LAND DEGRADATION & DEVELOPMENT
Land Degrad. Develop. (2011)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ldr.1137

IMPACT OF LAND USE CHANGE ON EROSION RISK: AN INTEGRATED REMOTE SENSING, GEOGRAPHIC INFORMATION SYSTEM AND MODELING METHODOLOGY

M. LEH[1]*, S. BAJWA[1] AND I. CHAUBEY[2]

[1]*Department of Biological and Agricultural Engineering, University of Arkansas, Fayetteville, AR, USA*
[2]*Department of Agricultural and Biological Engineering and Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN, USA*

Received 8 October 2010; Revised 27 April 2011; Accepted 27 May 2011

ABSTRACT

The objective of this study was to evaluate the impact of rapidly changing land use on erosion and sedimentation in a mixed land use watershed in the Ozark Highlands of the USA. The research combines a geographic information system-based soil erosion modeling approach with land use change detection to quantify the influence of changing land use on erosion risk. Five land use/land cover maps were generated or acquired for a 20-year period (1986 through 2006) at approximately 5-year intervals to assess land use change and to predict a projected (2030) land use scenario for the West Fork White River watershed in Northwest Arkansas. The Unit Stream Power based Erosion/Deposition model was applied to the observed and predicted land use to assess the impact on erosion. Total erosion from urban areas was predicted to increase by a factor of six between 1986 and 2030 based on the projected 2030 land use. Results support previous reports of increased urbanization leading to increased soil erosion risk. This study highlights the interaction of changes in land use with soil erosion potential. Soil erosion risk on a landscape can be quantified by incorporating commonly available biophysical data with geographic information system and remote sensing, which could serve as a land/watershed management tool for the rapid assessment of the effects of environmental change on erosion risk. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS: soil erosion modeling; land use change; USPED model; remote sensing; GIS

INTRODUCTION

Land use/land cover (LULC) change is a dynamic and complex process that can be exacerbated by a number of human activities. Factors driving LULC change include an increase in human population and population response to economic opportunities (Lambin *et al*., 2001). Despite the social and economic benefits of LULC change, this conversion of LULC usually has an unintended consequence on the natural environment. For example, LULC change has been shown to have negative effects on stream water quality (Zampella *et al*., 2007; Tang *et al*., 2005), quantity (White and Greer, 2006) and stream ecosystem health (Wang *et al*., 2000; Wang *et al*., 2001). Changing land use has also been shown to influence weather patterns (Stohlgren *et al*., 1998) and the generation of streamflow (Bronstert *et al*., 2002; Weng, 2001). Also, a number of studies have shown that increase in agricultural land use has direct consequences on sedimentation, nutrients and pesticides in streams (Osborne and Wiley, 1988; Soranno *et al*., 1996). Land use change detection is therefore a critical requirement for the assessment of potential environmental impacts and developing effective land management and planning strategies. Soil erosion is directly affected by land use change. Therefore, the modeling of land use change is important with respect to the prediction of soil erosion and degradation.

The prediction of erosion and/or degradation typically involves the use of empirical models such as the Universal Soil Loss Equation (Wischmeier and Smith, 1978), the Unit Stream Power Based Erosion/Deposition model (USPED) (Mitas and Mitasova, 1998) and physically based models such as the Water Erosion Prediction Project (Flanagan and Nearing, 1995) and the European Soil Erosion Model (Morgan *et al*., 1998) (Merritt *et al*., 2003). The Universal Soil Loss Equation together with its improved version, the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al*., 1997) is one of the most commonly applied models to estimate soil erosion (eg. Bewket and Teferi, 2009; Mutua *et al*., 2006; López-Vicente and Navas, 2010). Although USLE/RUSLE is the most widely applied model in soil erosion modeling, RUSLE was developed to be applied to one dimensional hillslopes with no provision for soil deposition (Kinnell, 2010). For estimating soil erosion on a watershed scale, Mitasova *et al*. (1996) showed that the USPED model, which is derived from the RUSLE model may be more

* Correspondence to: M. Leh, Department of Biological and Agricultural Engineering, University of Arkansas, Fayetteville, AR, USA.
E-mail: mleh@uark.edu

appropriate for modeling erosion risk on landscapes and complex terrain. Despite the numerous studies on the application of the USLE/RUSLE model, very few studies have used the USPED model to estimate erosion and deposition. Foster (1990) called for caution when interpreting results of process based models whose parameters may need to be re-calibrated for complex landscapes. Nonetheless, the USPED model has been used in a number of studies with varying degrees of success. Saavedra and Mannaerts (2005) obtained accuracies of between 23 and 52 per cent when comparing the USPED model estimates to four other erosion models in the Cochabamba province, Bolivia. Warren *et al*. (2005) reported USPED model estimates within 76–89 per cent of field observations of two military training areas in the US. Liu *et al*. (2007) reported significant linear relationship with an R^2 of 0·72 between modeled results and observed total suspended sediment in stream water for ten watersheds in western Georgia, USA. In a recent study by Capolongo *et al*. (2008), USPED-based erosion rates were found to be directly comparable with direct field measurements in Southern Italy. Pelacani *et al*. (2008) used the USPED model to demonstrate how the application of conservation practices on 4 per cent of the Orme catchment could reduce high erosion areas ($>20 \mathrm{Mg\,ha^{-1}\,y^{-1}}$) occurring in about 30 per cent of the watershed in Italy.

A number of studies have integrated geographic information system (GIS) analysis with soil erosion modeling for various geographic locations (eg. Fu *et al*., 2005; Yue-qing *et al*., 2009; Nekhay *et al*., 2009; Fu *et al*., 2006; Pelacani *et al*., 2008; Capolongo *et al*., 2008). Remote sensing (RS) has proved to be a useful, inexpensive and effective tool in LULC mapping and LULC change detection. RS can provide the data necessary for erosion modeling within a GIS. Given the complex nature of the erosion process, and the challenges of quantifying these processes, an integrated RS, GIS and modeling based approach is critical for the successful evaluation of the impact of land use change on land resources. An increasing number of studies have identified the importance of RS and GIS integration in erosion modeling. For example, Rahman *et al*. (2009) used RS, GIS and statistical analysis to assess soil erosion hazards for the northwestern Hubei province of China. In another study, Yuksel *et al*. (2008) reported great potential for producing accurate and inexpensive erosion risk maps by combining RS and GIS with the CORINE model for the Kartalkaya Dam Watershed in Turkey. Ismail and Ravichandran (2008) identified high soil erosion areas by combining field monitoring, RS and GIS with the RUSLE2 model for the Veppanapalli watershed in India. The European Environment Agency called for the use of high resolution land use maps in combination with remotely sensed data such as the Normalized Difference Vegetation Index when modeling soil erosion so as to capture seasonal variations in LULC (Gobin *et al*., 2003).

In this study, we used an integrated remote sensing-GIS and modeling approach to assess the effects of changing LULC and examined the risk of erosion potential caused by changing land use. The overall goal of this project was to use satellite imagery and GIS to evaluate long term change in land use patterns and identify the spatial distribution of sediment sources in NW Arkansas, USA. Specifically, this study was designed to answer the following research questions:

(1) What is the long term LULC change of a typical watershed in the Northwest Arkansas region?
(2) Can we identify trends of LULC change and predict possible scenarios of future land use?
(3) What are the impacts of LULC change on soil erosion potential within the watershed?

BACKGROUND

The NW Arkansas region in the USA is an area that has experienced a rapid metropolitan growth in the last decade. This urban growth has resulted in a rapid change in LULC patterns with activities such as agriculture, residential and commercial development, logging and mining. Recent LULC change studies in the region have focused on the response of stream channel morphology to LULC change over different temporal scales. For example, Ward (2007) reported an increase in stream channel width as a result of long term (1941–2004) land use change in the Illinois River Watershed. Conversely, Keen-Zebert (2007) observed significant variations in stream channel morphology for a rapidly urbanizing stream in Washington County, Arkansas. Shepherd *et al*. (2010) conducted geomorphic analysis for sub-watersheds with long term consistent land use in the Illinois River Watershed and identified a strong trend of increasing slope and channel cross sectional area within subwatersheds with significant urban land use.

Also, there has been an increased demand for high quality water resources in NW Arkansas. Competing demands for resources from agricultural and urban sources have resulted in conflicts over the past decade, and represent a significant impediment to economic development in the region. This conflict is driven by pollution from historically unregulated sources, including storm water runoff from municipal and agricultural lands. An overabundance of nutrients, pesticides, other chemicals and pathogens in the surface and ground waters from agricultural and urban activities are considered to be jeopardizing the availability of usable, high quality water (ADEQ, 2000). Agriculture (crop and livestock production) and forestry along with the processing of agricultural commodities and food are major sources of employment (accounting for one-fourth) for Arkansas. Rolling hills NW Arkansas region are home to thousands of poultry farms, numerous swine farms and pastures that produce abundant forage for numerous beef and dairy cattle. The land application of animal manure for perennial forage crops has been a standard practice for a long time. Long-term land application of animal manure has negative implications for surface and ground water quality because of increased runoff losses of nutrients (for example, nitrogen and phosphorous) and pathogens (Edwards *et al*., 1996; Sauer *et al*., 1999; Sharpley *et al*., 1993; Kingery *et al*., 1994). As a result, the non-point source transport of nutrients, sediment and pathogens associated with animal agriculture production activities is a major environmental concern in NW Arkansas. The transport of excess sediments into streams and lakes results in increased siltation, deterioration of aquatic life, increased concentrations of nutrients carried by sediments and thereby, an increase in the process of eutrophication and general degradation of water quality.

SITE DESCRIPTION

The West Fork of the White River (WFWR) watershed is a 321 km^2 watershed located in the Ozark and Boston Mountains of Northwest Arkansas (Figure 1). The WFWR is a major tributary of Beaver Lake—a domestic water resource for Northwest Arkansas, and has an approximate stream length of 54 km (ADEQ, 2004). High turbidity levels, excess sediment loads, and significant changes in stream morphology over the last four decades led the Arkansas Department of Environmental Quality to place the WFWR on the Arkansas 303(d) list, classifying it as an impaired stream (ADEQ, 2004). A 30-year average annual precipitation measured in the city of Fayetteville, north of the WFWR watershed was 1170 mm. Precipitation occurs with a low average monthly value of 50 mm in January and a high average monthly value of 130 mm in June. Typically, winters are short and summers are warm and humid. Mean annual high and low temperatures are 20·0 and 8·3°C, respectively (NOAA, 2006). A 2006 LULC analysis obtained from the University of Arkansas Center for Advanced Spatial Technologies (CAST) revealed that the watershed is 64 per cent forest land, 14 per cent agriculture/pasture and 14 per cent urban. The local topography of the WFWR watershed consists of ridges and valleys with elevation ranging from 348 m to 683 m in the southeastern boundary (Figure 1). The average slope within each of the land use classes is lowest in the barren land areas (5 per cent) and highest in the forest (17 per cent) and urban areas (8 per cent).

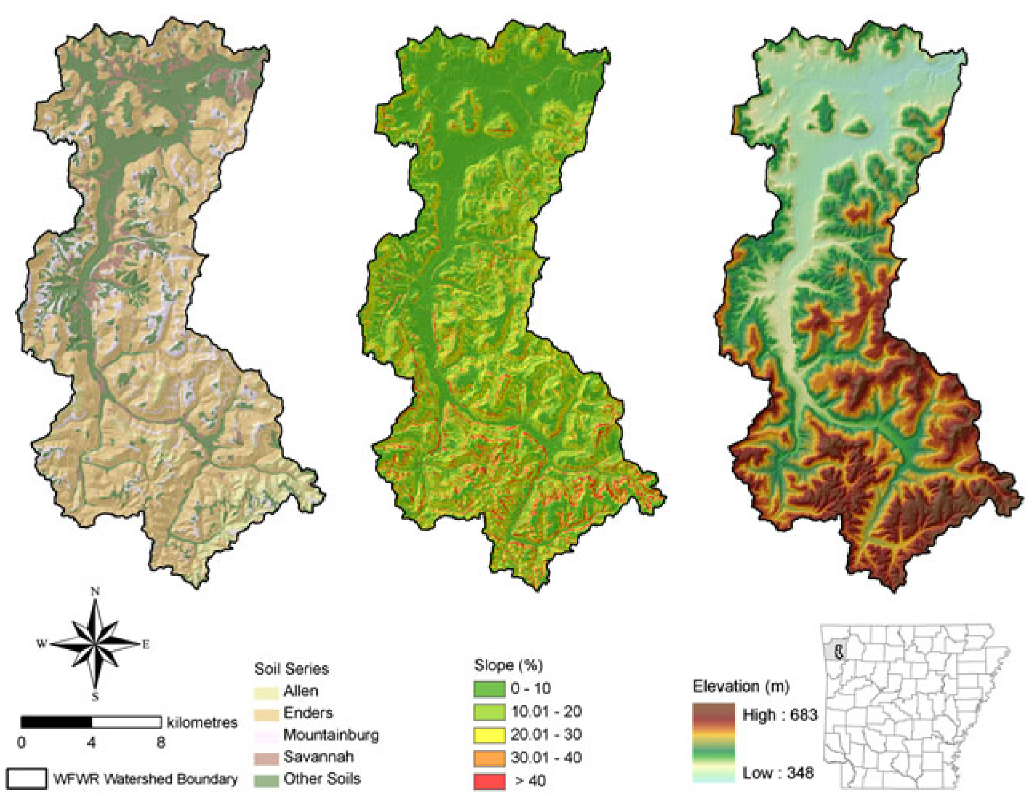

Figure 1. Soils, slope and elevation characteristics of the study site West Fork White River Watershed in Northwest Arkansas. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

The four major soils that account for over 70 per cent of the soils present within the WFWR watershed are the Allen series, characterized as well drained, moderately permeable soils found on benches and foot slopes of the Boston Mountain, the Enders Series that is moderately well drained, very slowly permeable found on mountain sides, the Mountainburg Series, which consists of shallow well drained rapidly permeable soils found on narrow ridges, steep hillsides and mountain slopes, and the Savannah Series (Figure 1), which are moderately well drained slowly permeable soils with a fragipan typically found on foot slopes and stream terraces (Harper *et al*., 1969).

METHODS

Image Classification

Landsat-5 TM images for the summers of 1986, 1991, 1996 and 2001 were acquired for this study. LULC data derived from landsat for 2004 and 2006 were obtained from the CAST database. Based on the 2004 and 2006 LULC data, eight land use categories were defined: urban low intensity, urban high intensity, barren land, water, herbaceous, forest, warm season grass and cool season grass. Urban high intensity areas were typically commercial and industrial areas with high intensity of impervious surfaces such as concrete and asphalt whereas urban low intensity were residential areas with a mix of impervious and natural settings. Herbaceous areas were typically transitional vegetation areas. Warm and cool season grass areas were typically pasture (grassland) areas (Gorham and Tullis, 2007). These classes were selected so as to make it easier to compare our classified maps with maps already available from the CAST database.

We used an integrated object-based and pixel-based analysis to classify each image. Images were first segmented into objects using Definiens Developer 7® (Definiens, Munich, Germany). The multi-resolution segmentation algorithm of Definiens employs a bottom-up merging technique where pixels are consecutively merged into larger objects based on predefined scale, color and shape parameters of the image (Definiens, 2008). Parameters were selected on a trial and error basis until a final set of parameters that resulted in a homogenous criterion for each image were obtained. The segmentation was conducted at a very fine scale, with scale parameters ranging between five and ten for each image. Once the segmentation was done, vector layers of segmented images were imported into Erdas Imagine® (Erdas Inc., Norcross, GA) and used as the basis to select training signatures. Approximately 700 sample points determined from historical aerial images in conjunction with interpretation of false color composite images were used to create the training signatures. Image classification was carried out using a pixel-based classification system with the maximum likelihood algorithm within Erdas Imagine. Classified maps were co-registered to the 2004 and 2006 LULC layers.

Classification accuracy was determined on a pixel basis in Erdas Imagine by generating random samples of pixels collected from aerial images and false color composites images, and comparing it to the classified images. Approximately 350 sample points were generated such that at least 40 pixels belonged to each LULC class. Accuracy was quantified by developing a confusion matrix for each image and computing the corresponding user's accuracy, producer's accuracy, overall accuracy and the Kappa coefficient of agreement.

LULC Change Detection and Future Land Use Projection

The Land Change Modeler (LCM) for Ecological Sustainability available in Idrisi Andes software (Clark Labs, Worcester, MA) was used to perform land use change analysis between the 1986 and 2004 land uses. The LCM is a useful tool that can be used to rapidly assess gains and losses in land cover classes, land cover persistence, transitions between categories, and to make LULC change predictions. LCM uses a three-stage (change assessment, transition potential modeling and change prediction) process to model land cover change between two time periods and to predict the future land cover. Setting the 1986 and 2004 land use layers as inputs, we modeled the LULC change within that time period. We computed the contribution of each of the land use classes to net change and assessed gains and losses of land use classes. In the transition potential stage, the variables that influence the transitions of interest are identified and how they influence future change is modeled. In the final stage, the relative amount of transition to a future date is calculated (Clark Labs, 2009). This was done by modeling each transition potential using a multi-layer perceptron (MLP) neural network. The transition potential modeling helped to determine the transition potential of each land cover class. The model was built by exploring the potential power of a set of static or dynamic variables (Table I) that potentially contributed to land cover change. The static variables expressed the potential for transition while remaining unchanging over the simulation period (Eastman, 2006). The dynamic variables on the other hand, were considered as time dependent variables that were recomputed at specific intervals during the period of the prediction. The land cover likelihood (Table I) was a map that showed how likely a particular LULC would occur if that area experienced transition (Eastman, 2006). The strength of the variables was assessed by the computation of Crammer's V (Ott *et al*., 1983) statistic, which gives a measure of association in a range of 0–1. High values of V indicate greater association. A number of other environmental variables such as soil properties (soil hydrologic group, soil erodibility,

Table I. Summary of environmental variables used in modeling transition potential of urban areas

Variable	Role	Basic layer	Largest Cramer's *V* for a class	*p*-value
Distance from disturbance	Dynamic	Land cover	0·4461	0·001
Terrain height	Static		0·1229	0·001
Distance from roads	Dynamic	Roads	0·3252	0·001
Slope	Static		0·5277	0·001
Distance from stream	Static		0·0525	0·001
Land cover likelihood	Static		0·4096	0·001
Aspect	Static		0·1881	0·001
Hillshade	Static		0·3985	0·001

soil hydraulic conductivity) were tested but were not found to be associated to the transition of any class. Typically, the integration of both environmental and socio-economic drivers of change is desired for land use modeling. However, the incorporation of data such as political, social and economic factors is limited by the lack of spatial data and the difficulty in integrating socio-economic factors with biophysical factors (Veldkamp and Lambin, 2001). For this study only, environmental variables were considered. Two dynamic and six static variables were found to be significant in predicting land use change (Table I). A MLP neural network with eight inputs, one hidden layer, a dynamic learning rate, and a momentum factor of 0·5 was used to generate the potential map for transition to each of the LULC classes. The MLP module generated random samples of each of the pixels that experienced transition for each of the classes. Half the samples were then used to train the model by developing multivariate functions to predict potential for transition, and the other half was used to test the model. An accuracy rate of 70 per cent was obtained between the training and testing data sets.

The transition potential model served as the basis for the dynamic land cover change prediction. By assuming that the trend in urban development remained the same, the projected land cover for year 2006 and 2030 was predicted by using a Markov chain analysis to model the transitions. Basically, the Markov-chain model calculates the probability of transition of the land use at time $t+1$ based only on land use category at time t (Kocabas and Dragicevic, 2006). Using the 1986 and 2004 land use data to calibrate the model, a past to present (1986–2006) and past to future simulation (1986–2030) was performed. Because 2006 LULC data was already available, this provided the opportunity to validate the model with the 2006 data. The simulated result was assessed visually and quantitatively by cross tabulation with the 'actual' 2006 LULC data.

Predicting Present and Future Soil Erosion Risk

The USPED model is a 2-dimensional modification of the widely used RUSLE that accounts for deposition. The RUSLE model in its basic form is computed as follows:

$$T = RK(LS)CP \tag{1}$$

Where: T is an estimate of soil loss, R is the rainfall erosivity factor, K is the soil erodibility factor, C is the cover management factor, P is the supporting practice factor, and LS is the combined slope length and slope steepness factor. The USPED assumes that erosion and deposition depend on the sediment transport capacity of runoff (Mitasova and Mitas, 2001). Flow convergence is incorporated in the USPED model by computing the LS factor based on upslope contributing area A (Mitasova *et al.*, 1996):

$$LS = A^m(\sin\beta)^n \tag{2}$$

Where: β is the slope angle in degrees, m and n are empirical constants that depend on flow and soil properties. Values of m range from 1·2–1·6 and n 1·0–1·3. Lower values of m and n indicate situations were sheet flow dominates and higher values indicate that rill flow dominates (Moore and Wilson, 1992; Mitasova and Mitas, 2001).

Erosion and deposition (ED) are then computed as a change in sediment flow in the direction of flow:

$$ED = \frac{d(T\cos a)}{dx} + \frac{d(T\sin a)}{dy} \tag{3}$$

Where: a is the direction of flow or aspect in degrees.

GIS layers of the RUSLE factors used in the model were derived from a number of sources. An R-factor of 4595·5 MJ mm ha^{-1} h^{-1} y^{-1} was obtained from an isoerodent map of Arkansas (Renard *et al.*, 1997). Soil K factor, which ranged from 0·0099 to 0·0645 Mg ha h ha^{-1} MJ^{-1} mm^{-1} for the watershed was obtained from the Natural Resource Conservation Service (NCRS) Soil Survey Geographic (SSURGO) soil database, and P factor was assumed to be 1. Because the objective of this research was to identify the influence of land use change on the spatial distribution of erosion/deposition, the land use maps for 1986, 2006 and 2030 were reclassified to convert to C factor values based on values derived from literature (Storm *et al.*, 2006; Fernandez *et al.*, 2003; Renard *et al.*, 1997; Haan *et al.*, 1994) (Table II). Upslope contributing area was computed using a digital elevation model (DEM) of the watershed through the D-infinity algorithm implemented in the *r.flow* module of the Geographic Resources Analysis Support System (GRASS) GIS. The DEM layer was downloaded from Geostor, Arkansas's Geodata clearinghouse (http://www.geostor.

Table II. Summary of *C*-factor values used in the USPED model

LULC	*C*-factor
Urban low intensity	0·042
Urban high intensity	0·003
Barren land	0·5
Water	0
Herbaceous	0·077
Forest	0·004
Warm season grass	0·038
Cool season grass	0·036

LULC, land use/land cover.

arkansas.gov). This DEM was a 5 m resolution ancillary product of the 2006 statewide ortho image acquisition generated from a Leica ADS40® sensor with vertical and horizontal accuracies of 7·6 m and 5 m RMSE (95 per cent confidence level), respectively. Several studies have indicated that high resolution DEM data are well suited for modeling landscapes of complex terrain (Mitasova *et al*., 1996; Zhang and Montgomery, 1994).

RESULTS AND DISCUSSION

Image Classification

LULC classification maps of the study area were produced for each of the years 1986, 1991, 1996 and 2001. Kappa coefficient of agreement ranged between 0·42 and 0·97 for each of the individual land use classes (Table III). The importance of the use of Kappa analysis for evaluating accuracy is that it provides a means to assess if a classified LULC map is significantly better than a randomly generated map (Pontius, 2000). Overall Kappa was 0·88, 0·86, 0·88 and 0·93 for 1986, 1991, 1996 and 2001, respectively. The producer's accuracy, which shows the probability that a pixel location of a land use class is correctly shown on the map (Story and Congalton, 1986), ranged between 0·43 and 0·98. The user's accuracy, which shows the probability that a pixel location on the map correctly identifies the land use class location as it exists in the field (Story and Congalton, 1986), ranged between 0·42 and 0·98 (Table III). Classes with the lowest accuracies are the barren and herbaceous land. One possible reason for the misclassification of barren land is confusion between actual barren land, construction sites and cleared agricultural land. Another source of error may be inaccurate reference points. Because the classification was performed on historical data, field verification was not possible. Training samples and testing samples were derived from aerial images and digital ortho quarter quads of the study sites, and visual interpretation could be a possible source of error. Based on the kappa and overall accuracies, the LULC classification was considered

Table III. Classification accuracy of classified land use for 1986, 1991, 1996 and 2001

Land use	1986			1991			1996			2001		
	Kappa	User's accuracy	Producer's accuracy	Kappa	User's accuracy	Producer's accuracy	Kappa	User's accuracy	Producer's accuracy	Kappa	User's accuracy	Producer's accuracy
Urban low intensity	0·92	0·93	0·88	0·83	0·83	0·73	0·88	0·88	0·78	0·82	0·82	0·75
Urban high intensity	0·80	0·81	0·69	0·70	0·70	0·71	0·89	0·89	0·70	0·84	0·84	0·72
Barren land	0·87	0·87	0·86	0·77	0·78	0·79	0·87	0·88	0·43	0·89	0·90	0·84
Water	0·95	0·97	0·98	0·81	0·81	0·98	0·86	0·87	0·76	0·91	0·91	0·96
Herbaceous	0·83	0·86	0·98	0·42	0·42	0·69	0·44	0·44	0·85	0·52	0·52	0·68
Forest	0·97	0·97	0·98	0·90	0·98	0·98	0·88	0·97	0·98	0·95	0·98	0·98
Warm season grass	0·80	0·82	0·59	0·84	0·85	0·82	0·81	0·81	0·63	0·82	0·82	0·81
Cool season grass	0·76	0·79	0·85	0·89	0·90	0·82	0·90	0·91	0·93	0·94	0·96	0·98
Overall accuracy	0·91			0·96			0·96			0·96		
Overall Kappa	0·88			0·86			0·88			0·93		

to be satisfactory, which is within the generally recommended value of 85 per cent or better (Foody, 2002).

LULC Change Analysis

The LULC change analysis showed that urban, barren, herbaceous and warm season grass classes experienced increased areas, whereas forest and cools season grass areas decreased (Table IV). Urban low intensity areas grew steadily from 1986 to 2006, whereas urban high intensity areas were somewhat steady until 2001/2004 where there was a sharp increase in high intensity urban areas and then stabilized in 2006. Overall, population growth, increase in the number of housing units, and the completion of Interstate 540 highway by 2000 were all major factors that may have contributed to this spur. In general, urban areas increased by more than 30 km^2 between 1986 and 2006. Although forest cover decreased by as much as 20 km^2 between 1986 and 2006, this accounted for only 6 per cent of the watershed area. Cool season grass experienced the greatest loss of cover from approximately 21 per cent in 1986 to just less than 10 per cent in 2006. The herbaceous areas increased considerably between 2004 and 2006. The forest and the pasture areas explained the greatest increase in urban areas over the entire period. To examine the relationship between urban area and population growth, census population data of West Fork for 1980 through 2000 was used to interpolate the population for the different land cover years (Table V). A careful analysis of the data revealed an interesting trend for the period. Although population growth was 19 per cent for 1986–1996, the total urban area growth was 44 per cent. For 1996–2006, urban population growth was 23 per cent, and the urban area growth was 118 per cent. Hence, there appeared to be a decrease in urban population density from 1996 onwards. A possible reason for this trend is the high rate of urban housing development in anticipation of continuing future population growth similar to those witnessed during 1996–2006. The NW Arkansas region experienced a housing 'boom' in the late 1990s to early 2000s. López *et al*. (2001) reported a similar trend in land cover change analysis for Morelia city in Mexico and identified a threshold year beyond, which a dramatic decrease in population density was observed.

Table V. Population data for the West Fork White River Watershed

Year	Population (persons)	Total urban area (km^2)	Population density (persons/km^2)
1986*	1575	14·18	111
1991#	1607	16·51	97
1996*	1868	20·46	91
2001#	2042	26·24	78
2006*	2303	44·54	52

*Interpolated from 1980–2000 census data.
#Value assumed to be same as previous year's census data.

LULC Change Model Validation and Future Scenarios

The land cover change model was validated by cross tabulating the 'actual' land cover for 2006 with the predicted land cover for 2006. The Kappa index of agreement between the actual land use and the projected 2006 land use ranged from 0·48 to 0·91 for each of the land use classes (Table VI). The producer's accuracy ranged between 0·32 and 0·98, whereas the user's accuracy ranged between 0·48 and 0·97. The highest errors occurred in the barren land classification for the producer's accuracy and water and cool season grass areas for the user's accuracy. It should be pointed out that because we only modeled biophysical drivers that affected urban growth, the classifications of the other classes were not expected to be highly accurate. The incorporation of socio-economic drivers of land use change is

Table IV. Land use land cover distribution for 1986–2006

Land use	1996		1991		1996		2001		2004		2006	
	Area (km^2)	Cover (%)	Area (km^2)	Cover (%)	Area (km^2)	Cover (%)	Area (km^2)	Cover (%)	Area (km^2)	Cover (%)	Area (km^2)	Cover (%)
Urban low intensity	8·23	2·58	9·71	3·04	14·46	4·53	17·53	5·49	24·84	7·78	25·76	8·07
Urban high intensity	5·93	1·86	6·80	2·13	6·00	1·88	8·72	2·73	16·41	5·14	18·77	5·88
Barren land	0·35	0·11	1·09	0·34	0·42	0·13	2·20	0·69	2·11	0·66	0·61	0·19
Water	1·05	0·33	0·83	0·26	1·05	0·33	1·15	0·36	0·80	0·25	1·12	0·35
Herbaceous	1·72	0·54	1·56	0·49	0·80	0·25	2·55	0·80	4·76	1·49	17·81	5·58
Forest	231·68	72·57	220·00	68·91	226·93	71·08	222·07	69·56	216·52	67·82	211·54	66·26
Warm season grass	3·64	1·14	7·76	2·43	3·32	1·04	6·54	2·05	22·41	7·02	12·99	4·07
Cool season grass	66·65	20·88	71·51	22·40	66·28	20·76	58·49	18·32	31·41	9·84	30·65	9·60

Table VI. Classification accuracy of LCM model used to validate 2006 land use data

Land use	Kappa	User's accuracy	Producer's accuracy
Urban low intensity	0·89	0·90	0·80
Urban high intensity	0·87	0·87	0·98
Barren land	0·63	0·63	0·32
Water	0·48	0·48	0·79
Herbaceous	0·60	0·60	0·92
Forest	0·90	0·97	0·95
Warm season grass	0·84	0·85	0·80
Cool season grass	0·56	0·58	0·71
Overall accuracy	0·90		
Overall Kappa	0·82		

critical for the accurate representation of land use change (Veldkamp and Lambin, 2001). However, as pointed out by Verburg *et al*. (2004), the integration of social, political, policy and economic factors into land use change modeling is often not successful because of difficulties in quantifying socio-economic factors and integrating such data with other environmental data. Nonetheless, the general performance of our land cover prediction model was acceptable with an overall Kappa Index of 0·82 and overall accuracy of 0·90 (Table VI).

The projected land use land cover map for 2030 shows a distribution of urban areas primarily expanding from the center of the disturbed areas (Figure 2). This distribution was supported by the relatively high Cramer's V (V=0·4661, $p<0{\cdot}001$) used to test the explanatory variable distance from existing disturbed areas (Table I). A comparison of the 2006 LULC with the projected 2030 LULC data showed that low intensity urban areas were projected to increase by over 75 per cent, whereas high intensity urban areas increased by 14 per cent. This trend followed the observed past LULC trend, which showed that, with the exception of year 1996, there was an increase in both low intensity and high intensity areas for the period 1986–2006. The barren and warm season grasses were projected to have the highest increase in LULC (Table VII). The herbaceous areas were projected to decrease the most during this period.

Soil Erosion/Deposition Risk Assessment

The soil *ED* values estimated for 1986, 2006 and 2030 were reclassified based on degree of severity into seven classes (Table VIII). The spatial distribution patterns of the different erosion intensity classes for the different LULC classes are

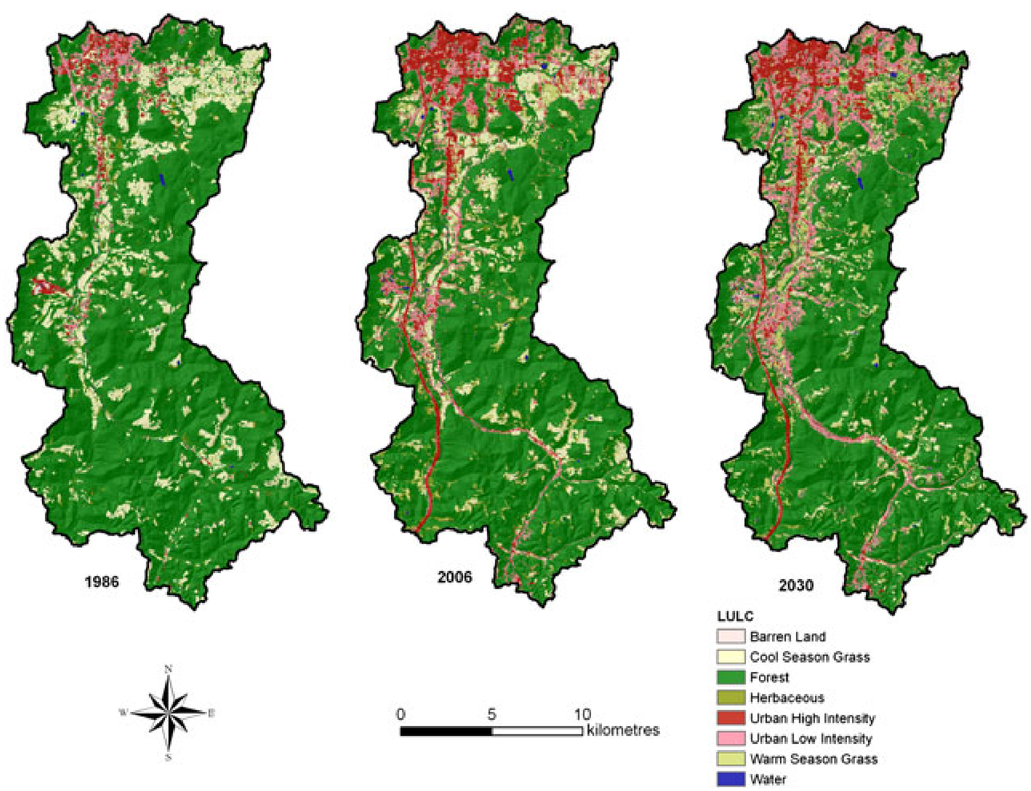

Figure 2. Land use land cover map for 1986, 2006 and projected 2030. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

Table VII. Projected land use land cover for 2030

LULC Description	Area (km^2)	Cover (%)
Urban low intensity	45·21	14·16
Urban high intensity	21·44	6·71
Barren land	1·89	0·59
Water	0·81	0·25
Herbaceous	4·88	1·53
Forest	187·55	58·75
Warm season grass	34·11	10·68
Cool season grass	23·36	7·32

LULC, land use/land cover.

shown in Figure 3. As was expected, the highest rates of erosion were found along the steep slopes (mountainous areas), whereas the highest deposition rates were found in the lower elevation areas (Figure 3). Rates of soil transport ranged between 0 and 190 $Mg ha^{-1} y^{-1}$ for erosion and between 0 and 200 $Mg ha^{-1} y^{-1}$ for deposition across each land use. Table VI shows that over 40 per cent of the WFWR watershed area was stable in 1986, but this area decreased to just 34 per cent in 2006 and 2030. Over 36 per cent of the watershed area experienced erosion in 1986, whereas over 39 per cent of the area experienced erosion in 2006 and 2030. High erosion and deposition areas were also located along the West Fork White River and its tributaries (Figure 3). This suggests that perhaps more widespread use of riparian buffers along major rivers would be an appropriate best management practice in this region. This result complements recent studies that have identified riparian areas as critical zones for stream channel stability in NW Arkansas (Keen-Zebert, 2007). In fact, other studies have identified sources such as streambank erosion as major contributors of sediment yield (accounting for up to 60 per cent of the sediment) in the WFWR watershed (ADEQ, 2004; Srivastava, 2006; Leh, 2011).

Mean erosion rates ranged from 0·06 to 3·20 $Mg ha^{-1} y^{-1}$, whereas deposition rates ranged from 0·06 to 1·61 $Mg ha^{-1} y^{-1}$ for each land use (Table IX). Generally, erosion rates dominate deposition rates. Total erosion was predicted to increase about 22 per cent, whereas deposition increased 14 per cent by 2030. Mean erosion rates were highest in the barren land and lowest in the urban high intensity areas. Although the forest areas experienced low mean erosion rates, the total erosion from this LULC class was the greatest because it covered the largest area of the watershed. Total erosion from urban areas in 1986 was predicted to be 258 $Mg y^{-1}$, however this number would increase by over 550 per cent in 2030 (Table IX). This clearly showed that increased urbanization enhanced the risk of erosion within the WFWR watershed. Our results are consistent with other reported studies that have associated increased urbanization with high potential for soil erosion (Junior *et al.*, 2010; Ward, 2007; Nelson and Booth, 2002; Ormerod, 1998). Ricker *et al.* (2008) observed significant increases in erosion rates (up to 139 $Mg y^{-1}$) from urban areas for a sub-watershed of the Rappahannock River in Virginia.

Two other major sources of increased erosion are the barren and warm season grass LULC classes. The total erosion in the barren land area was 130 $Mg y^{-1}$ in 1986 and this value was projected to increase to 599 $Mg y^{-1}$ by 2030. Increased erosion risk in barren areas was not surprising because larger barren coverage meant larger areas without protective soil cover and therefore increased risk of erosion. In the case of the warm season grass areas, total erosion was 97 $Mg y^{-1}$ in 1986 and this value was projected to increase to 750 $Mg y^{-1}$ by 2030 (Table IX). Although the increase in erosion risk in the warm season grass areas (563 per cent increase) are comparable with increased erosion risk in urban areas (555 per cent increase), urban LULC areas increased 371 per cent, whereas the increase in warm season grass area was 837 per cent. This suggests that urbanization has a greater influence on erosion risk than the warm season grass areas.

Limitations and implications for sediment/erosion control and conservation planning

The results presented here are based on model estimates without field verification. Therefore, the quantitative

Table VIII. Predicted erosion and deposition risk areas for 1986, 2006 and 2030 land use

Classification	Erosion/ deposition [$Mg ha^{-1} y^{-1}$]	1986		2006		2030	
		Area (km^2)	Cover (%)	Area (km^2)	Cover (%)	Area (km^2)	Cover (%)
High erosion	>−5	0·83	0·26	1·01	0·32	1·00	0·31
Medium	−1–−5	6·74	2·11	8·19	2·56	7·74	2·42
Low	−0·02–−1	107·89	33·80	113·39	35·52	112·21	35·15
Stable	−0·02–0·02	137·67	43·12	126·34	39·57	128·37	40·21
Low	0·02–1	57·11	17·89	59·43	18·62	59·35	18·59
Medium	1–5	6·76	2·12	8·16	2·56	7·79	2·44
High deposition	>5	2·24	0·70	2·72	0·85	2·80	0·88

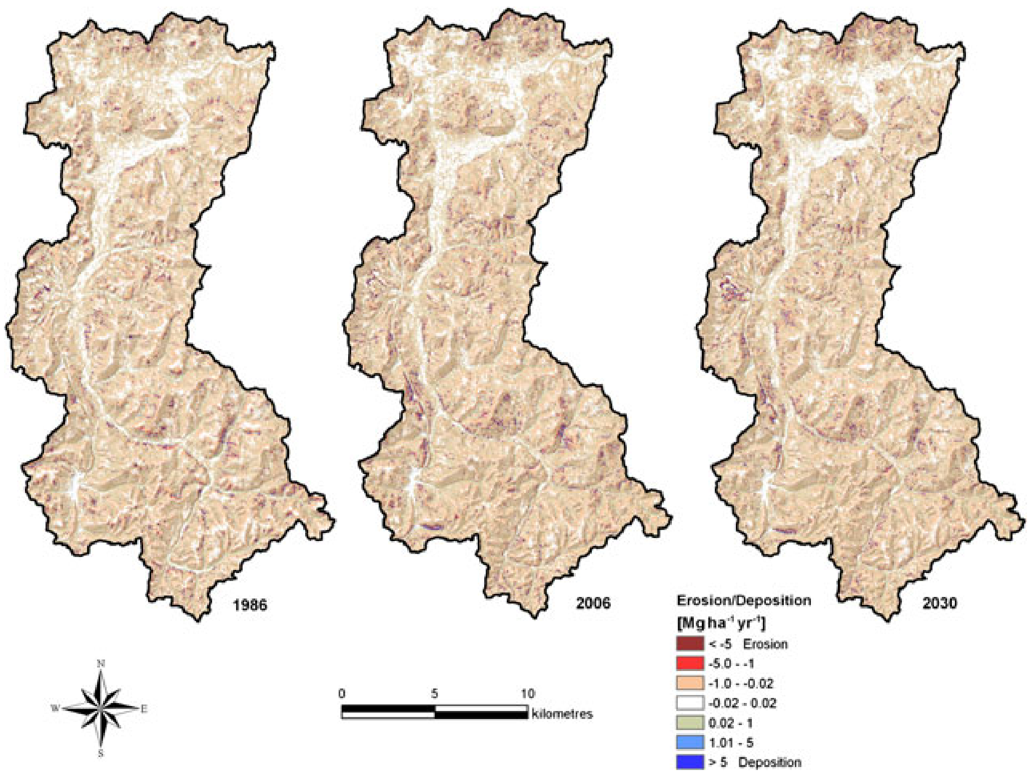

Figure 3. Predicted erosion/deposition potential maps for 1986, 2006 and 2030 land use created using the USPED model. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

results from this study should be interpreted with caution. One of the challenges of modeling soil erosion at the watershed scale is the lack of reliable data for comparing estimates (Gobin *et al*., 2003). Another limitation is the use of only environmental variables in predicting future LULC. As previously pointed out, studies have indicated that socio-economic drivers play critical roles in driving land use change (Lambin *et al*., 2001) and the major drawback in the use of such data in land use modeling is its availability at spatial scales and the difficulty in their integration with environmental data. Nonetheless, a number of studies have successfully integrated both environmental and socio-economic factors in modeling land use change (Luo *et al*., 2010; Gellrich and Zimmermann, 2007).

Another shortcoming of our study is in the discrimination of the urban areas. Model estimates from the urban areas included cleared construction sites and covered surfaces such as roads, roofs and other impervious surfaces. Obviously, model estimates for the surfaces already covered with concrete and asphalt would be expected to be low because there is no direct contact with soil. However, areas such as construction sites and rural county roads can be sources of high erosion risk. Road sideslopes contribute up to 90 per cent of total soil loss from forestlands (Swift, 1984). Also, predicted *ED* rates from construction and urban development sites would be expected to be high because these areas experience severe amounts of soil disturbance and loss of vegetative cover. Perhaps the use of high resolution LULC that is able to separate areas such as unpaved rural roads and other uncovered surfaces from concrete and paved surfaces would give more accurate results.

Nonetheless, the methods described are directly applicable to the development of a successful soil conservation and management plan. Tools required for a successful conservation plan include erosion prediction technology, soil loss tolerance measures, land use data, soil survey data, topographic data and specifications of conservation practices (Toy *et al*., 2002). Erosion risk maps such as the ones generated in this study could be used as baseline data to obtain information on the spatial variability of upland erosion. These data can be incorporated in landscape management and erosion control strategies. Because of the popularity of erosion models such as the RUSLE model, most of the geospatial data required for the USPED model could be easily obtained or computed. Elevation data (DEM) are available globally and at very high resolutions in certain areas. Remotely sensed data such as the normalized difference vegetation index (NDVI), which is often used as an indicator of vegetation growth can be easily determined and compared at different periods to estimate the vegetation cover status

Table IX. Mean and total annual estimates of erosion/deposition by land use for observed (1986 and 2006) and projected (2030) land use using the USPED model

Land use	1986	2006	2030			
	Mean ($Mg ha^{-1} y^{-1}$)	Total ($Mg y^{-1}$)	Mean ($Mg ha^{-1} y^{-1}$)	Total ($Mg y^{-1}$)	Mean ($Mg ha^{-1} y^{-1}$)	Total [$Mg y^{-1}$)
Erosion						
Urban low intensity	−0·252	−206	−0·344	−871	−0·413	−1544
Urban high intensity	−0·089	−51	−0·059	−110	−0·080	−165
Barren land	−2·537	−130	−1·946	−117	−3·200	−599
Herbaceous	−0·830	−807	−0·827	−1446	−0·831	−396
Forest	−0·092	−2203	−0·112	−2368	−0·112	−2383
Warm season grass	−0·311	−112	−0·326	−421	−0·298	−750
Cool season grass	−0·308	−1517	−0·193	−589	−0·225	−322
Total erosion		−5027		−5922		−6159
Deposition						
Urban low intensity	0·237	194	0·310	783	0·363	1257
Urban high intensity	0·072	42	0·063	118	0·074	153
Barren land	1·543	79	1·219	73	1·610	302
Herbaceous	0·614	597	0·595	1039	0·618	294
Forest	0·085	2031	0·104	2195	0·096	2032
Warm season grass	0·270	97	0·273	353	0·253	636
Cool season grass	0·261	1282	0·171	522	0·193	277
Total deposition		4322		5083		4951
Net soil loss		−705		−839		−1208

when combined with LULC (Gobin *et al*., 2003). In the US, soil databases such as the United States Department of Agriculture-NRCS SSURGO database contain detailed soil property information including soil *K*-factor data.

From erosion risk maps, areas of high erosion can be quickly identified, and management efforts can be directed at these high priority areas. For example, our study identified the areas along the West Fork White River as high erosion/deposition zones. Soil conservation/erosion control strategies could include riparian buffers along streambanks combined with in-channel grassed waterways. Brion *et al*. (2010) showed that riparian land use can have significant effects on stream water quality for a mixed agricultural watershed in Fayetteville, Arkansas. Urban areas susceptible to high erosion may require erosion control structures such as sediment control basins combined with water retention basins for surface runoff management. Site preparation could also be planned such that construction occurs in phases. For the agricultural areas, surface cover could be protected by minimizing agricultural practices that involve direct mixing of the soil.

SUMMARY AND CONCLUSIONS

Long term land use change analysis was performed to detect, delineate and map the landscape dynamics in the West Fork White River watershed from 1986 to 2006 and consequently to predict a possible scenario of future land use based on past land use and other commonly available biophysical data. Several environmental drivers of change within the WFWR watershed were also explored. Urban land cover grew from over 4 per cent of the total land cover in 1986 to over 13 per cent in 2006 and is expected to grow to over 17 per cent by 2030 assuming the nature of development remains the same. Overall, the forest and the pasture areas explained the greatest increase in urban areas.

Erosion potential maps were also generated based on the past (1986), current (2006) and future (2030) land cover and other spatially derived parameters using the USPED model. The goal was to identify the effects of long term land use change on the spatial distribution of erosion potential using readily available spatial data such as topography and soil data. The integration of the topographic, climatic and remotely sensed data, within a GIS environment provided an effective means of assessing sediment transport within the catchment. This study demonstrates the use of readily available tools to assess the effects of alternate land management activities on soil erosion.

ACKNOWLEDGEMENT

This research project was conducted with grant support from USEPA R6 Project No. X7-97691401-0.

REFERENCES

Arkansas Department of Environmental Quality (ADEQ). 2004. Data Inventory and Nonpoint Source Pollution Assessment for West Fork White River Watershed. Arkansas Department of Environmental Quality.

Arkansas Department of Environmental Quality (ADEQ). 2000. Arkansas Water Quality Inventory Report. Arkansas Department of Environmental Quality.

Bewket W, Teferi E. 2009. Assessment of soil erosion hazard and prioritization for treatment at the watershed level: Case study in the Chemoga watershed, Blue Nile basin, Ethiopia. *Land Degradation & Development* **20**: 609–622.

Brion G, Brye KR, Haggard BE, West C, Brahana JV. 2010. Land-use effects on water quality of a first-order stream in the Ozark Highlands, mid-southern United States. *River Research and Applications* DOI: 10.1002/rra.1394.

Bronstert A, Niehoff D, Bürger G. 2002. Effects of climate and land-use change on storm runoff generation: Present knowledge and modeling capabilities. *Hydrological Processes* **16**: 509–529.

Capolongo D, Pennetta L, Piccarreta M, Fallacara G, Boenzi F. 2008. Spatial and temporal variations in soil erosion and deposition due to land-levelling in a semi-arid area of Basilicata (Southern Italy). *Earth Surface Processes and Landforms* **33**: 364–379.

Clark Labs. 2009. *The Land Change Modeler for Ecological Sustainability*. IDRISI Focus Paper. Clark University, Worcester, MA.

Definiens. 2008. *Defieniens Developer 7 User Guide*. Munich, Germany.

Eastman JR. 2006. *IDRISI Andes Guide to GIS and Image Processing*, Clark University, Worcester, MA.

Edwards DR, Moore PAJ, Daniel TC, Srivastava P. 1996. Poultry litter-treated length effects on quality of runoff from fescue plots. *Transactions of the American Society of Agricultural Engineers* **39**: 105–110.

Fernandez C, Wu JQ, McCool DK, Stöckle CO. 2003. Estimating water erosion and sediment yield with GIS, RUSLE, and SEDD. *Journal of Soil and Water Conservation* **58**: 128–136.

Foody GM. 2002. Status of land cover classification accuracy assessment, *Remote Sensing of Environment* **80**: 185–201. DOI: 10.1016/S0034-4257(01)00295-4.

Foster GR. 1990. Process-based modelling of soil erosion by water on agricultural land. In *Soil Erosion on Agricultural Land*, Boardman JI, Foster DL, Dearing JA (eds). John Wiley & Sons: Chichester; 429–445.

Flanagan DC, Nearing MA. 1995. *USDA-Water Erosion Prediction Project (WEPP) Hillslope Profile and Watershed Model Documentation. NSERL Report No. 10*. National Soil Erosion Research Laboratory, USDA-Agricultural Research Service, West Lafayette, IN.

Fu G, Chen S, McCool DK. 2006. Modeling the impacts of no-till practice on soil erosion and sediment yield with RUSLE, SEDD, and ArcView GIS. *Soil & Tillage Research* **85**: 38–49.

Fu BJ, Zhao WW, Chen LD, Zhang QJ, Lu YH, Gulinck H, Poesen J.2005. Assessment of soil erosion at large watershed scale using RUSLE and GIS: A case study in the loess plateau of China. *Land Degradation & Development* **16**:73–85. DOI: 10.1002/ldr.646.

Gellrich M, Zimmermann NE. 2007. Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: A spatial statistical modelling approach. *Landscape and Urban Planning* **79**: 65–76. DOI: 10.1016/j.landurbplan.2006.03.004.

Gobin A, Govers G, Jones R, Kirkby M, Kosmas C. 2003. Assessment and reporting on soil erosion. Back ground and workshop report. EEA Technical Report No. 94. European Environment Agency, Copenhagen. Available at http://www.environmental-expert.com/Files/8909/articles/3028/tech_94.pdf. (verified November 2010).

Gorham BE, Tullis JA. 2007. *Arkansas Land Use and Land Cover (LULC) 2006*. Arkansas Natural Resource Commission Final Report, Arkansas Natural Resource Commission: Little Rock, AR.

Haan CT, Barfield BJ, Hayes JC. 1994. *Design Hydrology and Sedimentology for Small Catchments*. Academic Press: New York, NY.

Harper MD, Phillips WW, Haley GJ. 1969. *Soil Survey of Washington County, Arkansas. U. S. Department of Agriculture, Soil Conservation Service*, U.S. Government Printing Office, Washington, DC.

Ismail J, Ravichandran S. 2008. RUSLE2 model application for soil erosion assessment using remote sensing and GIS. *Water Resources Management* **22**: 83–102. DOI: 10.1007/s11269-006-9145-9.

Junior OC, Guimaraes R, Freitas L, Gomes-Loebmann D, Gomes RA, Martins E, Montgomery DR. 2010. Urbanization impacts upon catchment hydrology and gully development using mutli-temporal digital elevation data analysis. *Earth Surface Processes and Landforms* **35**: 611–617. DOI: 10.1002/esp.1917.

Keen-Zebert A. 2007. Channel responses to urbanization: Scull and Mud Creeks in Fayetteville, AR. *Physical Geography* **28**: 249–260.

Kingery WL, Wood CW, Delaney DP, Williams JC, Mullins GL. 1994. Impact of long-term land application of broiler litter on environmentally related soil properties. *Journal of Environmental Quality* **23**: 139–147.

Kinnell PIA. 2010. Event soil loss, runoff and the Universal Soil Loss Equation family of models: A review. *Journal of Hydrology* **385**: 384–397.

Kocabas V, Dragicevic S. 2006. Coupling Bayesian networks with GIS-based cellular automata for modeling land use change. *Geographic Information Science* **4197**: 217–233.

Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skånes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Vogel C, Xu J. 2001. The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change* **11**: 261–269. DOI: 10.1016/S0959-3780(01)00007-3

Leh MDK. 2011. *Quantification of sediment sources in a mixed land use watershed: A remote sensing and modeling approach. PhD Thesis*. University of Arkansas: Fayetteville, AR.

Liu J, Liu S, Tieszen LL, Chen M. 2007. *Estimating soil erosion using the USPED model and consecutive remotely sensed land cover observations. Proceedings of the 2007 Summer Computer Simulation Conference*. Society for Computer Simulation International: San Diego, CA. 16:1–16:6.

López E, Bocco G, Mendoza M, Duhau E. 2001. Predicting land-cover and land-use change in the urban fringe: A case in Morelia city, Mexico. *Landscape and Urban Planning* **55**: 271–285. DOI: 10.1016/S0169-2046(01)00160-8.

López-Vicente M, Navas A. 2010. Routing runoff and soil particles in a distributed model with GIS: Implications for soil protection in mountain agricultural landscapes. *Land Degradation & Development* **21**: 100–109.

Luo G, Yin C, Chen X, Xu W, Lu L. 2010. Combining system dynamic model and CLUE-S model to improve land use scenario analyses at regional scale: A case study of Sangong watershed in Xinjiang, China. *Ecological Complexity* **7**: 198–207. DOI: 10.1016/j.ecocom.2010.02.001.

Merritt WS, Letcher RA, Jakeman AJ. 2003. A review of erosion and sediment transport models. *Environmental Modeling and Software* **18**: 761–799.

Mitas L, Mitasova H. 1998. Distributed erosion modeling for effective erosion prevention. *Water Resources Research* **34**: 505–516.

Mitasova H, Mitas L. 2001. Multiscale soil erosion simulations for land use management. In *Landscape Erosion and Landscape Evolution Modeling*, Harmon R, Doe W (eds). Kluwer Academic/Plenum Publishers: Dordrecht; 321–347.

Mitasova H, Hofierka J, Zlocha M, Iverson LR. 1996. Modeling topographic potential for erosion and deposition using GIS. *International Journal of Geographical Information Science* **10**: 629–641.

Moore ID, Wilson JP. 1992. Length-slope factors for the revised universal soil loss equation: Simplified method of estimation. *Journal of Soil and Water Conservation* **47**: 423–428.

Morgan RPC, Quinton JN, Smith RE, Govers G, Poesen JWA, Auerswald K, Chisci G, Torri D, Styczen ME. 1998. The European soil erosion model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surface Processes and Landforms* **23**: 527–544.

Mutua BM, Klik A, Loiskandl W. 2006. Modelling soil erosion and sediment yield at a catchment scale: The case of Masinga catchment, Kenya. *Land Degradation & Development* **17**: 557–570.

National Oceanic and Atmospheric Administration (NOAA). 2006. Washington County, Arkansas Climatology. National Oceanic and

Atmospheric Administration, Washington, DC. Available at http://www.srh.noaa.gov/tsa/?n=climo_washington (verified May 2010).

Nekhay O, Arriaza M, Boerboom L. 2009. Evaluation of soil erosion risk using analytic network process and GIS: A case study from Spanish mountain olive plantations, *Journal of Environmental Management* **90**: 3091–3104.

Nelson EJ, Booth DB. 2002. Sediment sources in an urbanizing, mixed land-use watershed. *Journal of Hydrology* **264**: 51–68.

Ormerod LM. 1998. Estimating sedimentation rates and sources in a partially urbanized catchment using caesium-137. *Hydrological Processes* **12**: 1009–1020.

Osborne LL, Wiley MJ. 1988. Empirical relationships between land use/cover and stream water quality in an agricultural watershed. *Journal of Environmental Management* **26**: 9–27.

Ott L, Larson RF, Mendenhall W. 1983. *Statistics: A Tool for the Social Sciences*. Duxbury Press: Boston, MA.

Pelacani S, Märker M, Rodolfi G. 2008. Simulation of soil erosion and deposition in a changing land use: A modelling approach to implement the support practice factor. *Geomorphology* **99**: 329–340.

Pontius RG. 2000. Quantification error versus location error in comparison of categorical maps. *Photogrammetric Engineering and Remote Sensing* **66**: 1011–1016.

Rahman MdR, Shi ZH, Chongfa C. 2009. Soil erosion hazard evaluation-an integrated use of remote sensing, GIS and statistical approaches with biophysical parameters towards management strategies. *Ecological Modelling* **220**: 1724–1734.

Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC. 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook No. 703*. USDA- Agricultural Research Service: Washington, DC.

Ricker MC, Odhiambo BK, Church JM. 2008. Spatial analysis of soil erosion and sediment fluxes: A paired watershed study of two Rappahannock River Tributaries, Stafford County, Virginia. *Environmental Management* **41**: 766–778.

Saavedra CP, Mannaerts CM. 2005. *Erosion estimation in an Andean catchment combining coarse and fine resolution satellite imagery. Proceedings of the 31st International Symposium on Remote Sensing of Environment: Global Monitoring for Sustainability and Security*. Russian Federation: St Petersburg.

Sauer TJ, Daniel TC, Moore JPA, Coffeey KP, Nichols DJ, West CP. 1999. Poultry litter and grazing animal waste effects on runoff water quality. *Journal of Environmental Quality* **28**: 860–865.

Sharpley AN, Daniel TC, Edwards DR. 1993. Phosphorus movement in the landscape. *Journal of Production Agriculture* **6**: 492–500.

Shepherd SL, Dixon JC, Davis RK, Feinstein R. 2010. The effect of land use on channel geometry and sediment distribution in gravel mantled bedrock streams, Illinois river watershed, *Arkansas. River Research and Applications* DOI: 10.1002/rra.1401.

Soranno PA, Hubler SL, Carpenter SR, Lathrop RC. 1996. Phosphorus loads to surface waters: A simple model to account for spatial pattern of land use. *Ecological Applications* **6**: 865–878. DOI: 10.2307/2269490.

Srivastava R. 2006. *Comparison of the hydrology and sediment modeling components of SWAT and AnnAGNPS models*. MS Thesis. University of Arkansas, Fayetteville, AR.

Stohlgren TJ, Chase TN, Pielke RA, Kittel TGF, Baron JS. 1998. Evidence that local land use practices influence regional climate, vegetation, and stream flow patterns in adjacent natural areas. *Global Change Biology* **4**: 495–504.

Storm DE, White MJ, Brown GO, Smolen MD, Kang RS. 2006. Protocol to Determine the Optimal Placement of Riparian/Buffer Strips in Watersheds. Oklahoma Water Resources Research Institute. Available at http://ojs.library.okstate.edu/osu/index.php/OWRRI/article/view/51/39. (verified November 2010).

Story M, Congalton R. 1986. Accuracy assessment: A user's perspective. *Photogrammetric Engineering and Remote Sensing* **52**: 397–399.

Swift LW. 1984. Soil losses from roadbeds and cut and fill slopes in the Southern Appalachian Mountains. *Southern Journal of Applied Forestry* **8**: 209–216.

Tang Z, Engel BA, Pijanowski BC, Lim KJ. 2005. Forecasting land use change and its environmental impact at a watershed scale. *Journal of Environmental Management* **76**: 35–45. DOI: 10.1016/j.jenvman.2005.01.006.

Toy TJ, Foster GR, Renard KG. 2002. *Soil Erosion: Processes, Prediction, Measurement, and Control*. John Wiley & Sons: New York, NY.

Veldkamp A, Lambin EF. 2001. Predicting land-use change. *Agriculture, Ecosystems and Environment* **85**: 1–6.

Verburg PH, Schot PP, Dijst MJ, Veldkamp A. 2004. Land use change modelling: Current practice and research priorities. *GeoJournal* **61**: 309–24.

Wang L, Lyons J, Kanehl P. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. *Environmental Management* **28**: 255–266.

Wang L, Lyons J, Kanehl P, Bannerman R, Emmons E. 2000. Watershed urbanization and changes in fish communities in southeastern Wisconsin streams. *Journal of the American Water Resources Association* **36**: 1173–1189.

Ward JV. 2007. *Changing Patterns of Land use and Basin Morphometry: Impacts on Stream Geomorphology in the Illinois River Basin Northwest Arkansas 1941–2004. PhD Thesis*. University of Arkansas: Fayetteville, AR.

Warren SD, Mitasova H, Hohmann MG, Landsberger S, Iskander FY, Ruzycki TS, Senseman GM. 2005. Validation of a 3-D enhancement of the Universal Soil Loss Equation for prediction of soil erosion and sediment deposition. *Catena* **64**: 281–296.

Weng Q. 2001. Modeling urban growth effects on surface runoff with the integration of remote sensing and GIS. *Environmental Management* **28**: 737–748.

White MD, Greer KA. 2006. The effects of watershed urbanization on the stream hydrology and riparian vegetation of Los Peñasquitos Creek, California. *Landscape and Urban Planning* **74**: 125–138.

Wischmeier WH, Smith DD. 1978. *Predicting Rainfall Erosion Losses- A Guide to Conservation Planning. Agriculture Handbook No. 537*. USDA-Agricultural Research Service: Washington, DC.

Yue-qing X, Jian P, Xiao-mei S. 2009. Assessment of soil erosion using RUSLE and GIS: A case study of the Maotiao River watershed, Guizhou Province, China. *Environmental Geology* **56**: 1643–1652. DOI: 10.1007/s00254-008-1261-9.

Yuksel A, Gundogan R, Akay AE. 2008. Using the remote sensing and GIS technology for erosion risk mapping of Kartalkaya dam watershed in Kahramanmaras, Turkey. *Sensors* **8**: 4851–65. DOI: 10.3390/s8084851.

Zampella RA, Laidig KJ, Lowe RL. 2007. Distribution of diatoms in relation to land use and pH in blackwater coastal plain streams. *Environmental Management* **39**: 369–384.

Zhang W, Montgomery DR. 1994. Digital elevation model grid size, landscape representation, and hydrologic simulations, *Water Resources Research* **30**: 1019–1028.

