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Research papers

Assessment of urban pluvial flood risk and efficiency of adaptation options through simulations – A new generation of urban planning tools

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ABSTRACT

We present a new framework for flexible testing of flood risk adaptation strategies in a variety of urban development and climate scenarios. This framework couples the 1D-2D hydrodynamic simulation package MIKE FLOOD with the agent-based urban development model DAnCE4Water and provides the possibility to systematically test various flood risk adaptation measures ranging from large infrastructure changes over decentralised water management to urban planning policies. We have tested the framework in a case study in Melbourne, Australia considering 9 scenarios for urban development and climate and 32 potential combinations of flood adaptation measures. We found that the performance of adaptation measures strongly depended on the considered climate and urban development scenario and the other implementation measures implemented, suggesting that adaptive strategies are preferable over one-off investments. Urban planning policies proved to be an efficient means for the reduction of flood risk, while implementing property buyback and pipe increases in a guideline-oriented manner was too costly. Random variations in location and time point of urban development could have significant impact on flood risk and would in some cases outweigh the benefits of less efficient adaptation strategies. The results of our setup can serve as an input for robust decision making frameworks and thus support the identification of flood risk adaptation measures that are economically efficient and robust to variations of climate and urban layout.

1. Introduction

The implementation of flood adaptation measures often involves very long planning horizons of 30 and more years, because measures are either time-consuming to implement, or require large investments, or both. Commonly, adaptation measures would be selected based on predictions of flood risk over the planning horizon. However, this approach is problematic, because typically only little is known about the future. For example, studies in various locations have shown that flood risk is strongly affected by climate change and urban growth and anticipated to increase over the next century (Ehret et al., 2008; Hinkel et al., 2014; Muis et al., 2015; Muller, 2007; Semadeni-Davies et al., 2008; Zhou et al., 2012; Zhu et al., 2007). However, projections of sea levels and rainfall are subject to large uncertainties (Hall et al., 2014; Madsen et al., 2014; Sun et al., 2007; Sunyer et al., 2014). Similarly, spatial and temporal projections of urban development depend on uncertain projections of population growth and economic development (Cohen, 2004; Granger and Jeon, 2007) and future societal preferences are virtually unknown.

In such a context, flood adaptation options or, more generally, policies based on predictions of the future conditions can prove to be very fragile (Walker et al., 2001) and necessary investments may well be postponed for fear of making irreversible choices (Aerts et al., 2014). As proposed already by Walker et al. (2001), new decision tools therefore point in the direction of testing adaptation options for a variety of potential future developments and assessing their robustness (Gersonius et al., 2012; Kwakkel et al., 2015; Prudhomme et al., 2010). Such scenario based evaluations have become quite common in the assessment of flood risks

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(Huong and Pathirana, 2013; Muis et al., 2015; Poelmans et al., 2011; Sekovski et al., 2015), but are difficult to apply for design purposes due to the simulation effort involved and are therefore usually performed only for few selected scenarios (Zhou et al., 2012) or apply very simplified models (Kwakkel et al., 2015; Zhu et al., 2007).

In this article, we demonstrate the development and application of a tool which allows for a systematic assessment of flood adaptation options in urban environments for a variety of potential futures. We have linked the urban development model DAnCE4-Water (Urich and Rauch, 2014) with the 1D-2D hydrodynamic modelling engine MIKE FLOOD (DHI, 2013) to allow dynamic linkages between climate change impacts, city development, and adaptation options. DAnCE4Water applies an agent-based approach to simulate the evolution of the urban form at parcel level detail and thus directly provides information on the shape and location of urban features such as buildings or streets. This approach allows for a consideration of spatio-temporal interdependencies between flood hazard, exposure and vulnerability as suggested by Merz et al. (2014) as these may lead to undesired surprises in flood risk management (Merz et al., 2015). Further, the effect of, e.g., zoning policies can directly be modelled in an easily understandable manner. The agent-based approach was therefore preferred over the raster based black box methods applied in most other hydrological studies considering urban development or land use change (Barreira González et al., 2015; Hoymann, 2010; Muis et al., 2015; Poelmans and Van Rompaey, 2010; Sekovski et al., 2015). In line with a general development in the field of urban modelling (Batty, 2009), the purpose of this setup is not to predict future developments, but to perform exploratory analysis and to support dialogue between stakeholders.

Urban flood adaptation measures can take effect on runoff formation, transport and retention in the drainage network, as well as surface flow paths. A tool for assessing the effect of adaptation measures thus needs to be able to consider all of these effects. For this reason, we chose to apply a coupled 1D-2D hydrodynamic model for the assessment of flood hazards. Despite their complexity, such models have been shown to be applicable also for large urban catchments (Henonin et al., 2015; Russo et al., 2015) and in an automated manner (Meneses et al., 2015).

The aim of this paper is

1. to illustrate the new tool for systematic testing of flood risk adaptation options,
2. to demonstrate that it is possible to assess various adaptation options for a variety of future pathways using a detailed urban development and hydrodynamic modelling approach,
3. to highlight opportunities for further development of such a setup, and
4. to demonstrate the benefits of systematically screening adaptation options for a variety of potential futures.

2. Material and methods

2.1. General setup

Our aim was to provide a new tool that supports the systematic assessment of a variety of flood adaptation options under a variety of potential urban development and climate scenarios. Fig. 1 illustrates the modelling setup we applied. In this setup, the urban development modelling platform DAnCE4Water (Urich and Rauch, 2014) was integrated with the hydrodynamic model MIKE FLOOD using ArcPy (ESRI, 2012) and the GDAL libraries (GDAL Development Team, 2014) through Python.

We tested so-called pathways defined by different combinations of:

- Scenarios, manifested in varying external drivers such as
  - o different population growth rates and
  - o climate scenarios,
- Flood adaptation strategies such as
  - o infrastructural measures to be implemented or
  - o land use management strategies.

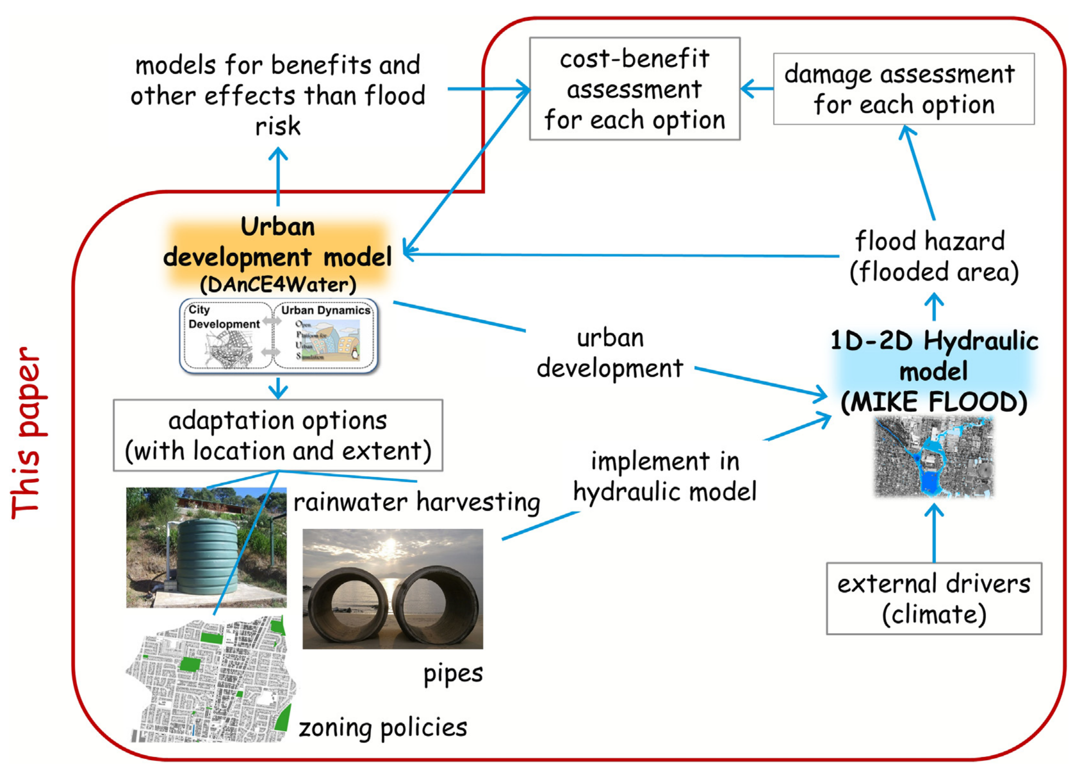

Fig. 1. Schematic coupling between urban development model (DAnCE4Water) and 1D-2D hydrodynamic model (MIKE FLOOD).