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Spatio-temporal impacts of climate and land-use changes on the groundwater and surface water resources of a lowland catchment

Abstract

The Kleine Nete is one of several catchments in Belgium that is used as a source of fresh water, and contains a number of ecological important areas, which are frequently flooded. The average slope of the catchment is very small resulting in low flow velocity. The distributed hydrological models, WetSpa, WetSpass and MODFLOW, are used for simulating the hydrological behaviour of the catchment. Peak discharges are simulated with a Nash-Sutcliffe efficiency of 84% and 81% respectively for calibration and verification periods. Antecedent soil moisture conditions play a major role in the production of peak discharges during the winter periods, which are characterized by low intensity rainfall but of long duration. Peak discharges in the summer are mostly limited to high intensity rainfall regardless of the antecedent soil moisture conditions. In general, runoff generated in the summer is low compared to the winter due to a combination of several factors like dry soil, high evapotranspiration, and high interception and depression storage losses. Recharge to the aquifer, estimated by WetSpass and WetSpa models, accounts for 36% of the annual precipitation and occurs predominantly during the winter. The discharge areas occupy about 10% of the catchment and the average discharge flux is 314 $mm\ y^{-1}$. A small percentage of inflow to the aquifer comes from canals and lakes. The sandy nature of the aquifer allows distinct groundwater head fluctuations between summer and winter, which implies that changes in climatic conditions that alter precipitation and potential evapotranspiration, could easily affect the groundwater balance and interaction with surface water.

Recent increase in flood frequency in the catchment is partly attributed to land-use changes. The CLUE-S model is used to derive future annual land-use changes in the catchment. Four land-use scenarios based on the SRES emission are considered. Comparison of the model calculated suitability and the current state of the land-use type shows satisfactory agreement, while all future land-use scenarios depict a large increase of urbanization and decrease a of agricultural land-use types. Winter and summer river discharge, peak discharges and flood frequencies increase, while the groundwater shows a decline in head throughout the seasons. Under extreme scenarios the annual flood frequency in 2020 increased by 85%. The effect on groundwater on the overall catchment is very small; however, the local groundwater head decline could reach up to 1.15 *m*.

Like the land-use changes, part of the change in water balance in the catchment is attributed to climate change. Analysis of long term weather records indicates that annual mean temperatures increased by about 1°C since the 1950s and are expected to rise by about 3.3°C by the end of the 21st century. The Seasonal Kendall trend test shows a significant annual increase in precipitation, PET and temperature at 5 and 10% levels. The current trends indicate 13 *mm* increase per decade in PET, while the precipitation increase ranges from 19 to 53 *mm* per decade. A sensitivity study of climate change on the hydrology of the catchment is modelled using wet (greenhouse), cold or NATCC (North Atlantic Thermohaline Circulation Change) and dry climate scenarios. Low, central and high estimates of temperature changes are adopted for the wet scenarios. Seasonal and annual water balance components including groundwater recharge are simulated using the WetSpass model, while annual groundwater heads and discharge are simulated with a steady-state MODFLOW groundwater model. WetSpass results for the wet scenarios show that winters will be more wet and summers more dry compared to the present situation. MODFLOW results for the wet high scenario show that groundwater levels will increase by as much as 1 *m*, which could affect the distribution and characteristics of the wetlands. Results obtained for cold scenarios depict drier winters and wetter summers relative to the present. The dry scenarios predict dry conditions for the whole year, with no

recharge in the summer. Average annual groundwater levels drop by half a meter, with maximum 1.5 *m* in the eastern part of the Campine Plateau, which could endanger aquatic ecosystems.

Transient simulations, which encompass both the greenhouse and dry scenarios are conducted in order to assess the future hydrology of the catchment. Future precipitation predicted by downscaling from the A2 emission of the HadCM3's GCM show similar but more mild monthly changes as present, ranging from 50% increase in March to 25% decrease in August. This leads to a 13% increase and 6% decrease in river discharge respectively for March and August. However, the groundwater head does not depict high fluctuation between summer and winter as observed for the river discharge, owing to the aquifer storage characteristics. The groundwater head increased by about 25 *cm* in the winter, while in the summer it remained at the same level as the present condition. The overall effects of climate change are expected to result in more floods in the winter, and the 'wetness' and 'dryness' is likely to have more effect on the diversity and distribution of aquatic plants and animals.