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Fit for purpose? Building and evaluating a fast, integrated model for exploring water policy pathways

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A B S T R A C T

Exploring adaptation pathways is an emerging approach for supporting decision making under uncertain changing conditions. An adaptation pathway is a sequence of policy actions to reach specified objectives. To develop adaptation pathways, interactions between environment and policy response need to be analysed over time for an ensemble of plausible futures. A fast, integrated model can facilitate this. Here, we describe the development and evaluation of such a model, an Integrated Assessment Metamodel (IAMM), to explore adaptation pathways in the Rhine delta for a decision problem currently faced by the Dutch Government. The theory-motivated metamodel is a simplified physically based model. Closed questions reflecting the required accuracy were used to evaluate the model's fitness. The results show that such a model fits the purpose of screening and ranking of policy options and pathways to support the strategic decision making. A complex model can subsequently be used to obtain more detailed information.

1. Introduction

Decision makers from governments, NGOs, and businesses sometimes face deep uncertainties associated with the future conditions against which policies must be developed. Deep uncertainties are severe uncertainties that can arise (i) from multiple possible futures without knowing relative probabilities (Lempert et al., 2003), for example due to climate change, population growth, and economic developments; (ii) from multiple worldviews including different values to evaluate the system (Rotmans and De Vries, 1997); and (iii) from policy responses to environmental events and trends (Haasnoot et al., 2012) that cannot be considered independently (Hallegatte et al., 2012). Despite these deep uncertainties, decisions need to be taken.

To address deep uncertainties, literature suggests to use adaptive policies that can be changed over time (e.g. Walker et al., 2001; Albrechts, 2004; Hallegatte, 2009; Ranger et al., 2010; Walker et al., 2013). Adaptive management has been adopted in various policy domains, including water management (Swanson and Bhadwal, 2009; Walker et al., 2010). Adaptive policy plans are currently being developed for the water management of New York City (Rosenzweig et al., 2011), and the Rhine Delta (Delta Programme, 2012), and have been established for the Thames Estuary (Reeder and Ranger, online; Ranger et al., 2013). Development of such adaptive plans requires exploration of different futures and assessments of impacts of these futures and adaptation actions, which is generally done by means of scenario analysis (e.g. Carter et al., 2007).

Exploring adaptation pathways (Haasnoot et al., 2012, 2013) constitutes a novel approach to develop a dynamic adaptive policy plan. An adaptation pathway describes a sequence of policy actions over time that aim to achieve (a set of) specified objectives. A pathway emerges from a set of time-varying boundary conditions of the water system, their impact, and the policy responses in terms of actions. An ensemble of such pathways provides insight into the potential consequences of different policy actions, potential lock-

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ins and path dependencies of actions, and factors that dominate the emerging pathways. This may provide insight in which policy actions constitute a robust plan, being (almost) insensitive to uncertain future developments and events, and which actions are flexible for adequate adaptation to changing conditions (Haasnoot, 2013). To explore adaptation pathways for this purpose, a multitude of plausible futures and sequences of policy actions needs to be evaluated. Often, a computational model is used to support such an exploratory scenario analysis (Rotmans and De Vries, 1997; Lempert and Schlesinger, 2000). Two main requirements of such a model can be identified.

Firstly, to assess impacts of environmental changes and policy actions on relevant outcome indicators for the decision making in complex systems such as river deltas, an *integrated* assessment is needed (Jakeman and Letcher, 2003; Welsh et al., 2012; Laniak et al., 2013; EEA, 2013; Kelly et al., 2013). Integrated Assessment has been defined as a 'meta-discipline' that integrates knowledge and makes it available for decision making processes (TIAS, 2011). In this study, *integrated* refers to the integrated treatment of social, economic and environmental issues and the integration of different systems and processes. The Integrated Assessment Model (IAM) needs to be applied to analyse the whole system including its state, impacts of changing boundary conditions and relevant feedbacks within the system or resulting from policy responses. IAMs have been applied to analyse climate change and the effects of emission mitigation strategies on global and regional scale (e.g. Rotmans and Van Asselt, 1996; Van der Sluijs, 2002; Van Vuuren et al., 2009; Carnevale et al., 2012; de Vos et al., 2013; Schwanitz, 2013) and to assess adaptation strategies on regional scale (e.g. Carmona et al., 2013; Catenacci and Giupponi, 2013). Giupponi et al. (2013) give an overview of successes, shortcomings, and new approaches of integrated global change modelling. In this study, we apply the IAM concept for adaptation analysis on a regional to local scale and to the river delta domain. Following the decision tree of Kelly et al. (2013) a knowledge-based model would be an appropriate model for this study as it can support decision making under uncertainty and the system processes are quite well understood.

Secondly, to execute large number of simulation runs, a limited execution time is required, which implies that the model should be *fast*. One knowledge-based approach for the development of a fast model is 'metamodelling'. Metamodels are models intended to mimic the behaviour of complex models (Davis and Bigelow, 2003; Walker and Van Daalen, 2013). Metamodels are generally thought of as statistically inferred constructs. Davis and Bigelow (2003) introduced the term theory-motivated metamodel for a model of which the structure is motivated in part by phenomenological considerations and in part by statistical analyses. Metamodels have been built for simulating rainfall-runoff (Jakeman and Hornberger, 1993), analysing airport policies (Kwakkel et al., 2010), assessing flood risks (Ward et al., 2011; Kramer et al., 2012), and identifying promising flood management actions (Schijndel, 2005).

This paper focuses on how an appropriate model for exploring adaptation pathways in water management can be built and evaluated. An appropriate model represents the dominant processes and natural variability, and the relevant policy actions and outcome indicators for decision making, but without unnecessary detail (Booij, 2003). The challenge is to make the model fast enough to do many calculations for long time-series (up to 100 years), while keeping sufficient mechanistic and spatial detail to represent the whole system (integrated model) for supporting strategic decision making.

We illustrate the development of a fast, integrated model by means of a case for the Rhine delta in the Netherlands. At the time of writing, the Dutch Government is working on a large study, the Delta Programme, which aims to prepare the Netherlands for climate change and sea level rise with a dynamic adaptive plan that guarantees efficient flood protections and fresh water supply now and in the future (Delta Programme, 2012).

In the process of building and evaluating a model for exploring adaptation pathways we adopted a step-wise approach similar to any other model (e.g. Jakeman et al., 2006; Gupta et al., 2012; Walker and Van Daalen, 2013; Bennett et al., 2013). This paper follows these steps.

1. *Definition of model purpose and context*: based on the objectives of the Delta Programme, the purpose of the model is defined in terms of the scenarios, policy actions, outcome indicators, and relevant processes that should be simulated with the model (Section 2).
2. *Conceptualization of the system*: the main characteristics of water management in the Rhine delta are described in a conceptual structure of the model (Section 3).
3. *Implementation in the model*: the model structure and parameters are described. To make the model fast and integrated, the model consists of theory-motivated metamodels describing the complete cause-effect chain, and is referred to as an Integrated Assessment Metamodel (IAMM) (Section 4).
4. *Evaluation of the model*: evaluation of IAMs has received more attention, but a common framework is lacking. Recently, Schwanitz (2013) proposed a framework for evaluation of IAMs on global change. We use the approach of closed questions. This was inspired by Guillaume and Jakeman (2012) who focused on the adequacy of the model in answering policy questions rather than on quantifying the models accuracy. This study's main question is: *Given the simplifications associated with the model, does the model produce credible outcomes with sufficient accuracy for the screening and ranking of promising actions and pathways in order to support the strategic adaptive planning decisions in the Rhine delta?* In cooperation with potential end-users appropriate performance metrics were defined for a set of sub-questions the model should be able to answer (Section 5).

2. Model purpose and context

The purpose of the model is to support the strategic decision making of the Delta Programme that runs from 2009 to 2014. The main objective of the *Delta Programme* is to propose a set of strategic decisions 'to protect the Netherlands from flooding and to ensure adequate supply of freshwater for generations ahead' (Delta Programme, 2010, 2011). This should result in a dynamic adaptive plan that contains short-term actions and a long-term vision for action to adapt to changing conditions, if necessary. The time horizon of the progamme is 2100. After 2014 the details of the actions will further designed in follow-up studies. To prepare the decisions, the potential impacts of climate change, sea level rise, socio-economic developments and policy actions need to be assessed. Climate change and sea level rise may result in an increased flood risk during winter and lower water availability during summer (e.g. Delta Committee, 2008). In addition, water demands from the regional areas to the national water system may increase due to less rain, more salt intrusion, and/or changes in the agricultural sector. Socio-economic developments may change fresh water demands and potential flood damage and casualties.

The focus of this paper is on flood and drought risk management in the main lower Rhine river branches, IJsselmeer lakes, and rural areas (Fig. 1). In the Delta Programme the following questions for decisions on policy options have been identified for flood risk: What policy actions are needed to guarantee compliance with flood protection standards? How can the Rhine discharge distributed