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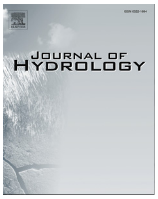

Uncertainty of climate change impact on groundwater reserves – Application to a chalk aquifer

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SUMMARY

Recent studies have evaluated the impact of climate change on groundwater resources for different geographical and climatic contexts. However, most studies have either not estimated the uncertainty around projected impacts or have limited the analysis to the uncertainty related to climate models. In this study, the uncertainties around impact projections from several sources (climate models, natural variability of the weather, hydrological model calibration) are calculated and compared for the Geer catchment (465 km^2) in Belgium. We use a surface–subsurface integrated model implemented using the finite element code HydroGeoSphere, coupled with climate change scenarios (2010–2085) and the UCODE_2005 inverse model, to assess the uncertainty related to the calibration of the hydrological model. This integrated model provides a more realistic representation of the water exchanges between surface and subsurface domains and constrains more the calibration with the use of both surface and subsurface observed data. Sensitivity and uncertainty analyses were performed on predictions. The linear uncertainty analysis is approximate for this nonlinear system, but it provides some measure of uncertainty for computationally demanding models. Results show that, for the Geer catchment, the most important uncertainty is related to calibration of the hydrological model. The total uncertainty associated with the prediction of groundwater levels remains large. By the end of the century, however, the uncertainty becomes smaller than the predicted decline in groundwater levels.

1. Introduction

Groundwater is an essential component of the water supply of several countries. It is also crucial for some specific groundwater dependent ecosystems. It is expected that water extraction from groundwater reserves will increase in some areas because of the foreseen increase in the water demand (Holman et al., 2012; Zhou et al., 2010). Long-term variations in temperature and precipitation, related to climate change, will also have an impact on future groundwater availability. Several studies have aimed at quantifying this impact for a variety of groundwater systems (e.g. Armandine Les Landes et al., 2014; Brouyère et al., 2004a; Goderniaux et al., 2009; Green et al., 2011; Herrera-Pantoja and Hiscock, 2008; Holman et al., 2012; Scibek et al., 2007; Van Roosmalen et al., 2009; Woldeamlak et al., 2007). These studies suggest that, compared to surface water, groundwater appears less vulnerable to extreme events such as droughts. This lower vulnerability is mainly explained by the significant water volumes stored in aquifers and that most often groundwater recharge occurs during periods that are longer than the typical duration of a drought. Its lower vulnerability makes groundwater a highly valuable water resource that is easier to distribute and manage.

Estimating the impact of climate change on groundwater reserves requires an adequate characterization of the concerned aquifers and robust modelling tools. Additionally, these estimations are affected by a series of uncertainties, such as the prediction of future greenhouse gas emissions and the uncertainty associated to climate and hydrological models. Quantifying these uncertainties is crucial to provide confidence intervals for predictions and therefore increase their credibility. Some of the previous studies have incorporated uncertainty analysis. For example, Ali et al. (2012), Jackson et al. (2011), Stoll et al. (2011), and Sulis et al. (2012) use input scenarios from more than one climate model (General Circulation Model – GCM or Regional Climate Model – RCM), while others account for different greenhouse gas emissions

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scenarios (e.g. Dams et al., 2012; Neukum and Azzam, 2012; Serrat-Capdevila et al., 2007). The uncertainty analysis is, however, usually limited to the climatic part and uncertainty from other components, such as the hydrological model is often not estimated. Developing a numerical model always requires some level of a simplification of real systems and this simplification can have an impact on model predictions. Therefore, the ability of a model to satisfactorily reproduce reality, in accordance with the system's stresses, needs to be carefully evaluated.

The two main objectives of this paper are: (1) to estimate the uncertainty related to hydrological model projections in the context of climate change; and (2) to compare this source of uncertainty with sources of uncertainties related to the climate models (RCM and GCM), to the natural variability of the weather, and to the statistical downscaling method.

The different sources of uncertainties are considered for the Geer catchment (465 km^2) in Belgium (Fig. 1), for which a catchment-scale fully-integrated surface–subsurface model has been developed. The parameterization of this hydrological model, a sensitivity analysis of the parameters, and the calibration of the model are presented in detail. The assessment of prediction uncertainty linked to this catchment-scale integrated model, the comparison with different sources of uncertainty, and the combination with advanced climate change scenarios bring new insights in the rising research on the impact of climate change.

2. Previous studies

The catchment-scale fully-integrated surface–subsurface model of the Geer basin has been developed with the finite element simulator HydroGeoSphere (Brunner and Simmons, 2012; Therrien et al., 2010). The modelling approach, involving the catchment-scale fully integrated surface–subsurface model, is described in Goderniaux et al. (2009). In Goderniaux et al. (2011), six RCMs were statistically downscaled and applied as input to the surface–subsurface hydrological model to quantify their impact on groundwater resources. These scenarios correspond to six contrasted Regional Climate Models (RCM) selected from the PRUDENCE ensemble. Their boundary conditions are taken from two different GCMs (see Fig. 2) and correspond to the SRES A2 (medium–high) greenhouse gas emissions scenario (Nakicenovic et al., 2000). As shown in Fig. 2, mean annual temperature changes ranging between +3.5 °C (HIRHAM_H) and +5.6 °C (RCAO_E) are projected for the 2071–2100 period, as provided by the PRUDENCE project. All scenarios predict that temperature will increase and that the increase will be greater in summer than winter. The RCMs consistently project that annual precipitation will decrease for the 2071–2100 period but the predicted decrease ranges from −1.9% (ARPEGE_H) to −15.3% (HAD_P_H), which represents a large range of variation. The projected decrease in precipitation is a result of large projected decreases during summer months, which are only partly offset by increases in winter precipitation. These six RCMs were statistically downscaled using a stochastic weather generator (WG) (Blenkinsop et al., 2013), which considers changes in the climatic means and also in the distribution of wet and dry days. It allowed generating a large number of equiprobable climate change scenarios representative of a full transient climate between 2010 and 2085 (the middle of the 2071–2010 period). These scenarios accounted for the transient nature of future climate change, and enabled the assessment of

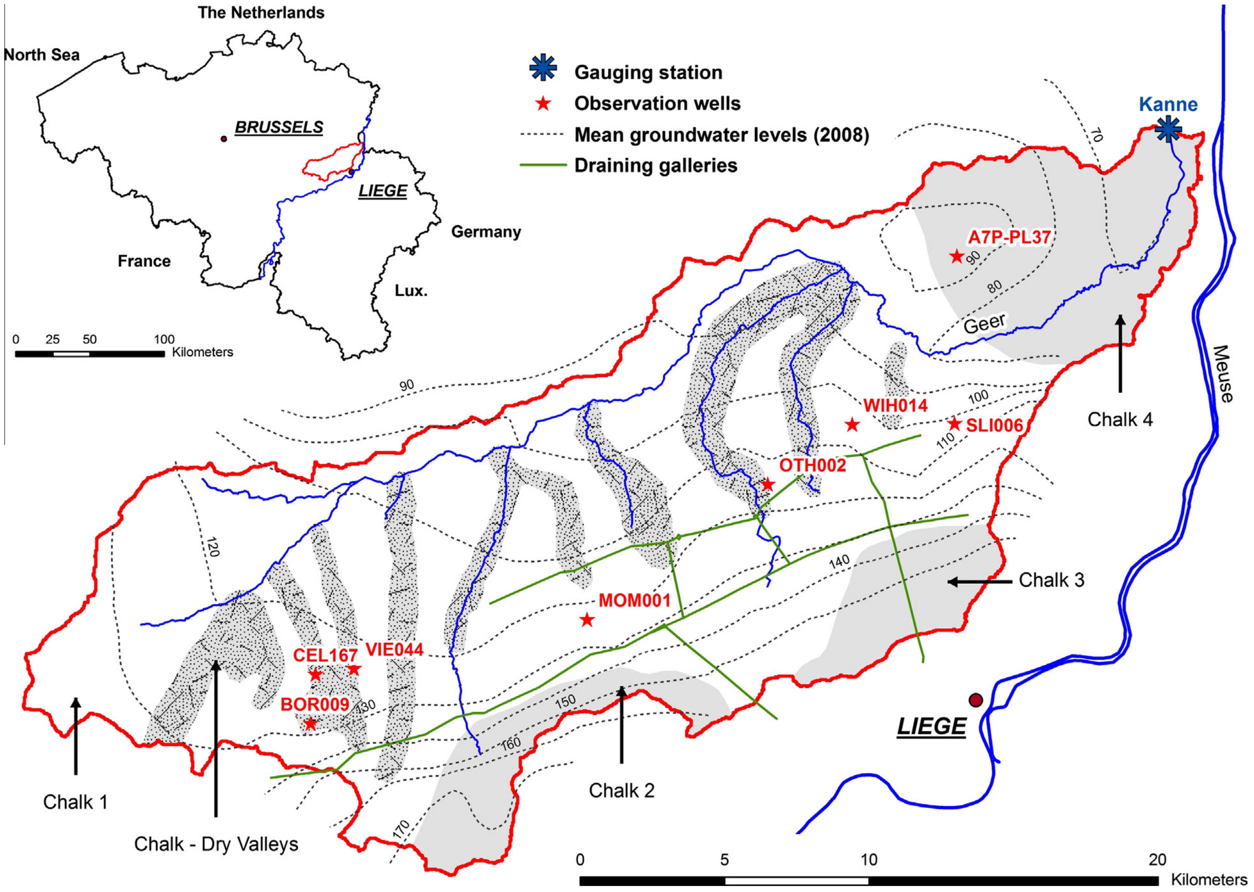

Fig. 1. Location of the Geer catchment in Belgium. The different zones correspond to different values of the hydraulic conductivity.