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Projected vegetation changes are amplified by the combination of climate change, socio-economic changes and hydrological climate adaptation measures

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ABSTRACT

Climate change is projected to strongly affect the hydrological cycle, altering water availability and causing successive shifts in vegetation composition and distribution. To reduce potential negative effects on vegetation, policymakers may implement hydrological climate adaptation measures, which may -in turn- require land use changes to be successful. Policy driven land use changes should therefore be taken into account when evaluating climate change and adaptation effects on the water-vegetation system, but this is rarely done. To support such policy interventions, we applied a coupled land use – hydrology – vegetation model to simulate effects of (i) climate change, (ii) socio-economic change, (iii) hydrological measures and (iv) policy driven land use change, alone and in interaction, on vegetation communities in the Netherlands. We simulated two climate scenarios for 2050 that differed in predicted temperature (+0.9 °C and +2.8 °C) and precipitation changes (groundwater recharge +4% or −14%). The associated socio-economic scenarios differed in the increase of gross margins per agricultural class. The land use changes concerned agricultural changes and development of new nature areas from agricultural land. Individually, land use changes had the biggest effect on vegetation distribution and composition, followed by the hydrological measures and climate change itself. Our results also indicate that the combination of all four factors triggered the biggest response in the extent of newly created nature areas (+6.5%) and the highest diversity in vegetation types, compared to other combinations (max. +5.4%) and separate factors. This study shows that an interdisciplinary, coupled modelling approach is essential when evaluating climate adaptation measures.

1. Introduction

Climate change predictions indicate significant changes in the hydrological cycle (IPCC, 2013), including changes in precipitation patterns and in potential evaporation (Alexander et al., 2006; Rajczak et al., 2013; van Haren et al., 2013; Vautard et al., 2014). These changes may increase the risk of flooding and/or drought, depending on the region, thereby modifying water availability (Bakker and Bessembinder, 2007; Briffa et al., 2009; Arnell and Gosling, 2013; IPCC, 2013; Rajczak et al., 2013; Zolina et al., 2013). Water availability is an important environmental factor that drives plant species composition worldwide (Weltzin et al., 2003; Ordoñez et al., 2010; Bartholomeus et al., 2011; Douma et al., 2012b; Witte et al., 2012). Changes in water availability therefore also affect vegetation distribution and composition. Moreover, many agricultural practices are located on groundwater dependent lands and will be affected too. To reduce potential negative effects of climate change on these systems, policymakers intend to implement hydrological climate adaptation measures to ensure sufficient water availability for agriculture and plant communities. The goal of these measures is to increase the resilience of the water-vegetation system to climate change (Van der Knaap et al., 2015).

Successful implementation of the aforementioned hydrological

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measures in areas with multiple land uses may require policy-driven land use change. This is especially true for hydrological measures that lead to higher groundwater tables. Farmers with parcels that are susceptible to waterlogging, may find themselves in an unfavourable situation if such measures are implemented. They may be forced to take such parcels out of production or use them less intensively, and if so, they are likely to demand some kind of compensation. This, therefore, requires a sound land use policy to stimulate local support for these measures. Furthermore, land use will also develop in response to socio-economic changes, such as fluctuations in market prices, national and European policy, and internal dynamics such as farmers retiring with or without having a successor. Since land use changes are known to affect local and regional hydrology (Qiu et al., 2011), it is essential to take them into account to successfully simulate the effects of climate change and hydrological measures on hydrology, agricultural productivity, and vegetation.

Until recently most land use, hydrology and vegetation simulation-based studies focused on just one or two of the aforementioned factors. Models that combine multiple factors mostly take land use as a static condition, or use exogenous scenarios specifying land use change, which interact with hydrological processes through simplified or advanced hydrological models (Fohrer et al., 2001; van Roosmalen et al., 2009; Memarian et al., 2014). Moreover, hydrological changes that are projected upon vegetation communities do not take potential changes in land use into account, although land use changes can affect vegetation composition and distribution (Bakker et al., 2015c).

These previous studies show that the individual factors (i.e. land use and hydrology) can have profound effects on vegetation distribution and composition. However, due to interactions among these factors the combined effect may even be larger than expected based on the sum of the individual effects, but so far this is unknown. Since land use changes and the associated changes in hydrology and vegetation are all interdependent, a fully coupled, interdisciplinary land use – hydrology – vegetation simulation is required to better evaluate impacts of climate and socio-economic change, hydrological measures, and land use policy on vegetation distribution and composition. In this study, we developed and present such an approach and use this to test the necessity of using an interdisciplinary approach. This study is therefore a methodological research. We used three models: a hydrological model (MODFLOW-MetaSWAP) which has been calibrated and validated previously and is used by regional water managers in the Netherlands; an agent-based land use model (RULEX) which has been specifically developed for the Netherlands and which has been calibrated for our case-study region; and the trait-based vegetation model PROBE to simulate vegetation responses. These models were coupled and used to simulate the separate and combined effects of climate and socio-economic change, hydrological measures, and land use policy on vegetation distribution. Through this integration, we aimed to answer the following research questions:

- What is the combined effect of climate change, land use change (both socio-economic and policy driven), and hydrological measures on predicted vegetation distribution and composition?
- Which of these factors has the biggest effect?

We expect that the combined effect triggers the biggest changes in predicted vegetation distribution and composition.

2. Methods

2.1. Modelling framework and general approach

To assess the combined effects of socio-economic developments, climate change, hydrological measures and land use policy on land use change, hydrology, and vegetation, we coupled an agent-based land use model to a hydrological model and a vegetation model (Fig. 1). We assessed these different factors in a step-wise nested approach. In this modelling framework, vegetation responds to climate change, both directly and indirectly through hydrological changes (Step 1). The hydrological changes result in the first instance from climate change and the implementation of hydrological measures. The combined hydrological effects on vegetation are simulated in Step 2. The hydrological changes also affect land use. In turn, land use change will affect hydrological conditions, as different agricultural land uses (crops) have different evapotranspiration demands. Land use is also influenced by climate and socio-economic change: the demand for crops is driven by changes in climate (via biofuel demand), demographic developments, and diet changes, while supply is determined by growing conditions, which are also affected by climate change. These effects of the land use changes on vegetation are simulated in Step 3. Finally, land use policy measures allow farmers to take parcels out of production that are negatively affected by the hydrological measures, by selling them to a collective that is raised for this purpose (more information is given below). We combined these policy impacts with climate change, socio-economic change and hydrological measures in Step 4 to simulate the final vegetation response.

Within this conceptual framework, we implemented two climate change and associated socio-economic scenarios, which are based on the A1B, A2 and B1 scenarios developed by the IPCC (IPCC, 2007). They differ in climatological and socio-economic attributes and were downscaled to our case study area. We based our hydrological measures on Dutch policy measures aiming at increasing the water availability for both agriculture and nature areas in stream valley catchments. As these stream valleys are mostly used for farming, land use adaptation in these areas may be needed. Hereto, we implemented policy measures which were used to stimulate the development of agricultural land into nature areas. This resulted in nine scenarios, including a reference scenario. The modelling steps and the climate change scenario have been included in the scenario names (Table 1). The various components and scenarios of our approach are explained in more detail below (Sections 2.3–2.6).

2.2. Case study

We applied our integrated models to the stream valley catchment of the ‘Tungelroyse Beek’ (approx. 157 km^2), located in the southeastern part of the Netherlands (Fig. 2). Policy makers from the province and water boards expressed the ambition to increase water availability in this stream valley to anticipate on negative effects of climate change. These ambitions were based on the Dutch Administrative Agreement for Water Affairs (Ministry of Infrastructure and the Environment, 2011), which requires the development and implementation of regional targets for groundwater and surface water regimes before 2020. These targets aim at developing and maintaining a stable and resilient water system to support the allocated functions. The implemented land use policy was inspired by the European set-aside policy (European Commission). We formulated, in close collaboration with the policy makers of the area, a measure to accommodate those farmers that would be disadvantaged by the implementation of the hydrological measures. Although the set-aside legislation has been abolished in 2009, it serves as an example of how farmers, through policy, can contribute to nature development.

Agricultural land use is the dominant land use (ca. 67%, including grasslands), followed by urban and nature areas (both ca. 16%) and open water (ca.1%) (Straatman and Luijendijk, 2002). Mean annual temperature for the period 1980–2010 is 10 °C, with the mean highest temperature in July (18 °C) and mean lowest temperature in January (3 °C). The mean annual precipitation ranges from 750 to 775 mm and is evenly distributed over the year. The mean annual evaporation ranges from 570 to 580 mm and the yearly precipitation surplus ranges from 160 to 200 mm (KNMI, 2011). In the past, the catchment has been extensively drained for agricultural purposes, which led to a severe