The Impact Of Land Use Changes On The Hydrology Of The Grote Nete Basin (BELGIUM) Applying MIKE SHE

Farjana Akhter, Mohammad Abul Hossen

Abstract: Analysis of the impact of land use changes on the hydrology is a key issue to set up a proper land-use planning project. In this study one distributed model, MIKE SHE, was applied to the hydrological system of the Grote Nete catchment, a medium size catchment in Belgium. The existing Grote Nete MIKE SHE model was calibrated and validated using some additional parametersets (sensitivity analysis) which had not been tested and used in the initial model calibration to simulate the land use change impact on the hydrology of this catchment. The modelling results (calibration & validation) were verified by comparing with observed river discharges (4 discharge stations) and groundwater heads (10 wells of 4 geological units). In MIKE SHE, total 17 scenarios had been developed by changing the land use classes according to 4 hypothetical scenario categories and compared with the result of original (reference) calibrated model. The effect on discharges were analysed in terms of hydrological extremes (peak flows and low flows) that had been calculated applying Water Engineering Time Series PROcessing tool (WETSPRO tool) and the impact on groundwater conditions was expressed by the average monthly heads that were simulated by MIKE SHE. From the result of the hydraulic extremes it can be said that peak flows and low flows may increase or decrease with respect to the current (reference) scenario. The changes in groundwater heads, simulated by the MIKE SHE model, were insignificant. It was found that groundwater heads were negatively affected (up to - 1m decline) in summer and less affected (0.2 m decrease) in wet periods for all geological units. The drier groundwater conditions might have severe agricultural and ecological implications, as well as affect river low flows in all geological units. In this study, the hypothetical land use scenarios had been developed to see the impact on the hydrology of the Grote Nete catchment, although some scenarios did not give the expected results. So, future research may be concentrated in refining the presented approach to reduce the effects of the main uncertainties identified in the present study.

Index Terms: Distributed model, Grote Nete basin, Hydrology, Land use changes, MIKE SHE, Scenario development, Sensitivity analysis, WETSPRO tool.

1 INTRODUCTION

THE hydrology, mainly the hydrological cycle, describes the state of movement of water on, above and below the surface of the earth. In this study one distributed model code, MIKE SHE, is applied to the hydrological system of the Grote Nete catchment, a medium size catchment in Belgium, in order to assess the impacts of land use changes on its hydrology. Different land use changes are proposed and their effects simulated in existing hydrological and hydraulic river models for the Grote Nete river basin in Belgium. It is investigated whether the positive effects of the proposed land use scenarios can compensate the expected negative effects of existing land use changes, and whether the proposed changes can be designed so that they can be adapted gradually in time depending on the future trends of the land use scenarios. The changes of extreme runoff discharge (peak flow and low flow) values are analysed and evaluated. The advantage of using MIKE SHE model (an integrated surface water-groundwater model) is that it can analyze both surface water and groundwater at the same time. In this study the temporal changes in groundwater heads are also analyzed for the different geological units.

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Study Area

The Grote Nete catchment selected as the study area, is a middle size catchment which is the part of the Nete Catchment located in the Northeast of Flanders, 60 km north-east of Brussels (Figure 1).

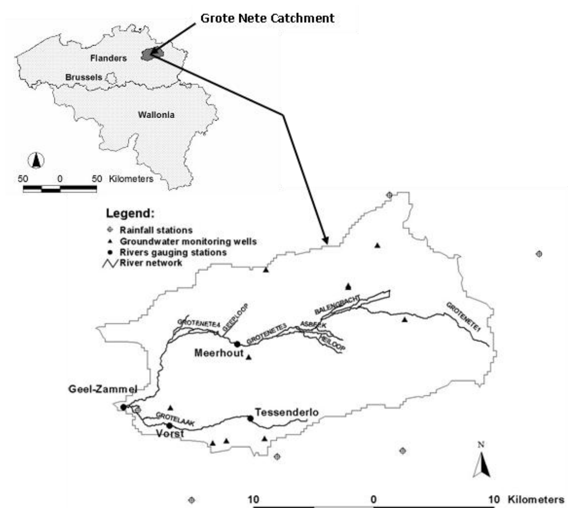

Fig. 1. The study area in Belgium and the river network along with the gauging stations.

The catchment is delineated upstream of the stream flow measuring station called Geel-Zammel, on the main Grote Nete river. The catchment covers an area of about 405 km2 (Yimam, 2010). The Grote Nete catchment is composed of three main rivers and their tributaries. The three main rivers in the catchment are Grote Nete, Molse Nete, and Grote Laak (Figure 1). The confluence of Grote Nete and Grote Laak rivers occurs just above the Geel-Zammel station.

Objectives

The main objective of this paper is to find out the impact of land use changes on the hydrology (groundwater and surface water) of the Grote Nete basin in Belgium applying MIKE SHE model.

2 METHODOLOGY

The overall methodology of this study mainly consists of three steps that are described as a structured way in the following diagram (Figure 2).

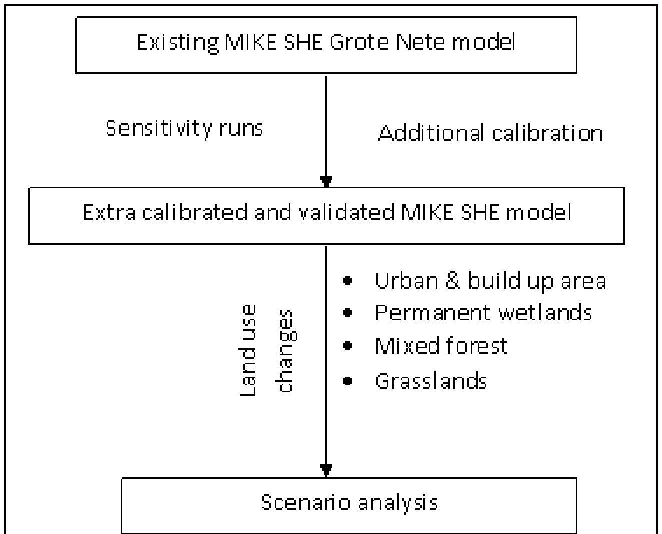

Fig. 2. The flow diagram of methodology

TABLE 1
EXAMPLE OF SOME SIMULATIONS THAT HAD BEEN TESTED IN CALIBRATION

Simulations	Saturated Zone		Unsaturated Zone
	Ss (1/m)	Sy	Ks
1			*10 for all soil types
2			/10 for all soil types
3	*10 for all layers	*10 for all layers	
4	/10 for all layers	/10 for all layers	
5	/10 for all layers		

Modelling and Statistical Tools

In this study one hydrological modelling tool (MIKE SHE) and one statistical tool (WETSPRO) had been used. MIKE SHE is an advanced, spatially distributed, physically based, flexible framework for hydrologic modelling (Abbott et al., 1986 cited in Vansteenkiste et al., 2010)). The components of this model are evapotranspiration, overland flow and river, unsaturated zone and saturated zone. Willems (2003) established a Water Engineering Time Series PROcessing tool (WETSPRO) which was selected as the tool for implementing time series analysis for model development. For scenario analysis extreme low and high flows are estimated applying this WETSPRO tool. At first base flow is separated and then extreme flows are estimated.

Existing Grote Nete MIKE SHE Model Set-up

The Grote Nete model that developed by Rubarenzya et al. (2007) and Vansteenkiste et al. (2010), are analyzed here by extra calibration. The selected flow stations and observation wells are shown in figure 3. The discharges on an hourly basis for the period 1998 to 2008 and the groundwater head on a daily basis were collected in the catchment. In the existing model the parameters such as: topography, rainfall measurements, evapotranspiration, land use, unsaturated flow and soil profiles, overland flow, channel flow and saturated zone were considered.

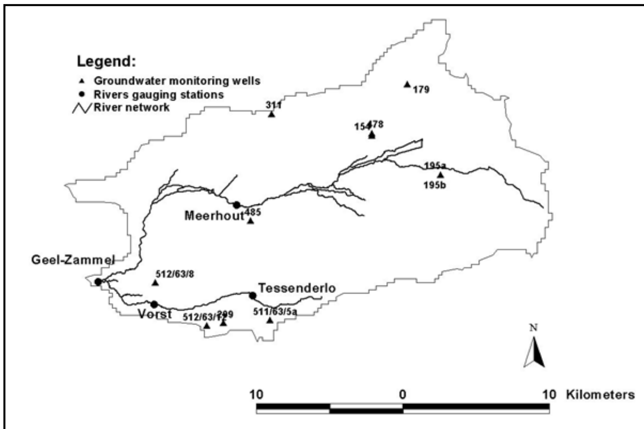

Fig. 3. Flow stations and observation wells in the catchment

Improvement of the Existing MIKE SHE Model

Existing model has been improved by applying calibration with sensitive parameter adjustment. This includes horizontal hydraulic conductivity (Kh), vertical hydraulic conductivity (Kv), specific yield (Sy) and specific storage (Ss). When the most appropriate parameters have been selected based on the sensitivity analysis and the model calibration is successfully done, the parameters can be applied to a validation period with new dataset.

Land Use Scenarios

The model was run applying different land use maps. The following scenarios are considered in this study.

i. Reducing urban area by other land use (wetlands, mixed forest and grasslands) types (3 scenarios)
ii. Structured expansion of urban area (4 scenarios)
iii. Random expansion of urban area (4 scenarios)
iv. Changing wetlands, mixed forest and grasslands (6 scenarios)

During the simulation of these scenarios in the MIKE SHE model, the land use map and the surface roughness both had to be changed. The land use determines the roughness of the soil surface and the surface roughness is important in the simulation for overland flow. During simulations both land use and surface roughness (expressed by the Manning Strickler)

were changed. The following Manning Strickler is handled for the different land use classes
.

TABLE 2
CONVERSION CODE OF LAND USE AND MANNING COEFFICIENT (VANSTEENKISTE ET AL., 2010)

Land Use	IGBP code (land use code)	Manning Strickler coefficient for MIKE SHE model
Deciduous needleleaf forest	3	2.5
Deciduous broadleaf forest	4	1.25
Mixed forest	5	1.82
Grasslands	10	6
Permanent wetlands	11	2
Croplands	12	13
Urban and Built-up	13	90
Water bodies	17	20

Impact Analysis of Land Use Scenarios
After simulation of the above land scenarios, the impact of the changed land use is quantified on surface water extremes (peak flows and low flow) and groundwater levels. The impact is quantified by comparing the simulation results of the reference run (with original land use map) with the results of the scenario run (with the changed land use). Impact on surface water and groundwater both are assessed, but here only impact on surface water is discussed in the next section 3.

3 ILLUSTRATIONS
In this section the result and interpretation has been performed together. The sensitivity of the different parameters, related calibration and validation and also different scenario analysis are described shortly. Both sensitivity analysis and finally calibration were done for the period 01/08/2002 to 31/12/2005. In every case only land use impact on surface water is discussed briefly.

TABLE 3
SY (XEVI, 1996) AND SS (VANSTEENKISTE ET AL., 2010) DIVIDED BY 10 ALL LAYERS

HCOV-code	Aquifer name	Coefficients Sy	Ss (1/m)
HCOV 0100	Quaternary aquifer system	0.03	1.00E-05
HCOV 0230	Pleistocene and Pliocene Aquifer	0.05	5.00E-04
HCOV 0240	Pliocene clay layer	0.025	1.00E-05
HCOV 0250	Miocene Aquifer system	0.025	1.00E-05

Sensitivity Results
Sensitivity analysis has been done adjusting land use parameters (Leaf Area Index, LAI, Root depth in mm and Crop coefficient, Kc) and saturated zone parameters (specific yield, Sy and specific storage, Ss) in the geological layers of the existing model. Finally adjusted sensitive parameters which give the accepted calibration is shown in table 3.

Calibration Results
The model results before and after extra calibration is compared for the four discharge stations - Geel-Zammel, Meerhout, Vorst and Tessenderlo. Here the result of Geel-Zammel has been shown in figure 4. This station shows good simulation performance both in dry period and wet period.

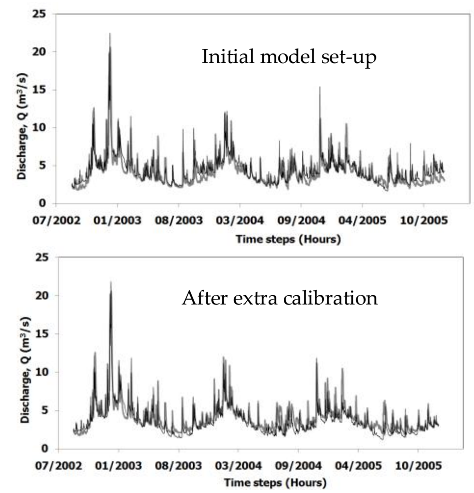

Fig. 4. Observed (ash line) and simulated (black line) runoff discharges for the station "Geel-Zammel"

The model performance also can be evaluated by analyzing the statistical measures that came from MIKE SHE simulation run which is shown in table 4. The efficiency shows that the model performs well after extra calibration.

TABLE 4
MODEL PERFORMANCE STATISTICS AT THE FOUR STATIONS

Station Name	NSE (Nash Sutcliff Efficiency) Initial model set-up	After extra calibration
Geel-Zammel	0.78	0.71
Meerhout	0.17	0.33
Vorst	0.51	0.68
Tessenderlo	0.26	0.53

Scenario Results
For every scenario simulation the model is run for 6 years (01/08/2002 to 30/12/2008) time period in order to make clear conclusion. The impact results would be better with the longer time series. The effects on discharges are analysed in terms of hydrological extremes (peak and low flows) and the impact on groundwater conditions is expressed by the average monthly heads that are simulated by MIKE SHE. First type scenario (Reducing urban area by other land use) results for Geel-Zammel station are presented in figure 5. In reference (current) scenario the runoff peaks are higher and the baseflow is lower than other scenario, because in reference scenario the urban area is already present and in other case it is absent. The changes of the scenario results are compared with reference scenario as percentage wise shown in table 5.

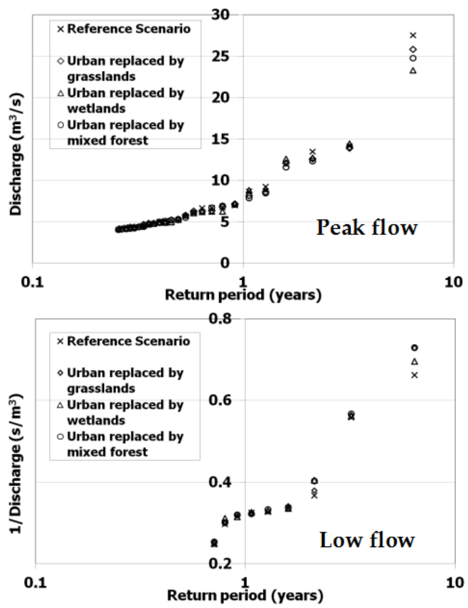

Fig. 5. Peak and low flows versus empirical return period for Geel-Zammel

TABLE 5

RELATIVE CHANGES IN NEARLY INDEPENDENT PEAK AND LOW FLOWS FOR THE SCENARIOS WITH RESPECT TO REFERENCE SCENARIO

Scenarios	Geel-Zammel		Vorst	
	Peak flows	Low flows	Peak flows	Low flows
Urban area replaced by wetlands	-1.35%	-2.27%	-2.73%	-7.11%
Urban area replaced by mixed forest	-2.46%	-2.76%	-7.99%	-15.96%
Urban area replaced by grasslands	-1.27%	-2.10%	-5.94%	-13.03%

4 CONCLUSION

This study was set out to investigate the impact of land use changes on the hydrology of the Grote Nete basin, a medium size catchment in Belgium, using a distributed hydrological model, MIKE SHE. The aim was to understand the extreme changes in surface water (low flow and high flow) and groundwater applying some new land use patterns within the Grote Nete catchment. As some new parameters (seasonal dependent vegetation parameters and adjusted saturated zone parameters) are applied in the existing MIKE SHE model, it showed higher efficiencies for the calibration and validation period at the basin outlet (Geel-Zammel station) and Vorst; while lower efficiencies were found for Meerhout and Tessenderlo. Peak flows showed slight under and overestimation at Geel-Zammel for respective calibration and validation period. On the other hand, peak flows were generally well approximated at Vorst, except for the lower return periods where model showed slight underestimation. Concerning the low flow, small underestimation were found for all stations over the whole period (calibration & validation), except Geel-Zammel for the higher return period where model showed slight overestimation. MIKE SHE model is also capable of simulating groundwater heads and their dynamics with reasonable accuracy. The scenario analysis was carried out for 6 years time period at Geel-Zammel and Vorst. The analysis showed that the extreme peak flow, low flow and groundwater head will increase or decrease little changing the land use types in comparison with the present condition. For the first scenario analysis ´reducing urban area by wetlands, mixed forests and wetlands´, the peak flows showed quite decreasing trend, especially for the scenario ´reducing urban area by mixed forest´ compared to the original one that we expected and the low flows also showed same trend as like as peak flows. While dealing with the groundwater level, the three scenarios showed quite lower groundwater head compared to the reference scenario (present scenario); the effect was less pronounced for the scenario - replacing urban area by wetlands. It should be expected higher groundwater head after reducing urban area, but found lower. This might be due to very high evaporation demands, location of wells, etc. Overall groundwater heads were negatively affected (-1m decline) in dry summer and less affected (0.2 m decrease) in winter periods. The drier groundwater conditions might have severe agricultural and ecological implications but also affect river low flows in all geological units. So, urbanization is important for balanced hydrology and urban area should not be replaced totally by other land use types. The second scenario was analyzed as ´structured expansion (5%, 10%, 20% & 40%) of urban area´ based on the idea that urban area may increase in future. The structured expanded urban area may be randomly spread over the basin. So, the third scenario analysis was ´random expansion (5%, 10%, 20% & 40%) of urban area´. The last scenario analysis was performed by other land use patterns (wetlands, mixed forest & grasslands) with urban area remain unchanged. Actually, no model can give appropriate prediction. Sometimes MIKE SHE also may give some strange results which are not expected. Large uncertainty in the rate and magnitude of the impact also existed in this study. So, future research may be concentrated in refining the presented approach to reduce the effects of the main uncertainties identified in the present study. The results of this study will then be used to study the impact of land use changes on the extreme peak flows (increased flood frequencies and flood risks), low flows and groundwater levels.

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