Case Study

Evaluation of Runoff Responses to Land Use Changes and Land Cover Changes in the Upper Huaihe River Basin, China

Qu Simin[1]; Bao Weimin[2]; Shi Peng[3]; Yu Zhongbo[4]; Li Peng[5]; Zhang Bo[6]; and Jiang Peng[7]

Abstract: Runoff changes in response to land use and land cover changes in the Huaihe River were drastic in the last few decades and are poorly understood because results from those studies are often equivocal. Hitherto, the methodology to quantify the effects of land use and land cover changes on the runoff response has been mainly the paired catchment approach, which is a blackbox, and usually restricted to small headwater basins where a control can be established. A model-based change-detection approach is developed in this study as an alternative to paired catchment methods. This approach is particularly suited to evaluating effects of land use and land cover changes on the hydrologic response in large to mesoscale watersheds in which suitable control is not possible. The Xinanjiang model was used to evaluate the newly implemented approach in the Dapoling watershed (with an area of 1,640 km^2) in the upper Huaihe river basin. Three schemes were used to examine changes in the data series: (1) Calibration for a period before (or after) changes and simulations of runoff that would have been observed without land use and land cover changes (reconstruction of runoff series); (2) comparison of calibrated parameter values for periods before and after the land use and land cover change; and (3) comparison of runoffs simulated with parameter sets calibrated for periods before and after the landcover change. The results show that, since 1976, the medium-coverage and high-coverage natural forest area has decreased, and the corresponding runoff has declined by nearly 25% from 1976 to 2005 attributable to the continuous expansion of tea gardens and human development. Model parameters, for example, the evapotranspiration coefficient KC, varied considerably from 0.64 to 0.94 attributable to the land use and land cover change within the watershed. This study demonstrates that the modeling approach may be a useful alternative to the paired watershed approach for examining land use and land cover changes and their impact on the runoff. **DOI:** 10.1061/(ASCE)HE.1943-5584.0000397.

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Introduction

With the continuous expansion of human development, dramatic changes have taken place on a global scale in land use and land cover patterns in catchments. The impacts of land use and land cover change on environment and sustainable development has received widespread concern (Potter 1991; Vorosmarty et al. 2000). On a catchment scale, such impacts on hydrological processes such as infiltration, recharge of groundwater, and runoff are reflected in the balance of supply-and-demand of water resources and water quality, which in turn significantly affect ecosystems, environment, and economy. Consequently, a better understanding of the impacts of land use and land cover change on hydrological processes is crucial for effective planning, management, and sustainable development of water resources. Although there is a long recognition of the simple but hard fact that changes in land use and land cover affect water cycle and the spatiotemporal variation of water resources, the quantitative relation between land use and land cover change and runoff generation is poorly understood. There are some difficulties in quantifying the hydrological consequences of land use change, for example, (1) the relatively short records of hydrological data; (2) the relatively high spatial and temporal variability of hydrological system; (3) the difficulties in controlling land-use change in real catchments; (4) the shortage of controlled small-scale experiments; (5) challenges in extrapolating or generalizing results from such studies to other basins. Given the complexity and diversity of land use change, it is important to choose appropriate methods to quantify the hydrological consequences of land use change.

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Earlier research that has investigated the consequences of land use change for hydrologic processes primarily focused on paired watershed approach (Schnorbus et al. 2004). In this approach, watershed is monitored pre-land use and post-land use change, and then statistical tests of hypotheses are applied to determine if land use change has affected the hydrological responses of the watershed. The paired watershed approach is helpful to advance our mechanistic understanding of the interaction of plant-soil-atmosphere, nevertheless there are some limitations (DeFries and Eshleman 2004); for instance, (1) many of the results derived from statistical analysis are equivocal and contradictory because of limited data availability; (2) there is a lack of control in the control basin; (3) the nature of the approach is that of cause-effect; (4) the approach is restricted to small, headwater basins. Probable reasons for this are (1) the difference attributable to land use change is usually smaller in large catchments than in small watersheds; (2) two small neighboring watersheds might receive a similar climatic input, whereas this becomes more unlikely for larger catchments.

Hydrological models for evaluating hydrological consequences of land use change at multiple scales have advanced at a rapid rate in recent years, owing largely to computer technology improvements. Modeling of land use change had rapidly evolved from black-box model (only concerned input and output, lack of physical understanding of hydrological processes) to distributed hydrological models (Refsgaard and Storm 1996) (demand of abundant observational data limited its application). Owing to its simple structure, easy accessibility to data, and satisfactory simulation results, the conceptual rainfall-runoff model (Beven and Kirkby 1979; Zhao 1984; Bergström 1976, 1992) has been widely used to assess land use effects on hydrology. Most of the studies on hydrological consequences of land use change are based on watershed hydrological model (Wang et al. 2006; Zhang et al. 2004; Yuan and Shi 2001; Jiang et al. 2004; Burns et al. 2005; Wan and Yang 2004). Most notable are studies of the effects of forest management practices. For example, forest cutting usually causes increases in water yield and flood peaks. However, studies of urbanization and agricultural management practices are much less common.

In a similar context, most of the studies on land use change effect on hydrological processes using hydrological models are based on analysis of residuals. This approach is sensitive to errors in precipitation and runoff observations during a single event. The main objective of this paper is to evaluate runoff responses to land use and land cover changes in the Dapoling watershed. Specifically the writers present a study that examines the change of model residuals, model parameters, and model simulations between different periods. The writers explore how land use and land cover changes affect runoff mechanisms through the comparison. In addition, the writers determine land use and land cover change from remote sensing data and compare it with results from modeling approach.

Study Catchments

The Huai River is located between latitudes 31°N and 35°N and longitudes 112°E and 121°E. It originates in the Tongbai Mountains of Henan province, flows into the Yangtze River, and covers four provinces. The length of the main channel of the Huai River is 1,000 km, and the total area of the watershed is $1.912^{*}10^{5}$ km^2. The Huai River can be divided into the upper, middle, and lower streams. The upper reaches around Wangjiaba, with a catchment area of 3.08×10^4 km^2, are regarded as the upper stream, where the channel bed slope and the flow velocity are large. Xixian stage is situated in the upper reaches of the Huai River. Xixian basin is located in the south of Henan province with a catchment area of 10,191 km^2. Most of the soils are light silty loam and sandy loam soil, a little part is underlain by silt clay (The Huaihe River Commission 2002). The main crops grown in the catchments are rice and wheat. Xixian basin is situated in the transition zone of northern subtropical region and warm temperate zone. Rainfall for the flood season is mainly affected by monsoon; and the long-term mean annual precipitation is 1,145 mm (calculated by the data from 1954 to 2000). Half of the precipitation (~50%) falls between June and September. Two large-size reservoirs, called Nanwan and Shishankou reservoir, and six middle-size reservoirs can be found in the basin. Dapoling station is chosen for study in this paper, which is situated in the upper reaches of Xixian basin with drainage basin of 1,640 km^2; the length of its main channel is 73 km (Fig. 1). In Fig. 1, DPL means Dapoling station, CTG means Changtaiguan station, ZGP means Zhuganpu station, and XX means Xixian station. The basin is covered mainly by hills. The river flows over a mountainous terrain with many tributaries and large slope; it is intermittent and vulnerable to zero flow in the dry season. There are not so many water conservancy projects in the basin, and rice is the dominant crop grown there.

Methods Data

Dapoling basin is chosen for land use and land cover change study in this paper; it has an area of 1,640 km^2. The basin is serviced by 13 precipitation stages and one discharge stage (Dapoling stage). There is no evaporation stage in this catchment; because of this, the Nanwan evaporation stage data are used for evaporation calculation. Series of observed data included daily precipitation of 13 rainfall stages, daily evaporation of Nanwan stage, and daily discharge of Dapoling stage from 1964 to 2005. Considering the need for a representative period for calibration and a suitable resolution for the detection of land use and land cover change effects, the total series were divided into 10-year periods, four periods in all: from 1964 to 1975, 1976 to 1985, 1986 to 1995 and 1996 to 2005. Other data for this study were generated or collected as follows: (1) the land use map of three periods (1980s, 1990s, and 2000s) was provided by Chinese Academy of Science; (2) climate data during 1964–2005 including daily maximum and minimum air temperature, wind speed, solar radiation, and relative humidity at two stations (Xinyang and Yingshan).

Xinanjiang Model

Xinanjiang model (Zhao 1984) was developed in 1973 by R. J. Zhao (in Hohai University, China). The model can basically be used for forecasting flood, runoff, and stream flow over a catchment. Initially the model was calibrated using the hydrological data obtained from the catchment of Xinanjiang reservoir. Use of the model has also spread to other fields of application such as water resources estimation, design flood and field drainage, water project programming, hydrological station planning, water quality accounting, etc.

On the basis of the model structure, runoff was separated only into two components (that is, direct runoff and groundwater runoff) using Horton concept of the final, constant, infiltration rate (Horton 1933). But in 1970, the model was modified using three components of runoff as surface runoff, interflow, and groundwater flow (Dunne and Black 1970). The main feature of the model is the concept of runoff formation on repletion of storage, which means that runoff is not produced until the soil moisture content of the aeration

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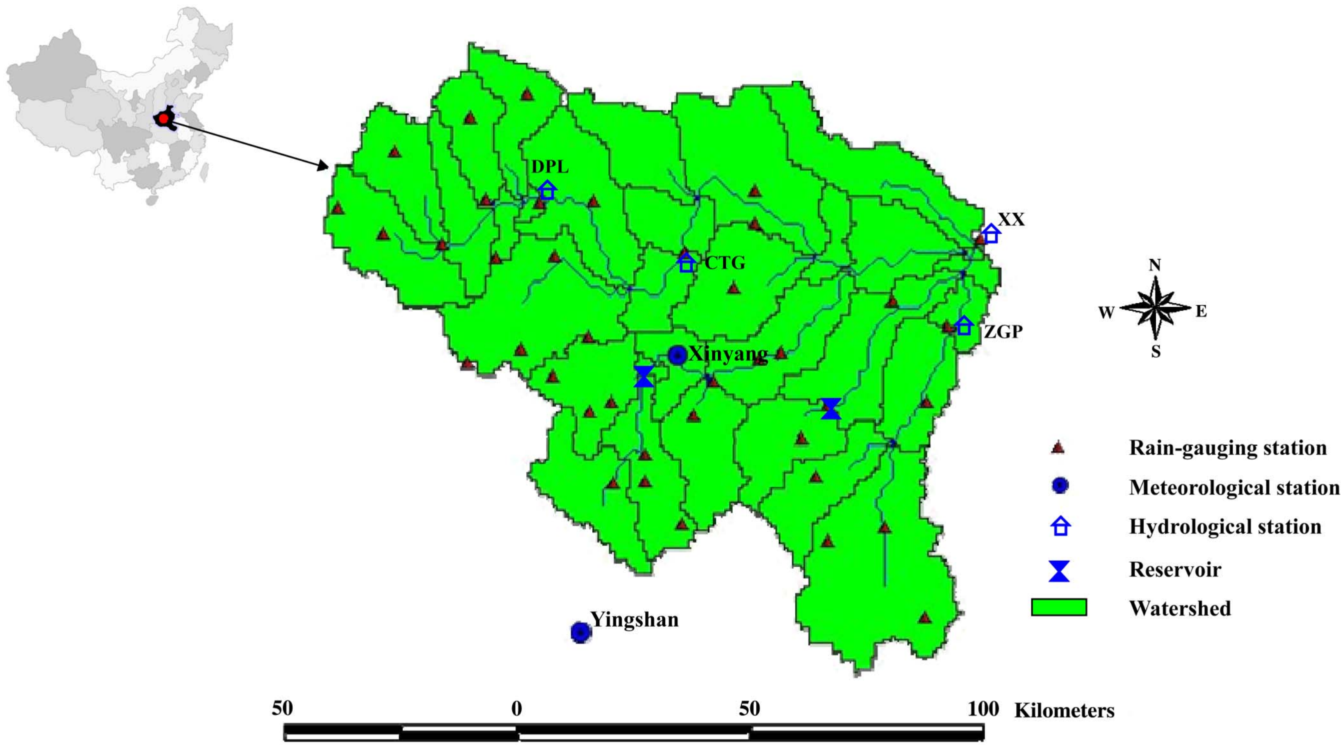

Fig. 1. Location of the study watershed

zone reaches the field capacity and thereafter runoff equals the rainfall excess without further loss. The validity of the model for excellent results is limited for humid and semihumid regions (Qu et al. 2007).

The inputs to the model are areal mean rainfall (P) and measured pan evaporation (EM). The outputs are the discharge from the whole basin (TQ) and the actual evapotranspiration (E), which includes the three components from upper (EU), lower (EL), and deeper (ED) layers. The state variables are the areal mean free water storage (S) and the areal mean tension water storage (W), which has three components WU, WL, and WD in the upper, lower, and deeper layers, respectively. RB is a direct runoff from impervious area and FR is the runoff contributing area factor that is related to W. The runoff produced from pervious area (R) is divided into three components, RS, RI, and RG, referred to as surface runoff, interflow, and groundwater flow, respectively. The three components are further transformed into QS, QI, and QG and together form the total inflow to the channel network of the subbasin. More detailed descriptions of the model can be found elsewhere (Qu et al. 2007). Basically, the whole basin is divided into a set of subbasins. The outflow from each subbasin is first simulated and then routed down through channels to the main basin outlet. On the basis of the concept of runoff formation on the repletion of storage, the simulation of outflow from each subbasin consists of four major parts, namely:

- The evapotranspiration, which generates the deficit of the soil storage (divided into three layers: upper, lower and deeper);
- The runoff production, which produces the runoff according to the rainfall and soil storage deficit;
- The runoff separation, which divides the previously determined runoff into three components: surface, subsurface, and groundwater;
- The flow routing, which transfers the local runoff to the outlet of each subbasin forming the outflow of the subbasin.

Normally, the soil moisture deficit often varies from place to place. To provide a nonuniform distribution of tension water capacity throughout the basin, a tension water capacity curve has been introduced in Xinanjiang model.

There are 14 parameters used in Xinanjiang model. Additionally, another two parameters are used for flow routing along the main rivers (see Table 1 for a list of the 16 model parameters). Generally the output is more sensitive to seven parameters (Zhao 1984; 1992) these are K, SM, KG, KI, CG, CS, and L.

Parameter Calibration

The Xinanjiang model was applied in the Dapoling watershed. The daily precipitation data (P) at each rainfall station and potential evaporation (EM) data at evaporation stations were used as inputs for the Xinanjiang model to simulate the discharge at Dapoling station.

For those insensitive parameters, some empirical values were assigned for them. But those sensitive parameters need to be calibrated according to the calibration criteria (Zhao 1984, 1992). The parameters of Xinanjiang model were calibrated on the basis of historical daily data at Dapoling station. The objective of daily Xinanjiang model is to keep water balance between years. Errors EE_i and relative residuals ER_i, between observed (R_{obs}) and simulated (R_{sim}) annual runoff are computed for each year:

$$EE_i = R_{\mathrm{obs},i} - R_{\mathrm{sim},i} \tag{1}$$

$$ER_i = \frac{R_{\mathrm{obs},i} - R_{\mathrm{sim},i}}{R_{\mathrm{obs},i}} \tag{2}$$

where $i = i$th year. If the average of ER_i is approximately zero and the sum of EE_i is the minimum, the calibration procedure stops. Additionally, Nash-Sutcliffe coefficient (DC) is calculated to evaluate the performance of discharge hydrograph simulation (Nash and Sutcliffe 1970).

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Table 1. Model Parameters and Variation Ranges

Parameter	Explanation	Unit	Lower bound	Upper bound
	Evapotranspiration calculation			
KC	Ratio of potential evapotranspiration to the pan evaporation		0.6	1.2
WUM	Tension water capacity of upper layer	mm	5	20
WLM	Tension water capacity of lower layer	mm	60	90
C	Deeper evapotranspiration coefficient		0.08	0.18
	Runoff generation calculation			
WM	Areal mean tension water capacity	mm	120	220
B	Exponential of the distribution of tension water capacity		0.1	0.4
IMP	Ratio of impervious area to the total area of the basin		0.01	0.02
	Water source separation			
SM	Free water storage capacity	mm	10	50
EX	Exponential of distribution water capacity		1	1.5
KG	Outflow coefficient of free water storage to the groundwater flow		0.2	0.6
KI	Outflow coefficient of free water storage to the interflow		0.2	0.6
	Concentration calculation			
CS	Recession constant of surface water storage		0.4	0.7
CI	Recession constant of interflow storage		0.5	0.9
CG	Recession constant of groundwater storage		0.990	0.998
KE	Residence time of water	*h*	0.5	1.5
XE	Muskingum coefficient		0	0.5

Change Detection

Three different methods are used to evaluate the land use and land cover effects on hydrological processes in Dapoling basin. First, time series of discharge are simulated and model residuals of different periods examined to check the variation in trend. Second, the best calibrated parameters of different periods are compared. Finally, comparison of the results for daily discharge simulation is done; this is achieved by using the best calibrated parameters for different time periods.

Model Residuals

Under the assumption that if the underlying surface characteristic of the basin remains unchanged, the runoff generation and concentration mechanism should be consistent, watershed modeling can be used to evaluate the land use and land cover change effect on hydrological processes by simulating time series of the discharge. The total series is divided into two periods, one is reference period A (before land use change) and the other is period B (after land use change).

If the underlying surface condition of the basin is continually consistent without any significant influence of human activity in a long period, values of ER_i should scatter around zero for years, i.e., obeying the normal distribution. Nevertheless, if the underlying surface condition is greatly influenced by human activity, such as land use change, model residuals will deviate from normal distribution and show some trend variation. The series of discharge from 1964 to 2005 were simulated by using the parameters calibrated for the reference period, from 1964 to 1975. Subsequently, model residuals of different periods were examined to check the variation in trend. For statistical analysis of the results, the nonparametric Wilcoxon rank-sum test was used to test whether there was a change in annual runoff between the two periods.

Parameters Comparison

Model parameters might be different when the model is calibrated to different time periods. The Xinanjiang model consists of 16 parameters and seven of them (K, SM, KG, KI, CG, CS, and L) are very sensitive to the calibration process (Zhao 1984, 1992). As a result, the calibration process is a time-consuming task. To reduce this complexity, a methodology for system decomposition and degeneration of dimensionality has been developed in the calibration of the Xinanjiang model. By decomposition, the model structure is analyzed hierarchically. The calibration is carried out from lower to higher hierarchy; to this end, different objective functions are used for different levels. The objective of degeneration is to reduce the number of parameters being optimized simultaneously to three or less. The reduction is based on the sensitivity analysis and structure constraint. For example, there are daily and hourly models for the Xinanjiang model. The objective function for the daily model is to keep the mean annual water balance, which means KC is the most important parameter that needs to be calibrated. Those insensitive parameter values (e.g., WUM, WLM, C, and so on) can be chosen by experience. In this study, daily model is used to calibrate the parameters. Obviously, differences in KC values are expected when there has been a land use and land cover change. Again, the Wilcoxon rank-sum test was used to test for changes in the parameter values.

Model Simulations Comparison

Another approach to evaluate land use and land cover change effect on hydrological processes is to run the model for some periods and compare the simulated runoff. In this study, daily precipitation of 13 rain gauges and evaporation of Nanwan gauge were used as the input data, whereas daily discharge was simulated with different parameter sets for different periods. The procedures briefly entail the following steps:

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1. Select the best parameter set for each period j (before and after a land use and land cover change).
2. Simulate daily discharge for the entire period using all the parameter sets.
3. Compare the simulations (i.e., using parameter set from the different period j).

Similar to the calculation of relative residuals, relative deviations, RD_j, between annual runoff simulated by the different parameter sets are computed as:

$$RD_j = \frac{R_{\mathrm{simA},j} - R_{\mathrm{simB},j}}{(R_{\mathrm{simA},j} + R_{\mathrm{simB},j})/2} \tag{3}$$

where R_{simA} and R_{simB} = annual runoff simulated with parameter sets selected based on period A with respect to period B.

Results and Discussion

Runoff Response in Dapoling Basin

On the basis of the results, it is evident that the Xinanjiang model has the potential to reproduce the observed runoff robustly well. Although the model efficiencies for the total series are not satisfactory, from 0.307 to 0.462; the probable reason for this could be that the daily model only maintains a balanced water volume at the expense of the overall model simulation efficiency. Most of the annual relative residuals are scattered around zero before land use change and varied in the range of 20% except for one point (Fig. 2). The total relative residual for the period 1964 to 1975 is zero, whereas that for the period 1976 to 1985 is 3.8% (Table 2); both are less than 5%. However, it is not the case for the period after land use change (1986 to 2005). The total relative residual for the period 1986 to 1995 stands at 13% (Table 2), more than 10%.

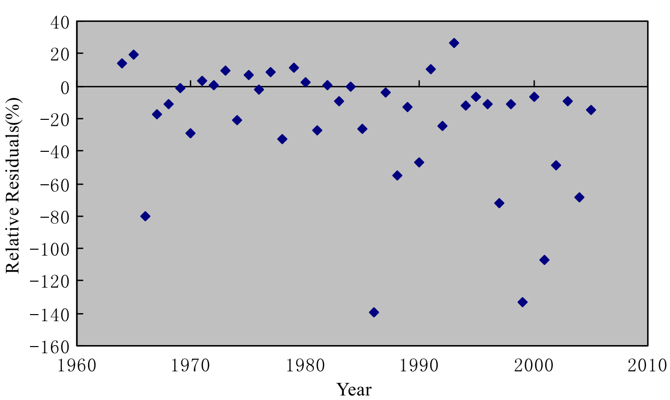

Fig. 2. Comparison of relative residuals for different periods (one point in the plot represents one year; reference period is from 1964 to 1975, the other period is from 1976 to 2005)

Table 2. Calibration for 1964–1975 Period and Simulation Results from Different Periods

Period	R_{obs}(mm)	R_{sim}(mm)	ER(%)	DC_{ave}[a]
1964–1975	4877	4870	0	0.462
1976–1985	3847	3994	−3.8	0.441
1986–1995	2979	3366	−13.0	0.307
1996–2005	4037	5071	−25.6	0.348

[a]DC_{ave}: Average of Nash-Sutcliffe coefficient of daily discharge for every year.

Additionally, the relative residual for the period 1996 to 2005 is 25.6%, larger than the value for the pre-land use change period (Table 2); precisely more than 20%. Although most of the annual relative residuals are still scattered around zero for post-land use change period, there are some points that are out of the range, i.e., > 20% (Fig. 2); the presence of outliers in this case indicate pronounced effect of human activities and anthropogenic variation resulting in change in land regime. The relative residuals differed significantly from those of the calibration period (1964 to 1975). The analysis of relative residuals shows significant decrease of annual runoff after 1986 corresponding to land use change; it implies that orchards or tea gardens consume more water and enhance more evaporation than the forest.

Even were there no land use change data, the scenario is evident as shown in Fig. 2. The same results can also be obtained through the analysis of precipitation-runoff relation curve of Dapoling basin for different time periods (Fig. 3). The slope of precipitation-runoff relation curve after land use change is smaller, indicating that the same climatic input (precipitation and evaporation) causes less output (runoff). Because of limited data availability, daily runoff is simulated by Xinanjiang daily model. In any future study, peak flood response can be compared to reflect the change of concentration processes.

Parameter Change Detection

Every parameter of the conceptual hydrological model has physical meaning; for example, KC of Xinanajing model, means the ratio of potential evapotranspiration to the pan evaporation. If KC increases, that means increase of evaporation, which will cause a decrease of runoff. The results in this study indicate a distinct pattern in the parameter changes. Most significant is the change of the ratio of potential evapotranspiration to the pan evaporation, KC; there is an obvious increase from 0.64 to 0.94 (Table 3). Higher ratio means higher evapotranspiration of the basin, which causes a decrease in runoff. Although the sum of outflow coefficient of free water storage to the groundwater flow, KG, and outflow coefficient of free water storage to the interflow KI is maintained constant, the single value of each parameter has changed. KI changed toward a larger proportion (increase of interflow), whereas KG decreased from 0.35 to 0.28 (Table 3), causing higher peak flows but also a quicker recession.

Model Simulation Comparison

Land use change effect on hydrological processes can also be evaluated by simulation of the same runoff series using the same climatic input but different parameter sets. If the difference is large,

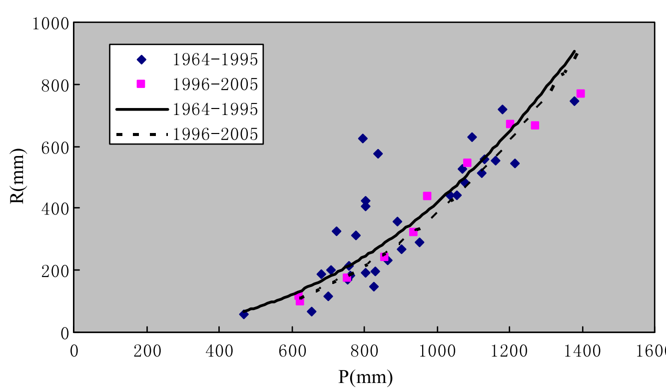

Fig. 3. Precipitation-runoff relationship curve (Dapoling station) (P = precipitation; R = runoff; these are annual sums of each year)

Table 3. Comparison of Parameters Calibrated for Different Periods

Parameter	1964–1975	1976–1985	1986–1995	1996–2005
KC	0.64	0.66	0.70	0.94
WUM	20	20	20	20
WLM	80	80	80	80
C	0.16	0.16	0.16	0.16
WM	150	150	150	150
B	0.3	0.3	0.3	0.3
SM	15	15	15	15
EX	1.5	1.5	1.5	1.5
KG	0.35	0.30	0.30	0.28
KI	0.35	0.40	0.40	0.42
CS	0.45	0.45	0.45	0.45
CI	0.88	0.88	0.88	0.88
CG	0.995	0.995	0.995	0.995
KE	1	1	1	1
XE	0.38	0.38	0.38	0.38

it implies that some land use change has occurred in the basin, whereas if the difference is small, it connotes no significant land use change has occurred. The total observed runoff series were simulated on the same climatic input series, such as precipitation and evaporation, using the parameter sets calibrated for pre-land use and post-land use change period. This is illustrated by simulating the runoff series using the parameter set for the period 1964 to 1975; the simulation results clearly show a seeming decrease in quality when parameter set from the period 1996 to 2005 was used (Fig. 4). This indicates that the underlying surface of the catchment system has changed a lot, toward runoff decreasing direction. For the 10-year period simulation, the difference is negligible for the period following the first 10-year period (1976 to 1985); however, the difference is more than 10% for the period 1986 to 1995 and goes to more than 20% for the last 10-year period (1996 to 2005) (Table 4), which implies that some land use change occurred after 1986 but became more significant after 1995. This is important to flood management and environmental implication, which means when establishing the water resources programming of this region, the decrease of runoff by land use change should be considered.

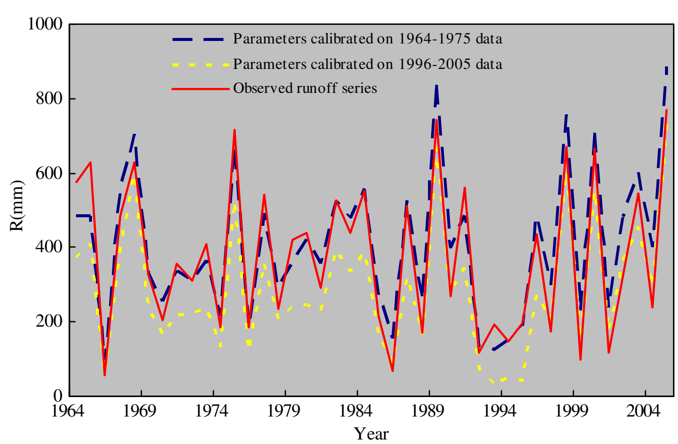

Fig. 4. Comparison of simulation results using the same parameters calibrated for different periods

Table 4. Simulation of Runoff using Different Parameter Set (Relative Differences when Using Parameter Sets Determined Based on Other Periods)

Period used to select first group of parameter sets	Period used to select second group of parameter sets: 1964–1975	1976–1985	1986–1995	1996–2005
1964–1975	0	0.029	0.117	0.224
1976–1985		0	0.034	0.203
1986–1995			0	0.175
1996–2005				0

Table 5. Land Use Changes in the Xixian Basin for Three Periods

Land use	Percentage (%) 1980s	1990s	2000s
Water	0.9	0.78	1.32
Urban	0.63	0.51	0.88
Woodland	38.55	40.69	38.06
Paddy field	17.02	27.23	17.15
Farmland	41.85	30.38	41.81
Grassland	0.57	0.06	0.54

Table 6. Statistics for Annual Rainfall, Temperature for Different Periods in Dapoling Watershed

Variables	Rainfall (mm)		Temperature (°C)	
Periods	1	2	1	2
Time	1964–1994	1995–2005	1964–1994	1995–2005
Length of record	31	11	31	11
Mean value	1109.9	1100.1	15.6	16.2
Max value	1515.4	1443.1	16.5	16.8
Min value	665.1	575.1	15.0	15.4
Standard deviation	221.69	260.68	0.42	0.50
Coefficient of variation				

Land Use Change

The dominant land use types of the Xixian watershed were farmlands and woodland (Table 5), which accounted for approximately 41.85% and 38.55% in 1980s, 30.38% and 40.69% in 1990s, 41.81% and 38.06% in 2000s, respectively. Table 5 shows that the main change of land use types between 1980s, 1995, and 2000s is the crossing over between farmland and paddy field. Compared with 1980s, paddy field increased from 17.02% to 37.23%, and farmland decreased from 41.85% to 30.38% in 1990s. Compared with 1990s, paddy field decreased from 37.23% to 17.15%, and farmland increased from 30.38% to 41.81% in 2000s, similar to the 1980s situation. Other changes in land use are insignificant.

Changes in Temperature and Rainfall

Statistics for the annual temperature, rainfall, and stream flow for different periods are listed in Table 6. Between periods 1 and 2, the mean values of annual temperature and rainfall increased by 0.6°C and 0.2 mm, respectively.

Conclusions

The effect of human activity (i.e., land use change) on hydrological processes in catchments has gained tremendous attentions all over

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the world; however, it remains poorly understood despite decades of researches and studies. Interestingly though, the runoff process of the outlet is the comprehensive response of the whole basin system to the input, precipitation, and thus invariably, the change of underlying surface in the basin precipitates a corresponding change of system response. In appreciation of this fact, a lot of studies focus on using change of output (i.e., runoff change) to reflect the variation in the underlying surface behavioral pattern (i.e., land use and land cover). Toward this end, hydrological modeling has become an effective method to exploring this change phenomenon. The results in this study showed that Xinanjiang model can simulate daily runoff well and bring to the fore details of the land use and land cover change; land use change leads to the decrease of runoff by nearly 25% from 1976 to 2005, it implies that the present land use pattern consumes more water and enhances more evaporation, which is contrary to some findings (Guo et al. 2006). In addition, the writers can point out when the land use change starts from the model residuals, which is consistent with the results from remote sensing data analysis. In the future, other widely applied hydrological models in China, for example, vertical-mixed runoff model, can be used to simulate the runoff, which may be compared with that of the Xinanjiang model.

Most of the studies (e.g., Guo et al. 2006; Li et al. 2007) use hydrological models to evaluate the land use change effect on hydrological processes focused on the output (i.e., runoff). But in reality, the best parameter set calibrated for different periods can also reflect the change of the system, for example, the parameters of KC, KI, KG in the Xinanjiang model. The increase of KC means higher evapotranspiration in the upper Huaihe river basin, which causes a decrease in runoff. The increase of KI and the decrease of KG in Dapoling basin reveal that the present land-use pattern cause high peak flows and quicker recession. Because of limited data availability, only evaporation and runoff calculation parameters have been compared, whereas water source separation and concentration parameter were not. For every model, parameter uncertainty problem exists; and how to reduce parameter uncertainty in hydrologic models used for forecasting still constitutes a herculean problem. In future study, parameter uncertainty will be considered in land use change detection.

The same series of runoff is simulated using different parameter sets calibrated on different time periods and the results compared. This can also be an alternative method for evaluating land use change in the basin. From the study in Dapoling basin, the upper basin of Huaihe river, it is evident that watershed hydrological modeling is not only useful for model development but to predict the land use change in the basin.

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