Assessing the impacts of land use changes on watershed hydrology using MIKE SHE

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Abstract A fully distributed, physically-based hydrologic modeling system, MIKE SHE, was used in this study to investigate whole-watershed hydrologic response to land use changes within the Gyeongancheon watershed in Korea. A grid of 200 × 200 m was established to represent spatial variations in geology, soil, and land use. Initial model performance was evaluated by comparing observed and simulated streamflow from 1988 to 1991. Results indicated that the calibrated MIKE SHE model was able to predict streamflow well during the calibration and validation periods. Proportional changes in five classes of land use within the watershed were derived from multi-temporal Landsat TM imageries taken in 1980, 1990 and 2000. These imageries revealed that the watershed experienced conversion of approximately 10% non-urban area to urban area between 1980 and 2000. The calibrated MIKE SHE model was then programmed to repeatedly analyze an artificial dataset under the various land use proportions identified in the Landsat TM imageries. The analysis was made to quantitatively assess the impact of land use changes (predominantly urbanization) on watershed hydrology. There were increases in total runoff (5.5%) and overland flow (24.8%) as a response to the land use change.

Keywords MIKE SHE · Streamflow · Hydrologic impact · Land use change · Satellite imageries

Introduction

Rapid economic development over the past several decades in Korea has caused rapid and uncontrolled expansion of towns and cities, loss of natural vegetation and open space, and a general decline in extent of wetlands and wildlife habitat. Changes in land cover and land use frequently result in significant impacts to hydrology by affecting the amount of runoff, soil moisture, and groundwater recharge over a range of temporal and spatial scales (Calder 1992; Im et al. 2003). However, the hydrologic effect of alteration in land use at a watershed scale is still an unresolved problem and is now a primary concern of most developing countries, which are commonly experiencing changes in land use patterns caused by increasing populations and demand for accommodations.

In recent years different types of hydrological models are being used to quantify the effects of land use changes on hydrological cycle (Fohrer et al. 2001; Lørup et al. 1998). Lørup et al. (1998) used the lumped hydrological model, NAM, to assess the long-term impacts of land use changes on runoff in six medium-sized (200–1,000 km²) rural watersheds in Zimbabwe. The NAM hydrological model was utilized to distinguish between the effects of climate variability and the effects of land use changes. On the same way, Wegehenkel (2002) applied the calibrated

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THESEUS model with afforestation scenarios in assessing the impact of land use changes on a watershed hydrology. The investigation found a significant discharge reduction and an increase in evapotranspiration. A few more attempts to implement lumped hydrological models for quantitative assessment of the influence of land use change have been reported (Hundecha and Bárdossy 2004; Siriwardena et al. 2006). A lumped model has been successfully applied to predict effects of land use changes on watershed hydrology around the world. Nevertheless, the hydrological processes are not well represented. Kuczera et al. (1993) and Beverly et al. (2005) stated that a particular care must be taken when applying such a model in a large watershed due to limitations in the conceptualization of hydrological processes involved.

Distributed physically-based models have the predictive capacity to assess the effect of land use changes on runoff across a range of scales, but require more intensive input data (Beven 1989; Refsgaard 1997). Typical examples of the distributed physically-based models are the Distributed Hydrology Soil Vegetation Model (DHSVM) (Thanapakpawin et al. 2007), THALES (Grayson et al. 1992), SHETRAN (Ewen and Parkin 1996), and MIKE SHE (DHI 1999). These models contain equations which have originally been developed for point scales and which provide detailed descriptions of flows of water and solutes. The variability of watershed characteristics is accounted for explicitly through the variations of hydrological parameter values among the different computational grid points (Refsgaard 1997). Recently, Thanapakpawin et al. (2007) used the DHSVM model in assessing hydrologic regimes with land use changes of the Mae Chame River in Thailand.

In this study, we utilized the MIKE SHE modeling system to evaluate hydrologic impacts of land use changes in a watershed with mixed land use. Since the first introduction of the SHE model by Abbott et al. (1986a, b), a number of publications describing tests and applications of the model have been reported. Applied examples of the initial version of the SHE model included Bathurst (1986), Jain et al. (1992), and Refsgaard et al. (1992). MIKE SHE has been widely used by many scientists, engineers, and water management personnel around the world (Feyen et al. 2000; Jayatilaka et al. 1998; Refsgaard 1997; Henriksen et al. 2003).

Our overall objective was to quantitatively evaluate the effects of land use changes on watershed hydrology within the 257.9 km² Gyeongancheon watershed in Korea. This study specifically sought to: (1) test the capabilities of the MIKE SHE modeling system for simulating streamflow from a mixed land use watershed; and (2) estimate hydrological responses under historical land use scenarios taken from multi-temporal satellite imageries.

Materials and methods

The MIKE SHE model

MIKE SHE is a deterministic, fully-distributed and physically-based hydrological and water quality modeling system (DHI 1999). It is capable of simulating hydrology and water quality processes occurring in watersheds and their underlying aquifers.

The MIKE SHE modeling system was designed with a modular structure. The water movement (WM) module in MIKE SHE is the basic module of the entire modeling system. It represents the finite differences and solutions of the partial differential equations that describe processes of overland, channel, saturated, and unsaturated flows. The watershed is represented by two analogous horizontal-grid square networks for surface and groundwater flow components. These are linked by vertical columns of nodes at each grid representing the unsaturated zone. The hydrologic simulation consists of subcomponents describing the processes of evapotranspiration, overland and channel flow, unsaturated flow, saturated flow, and channel/surface aquifer exchanges (Fig. 1).

A detailed description of the MIKE SHE can be found in DHI (1999). Several additional components comprise other hydrological processes in the modeling system. Rainfall interception is modeled by using a modified Rutter model (Rutter et al. 1971), which is an essential accounting procedure for canopy storage. The MIKE SHE uses the Kristensen and Jensen (1975) method for calculating actual evapotranspiration based on potential evapotranspiration, leaf area index, root depth for each vegetation type, and a set of empirical parameters. A finite difference approximation of the St. Venant equation is employed for solving two-dimensional overland flow and one-dimensional channel flow. Movement of water in unsaturated zones is assumed to be vertical and is modeled by the one-dimensional Richards equation using an implicit finite difference solution. Saturation zone computations are performed using the three dimensional Boussinesq equation for groundwater flow.

Model construction

Watershed description

The Gyeongancheon watershed is located near the metropolitan area of Seoul in Korea, and has experienced rapid changes in land use patterns due to urban sprawl over the past few decades. The Gyeongancheon, the main stream in the watershed, is one of the tributaries of the Han River that flows through the centre of Seoul and has the stream length of 30.0 km. The watershed covers an

Fig. 1 Schematic representation of MIKE SHE WM module (Refsgaard and Storm 1995)
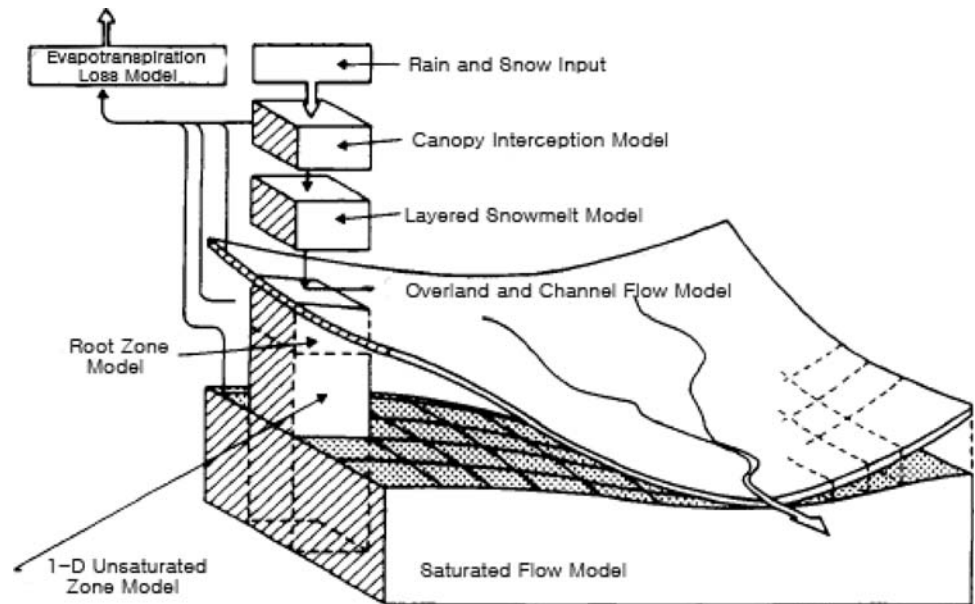
area of 257.9 km^2 and lies between 37°11′8″–37°21′1″N latitude and 127°10′47″–127°14′40″E longitude with a mean slope of 24.5%. It has elevations ranging from 40 to 580 m above sea level. Soils from coarse-textured crystalline rocks like granitic gneiss prevail throughout the watershed (KICT 2003). The mountainous areas of the watershed have no ground water components due to the existence of crystalline rocks and steeped topography. The watershed is characterized in climatology as a temperate monsoon zone, having very hot and humid summers, and cold and dry winters. The average maximum temperature in summer is about 28.3°C and the average minimum temperature in winter is about −6.2°C. The annual precipitation ranges from 500 to 1,500 mm (average of 1,268 mm) with a highly skewed monthly distribution. About two-thirds of the total annual rainfall is concentrated in the summer season from June to September. Figure 2 shows the outline of the watershed with the river networks.

The representation of watershed characteristics and input data are provided through the horizontal discretization of the watershed into an orthogonal network comprising grid square elements and reach links. The Gyeongancheon watershed was divided into a number of computational grids for the numerical solution of the governing equations. High grid resolution may be desirable to describe the watershed in fine detail, but computer processing time and the density of available input data should be considered when establishing grid size. As a compromise between detailed model output and computer capacity, a 200 × 200 m horizontal grid was applied in the Gyeongancheon watershed. About 6,500 horizontal grids cover the entire watershed.
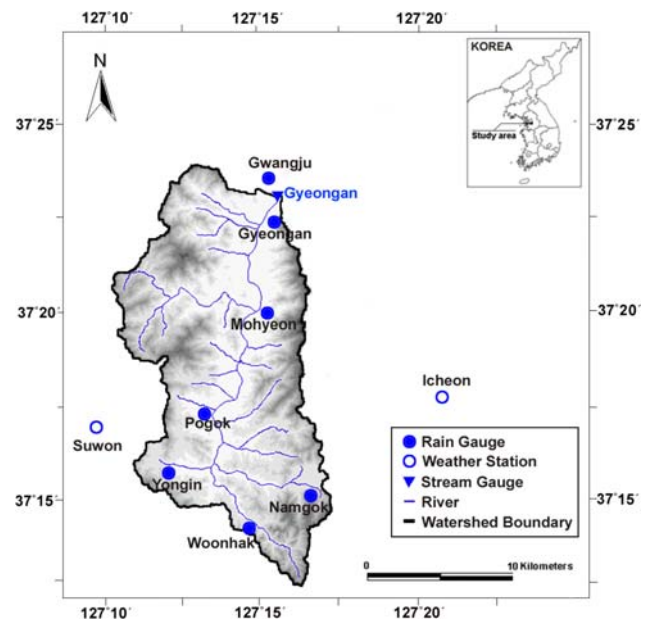

Fig. 2 The Gyeongancheon watershed with the monitoring network

Meteorological data

The MIKE SHE model required rainfall and potential evapotranspiration as climatic input data. Rainfall records were collected from seven rain gauges within and adjacent the watershed (Fig. 2). Rainfall data were used as an input in each grid on a daily basis for model set-up. It was spatially distributed according to a Thiessen polygon technique. The watershed was divided into Thiessen polygons enclosing a specific rain gauge in the middle of the polygon. Rainfall data of each grid was obtained from the point rainfall of rain

gauge within the polygon. A time series of potential evapotranspiration rates was also required for estimating soil evaporation and plant transpiration. The potential evapotranspiration was calculated using the FAO Penman-Monteith method (FAO 1998). The equation requires air temperature, relative humidity, wind speed, and radiation data. These meteorological data were obtained from the Suwon weather station, which is located about 10 km west of the watershed. Unlike rainfall data, these meteorological data can be assumed to be the same for the entire watershed.

Land use data

Land use data were primarily used to define vegetation-specific parameters in the model. Five land uses such as forest, paddy field, upland, urban area, and grassland were identified in the Gyeongancheon watershed for simulation purposes. The distribution of land use was classified from the National Geographic Information System (NGIS) land use coverage in 1990, which was developed by the Korea Institute of Construction Technology (KICT). About 68% of the watershed is forested area which is mostly dominated by needle-leaved (32%) and broad-leaved (55%) trees. The rest is distributed as paddy rice field (10.2%), upland area (9.0%), urban area (7.1%), and grassland (5.7%).

For each land use type, a set of parameters was entered in the MIKE SHE vegetation database. Parameters included empirical constants used in the simulation of actual evapotranspiration (C1, C2, Cint), and a time series for leaf area index (LAI) and root distribution function (RDF) that are given at each growth stage of the crop or vegetation.

Parameter values vary with a vegetation type for each land use classification, and ranges have wide variability. In this study, most information was obtained indirectly from published reports and papers because no field data were available for each land use. Values of Cint, C1, and C2 for each vegetation type were taken from the work of Vázquez and Feyen (2003). LAI and RDF were estimated for each type of land use and cover classification. Except for paddy rice, the LAI and RDF values were obtained from the crop database of the Soil and Water Assessment Tool (SWAT) model (Neitsch et al. 2005). The crop-related parameters, LAI and RDF, for paddy rice were derived from the measured data (RDA 2005).

The study area is located in a densely built-up region with roads, parking lots, and buildings. The satellite image analysis shows that the impervious surface of urban area vary 65–80%. For modeling purposes, the value of 0.01 for root depth and 0.01 for LAI were used to lower evapotranspiration in urban area.

Soil data

Soil types were identified for modeling water flow through soil layers. Soil profiles were reviewed for differences in soil texture, hydraulic conductivity, and depth to a horizon that would impede percolation. The spatial extent of soil units, their vertical properties, and characteristics of soil materials were derived from the Korea soil database (RDA 1992). Forty different types of soils were identified in the watershed. However, soils were reclassified into 12 major soil types because some have the same hydrologic and hydraulic characteristics. Depth of soil layers used for unsaturated flow simulation was derived from RDA's database (RDA 1992).

The MIKE SHE needs the water retention and unsaturated hydraulic conductivity functions to estimate the water content of unsaturated soil during the simulation. In this study, the van Genuchten equation was used to describe the retention curve and hydraulic conductivity. The van Genuchten parameters were estimated using the percentage sand, silt and clay as primary input data (Oogathoo 2006).

In the absence of spatially distributed data, we used a single-valued hydraulic conductivity for the saturated zone in the entire watershed. Sahoo et al. (2006) revealed that the well-calibrated MIKE SHE model having the single-valued hydraulic conductivity can reproduce sound the streamflow variations.

Overland flow component

Overland flow occurs when net rainfall exceeds the infiltration capacity of soil. The direction and velocity of overland flow are determined by ground surface slope. The input topography map is derived from the 30×30 m Digital Elevation Model (DEM) data processed by the Ministry of Environment, Korea. The governing equation for overland flow requires specification of a Strickler coefficient, detention storage, and a leakage coefficient. The Strickler coefficient describes ground surface resistance within each computational grid, which depends mainly on land use. The Strickler values for each land use were taken from the literature (Engman 1986). A value of 6 was used for forest. We adopted a value of 40 for Strickler coefficient for overland flow in urban area. Water accumulated on the ground surface until water depth exceeded detention storage. The detention storage applied in the Gyeongancheon watershed ranges from 0 to 60 mm, based on land use and cover information. A leakage coefficient with a uniform value of 1×10^{-7} s^{-1} was used to describe the water loss in the riverbed.

River and channel component

Flow and water levels were simulated within all reaches by MIKE 11. MIKE 11 is a fully unsteady river hydraulic model, dynamically coupled to MIKE SHE. A total of 21 branches totaling 30.0 km in length were established as part of the river hydraulic model. The geometry of each river branch, which is specified in terms of cross sections, was obtained from field survey data. Because cross section data were only available at the surface water monitoring stations, field survey was made along the MIKE 11 river networks to obtain a series of cross-sectional data. A constant flow boundary condition was applied to the upstream open ends of the main stream and four tributaries in the MIKE 11 river network. A water stage-discharge relationship was used for the boundary condition at the downstream end of the main stream.

Model calibration and validation

A distributed modeling system such as MIKE SHE requires a large number of model parameters to be specified. Parameters of MIKE SHE have a clear physical interpretation and can be explicitly defined from field measurements. However, calibration is frequently required to better reproduce measured watershed variables and to improve simulation results as measured values may not always be readily available. Initial values and ranges (minimum and maximum values) of primary parameters were assessed from measured field data, general characteristics of the model structure, and modeling experience prior to calibration.

For the calibration process, a "trial and error" procedure was applied to examine the influence of various model parameters, step by step, through statistical criteria. In this study, the model was calibrated and evaluated using a split sample procedure (McCuen 2002) against streamflow data collected at the outlet of the watershed. The intervals of the calibration and validation periods were chosen on the basis of availability of observations. Meteorologic and hydrologic data for the period of four years were available in the Gyeongancheon watershed. Data from January 1988 to December 1989 were used for the calibration effort, and the validation period started on the 1st of January 1990 until the 31st of December 1991. In the first step, parameters for interception and evapotranspiration were calibrated to match the overall water balance. In the second step, hydraulic conductivity of the soil was adjusted by comparing sets of simulated and observed streamflow at monitoring stations. Further adjustment was carried out by means of a graphical inspection of peak flows.

Primary parameters available for calibration and a possible range of each parameter are detailed in Table 1. Table 1 also shows the final values of hydrological parameters in the watershed during the calibration interval. Parameters were assumed to be constant throughout the entire simulation period. These values were within typical ranges of published values (Thompson et al. 2004).

A comparison of simulated daily streamflow values against data observed during the calibration period is presented in Table 2. Satisfactory agreement between the observed and simulated daily streamflow for the watershed outlet was obtained. Mean daily simulated and observed streamflow were 3.68 and 5.55 m^3 s^{-1}, respectively, with a difference of 33.6% for the calibration period. Table 2 reveals good statistical correlation between simulated and observed daily streamflows. The correlation coefficient and model efficiency (Nash and Sutcliffe 1970) for daily streamflow values were 0.89 and 0.54, respectively, for the calibration period. This result can be considered "good" according to the performance criteria of Henriksen et al. (2003), who stated that predictions with model efficiency ranging from 0.50 to 0.65 were indicated for a good model performance.

Validation was performed to define whether model parameters derived during calibration were generally valid. Parameters used during calibration were not changed during model validation. Simulated mean daily streamflow during the validation period was 10.09 m^3 s^{-1}, while observed value was 11.29 m^3 s^{-1}. The difference between the observed and simulated streamflow was 10.6%. There was a satisfying correlation of 0.80 between observed and simulated daily streamflow for the validation period.

Results showed that the simulated values during the validation period did not produce convincing outcomes.

Table 1 Calibrated parameter values of MIKE SHE in the Gyeongancheon watershed

Parameters	Parameter values			
	Initial	Final	Min	Max
Evapotranspiration coefficients				
C1	0.3	0.3	0.01	1.00
C2	0.2	0.2	0.05	0.50
C3	20	20	5	40
Surface Strickler coefficient ($m^{1/3}$ s^{-1})	6–30	6–30	1	30
Horizontal hydraulic conductivity (m s^{-1})	1×10^{-5}	1×10^{-6}	1×10^{-8}	1×10^{-3}
Vertical hydraulic conductivity (m s^{-1})	1×10^{-4}	2×10^{-5}	1×10^{-8}	1×10^{-3}
Specific yield	0.25	0.2	0.01	0.50
Channel flow manning coefficient ($m^{1/3}$ s^{-1})	20	35	10	35

Table 2 Model calibration and validation for daily streamflow in the Gyeongancheon watershed

Statistical criteria	Calibration	Validation
Mean daily streamflow (m^3 s^{-1})		
Observed	5.55	11.29
Simulated	3.68	10.09
Correlation coefficient	0.89	0.80
Model efficiency (Nash and Sutcliffe 1970)	0.54	0.38
Root mean square error (m^{3}s^{-1})	7.07	35.32
Mean absolute error (m^{3}s^{-1})	2.53	5.75

However, the model performance in streamflow prediction for the Gyeongancheon watershed has a comparable order of the magnitude to MIKE SHE applications to other watersheds. Oogathoo (2006) applied MIKE SHE to simulate surface runoff of the Canagagigue Creek watershed in Ontario. The correlation coefficients for daily streamflow had a range from 0.51 to 0.80, and the model efficiency values for daily streamflow varied from −0.85 to 0.48. Henriksen et al. (2003) also compared simulated streamflow using MIKE SHE to the observed daily streamflow for three watersheds in Denmark. Values of model efficiency for observed and simulated daily streamflow ranged from −0.01 to 0.87.

The resulting daily streamflow values for the simulation period are shown in Fig. 3. Stream discharge in Fig. 3 was plotted with logarithm transformation to represent well for low discharge. Visual comparison of simulated and observed streamflow during the calibration period shows that the model performed well in terms of the rainfall and runoff relationship in the Gyeongancheon watershed. Hydrographs at the watershed outlet were reasonably captured by the calibrated MIKE SHE model. For the validation period, the daily streamflow simulated by MIKE SHE corresponded to the observation time series (Fig. 3b). However, it indicated that the model underestimated streamflow for high flows and overestimated streamflow during low flows. This discrepancy was mostly due to the limitation of a model structure in representing hydrologic behavior of irrigated paddy rice.

Paddy rice has been cultivated under flooded condition with shallow water depth (<70 mm) from April to October in Korea. The paddy field is typically blocked by a levee to maintain a flooded cultivation system. Flooded water depth within the field is dependent to the outlet height, which is controlled by the farmer according to the rice growth stage.

Applying MIKE SHE in simulating the hydrologic behavior of level-terraced, irrigated paddy fields, a number of deficiencies can be found. Infiltration-based approach in MIKE SHE does not describe surface runoff in a paddy field, because surface runoff in the paddy fields may
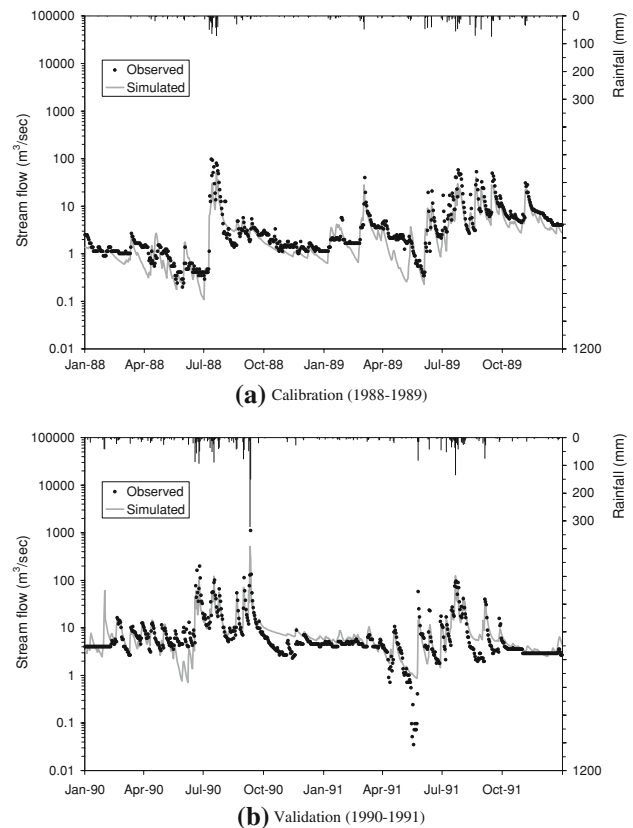
Fig. 3 Observed and simulated streamflows in the Gyeongancheon watershed **a** Calibration (1988–1989) **b** Validation (1990–1991)

depend on the difference between water depth and the height of the outlet. The unsaturated processes play a critical role in simulation of hydrologic response because it determines infiltration rate and the moisture extraction for soil evaporation. In paddy fields, however, water can be evaporated from water surface, and the unsaturated zone acts as a conduit for water flow. The MIKE SHE cannot support the representation of hydrologic cycle with the presence of standing water on the surface.

There was a large discrepancy in streamflow on May 1991, but the absolute deviation was about 1 m^3 s^{-1}. The comparison of observed and simulated daily streamflow in the watershed for the validation period returned slightly poorer results than those of the calibration period. A scatter plot for daily simulated and observed streamflow is also shown in Fig. 4.

Hydrologic effects of land use changes

Multi-temporal and repetitive satellite data offer unique opportunities for mapping and monitoring land use and land cover changes. Landsat TM satellite imageries were used in this study to identify changes in land use

Fig. 4 Scatter plot for daily observed and simulated streamflows in the Gyeongancheon watershed

(a) Calibration (1988-1989)   **(b)** Validation (1990-1991)
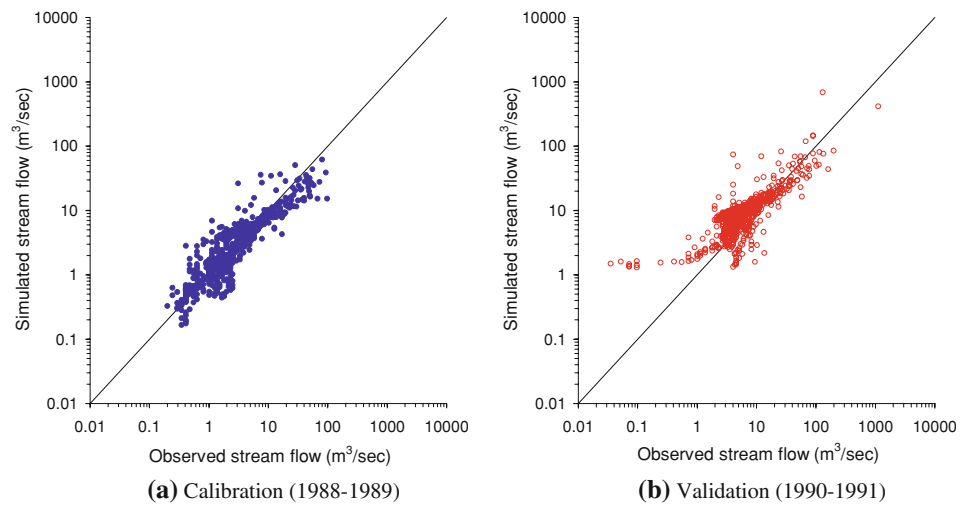
distribution in the Gyeonganchen watershed over a 20-year period from 1980 to 2000. Three Landsat scenes which have a resolution of 30 m were chosen for this study. One was taken on 15 February 1980 (LU 1980), another was on 26 April 1990 (LU 1990), and the other was taken on 17 May 2000 (LU 2000). A supervised classification was performed to identify five land cover features such as forest, rice paddy, upland, urban, and grassland. Proportional changes in land use during the intervening periods were determined by comparing the classification results of multi-temporal Landsat TM scenes (Table 3).

Between 1980 and 2000, the Gyeongancheon watershed experienced conversion of non-urban area to residential and commercial areas as a result of urban sprawl. The dominant land area in 1980 was forest, which covered 68.5% of the entire watershed, followed by rice paddy (12.5%), and upland (11.5%). Urban area played only a minor role (2.7%) in year 1980.

Forest cover a little decreased to 68.0% in 1990 and 57.0% in 2000. In scenario LU 2000, forest was replaced by other land uses, especially urban area. There was a 4.4% increase in urban area between 1980 and 1990 and an 8.9% increase in urban land use between 1990 and 2000. A slight

decrease in agricultural area occurred during the last two decades. The portion of rice paddy and upland areas decreased by 2.7 and 3.3%, respectively, between 1980 and 2000. Primarily as a result of golf course construction, grassland made up 9.0% of the total watershed area in 2000.

Land use maps for the Gyeongancheon watershed which were derived from Landsat TM scenes of 1980, 1990, and 2000 are presented in Fig. 5. A detailed comparison of these maps shows that land use changes are unevenly distributed within the watershed. The largest change in urban area cover is evident in the middle part of the watershed, where the city of Gwangju is located. Moreover, the reduction of forest is more obvious in the northern part of the watershed.

Effects of land use changes on hydrology were evaluated using MIKE SHE. Data derived from each of three multi-temporal satellite imageries served to establish land use-related input parameters in the MIKE SHE model. All other model parameters were kept constant during model runs. Measured time series of rainfall and meteorological data in the period of 2000–2004 was utilized during repeated model runs to avoid the effect of climate variability.

Table 4 shows the average annual values of modeled hydrological components and changes attributable to alterations in land use over two 10-year intervals on the Gyeongancheon watershed. There were slight increases in total runoff and overland flow as a response to the land use change. Percent increase in average total runoff was 10% over a 10-year period between 1980 and 1990, and 15% between 1990 and 2000. This situation was due primarily to the expansion of impervious surface in urban areas. The amount of impervious areas primarily controlled the amount of runoff generated from the watershed by decreasing the rates of infiltration and evapotranspiration. In terms of absolute changes, the annual volume of

Table 3 Land use identification of Landsat TM scenes for the Gyeongancheon watershed

Land use class	LU 1980 (2/15/1980)	LU 1990 (4/26/1990)	LU 2000 (5/17/2000)
Forest	68.5	68.0	57.0
Paddy field	12.5	10.2	9.8
Upland area	11.5	9.0	8.2
Urban area	2.7	7.1	16.0
Grassland	4.8	5.7	9.0

Fig. 5 Spatial distribution of land use derived from the Landsat TM satellite imageries
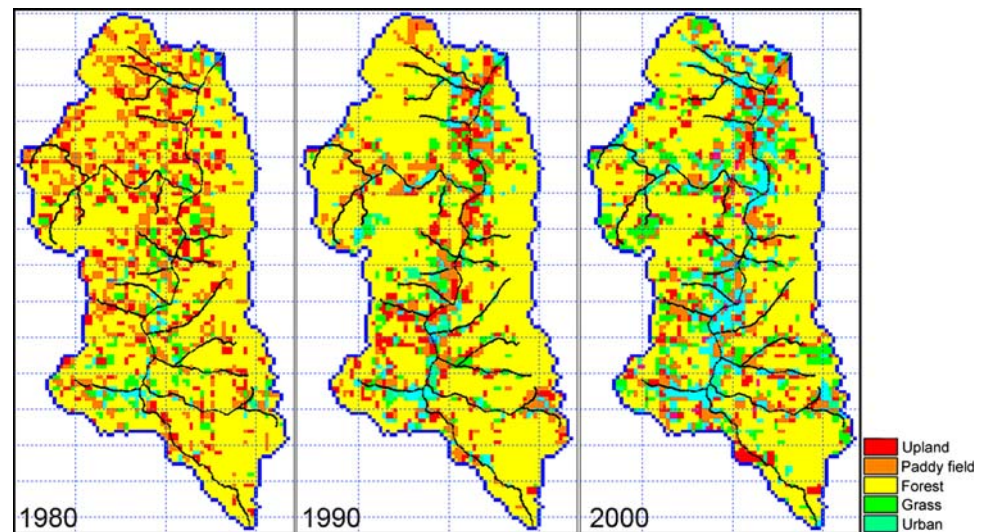

Table 4 Results of hydrologic simulation using three land use scenarios

Land use	Total runoff (mm)	Evapo-transpiration (mm)	Overland flow (mm)	Infiltration (mm)	Groundwater recharge (mm)
LU 1980	861	565	149	760	342
LU 1990	891	539	165	739	334
LU 2000	908	523	186	728	322

evapotranspiration declined from 521 mm under the LU 1980 scenario to 503 mm in LU 2000.

Results obtained the same pattern and trend from other studies (Lørup et al. 1998; Fohrer et al. 2001; Klöcking and Haberlandt 2002; Im et al. 2003). Klöcking and Haberlandt (2002) showed that urbanization causes an increase of surface runoff with a decrease in ground water recharge and a reduction of evapotranspiration. In addition, Im et al. (2003) found that an increases in impervious areas of up to 10.1% may lead to increases of 15.8% in streamflow volume with modeling approach for the future land use scenarios in the Polecat Creek watershed, US.

Conclusions

The MIKE SHE modeling system was applied to investigate the watershed-scale hydrologic impacts of land use changes within the 257.9 km^2 Gyeongancheon watershed. Simulated streamflow at the watershed outlet was close to observed values with respect to total flow, low flow, and partly peak flows for the calibration period. The model described the increase and subsequent recession in the hydrograph, but absolute peak flow was often underestimated at some rainfall events. This was likely due to the poor quality of input data and the limitation of model structure in representing hydrologic behavior of irrigated rice paddies. Good agreement was also observed between

simulated and observed total runoff volumes for the simulation period.

In this study, the MIKE SHE model was used as a tool for analyzing the impact of forest-to-urban land use conversion on watershed hydrology and water availability at the watershed outlet. There were slight increases in the whole watershed runoff and overland flow as a response to land use changes. These were due primarily to the growth and sprawl of urban areas. Urbanization may cause the expansion of impervious surface, which controlled runoff by decreasing the rates of infiltration and evapotranspiration. This is in accordance with the results by the same author (Im et al. 2003) that the conversion of forest area to urban and residential uses may alter the water balance components in a watershed.

Whole-watershed assessment of the hydrologic effects of land use changes is a vital prerequisite for water resources development and management. Adoption of distributed models like MIKE SHE requires detailed information on temporal and spatial scales, but can precisely identify the effects of changing land use and land cover on hydrologic function in watersheds. Nevertheless, the use of distributed model for assessing the effects of land use changes in Korea's watersheds has drawbacks nowadays. One reason is the availability of the long-term experimental data which can be used for model parameterization. In addition, the inability of model structure to represent the hydrological processes that occurred in irrigated paddy rice fields could impede the use

of MIKE SHE on agricultural watersheds in Korea. Although the procedure which was adopted in this study to simulated hydrological responses from the Gyeongancheon watershed resulted in reasonable reproductions of stream-flows for the simulation period, it is not the ideal solution to represent complex hydrological systems found in the floo-ded paddy fields.

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