding of this study is that the adaptation pathways map for the sustainable grey landuse scenario economically outperforms those of the other outlined land uses. This provides a valuable insight for policy makers, as it implies that if carefully planned development is undertaken, the requirements of storm water management can be met in a sustainable manner, while simultaneously freeing up land for other purposes. This is especially important in the context of highly dense urban areas such as Singapore, where land is a scare resource.

1. Introduction

Policies that cannot perform effectively under dynamic and uncertain conditions run the risk of not achieving their intended purpose, and becoming a hindrance to the ability of individuals, communities and businesses to cope with and adapt to change. Experience demonstrates that policies crafted to operate within a certain range of conditions are often faced with unexpected challenges outside of that range. The result is that many policies have unintended impacts and do not accomplish their goals (Swanson and Bhadwal, 2009).

Traditional water resources planning and analysis methods are based on requirements that are unrealistically deterministic (Medellín-Azuara et al., 2007). The current practice consists of three phases. First, the 'best estimates' of the future are outlined based on central estimates of climate change and extrapolations of current socio-economic scenarios (Middelkoop· et al., 2012). Then, system designers develop design concepts and select parameters that enable the system to perform optimally under the predictions. Economic evaluation of the design is then conducted, for which standard methodologies, like discounted cash flow (DCF) analysis, optimization, and scenario planning, are applied to achieve the best optimal design (DE Neufville and Scholtes, 2011). Essentially, this approach can be summarized as "predict then build". The main problem with this approach is the reliance on estimated climate scenarios. Whilst climate science can potentially reduce uncertainty due to model errors and, to some extent from internal variability, this uncertainty reduction will be a gradual and lengthy process. Nevertheless there will always be some irreducible uncertainty related to future emissions (Gersonius et al., 2012). As the performance of storm water management infrastructure is directly impacted by climatic parameters considered during the design phase, the lack of ability to predict the future with precision is the biggest challenge in outlining the long term plans using traditional approaches.

To address the deeply uncertain nature resulting from long-term changes and the complexity of interventions among involved system, it is becoming necessary to develop strategies that respond more flexibly and strategically than traditional planning strategies, i.e. develop strategies that can be changed over time in response to how the climatic and anthropogenic future unfolds. This requires a fundamental change in the way we plan infrastructure for the future: instead of dealing with the complexity of what is most likely to happen, the question that we

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need to ask is that, given that we cannot perfectly predict the climate, what actions can we take today to best prepare for the future? This argues for taking small-step interventions along shorter time lines in order to avoid future lock-ins, reduce potential regrets or to seize the advantage of possible adaptation opportunities (Gersonius et al., 2012; Dessai and Hulme, 2007; Haasnoot et al., 2013).

In the context of climate adaptation policy making, relevant approaches include Robust Decision Making (Lempert et al., 2003), Adaptive Policy Making (Walker et al., 2013, 2001), Adaptation Pathways (Middelkoop· et al., 2012; Haasnoot et al., 2011), Dynamic Adaptation Policy Pathways (Haasnoot et al., 2013; Kwakkel et al., 2014) and Real Options analysis (Gersonius et al., 2012; Zhang and Babovic, 2012; Hu and Cardin, 2015; Deng et al., 2013; Swart et al., 2004). In addition, there are other methodologies, tools and techniques to deal with uncertainties in general. A few examples are: scenario planning (Swart et al., 2004), assumption based planning (Dewar, 2002), Monte Carlo Analysis (Zhang and Babovic, 2012) and Multi-layer decision analysis (Harvey et al., 2012). In addition to these, other approaches developed in this regard are extensively reviewed by Jones and Preston (Jones and Preston, 2011), Dessai and Van Der Sluijs (Dessai and Van Der Sluijs, 2007) and Walker, Haasnoot and Kwakkel (Walker et al., 2013). These methodologies and tools have different strengths and limitations (Hall et al., 2012). In order to develop robust climate adaptation strategies, correct framing of uncertainty and selection of appropriate approaches is of great importance. Currently there is no one agreed procedure for the development of an adaptive strategy to climate change.

This study contributes to the body of research work by building on the idea of designing dynamic adaptive pathways in the face of deep uncertainties. This planning paradigm, in one form or the other has been receiving increasing attention in various domains; however, there are only a handful of studies that incorporate the adaptive pathway approach to answer problems that arise in the field of water management (Swanson and Bhadwal, 2009; Middelkoop· et al., 2012; Haasnoot et al., 2013; Ranger et al., 2013; Barnett et al., 2014; Van Veelen et al., 2015; Kwadijk et al., 2010; Gersonius et al., 2014; Rosenzweig et al., 2011; Yohe and Leichenko, 2010; Lowe et al., 2009; Sayers, 2012; Wilby and Keenan, 2012; Manning et al., 2015; Jeuken and Reeder, 2011). Among these, the studies that use the adaptation pathway approach to address storm water management are even fewer (Gersonius et al., 2014; Ranger et al., 2013; Haasnoot et al., 2013).

Experience says that implementation of adaptive strategies at city or neighbourhood level is generally constrained by a lack of insight into the costs and benefits of adaptation (Intergovernmental Panel On Climate Change. Working Group, 2007). Albeit the Adaptation Tipping Point and Adaptation Pathways approaches provide the flexibility to adjust to uncertainties as they unfold they do not shed light on whether the flexibilities are worth their costs. We apply the concept of adaptation tipping points and adaptive pathways to a case study in Singapore and undertake a cost benefit analysis to serve as a worthwhile extension (Haasnoot et al., 2013) of this approach. The objectives of performing this assessment are threefold: the first is to develop adaptation pathways under all climatic and land use scenarios. The second is to compare the economic performance of the developed pathways under all scenarios and the third is to aid policymakers in developing long term adaptive plans by identifying the preferred configuration of land use and adaptation actions.

The rest of this paper elaborates on the methodology used to develop the adaptation tipping points, adaptive pathways and perform the cost benefit assessment. Results are discussed and conclusions are drawn wherein we analyse the benefits of this approach from the engineering, urban planning and policy making perspective.

2. Methodology: development of the adaptation pathways maps

The methodology for the building Adaptation Pathways (Haasnoot et al., 2013) has been modified and refined to develop long term adaptable plans for the design of urban drainage and flood prevention infrastructure for the Kent Ridge catchment, Singapore. It is shown in Fig. 1.

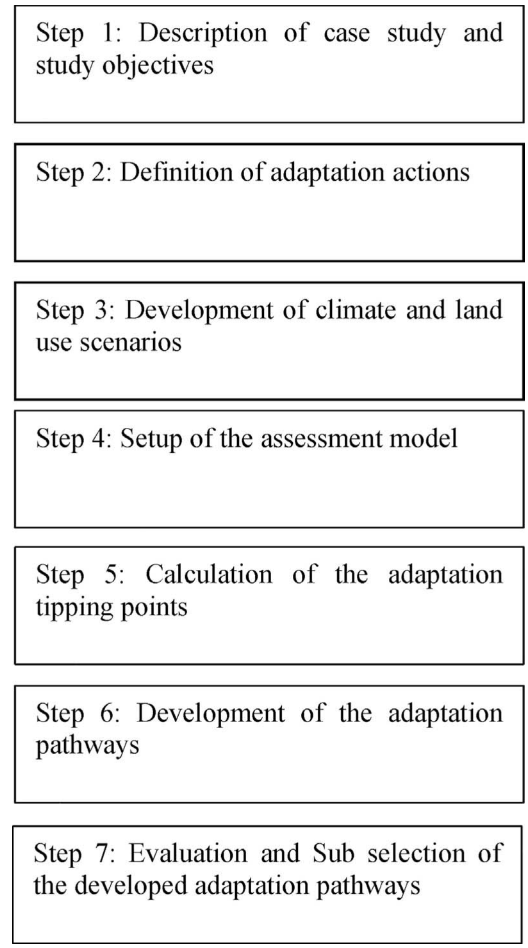

Fig. 1. Methodology.

The first step of this assessment is describing the case study and outlining the current situation in order to better understand the objectives. In the second step we identify and develop a portfolio of adaptive actions that can be implemented to ensure no flooding over the planning horizon. The next step is the development of scenarios, over which the adaptive actions will be assessed. The scenarios can encompass a large range of parameters, depending on the requirements of the study. For this assessment, combinations of climatic and land-use scenarios have been developed. The fourth step is to setup an assessment model. Thereafter, the tipping points of the adaptation actions in isolation and combination are calculated. The adaptation measures are then assembled in sequences to form the adaptation pathways maps. In the final step, an economic assessment is carried out to sub-select the preferred set of pathways.

2.1. Introduction to the case study

Singapore's Second National Climate Change Study determines that annual rainfall totals show a statistically significant upward trend over the last 30 years (CCRS, 2015) Singapore has become hotter and more prone to heavier storms (PUB, 2016). The Expert Panel for Drainage Design and Flood Protection Measures concluded that "a wider range of interventions is required to help Singapore secure a more adequate drainage system for the future. By implementing a range of appropriate measures that cover every spectrum of the drainage system from its