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LUCC and its impact on run-off yield in the Bai River catchment—upstream of the Miyun Reservoir basin

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Abstract

Aims

The Miyun Reservoir is the most important drinking water source for Beijing—the capital of China with a population of more than 16 million. Since the 1980s, the inflow to the reservoir has been decreasing, which seriously threatens the security of water use in Beijing. Our goal was to analyze the impact of land use and cover change (LUCC) on run-off yield in the upstream of the Miyun Reservoir.

Methods

In this study, the Soil andWater Assessment Tool (SWAT) was used to simulate the impacts of LUCC on the run-off yield in the Bai River catchment—upstream of the Miyun Reservoir basin in northern China. The investigation was conducted using two 6-year historical streamflow records: from 1986 to 1991 and from 2000 to 2005. A split sample procedure was used for model calibration and validation. The data from 1986 to 1988 and from 2000 to 2002 were used for calibration, while those from 1989 to 1991 and from 2003 to 2005 for validation. The SWAT calibration was based on monthly measured discharge at Zhangjiafen station at the catchment outlet from Bai River catchment. Additionally, the influence of LUCC on the surface run-off was distinguished from that of climate change on the surface runoff through SWAT scenarios modeling, the two-way analysis of variance (ANOVA), and the rainfall–run-off double-mass analysis in the Bai River catchment.

Important Findings

We found that the SWAT model could be used successfully to accurately simulate run-off yield and different LUCC patterns affecting water quantity in this catchment. During calibraion for the two periods the simulated monthly run-off satisfactorily matched the observed values, with the Nash–Sutcliffe coefficient >0.9 and 0.7 and a coefficient of determination of 0.9 and 0.65 at the outlet station (Zhangjiafen station), while during validation for the two periods the obtained values were 0.85, 0.65 and 0.9, 0.65, respectively. During the period of 1986–91, both the SWAT scenarios modeling and the analysis of the two-way ANOVA method showed that LUCC and climate change had some impact on run-off, and the impact of climate change was more significant than that of LUCC. Compared with the period during 1986–91, the run-off yield in the period during 2000–05 significantly decreased. The obtained results from the rainfall–run-off double-mass analysis indicate that since 1998 LUCC has had an increasing influence on the run-off, while the response of the run-off to rainfall has been decreasing. Since 1998, the LUCC has been a major driving force for run-off change in Bai River catchment.

Keywords: LUCC • Miyun Reservoir • run-off • SWAT • ANOVA

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INTRODUCTION

Land use and cover change (LUCC) is a key factor controlling the hydrological behavior of catchments (Hörmann *et al.* 2005) and is generally assumed to be responsible for changes in hydrological dynamics of catchments (Huismann *et al.* 2009, Asbjornsen *et al.* 2011). There are several different approaches to quantify the impacts of land use change on catchment

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hydrology including paired catchments approach, time series analysis and hydrological modeling. Paired catchments approach is often used to reveal differences in the hydrological behavior of similar catchments in context of different land use or land cover and may compensate for climate variability in small experimental catchments (e.g. Germer *et al.* 2009; Giertz *et al.* 2005). However, it is difficult to apply for any large catchments because of the difficulties in finding two similar medium or large-sized catchments (Lorup *et al.* 1998). Time series analysis is a statistical method that requires long-term data series, which is often not available, through examination of the gradual changes and associated changes in catchment properties or human impacts (Wang *et al.* 2009). Clearly, there is a need for use of a more comprehensive and physically based tool in order to obtain as much information as possible from limited existing data. The hydrological model application is the basis to gain knowledge on the cause-and-effect relationship between LUCC and hydrological change (Wagener 2007; Waring and Landsberg 2011).

The Bai River catchment situated in the upstream of the Miyun Reservoir is one of the important surface water sources of drinking water for Beijing. The catchment area is 9 227.5 km^2, lies between 115°25′–117°E and 40°25′–41°30′N, accounts for nearly 60% of the total area of the upper Miyun Reservoir basin (Fig. 1). Due to the decrease in incoming water from the upstream, the water level of the Miyun Reservoir has been declining continuously (Wang *et al.* 2004).

In this study, the physically based and distributed hydrological model Soil and Water Assessment Tool (SWAT) (Neitsch *et al.* 2005) is calibrated and validated for the Bai River catchment in the upstream of the Miyun Reservoir. Based on the SWAT simulation of relationship between precipitation and run-off, we analyzed the influence of human activity on run-off into the Miyun Reservoir and explored the influence of the LUCC spatial–temporal pattern on run-off generation. Moreover, the influence of the LUCC on the surface run-off was distinguished from that of climate change on the surface run-off through the rainfall–run-off double-mass analysis in the Bai River catchment. The study provides direct evidence for the planning of ecological construction projects and water resource management in northern China.

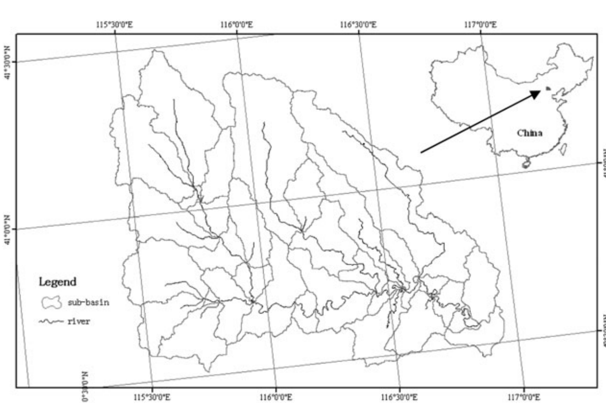

Figure 1: the location for the Bai River catchment.

ANALYSIS OF LUCC

With the support of ArcGIS9.2, the land use structure and land cover change of the Bai River catchment from 1990 to 2000 was obtained through overlay analysis of the Bai River catchment map and the land use maps for the three study periods. The grassland, farmland and forest are the main land use types in the Miyun Reservoir basin (Table 1). Specifically, grassland accounts for 28.4%, farmland for 22.2% and forest for 47.4% of the Bai River catchment in 1990, while these figures were 28.0%, 22.3% and 47.5%, respectively, in 2000, showing no significant changes between the two periods. The land cover composition in 1995 though was different, with 16.1%, 14.9% and 67.5%, respectively, for the three cover types (Pang *et al.* 2010). Overall, the vegetation cover remains high, which is mainly attributed to the long-time attention to the ecological construction of water source area. However, due to shallow soil layer, the region is prone to soil erosion.

MATERIALS AND METHODS

SWAT model input

Original digital spatial data in the study include digital elevation model (DEM) data, land use map, soil type map and river drainage map from the Data Center for Resources and Environmental Science Chinese Academy of Science (RESDC). The grid size of DEM is 100 × 100 m, and the land use and soil maps are correspondingly conversed to ESRI Grid format with the same spatial resolution. Because of the influence of the precision of DEM and human factors, the river network generated by the DEM might differ slightly from the real stream structure. Consequently, we revised the river network of DEM using a 1:250 000-scale drainage map by removing vector lines of stream banks and lake shorelines. All input spatial data were processed into a uniform geographic coordinate and projection to meet the demand of the SWAT simulation using the Albers equivalent conical projection.

Meteorological and hydrological data required to construct the SWAT model are shown in Table 2. The meteorological data include rainfall, daily mean temperature and solar radiation, etc. and have great influence on hydrological processes, crop growth and the transformation and degradation of the nutrient. The continuity of daily meteorological data has particularly prominent influence on the simulation results. Due to the insufficiency of monitoring stations and lack of monitoring data, it is necessary to build a random weather model (i.e. weather generator), which can be used to simulate given climatic conditions. Weather generator WXGEN embedded within the SWAT model is an effective tool to generate climate data and auto-complement missing data for SWAT modeling (Sharpley and Williams 1990), thus WXGEN is also the basis for simulation of the impact of climate change on the

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Table 1: the area of different land use types during 1990–2000

Year	Area and ratio	Farmland	Forest	Grassland	Water body	Urban	Virgin land
1990	Area (km^2)	2038.2	4362.6	2612.3	126.0	44.3	13.3
	Proportion (%)	22.2	47.4	28.4	1.4	0.5	0.1
1995	Area (km^2)	1372.6	6210.4	1481.7	89.2	36.1	6.7
	Proportion (%)	14.9	67.5	16.1	1.0	0.4	0.1
2000	Area (km^2)	2052.6	4368.6	2577.6	137.2	47.5	13.3
	Proportion (%)	22.3	47.5	28.0	1.5	0.5	0.1

Data source: we used the data sets developed by the Data Center for Resources and Environmental Sciences Chinese Academy of Sciences (RESDC) from the Landsat TM/ETM scenes with a spatial resolution of 30 × 30 m, and 520 scenes of remotely sensed images of Landsat TM/ETM were interpreted into land use/cover categories at scale of 1:100 000 under overall digital software environmental after being geo-referenced and ortho-rectified (Liu *et al.* 2002).

Table 2: meteorological and hydrological data

Data	Data item	Format	Station and location		Sources
Meteorological data	Precipitation, maximum and minimum temperature, solar radiation, sunshine percentage, weed speed and relative humidity	DbaseIII	Duolun	42°11′–116°28′	State Meteorological Administration
			Huailai	40°24′–115°30′	
			Zunhua	40°12′–117°57′	
			Zhangjiakou	40°47′–114°53′	
Hydrological data	Run-off	Text	Zhangjiafen	40°37′–116°47′	Hydrological Statistical Yearbook

hydrological processes and water quality. The weather generator used in the study was constructed on the basis of the meteorological data from the weather stations in Duolun, Huailai, Zunhua and Zhangjiakou counties, which are the nearest monitoring sites to the Bai River catchment.

Soil data for the SWAT model consist of two groups: soil physical data and soil chemical data. Physical properties of soil, including thickness, density, organic carbon, available effective water and saturated hydraulic conductivity, determine the movement of water and air in the soil profile and also play an important role in the water cycle of the hydrologic response units. Since the existing data are insufficient to build soil database for the SWAT model, some soil parameters (e.g. available effective water and saturated hydraulic conductivity) were estimated by the Soil-Plant-Atmosphere-Water (SPAW) program developed by the United States Department of Agriculture (Saxton *et al.* 1986; Saxton and Rawls 2005). SPAW can approximately simulate the spatial distribution of the soil parameters and the further results need to be refined in the process of the SWAT model calibration.

SWAT model evaluation criteria

At present, there are various evaluation criteria of the model efficiency and different efficiency criteria should be combined together to calibrate and validate the model. In this study, three well-accepted criteria: the comparison of hydrographs, Nash–Sutcliffe efficiency coefficient E_{NS} and deterministic coefficient r^2 are used to evaluate the model efficiency. Previous literature suggested that the simulation effect is good when $E_{NS} > 0.75$, average when $0.36 \leqslant E_{NS} \leqslant 0.75$ and not satisfactory when $E_{NS} < 0.36$. During the evaluation process, r^2 is combined with the curve slope fitted by the observed and simulated values b, when r^2 is used. We adopt the weight format of r^2, wr^2.

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \tag{1}$$

$$r^2 = \left(\frac{\sum_{i=1}^{n} (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^{n} (P_i - \bar{P})^2}} \right)^2 \tag{2}$$

$$wr^2 = \begin{cases} |b| \cdot r^2, & b \leqslant 1 \\ |b|^{-1} \cdot r^2, & b > 1 \end{cases} \tag{3}$$

where O_i and P_i are, respectively, observed and predictive value at the time i, is the average observed value, is the average predictive value, w is the weight factor and b is the slope of the fitted linear regression curve.

Sensitivity analysis, calibration and validation

The sensitivity analysis method implemented in SWAT is called the Latin Hypercube One-factor-At-a-Time (LH-OAT),

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Table 3: the sensitivity analysis of outflow in Zhangjiafen monitoring station

Parameters	Descriptions	Simulating processes
CN2[1]	Initial SCS CN II value	Surface run-off
SOL_AWC[4]	Available water capacity (mm H_2O/mm soil)	Soil water
SOL_K[9]	Saturated hydraulic conductivity (mm/h)	Soil water
ESCO[3]	Soil evaporation compensation factor	Evapotranspiration
ALPHA_BF[2]	Baseflow alpha factor (days)	Ground water
CH_K2[10]	Channel effective hydraulic conductivity (mm/h)	Surface run-off
SOL_Z[5]	Soil depth (mm)	Soil water
SURLAG[8]	Surface run-off lag time (days)	Surface run-off
CANMX[6]	Maximum canopy storage (mm)	Evapotranspiration
SLOPE[7]	Average slope steepness (m/m)	Soil water

The superscripts of each parameter are their corresponding orders of the sensitivity analysis of run-off. SCS, Soil Conservation Service, USDA.

which combines the strength of global and local sensitivity analysis methods (Griensven *et al.* 2006; Holvoet *et al.* 2005; Morris 1991). Table 3 shows the results of the sensitivity analysis of 10 parameters used in the simulation of outflow processes at Zhangjiafen monitoring station. The sensitivity analysis shows that initial Soil Conservation Service (US Department of Agriculture) CN II value (CN2) is the most sensitive parameter for outflow processes of Zhangjiafen gauging station. The sensitive parameters seemed to vary by catchment. These parameters were modified during the model calibration. After sensitivity analysis, both calibration and validation were done at monthly time step.

The SWAT model was calibrated and validated using the monitoring data from Zhangjiafen hydrological station (116°47′E, 40°37′N). The watershed area is ~8 506 km^2. There are two modeling periods: 1986–91 and 2000–05. The calibration was based on the observed data from 1986 to 1988 and 2000 to 2002, while the validation periods were from 1989 to 1991 and 2003 to 2005. Three well-accepted methods (i.e. comparison of hydrographs, Nash–Sutcliffe efficiency coefficient E_{NS} and the deterministic coefficient r^2) were applied in this study.

The time step for the run-off simulation in the two periods was set at 1 month. The E_{NS}, r^2 and b values for monthly run-off simulation for 1986–91 were 0.92, 0.92 and 1.01, respectively, in the calibration period and 0.87, 0.9 and 1.21 in the validation period (Table 4). The E_{NS}, r^2 and b for monthly run-off simulation for 2000–05 were 0.71, 0.67 and 0.94, respectively, in the calibration period and 0.67, 0.65 and 0.82 in the validation period. The simulation result for the first period is better than that for the second period, likely because human activities (e.g. cultivation, soil and water conservation, land use and management) were considered in the run-off simulation of the SWAT model. Overall the simulated results in the Bai River catchment have good agreement with the observed ones.

Two-way analysis of variance

Two-way analysis of variance (ANOVA) (Fujikoshi 1993; Rasch *et al.* 2009) was applied to analyze the significance of the impact of climate and LUCC on the run-off. Usually,

Table 4: the simulation results of run-off into Miyun Reservoir

	Zhangjiafen station		
Simulation period	E_{NS}	r^2	b
Calibration for 1986–88	0.92	0.92	1.01
Calibration for 2000–02	0.71	0.67	0.94
Validation for 1989–91	0.87	0.9	1.21
Validation for 2003–05	0.67	0.65	0.82

a two-way test generates three P-values, one for each parameter independently and one measuring the interaction between the two parameters. Additional, the F-test was also used to analyze the significant of the each factor at P = 0.05. The F-test is the mean square for each main effect and the interaction effect divided by the within variance. The numerator degrees of freedom come from each effect and the denominator degrees of freedom are the degrees of freedom for the within variance in each case. We can compare the F-value with the crit F-value at the different significant level and obtain the significance effect of the two factors on the observation.

RESULTS AND DISCUSSIONS

Significance of climate change and LUCC on run-off

There are three levels of climate and LUCC in our ANOVA. The three levels for climate change were identified based on the annual precipitation as the index as wet year (i.e. the guarantee rate > 70%), normal year (the guarantee rate is 30–70%) and dry year (the guarantee rate is <30%), while the three levels for LUCC were phase I and II, which represent the LUCC in the period of 1986–91 and 2000–05, respectively. The P-value of LUCC is 0.045, showing a significant difference among two levels of LUCC (Table 5). Similarly, climate change was also significant. The F-tests show that the F-values of the factors of climate change and LUCC are 34.81 and 20.19, while the F-values are 19 and 18.51, respectively. Therefore, the two

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Table 5: the results from two-way ANOVA

	Sum of squares	Degree of freedom	Mean square	*F*-value	*P*-value	*F* crit
LUCC	179.3067	1	179.3067	20.79722	0.044872	18.51282
Climate change	600.3233	2	300.1617	34.81481	0.027921	19
Error	17.24333	2	8.621667			
Sum	796.8733	5				

factors are all significant impact on run-off with the impact of climate change is more significant than that of LUCC.

Effects of LUCC on run-off into the Miyun Reservoir

The SWAT model is a distributed hydrological model that can simulate the response of LUCC to hydrology processes and a good platform for studying the effects of LUCC on water resources. Based on the analysis of the land use maps in the three periods, the areas of different land use types in 1995 change larger than those of 1990–2000, while these proportions of different land use type are similar in 1990 and 2000. We thus selected the land use data in 1990 and 1995 as the input of the SWAT for simulating run-off under the two LUCC scenarios (Table 6). The different sums of run-off into the Miyun Reservoir with the meteorological conditions of 1986–91 and the land use conditions of 1990 and 1995 are reported in Table 6.

Our simulations show that the run-off into the Miyun Reservoir declines slightly under the land use condition in 1995 compared with that in 1990. By contrast, the area of farmland and grassland in 1995 decreases by 7.3% and 12.3%, respectively, while that of the forest increases by 20.1%. The total area for the three land types accounts for over 80% of the whole river catchment, suggesting the land uses changed significantly from 1990 to 1995. However, according to the simulated results, the changes in average annual run-off from 1986 to 1991was minor with 4.0% decrease. Clearly, LUCC had little influence on the run-off into the Miyun Reservoir.

Table 6: the run-off from the Bai River catchment under different scenarios

Year	Run-off (10^8 m^3) LUCC-1990	LUCC-1995
1986	3.02	2.78
1987	4.22	4.06
1988	3.60	3.46
1989	3.19	3.15
1990	3.65	3.55
1991	4.77	4.53
Average	3.74	3.59

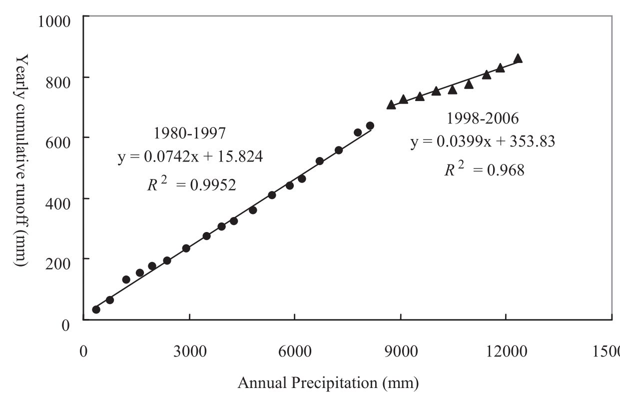

Figure 2: double-mass curve of annual rainfall and run-off in the Bai River catchment.

Rainfall–run-off change and related effects of LUCC

Double-mass analysis is a common method in time series analysis and for quantifying the trends change. The theory of double-mass curve analysis is that if data values for two variables change proportionally over time, a graph of the accumulation of one quantity against the accumulation of another quantity during the same time period will plot as a straight line (Alansi *et al.* 2009; Zhao *et al.* 2004). There seemed a point of inflexion of the double-mass curve in 1998 because the inflexion passed 99.9% confidence test (Fig. 2). Obviously, the total rainfall–run-off series can be divided into two stages: 1980–97 and 1998–2006. Between the two stages, the average annual run-off totally declined, while the rainfall increased. Thus, the response of the run-off to the rainfall also declined. On the other hand, the detected change proves the enhancing effect of LUCC. In 1980–97, the ecological construction activities that changed land cover in the Bai River catchment were limited, thus the LUCC impact on the relationship between rainfall and run-off in that period was relatively small. However, the fitting double-mass curve clearly deviates to the right after 1998 with its slope declining from 0.0742 to 0.0399. These evidences indicate that LUCC in the second stage is larger, and it increases the total evaporation and infiltration, weakens the run-off generation, so that the total run-off from the Bai River catchment decreases.

CONCLUSIONS

The SWAT modeling, ANOVA and the rainfall–run-off double-mass analysis were used to analyze the influence of LUCC on the surface run-off to distinguish the impact of climate change

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on the surface run-off in the Bai River catchment. The LUCC in the Bai River catchment include three main land use types: farmlands, forests and grasslands that are all under influences of agricultural activities. Our modeling exercises indicate that as a result of LUCC the annual average run-off generation in different land use decreased in 2000–05 compared to 1986–91. Based ANOVA, we found that both LUCC and climate change are significant factors for run-off, but the impact of climate change is more significant than that of LUCC during 1986–91. The SWAT scenarios modeling further showed that the LUCC has slight influence on annual run-off generation compared with climate change, and the increasing of forest from 1990 to 1995 weakened the surface run-off generation in the Bai River basin.

The impact of climate change and LUCC on the reservoir inflow can be better distinguished by using the rainfall–run-off double-mass curve to describe the tendency and variation of the annual run-off in the Bai River catchment. Our results indicate that since 1998 LUCC has had an increasing influence on the run-off, while the response of the run-off to rainfall has been decreasing. In sum, it seemed that the impact of the climate change on run-off in the Bai River basin is more significant than that of the LUCC before 1991. Since 1998, the influence of LUCC has gradually increased, which is in agreement with previous study of Wang *et al.* (2009).

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Conflict of interest statement. None declared.

REFERENCES

Alansi AW, Amin MSM, Halim GA, *et al.* (2009) The effect of development and land use change on rainfall-runoff and runoff-sediment relationships under humid tropical condition: case study of Bernam Watershed Malaysia. *Eur J Sci Res* **31**:88–105.

Asbjornsen H, Goldsmith GR, Alvarado-Barrientos MS, *et al.* (2011) Ecohydrological Advances and Applications in Plant-Water Relations Research: A Review. *J Plant Ecol* **4**:3–22.

Fujikoshi Y, *et al.* (1993) Two-way ANOVA models with unbalance data. *Discrete Math* **116**:315–34.

Germer S, Neill C, Vetter T, *et al.* (2009) Implications of long-term land-use change for the hydrology and solute budgets of small catchments in Amazonia. *J Hydrol* **364**:349–63.

Giertz S, Junge B, Diekkrüger B (2005) Assessing the effects of land use change on soil physical properties and hydrological processes in the sub-humid tropical environment of West Africa. *Phys Chem Earth* **30**:485–96.

Griensven AV, Meixner T, Grunwald S (2006) A global sensitivity analysis tool for the parameters of multi-variable catchment models. *J Hydrol* **324**:10–23.

Holvoet K, van Griensven A, Seuntjens P (2005) Sensitivity analysis for hydrology and pesticide supply towards the river in SWAT. *Phys Chem Earth* **30**:518–26.

Hörmann G, Horn A, Fohrer N (2005) The evaluation of land-use options in mesoscale catchments—prospects and limitations of eco-hydrological models. *Ecol Model* **187**:3–14.

Huismann JA, Breuer L, Bormann H, *et al.* (2009) Assessing the impact of land use change on hydrology by ensemble modelling (LUCHEM) III: scenario analysis. *Adv Water Resour* **32**:159–70.

Liu JY, Liu ML, Deng XZ, *et al.* (2002) The land use and land cover change database and its relative studies in China. *J Geogr Sci* **12**:275–82.

Lorup JK, Refsgaard JC, Mazvimavi D (1998) Assessing the effect of land use change on catchment runoff by combined use of statistical tests and hydrological modelling: case studies from Zimbabwe. *J Hydrol* **205**:147–63.

Morris MD (1991) Factorial sampling plans for preliminary computational experiments. *Technometrics* **33**:161–74.

Neitsch SL, Arnold JG, Kiniry JR, *et al.* (2005) *Soil and Water Assessment Tool Theoretical Documentation (Version 2005)*. Temple, TX: Grassland, Soil and Water Research Laboratory, Agricultural Research Service, and Blackland Research Center, Texas Agricultural Experiment Station 494.

Pang JP, Liu CM, Xu ZX (2010) Impact of land use change on runoff and sediment yield in the Miyun Reservoir catchment. *J Beijing Norm Univ (Nat Sci)* **46**:290–9.

Rasch D, Rusch T, Šimečková M, *et al.* (2009) Tests of additivity in mixed and fixed effect two-way ANOVA models with single sub-class numbers. *Stat Pap* **50**:905–16.

Saxton KE, Rawls WJ (2005) *Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions [EB/OL]*. http://users.adelphia.net/~ksaxton/SPAW%20Download.htm (16 August 2006, date last accessed).

Saxton KE, Rawls WJ, Romberger JS (1986) Estimating generalized soil-water characteristics from texture. *Soil Sci Soc Am J* **50**:1031–6.

Sharpley AN, Williams JR (1990) *EPIC-Erosion Productivity Impact Calculator, 1. Model Documentation*. Washington, DC: Agricultural Research Service, USDA.

Wagener T (2007) Can we model the hydrological impacts of environmental change? *Hydrol Process* **21**:3233–6.

Wang G, Xia J, Chen J (2009) Quantification of effects of climate variations and human activities on runoff by a monthly water balance model: a case study of the Chaobai River basin in northern China. *Water Resour Res* **45**:W00A11, doi:10.1029/2007WR006768.

Wang XY, Wang XF, Wang QP (2004) Estimation of nonpoint source pollution load in the Miyun Reservoir catchment. *J Geogr Sci* **24**:227–31.

Waring RH, Landsberg JJ (2011) Generalizing plant water relations to landscapes. *J Plant Ecol* **4**:101–113.

Zhao WW, Fu BJ, Meng QH (2004) Effects of land use pattern change on rainfall-runoff and runoff-sediment relations: a case study in Zichang Watershed of the Loess Plateau of China. *J Environ Sci* **16**:436–42.

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