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ADDRESSING UNCERTAINTY: THE ECONOMICS OF LAND USE PLANNING

NISHTHA MANOCHA[1] and VLADAN BABOVIC[2]

[1]*Department of Civil and Environmental Engineering, National University of Singapore, Singapore 117576.*
E-mail: nishtha.m@u.nus.edu

[2] *Department of Civil and Environmental Engineering, National University of Singapore, Singapore 117576.*
E-mail: vladan@nus.edu.sg

Urban Resilience is the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience. This study looks at the role that infrastructure development and planning can play in ensuring that cities are resilient and adaptable to the uncertain climatic, demographic and socio-economic futures that will unfold. The concept of adaptation tipping points and adaptation pathways is applied to a case study in Singapore for the planning of long-term urban drainage infrastructure. Scenarios developed in this study cover a range of climatic and land-use futures. To study the impact of land use changes 3 scenarios, namely: Current, Green and Sustainable Grey were developed. To understand and justify if the flexibility imparted was worth its cost, economic assessments were performed. This is a valuable extension of the existing framework as it helped to identify the preferred configuration of land use and phase adaptation actions. This understanding is beneficial to decision makers, as it helps in establishing an approximate time scale for adaptation giving time to outline and implement relevant policies.

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1. Introduction

Climate adaptation decisions have to be made under a blanket of deep uncertainty. Given the inability to accurately predict the climatic and socio economic future, there is a need to use better, adaptive and flexible approaches to design strategies that are able to cater to multiple futures. Among various approaches developed, the adaptation tipping point (Kwadijk, Haasnoot et al. 2010, Reeder and Ranger 2011, Middelkoop·, Beek· et al. 2012) and adaptation pathway (Haasnoot, Middelkoop et al. 2011, Middelkoop·, Beek· et al. 2012) approaches are now gaining popularity. The case study presented in this paper illustrates the development and economic assessment of adaptation pathway maps for storm-water management of a tropical urban catchment. To reflect the various perspectives that policymakers may have, conventional grey and sustainable green solutions are used in isolation and combinations to develop the candidate pathways. Further, the performance of these solutions are assessed over three different land-use perspectives to understand the impact that land use planning can have for storm-water management in a densely populated area.

2. Methodology

The first step in this study was the development of adaptation pathway maps. The methodology presented in a previous study (Haasnoot, Kwakkel et al. 2013) is modified and applies here. The steps involved are as follows:

Step 1: Introduction to the case study: Description of current and future situation
Step 2: Model Development: Undertaking a flooding assessment.
Step 3: Defining adaptive actions
Step 4: Development of Scenarios
Step 5: Calculation of sell by dates and development of pathways

Following the development of adaptation pathway maps, economic assessment was carried out to study the economics of a changing landuse.

2.1. *Introduction to the case study*

The Kent Ridge Catchment is a tropical urban catchment (85000 square meters) located in the south of Singapore, within the campus of the National University of Singapore. This catchment contains all the main land use types of Singapore and hence can be considered as reasonably representative from a hydrological point of view. The objective of this study is to develop long term adaptive plans that ensure that there is no flooding in the Kent Ridge Catchment over the planning horizon of now until the year 2100.

2.2. *Model Development*

The purpose of the model developed is to assess the adaptation tipping point, in terms of a maximum rainfall that a given configuration of the adaptation actions can withstand. A mass balance based model was developed to undertake a flooding assessment of the Kent Ridge Catchment. It was based on a model previous developed for the Kent Ridge Catchment (Deng, Cardin et al. 2013).

2.3. *Defining Adaptive Actions*

The following configurations shown in Table 1 were used as the adaptive actions. The configurations below draw inspiration from the broad national objectives set for future developments. They include both grey and green solutions. The notations used in this table are used to address the given configurations throughout the paper.

Table 1 : Adaptation Actions

Configuration	Notation	Description
Current Drainage Configuration	A	The current configuration is maintained
Drainage Increase C1	B	15% increase from baseline drainage capacity
Drainage Increase C2	C	20% increase from baseline drainage capacity
Drainage Increase C3	D	30% increase from baseline drainage capacity
Drainage Increase C4	E	50% increase from baseline drainage capacity
Porous Pavements C1	F	50% of all available pavements covered
Porous Pavements C2	G	60% of all available pavements covered
Porous Pavements C3	H	80% of all available pavements covered
Green Roofs C1	I	20% of all available roof space covered
Green Roofs C2	J	35% of all available roof space covered
Green Roofs C3	K	50% of all available roof space covered

Combination 1	L	Green Roofs C1 and Porous Pavements C1
Combination 2	M	Green Roofs C2 and Porous Pavements C1
Combination 3	N	Green Roofs C3 and Porous Pavements C1
Combination 4	O	Green Roofs C1 and Porous Pavements C2
Combination 5	P	Green Roofs C2 and Porous Pavements C2
Combination 6	Q	Green Roofs C3 and Porous Pavements C2
Combination 7	R	Green Roofs C1 and Porous Pavements C3
Combination 8	S	Green Roofs C2 and Porous Pavements C3
Combination 9	T	Green Roofs C3 and Porous Pavements C3

2.4. *Development* of Scenarios

In order to study the impact of both climate and anthropogenic sources on long term flooding, both climatic and landuse scenarios are developed for this study. The well accepted International Panel on Climate Change (IPCC) scenarios were used as a guiding basis to outline the used climate scenarios.

Table 2 : Climate Scenarios

Baseline	Extrapolation of historical trend
W1 (Wet 1)	10% wetter climate (2016-2100), compared to baseline
W2 (Wet 2)	25% wetter climate (2016-2100), compared to baseline
D1 (Dry 1)	10% dryer climate (2016-2100), compared to baseline

Human intervention is modelled based on changing the land use of the existing catchment. In order to study the impact that changing land use can have on the runoff from the catchments, 3 scenarios, namely: Business as Usual (BAU), Green and Sustainable Grey have been developed. The Business as Usual (BAU) scenario is representative of the current practices of land use. In the green scenario, a sustainable approach is followed which encompasses an increase in green areas including the change in vegetation to one that is more effective for storm water management. The buildings (described in terms of roof area) is kept constant suggesting that taller buildings and better practices will replace existing ones to cater to the population growth.

It is intuitive that economic development coupled with a growing urban population warrants creation of addition housing, industrial and commercial spaces. However creation of such grey infrastructure can have an adverse impact on storm water management. This study aims to address this particular dilemma by introducing a "sustainable grey" land use. The sustainable grey landuse allows for construction of buildings on account of green spaces but mandates retrofitting the developments in a predefined proportion with storm water management solutions such as green roofs and/or porous pavements.

The following table gives an overview of the 3 land-use scenarios:

Table 3: Landuse Scenarios

	BAU	Green	Grey
Land use type	%	%	%
Impervious	10	5	15
Grass on steep slope	10	10	10
Grass on mild slope	18	13	18
Mixed grass and trees	15	15	10
Natural Vegetation	30	40	12
Roofs	17	17	35

2.5. *Calculation of sell by dates and development of pathways*

The sell by date or the tipping point, is similar to a threshold amount of rainfall beyond which, the particular configuration ceases to perform as expected and causes flooding. These were calculated by means of the assessment model developed. Using the sell by dates, adaptation pathway maps were drawn. The pathways developed are available in a previous study (Manocha and Babovic 2017).

2.6. *Economic Assessment*

To understand and justify if the flexibility imparted by means of an adaptive approach was worth its cost, economic assessments were performed. This is a valuable extension of the existing framework as it helped to identify the preferred configuration of land use and sub-select adaptation actions that should be implemented at the current time frame and the ones that can be implemented at a later time step. This understanding is beneficial to decision makers, as it helps in establishing an approximate time scale for adaptation giving time to outline and implement relevant policies.

3 Results and Discussions

When comparing the adaptation pathways across the three landuse scenarios, the preferred pathways are different. This suggests that changing the landuse within the catchment impacts the storm water management strategies and subsequently the cost of adaptation. To understand if changes in landuse can significantly affect the economic performance of the various adaptation actions developed, the Wilcoxon rank-sum test was carried out. The Net Present Value of all the pathways developed was used to carry out this analysis.

The hypotheses used for the test are as follows:

$$H_0 = \mu_1 = \mu_2$$
$$H_1 = \mu_1 < \mu_2$$

Interpreting the results from Table 4, it is interesting to note that the sustainable grey landuse economically outperforms the Current and the Green landuse in 3 of the 4 climatic scenarios. The results thus are particularly intriguing for land scarce nations such as Singapore as it means that carefully planned development can alleviate the stress on land resources while meeting storm water management requirements.

Table 4: Significance testing of Net Present Value across different climate and land use scenarios

Climate Scenario	Landuse (parameter 1)	Landuse (parameter 2)	p Value	Better landuse
Baseline	Green	Sustainable Grey	0.01250	Sustainable Grey
Baseline	Current	Sustainable Grey	0.00000	Sustainable Grey
Baseline	Current	Green	0.37474	Equal
W1	Green	Sustainable Grey	0.00016	Sustainable Grey
W1	Current	Sustainable Grey	0.00001	Sustainable Grey
W1	Current	Green	0.00008	Green
W2	Green	Sustainable Grey	0.21794	Equal
W2	Current	Sustainable Grey	0.00009	Sustainable Grey
W2	Current	Green	0.00015	Green
D1	Green	Sustainable Grey	0.00000	Sustainable Grey
D1	Current	Sustainable Grey	0.00000	Sustainable Grey
D1	Current	Green	1.00000	Equal

4 Conclusions

Adaptation pathways for the sustainable grey landuse scenario economically outperform 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. The broader value of this method is that it helps to bridge the gap between the highly uncertain and long-term climate change and short term decision-making horizons of urban planning and development.

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