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Estimating land-use change impacts on direct runoff and non-point source pollutant loads in the Richland Creek basin (Illinois, USA) by applying the L-THIA model

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Abstract

An export coefficient approach to hydrological and non-point source (NPS) pollution modeling enables quick and simple assessment of long-term impacts for planning purposes. An export coefficient and geographic information system based L-THIA (Long-Term Hydrologic Impact Assessment) model was applied to the Richland Creek basin (Illinois, USA) to assess the impacts of future urban growth on direct runoff, NPS total nitrogen (TN), total suspended particles (TSP), and total phosphorous (TP) loads. The model predicted that mean annual direct runoff and TSP loading would increase by around 7% and 4% respectively by 2030 with moderate and rapid urban growth simulated by a land-use change model, while TN and TP loads would change little. Such changes are due to the projected land-use change patterns, mainly from agriculture to commercial/industrial or low-intensity residential, and to the different contributions of land-uses to runoff and NPS pollutant loads. At a subbasin scale, the most developed subbasin is projected to experience the greatest increase in commercial/industrial land at the expense of agricultural land and thus notable increases in runoff and TSP load. The changes in runoff and TSP load in other subbasins and the changes in TN and TP loads in all the subbasins show little spatial variability even though the range of per cent increases in low-intensity residential is extremely wide. This study reveals the effect of different 'urban' land-use types on water quality and suggests that proper simulation or planning of different urban land-use types must be carried out for impact assessments.

Keywords: land-use change; runoff; non-point source pollution; hydrological model

Introduction

Nutrients from agricultural fertilizers are major causes of water quality problems in the State of Illinois, United States (IEPA 1996; IEPA 2002). Nitrogen (N) and phosphorus (P) are the main nutrients in agricultural fertilizers and the major causes of eutrophication (Carpenter et al. 1998). Suspended particles (SP) are a good indicator of soil erosion in agriculturally-dominated drainage basins (Mattikalli and Richards 1996). Soil sediment from natural sources such as volcanic eruptions and weathering is not regarded as pollution, but enhanced sediment yields from human activities (e.g. agriculture, urban development) are pollution (Novotny 2003). Excessive sediment loading deteriorates aquatic habitat, reduce storage capacity in reservoirs, and adsorb nutrients, especially phosphorus (Heathwaite and Dils 2000; Novotny 2003). SP is not only from soil erosion but also from other sources in urban areas such as street refuse, vehicle traffic, and construction sites, and various pollutants are attached to SP (Novotny 2003). Therefore, N, P and SP have been regarded as important parameters of water quality (Mattikalli and Richards 1996). Such pollutants are generally called non-point source (NPS) pollutants, as they originate from diffuse sources. NPS pollution is "the principal obstacle to successful cleanup of water resources" (Benfield et al. 1999) and surface water carries the highest load of particulate pollutants (Novotny and Olem 1994).

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NPS pollutant loads are significantly influenced by land-use changes since land-use changes modify the sources of pollutants and the way they are carried to streams. It is widely known that urban development increases impervious land surface, which in turn increases direct runoff (Dunne and Leopold 1978; Walesh 1989; Singh 1992). As NPS pollutants are carried by runoff, increased direct runoff can result in an increase in these pollutant loads. Different land-use types contribute to NPS pollutant loads with different magnitudes, primarily depending on their event mean concentrations (EMC) (Novotny 2003; Engel 2001), which is a measure of the amount of pollutants carried in unit volume of runoff. Jones et al. (2001) argue that the amount of agriculture, riparian forests and roads explain a high percentage of variations in N, P and sediment loads. In a study by Tong and Chen (2002), agriculture and impervious urban land-uses were found to produce much higher N and P than other land-uses. Many other studies point out that urban land-uses play an important role in water quality.

There have been numerous attempts to apply water quality models under various land-use conditions, including those of Mattikalli and Richards (1996), Bhaduri et al. (2000), Payraudeau et al. (2004), and Fohrer et al. (2005) just to name a few. What this paper is particularly concerned about is applying models with future urban growth or development scenarios, since it is important to test various scenarios before they result in irreversible environmental impacts. Recent relevant studies include those of Chang (2004), Wang et al. (2005), and Tang et al. (2005). Chang (2004) applied a geographic information system (GIS) based GWLF (Generalized Watershed Loading Function; Haith and Shoemaker 1987) model to assess the impact of climate change and urban growth in 2030 on the water quality of the Conestoga River basin in Pennsylvania, USA. Wang et al. (2005) applied a simple NPS pollutant loading model L-THIA (Long-Term Hydrologic Impact Assessment; Engel 2001) with a series of future land-use scenarios produced from a dynamic land-use change model (LEAM) to analyze the temporal changes of direct runoff and NPS pollutant loads in the Metropolitan St. Louis Area, USA. Tang et al. (2005) also applied L-THIA with land-use scenarios from a land-use change model to the Muskegon River basin in Michigan, USA.

GWLF model adopted by Chang (2004) is a process-based model like HSPF (Hydrological Simulation Program – Fortran; Bicknell et al. 2001) or SWAT (Soil and Water Assessment Tool; Arnold et al. 1998) models producing streamflow time series and calculating NPS pollutant loads based on the streamflow and land-use characteristics. On the other hand, L-THIA takes a simple export coefficient approach. Johnes (1996) states that a simple export coefficient modeling approach can predict pollutant loading as a function of the export of pollutants from each source in the study area. Such an approach is generally for steady-state analysis at long-term scales or initial assessments of environmental impacts and has been adopted widely in spite of its simplicity (e.g. Soranno et al. 1996; Whitehead et al. 2002; Wade et al. 2004).

The motives for this research were (1) limitations of previous L-THIA application studies and (2) the need for initial assessment from the local community using a simple NPS pollutant model. The previous L-THIA applications with future urban growth scenarios missed watershed-scale analyses (Wang et al. 2005) or did not differentiate urban land-use categories (Tang et al. 2005) in land-use change simulations. This article examines the potential impact of future land-use changes on NPS pollutant loads by applying L-THIA in the Richland Creek basin, Illinois, which is nested in the Metropolitan St. Louis Area. The analysis is performed for each subbasin which will experience land-use changes in different ways, and it is expected to show the impact of the changes in different urban land-use categories. This approach is also used to identify the most sensitive areas to land-use changes in terms of NPS pollutant loading, as a few areas of a drainage basin can be largely responsible for high amounts of NPS pollutant loads (Tripathi et al. 2003). Process-based modeling can follow for further investigation.

Methods

The Study Region: the Richland Creek basin

The Richland Creek basin (RCB) is located in southwestern Illinois (Figure 1). The Richland Creek is a tributary of the Kaskaskia River, which eventually joins the Mississippi River at the southern tip of Illinois. The Kaskaskia River is the second largest river system within Illinois, and has been an important natural feature in southwestern Illinois throughout recorded history (SIRCD 2002). The Richland Creek was chosen since streamflow data are available and it is nested in the Metropolitan St. Louis Area, which was the site of LEAM model application project funded by the East-West Gateway Council of Governments (http://www.ewgateway.org/RegDev/Blueprint/BPModel/bpmodel.htm). Wang et al. (2005) assessed land-use change impacts on NPS pollutant loading in the area as a part of the project.

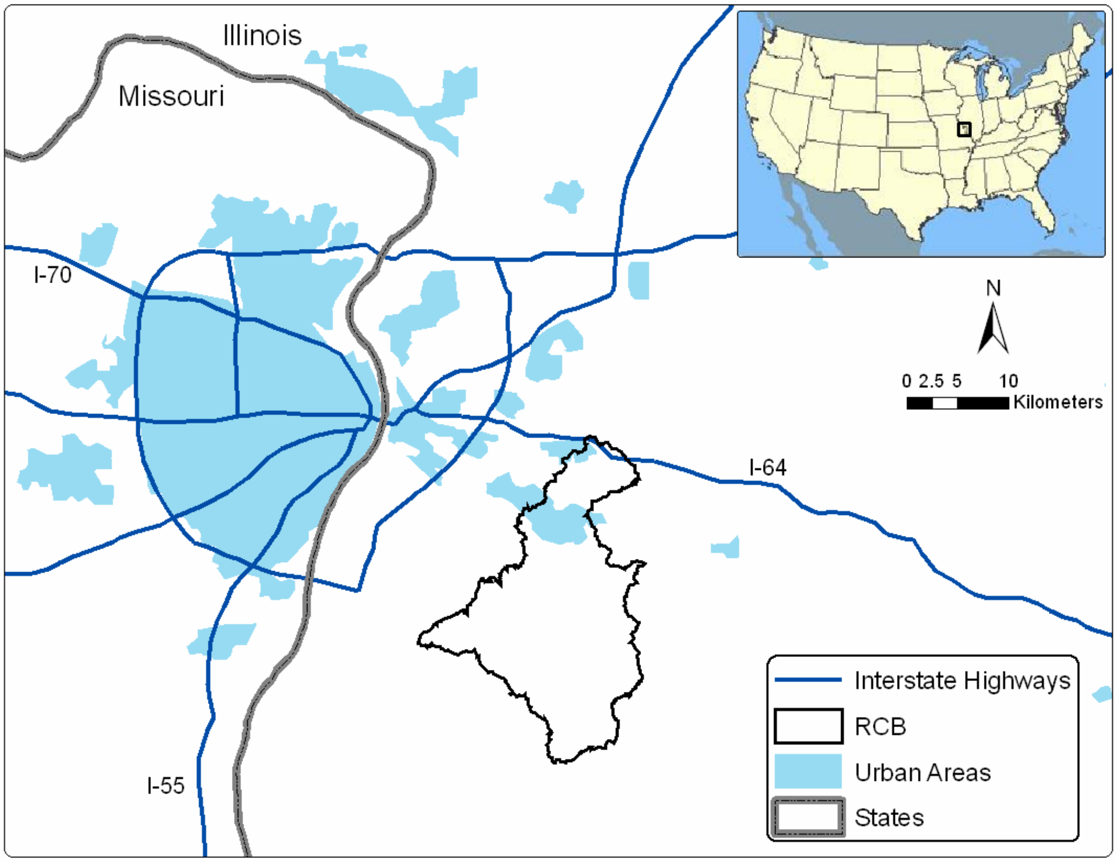

Figure 1. Location of the Richland Creek Basin (RCB)

The total drainage area of the RCB is 334km^2 (U.S. Geological Survey 2004). Figure 2 shows the area of each land-use type in the study region in 2000, based on the GIS land-use data. The GIS land-use data was produced by combining the1992 National Land Cover Data (U.S. Geological Survey 2006) and the 1999-2000 Illinois land-cover data (Illinois Department of Agriculture 2001); and reclassifying the land-use categories to satisfy L-THIA model requirements. UOS is urban open space, Ag is agriculture, LR is low-intensity residential, HR is high-intensity residential, G/P is grass/pasture, and C/I/I is commercial/industrial/impervious.

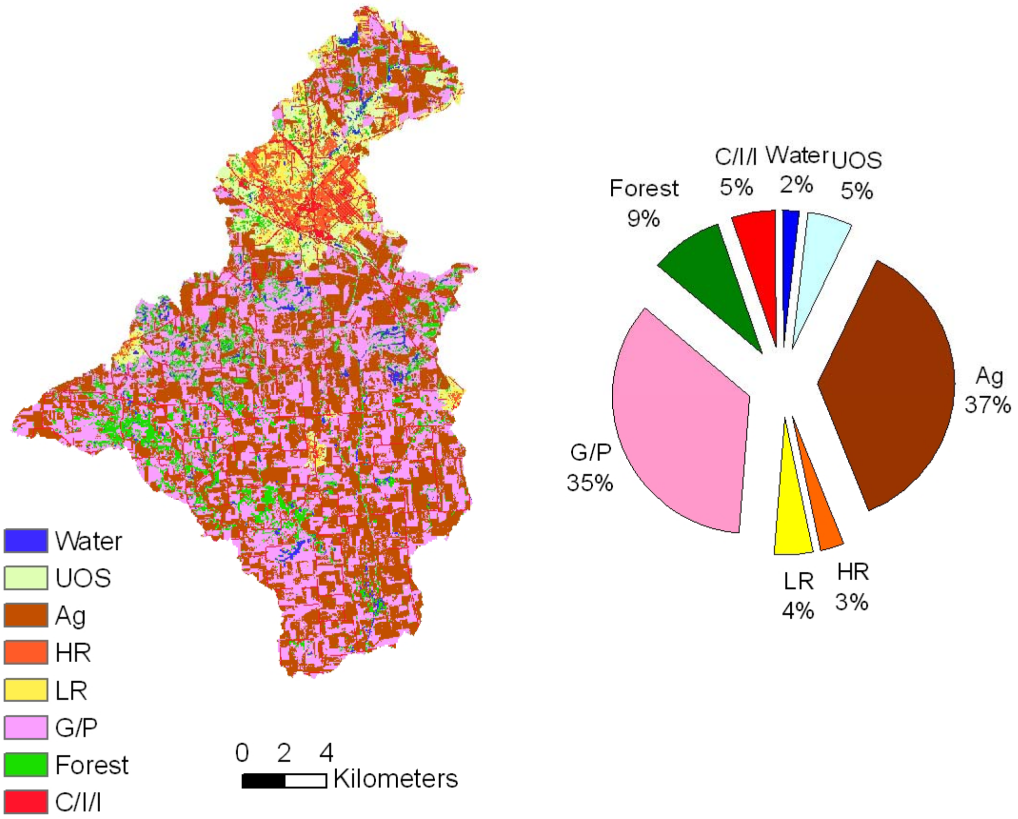

Figure 2. Land-use of the study region as of 2000 (source: U.S. Geological Survey 2006 and Illinois Department of Agriculture 2001). Here UOS is urban open space, Ag is agriculture, LR is low-intensity residential, HR is high-intensity residential, G/P is grass/pasture, and C/I/I is commercial/industrial/impervious

As for the climate, the study area receives an average annual precipitation at 1,000mm and has an annual mean temperature at 13.3°C calculated from measurements taken at the Illinois State Water Survey station (110510 Belleville SIU Research) located in St. Clair County (Illinois) from 1971 to 2000. Monthly mean temperature reaches above 25°C in July, and falls below 0°C in January. Spring (March – May) is the wettest season with precipitation at least 90mm/month, while January and February are the driest months with precipitation less than 50mm/month.

L-THIA NPS model

L-THIA (Engel 2001) is a hydrology and NPS pollutant loading model that uses the export coefficient approach. It calculates direct runoff and NPS pollutant loads in each tessellated grid cell of a study area. L-THIA is very easy to use, has ArcView GIS™ 3.3 interface, and has been adopted in several published articles (e.g. Bhaduri et al. 2000; Pandey et al. 2000; Bhaduri et al. 2001; Grove et al. 2001; Wang et al. 2005; Tang et al. 2005). The PLOAD model embedded in BASINS (Better Assessment Science Integrating point and Nonpoint Sources; USEPA 2001) is also based on the same approach and has similar functionality, but it reads only vector data sets, while L-THIA reads raster data sets, which require less computing time.

L-THIA is based on the curve number (CN) method of the U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS 1986). The CN method is a key component of many traditional hydrology models, and detailed equations are available at Soil Conservation Service (1986) and Engel (2001). As Figure 3 shows, it requires land use information and hydrological soil group (HSG) information as raster maps. L-THIA combines those maps to compute CNs in each cell and computes direct runoff as depth (and volume by multiplying by the cell area) taking daily precipitation into account. Then L-THIA calculates the amount of pollutants carried in unit volume of runoff from different land-use types using predefined EMC values. Table 1 shows EMC values suggested by Baird and Jennings (1996) for each land-use type and indicates that Ag is the most dominant source of all pollutants. Mean annual runoff and NPS pollutant loads from the study area during the simulation period are computed by summing the values from all the cells and dividing by the number of years.

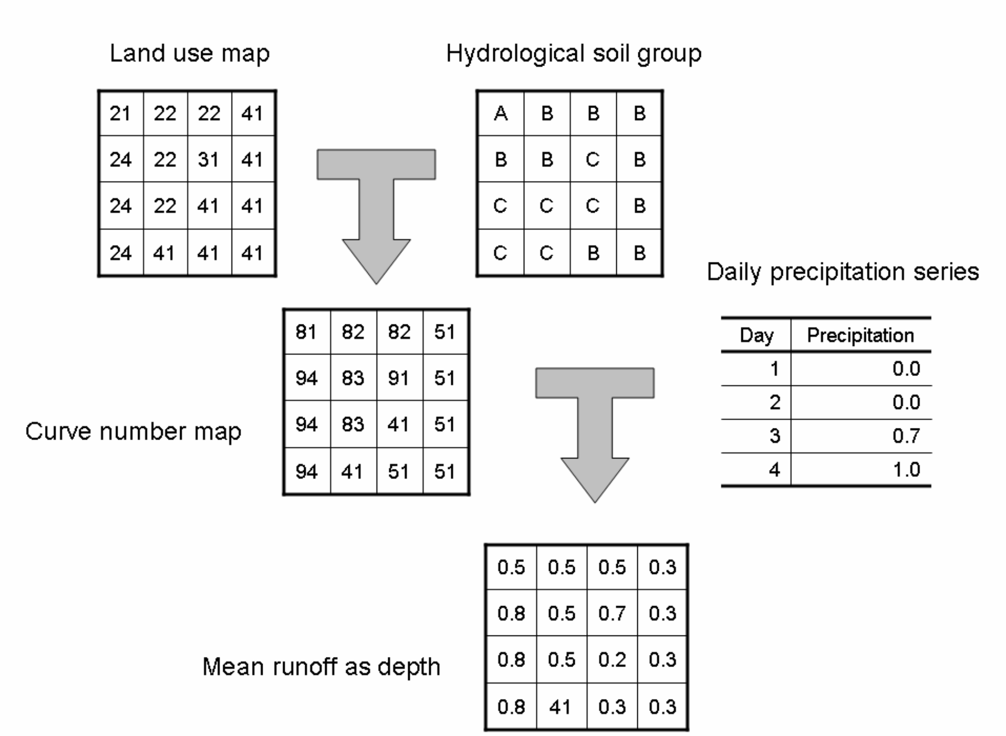

Figure 3. Overview of L-THIA (reproduced from Wang et al. 2005 with permission from Springer)

Table 1. Event mean concentration (EMC) of total nitrogen (TN), total suspended particles (TSP), and total phosphorus (TP) for the selected six land-uses (source: Baird and Jennings 1996). Here UOS is urban open space, Ag is agriculture, LR is low-intensity residential, G/P is grass pasture, and C/I/I is commercial/ industrial/impervious.

Land Use Name	TN (mg/liter)	TSP (mg/liter)	TP (mg/liter)
UOS	1.34	55.5	0.32
Ag	4.40	107.0	1.30
LR	1.82	41.0	0.57
G/P	0.70	1.0	0.01
Forest	0.70	1.0	0.01
C/I/I	1.26	60.5	0.28

For this study, daily precipitation time series for the period 1961-1990 was created as a text file from the data obtained from the National Climatic Data Center. The measurements were taken at the ISWS station (110510 Belleville SIU Research) (Figure 4). The thirty-year period is long enough for consistent L-THIA simulation results (Grove et al. 2001). The State Soil Geographic Database (STATSGO), a lumped data set at a state level, was obtained from the USDA Natural Resources Conservation Service website (http://soils.usda.gov) for hydrological soil group information. STATSGO contains a GIS layer for each state with numerous polygons, each of which has a unique identifier. A polygon identifier is associated with one or multiple soil components, and each component has unique soil characteristics including HSG. The percentage values of the components in each polygon are available, but their locations are not. Therefore, the most dominant component was selected, and the HSG of the selected component was assigned as the HSG of the polygon. Regarding land-use GIS data, a base land-use map as of the year 2000 was produced as described in Section 2.1 at the spatial resolution of 30m × 30m. Future land-use data as of 2030 were also used for scenario testing. Land-use scenarios are described in Section 2.4.

It should be mentioned that L-THIA is a very simple model and has several limitations. It is not a process-based dynamic model that simulates vertical water balance components such as direct runoff, interflow, base flow, evapotranspiration and percolation. It only calculates direct runoff from each cell using empirical coefficients. Therefore, it does not generally require calibration and is used to assess relative changes between different scenarios. It is also suitable for assessing long-term average conditions rather than temporal variations even though it uses daily precipitation data.

Subbasin Delineation Using BASINS

L-THIA model does not require watershed-based approach (e.g. Wang *et al.* 2005), since it calculates runoff from each cell without routing. However, since this article aims for subbasin-scale modeling and analysis, the Richland Creek basin was divided into several subbasins so that L-THIA could be run on each subbasin.

BASINS version 3.0 (USEPA 2001) was utilized with the National Elevation Dataset (NED) from USGS (http://seamless.usgs.gov) to delineate subbasins. BASINS contains tools to preprocess data for several hydrological models including HSPF, SWAT and PLOAD. Using BASINS, a virtually unlimited number of subbasins can be delineated. In this study, the threshold was selected so that the number of subbasins is minimized while main tributaries are represented as shown on a 1 / 150 000 scale topographic map. As a result, the study region was divided into seven subbasins (Figure 4) with subbasin areas ranging from 12.4km^2 to 121km^2.

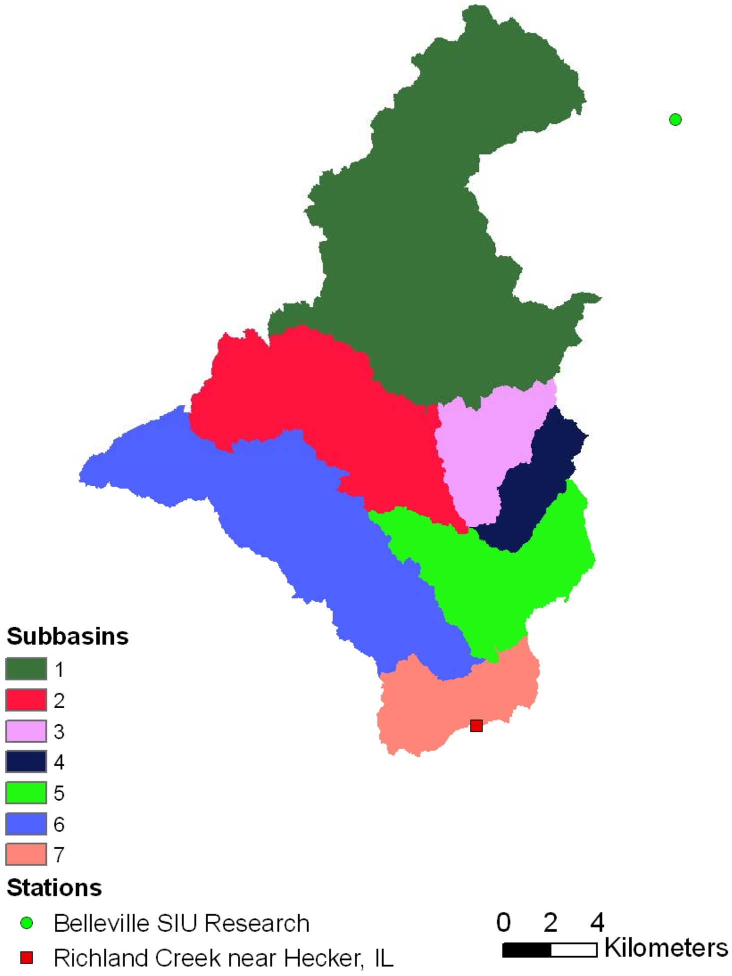

Figure 4. Subbasins delineated by BASINS along with weather (Belleville SIU Research) and streamflow (Richland Creek near Hecker, IL) stations

Each subbasin will be referred to by its identification number, from 1 through 7. A USGS streamflow gauging station (05595200 Richland Creek near Hecker, IL) is located at the outlet of Subbasin 7. The weather station is located about 4.1km from the nearest boundary of Subbasin 1.

Table 2 shows the land-use of each subbasin in terms of percentage. It shows that Subbasin 1 has the largest percentage (26%) of urban land (HR, LR and C/I/I) while Subbasin 5 has the largest percentage (55.3%) of agricultural land. The City of Belleville (population 41,429 in 2004) is nested in Subbasin 1. Overall, Subbasin 1 is very distinct from the rest, both in terms of size and land-use.

Table 2. Land-use of each subbasin in percentage (from USGS and IDA). Here UOS is urban open space, Ag is agriculture, HR is high-intensity residential, LR is low-intensity residential, G/P is grass pasture, and C/I/I is commercial/ industrial/impervious.

Subbasin Land use	1	2	3	4	5	6	7
Water	2.4	2.2	3.7	1.1	0.5	1.8	1.6
UOS	12.5	2.2	0.3	3.3	0.6	0.3	0.4
Ag	27.8	36.8	44.6	36.4	55.3	36.2	49.9
HR	7.3	1.0	0.0	1.6	0.1	0.0	0.0
LR	10.3	1.8	0.2	4.5	0.3	0.2	0.1
G/P	24.3	40.9	41.9	43.8	36.9	43.4	41.4
Forest	6.9	10.9	7.1	6.0	3.3	14.2	3.4
C/I/I	8.3	4.2	2.2	3.3	3.0	3.8	3.2
Total (%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total area (ha)	12105	5151	1871	1240	3258	6885	1974

Land-use Scenarios

Land-use Evolution and impact Assessment Model or LEAM (Deal 2001) was used for scenario development. LEAM was developed at the University of Illinois with funding from the National Science Foundation. Deal (2001) and Fang et al. (2005) offer detailed descriptions for building and calibrating LEAM and only a summary is given below as in Wang et al. (2005).

LEAM adopts the cellular automata (CA) approach, and mainly consists of model drivers and impact models. LEAMluc, composed of model drivers, refers to the part of LEAM that simulates the actual changes in land-use over the landscape. Model drivers are those forces contributing to land-use changes, generally human activities. The model drivers are run simultaneously in each grid cell, and the output is used to calculate the probability of a cell changing to an alternative land-use. The probability depends on both the local attributes of the cell (slope, distance to the closest ramp, road, etc.) and the state of neighboring cells in the last time step. LEAMluc produces time series of land-use maps under different policy and economic growth scenarios. These outputs in the form of land-use maps are then used as inputs to impact models that analyze long-term environmental and fiscal impacts. It should be noted that the output from LEAMluc is only one of likely outcomes of alternative land-use planning policies and economic conditions. It is subject to open dialogues with local stakeholders and agencies, and they finally decide whether to accept the model results. This study was conducted upon the acceptance of the model results by the East-West Gateway Council of Governments.

There are several assumptions or limitations inherent in LEAMluc. First, since land-use change in LEAM is based on CA, it is heavily dependent on neighborhood conditions. Therefore, LEAMluc is good at simulating continuous and simultaneous developments on a small scale, but it is not good at simulating large scale developments abruptly taking place in reality. Secondly, it is assumed that the land-use classification in NLCD and related corrections conducted for input to LEAMluc are largely correct. Thirdly, residential lands are treated equally. For example, LEAMluc does not distinguish

affluent neighborhoods from needy ones. In addition, as LEAMluc is intended to simulate sprawl-type urbanization processes, changes in high-intensity residential land are limited to a minimum.
For this study, LEAMluc was run to produce future land-use maps under high and base economic growth scenarios up to the year 2030. The population growth is assumed to be the only driver for regional economy. The base economic growth scenario, which can be called a ‘business-as-usual’ scenario, is that county population would change as projected by the U.S. Census Bureau. An arbitrary weight of 125% is given to the base population projection to generate the high growth scenario, which means that the population will grow 25% more than the U.S. Census Bureau projection.

As a result of the LEAMluc simulation, 60 land-use maps were created (30 years from 2001 to 2030 for two economic growth scenarios). The land-use data of the final simulation year (2030) from each scenario were selected as the base growth scenario (namely, Base 2030) and the high growth scenario (namely, High 2030) respectively. L-THIA was run with the initial land-use data (namely, 2000) representing the land-cover condition as of 2000 and the future scenarios (Base 2030 and High 2030) respectively. The simulations were conducted over the whole RCB first and later for each of seven subbasins.

Results

Assessment of Future Land-use Change

Figure 5 shows the projected changes in each land-use category except HR compared to the year 2000. When summed across subbasins, LR was projected to increase by more than 2000ha by 2030 in both scenarios. Ag was projected to decrease more than 900ha and C/I/I was projected to increase more than 600ha by 2030 in both scenarios. G/P was projected to decrease more than Ag, but it is not a key factor in runoff or NPS pollutant loading. The increase of LR is remarkably high in this area. When examined by subbasin, Subbasin 1, which the most developed and the largest, is projected to undergo substantial increases in LR and C/I/I and decreases in non-urban land-uses. Subbasins 2 and 6 show somewhat noticeable changes, while others show little changes.

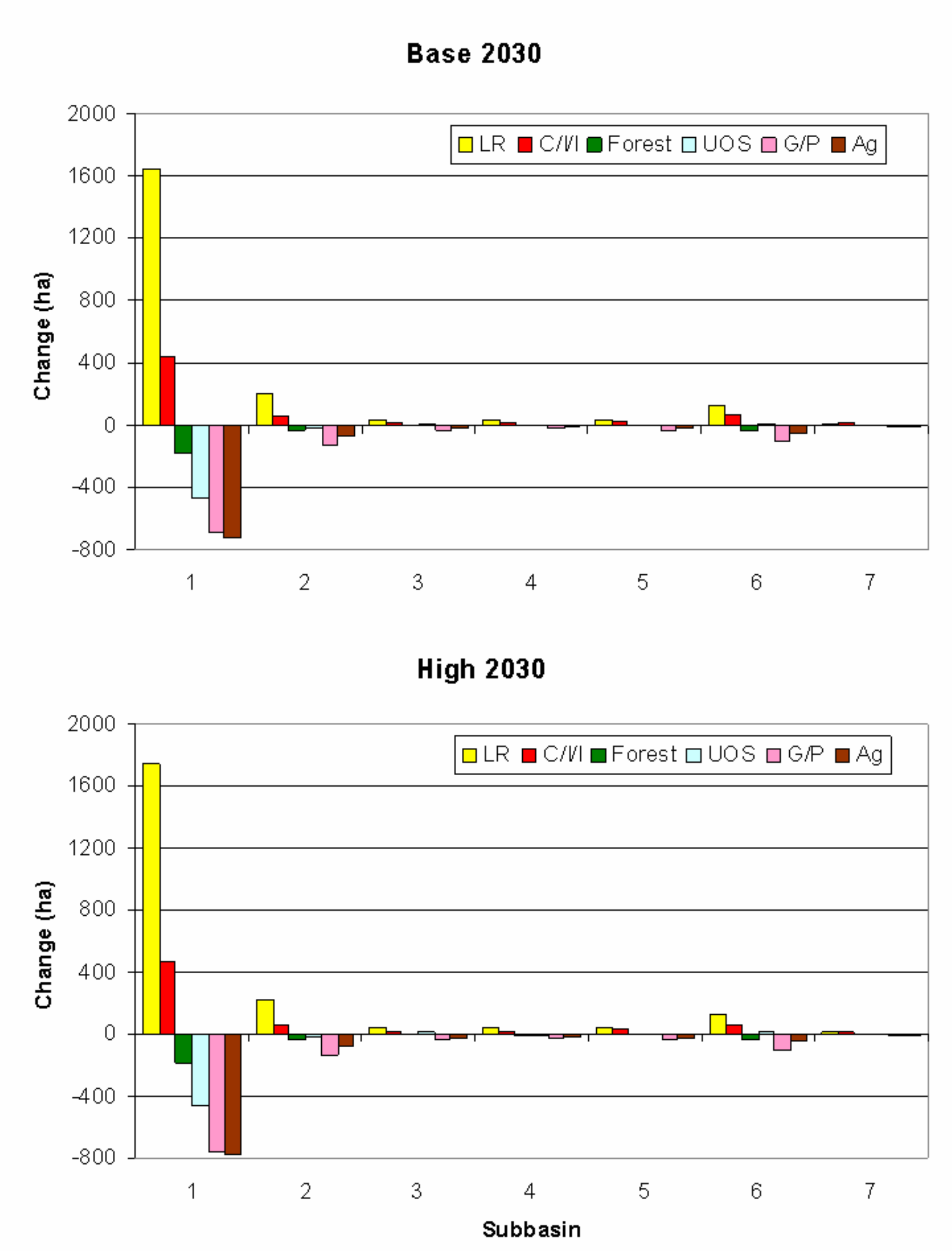

Figure 5. Projected changes in land-use under Base 2030 and High 2030 scenarios. Here LR is low-intensity residential, C/I/I is commercial/ industrial/impervious, UOS is urban open space, , G/P is grass pasture, and Ag is agriculture.

Changes in Direct Runoff and NPS Loads in the RCB

The results for the whole basin are presented in Figure 6. Mean annual direct runoff is projected to increase by around 7% by 2030, and mean annual TPS load is projected to increase by around 4%. Meanwhile, mean annual TN and TP loads are projected to increase by just less than 1%. All the variables show increases under both Base 2030 and High 2030 scenarios, but the increases in TN and TP loads are practically meaningless. Such small changes in TN and TP loads are thought to be due to loss of Ag.

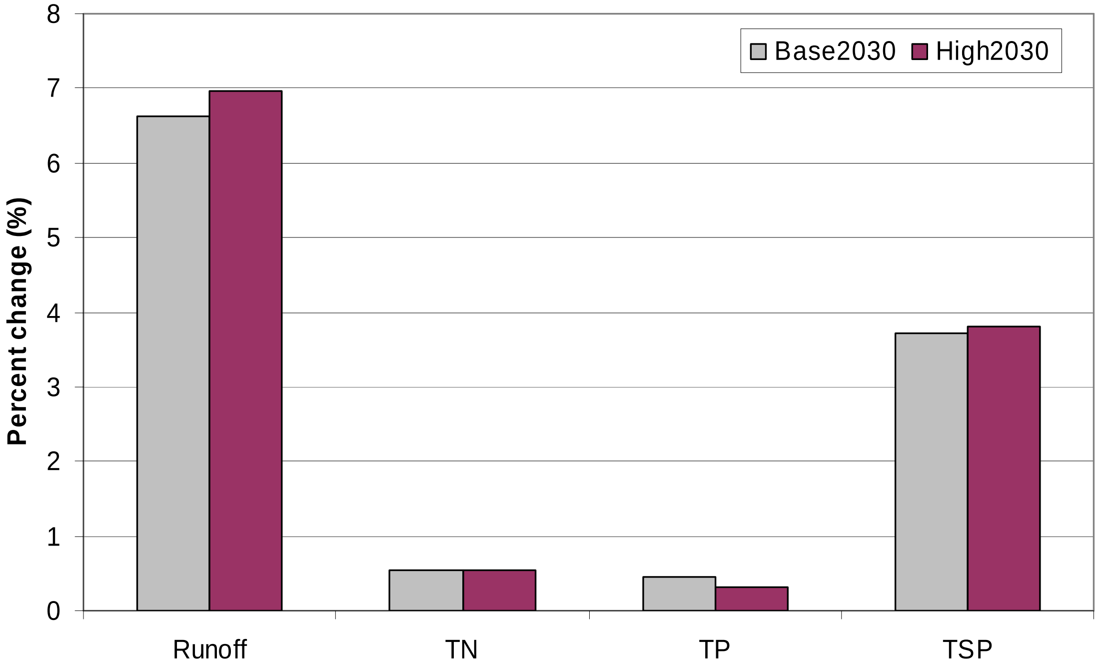

Figure 6. Percent changes in direct runoff and NPS pollutant loads under Base 2030 and High 2030 scenarios from the current condition

The changes in runoff and NPS pollutants can be better understood by examining their sources (Table 3). Three major sources of direct runoff in the region are Ag, C/I/I and G/P. The contribution of Ag and G/P to runoff volume decreased, while that of LR and C/I/I noticeably increased. As Table 3 shows, the contributions of Ag and G/P to runoff were predicted to decrease from 46% to 40% and from 19% to 16% respectively under both scenarios. C/I/I contributed 19% of runoff volume in 2000, but it would be as much as 25% in 2030. The contribution from LR was predicted to increase remarkably: from 3% to 7~8% in 2030. The substantial decrease in runoff volume from Ag and G/P is easily exceeded by the substantial increase in runoff volume from LR and C/I/I, resulting in an overall runoff increase in the RCB.

Table 3. Contribution of each land-use type to runoff volume, total nitrogen (TN), total phosphorus (TP), and total suspended particles (TSP) in absolute and percentage (in parentheses) values for 2000, Base 2030 and High 2030. Here UOS is urban open space, Ag is agriculture, LR is low-intensity residential, G/P is grass pasture, and C/I/I is commercial/ industrial/impervious.

Runoff (liters/yr)	2000		Base 2030		High 2030	
UOS	7.95E+08	(3)	6.04E+08	(2)	6.16E+08	(2)
Ag	1.21E+10	(46)	1.12E+10	(40)	1.12E+10	(40)
LR	7.26E+08	(3)	2.11E+09	(7)	2.20E+09	(8)
G/P	4.98E+09	(19)	4.57E+09	(16)	4.53E+09	(16)
Forest	8.66E+08	(3)	8.12E+08	(3)	8.10E+08	(3)
C/I/I	5.12E+09	(19)	7.06E+09	(25)	7.16E+09	(25)
HR	1.73E+09	(7)	1.75E+09	(6)	1.75E+09	(6)
Total	2.64E+10	(100)	2.81E+10	(100)	2.82E+10	(100)

TN (kg/yr)	2000		Base 2030		High 2030	
UOS	1.07E+03	(2)	8.08E+02	(1)	8.25E+02	(1)
Ag	5.34E+04	(77)	4.95E+04	(71)	4.91E+04	(70)
LR	1.32E+03	(2)	3.83E+03	(5)	4.01E+03	(6)
G/P	3.49E+03	(5)	3.20E+03	(5)	3.17E+03	(5)
Forest	6.07E+02	(1)	5.69E+02	(1)	5.68E+02	(1)
C/I/I	6.45E+03	(9)	8.89E+03	(13)	9.02E+03	(13)
HR	3.15E+03	(5)	3.18E+03	(5)	3.26E+03	(5)
Total	6.95E+04	(100)	7.00E+04	(100)	6.99E+04	(100)

TP (kg/yr)	2000		Base 2030		High 2030	
UOS	2.54E+02	(1)	1.93E+02	(1)	1.97E+02	(1)
Ag	1.58E+04	(83)	1.46E+04	(73)	1.45E+04	(76)
LR	4.14E+02	(2)	1.20E+03	(6)	1.26E+03	(7)
G/P	4.99E+01	(0)	4.57E+01	(5)	4.54E+01	(0)
Forest	8.67E+00	(0)	8.13E+00	(1)	8.11E+00	(0)
C/I/I	1.43E+03	(8)	1.98E+03	(13)	2.00E+03	(11)
HR	9.86E+02	(5)	9.97E+02	(1)	9.97E+02	(5)
Total	1.89E+04	(100)	1.90E+04	(100)	1.90E+04	(100)

TSP (kg/yr)	2000		Base 2030		High 2030	
UOS	4.41E+04	(3)	3.35E+04	(2)	3.42E+04	(2)
Ag	1.30E+06	(74)	1.20E+06	(66)	1.19E+06	(65)
LR	2.98E+04	(2)	8.64E+04	(5)	9.03E+04	(5)
G/P	4.98E+03	(0)	4.57E+03	(0)	4.53E+03	(0)
Forest	8.67E+02	(0)	8.13E+02	(0)	8.11E+02	(0)
C/I/I	3.10E+05	(18)	4.27E+05	(23)	4.33E+05	(24)
HR	7.09E+04	(4)	7.17E+04	(4)	7.17E+04	(4)
Total	1.76E+06	(100)	1.83E+06	(100)	1.83E+06	(100)

Unlike direct runoff, TN and TP come almost entirely from Ag. In 2000, 77% (53400kg/yr) of TN and 83% (15800kg/yr) of TP came from Ag, while no single source contributed more than 10%. As Ag contribution to runoff was predicted to decrease, that to TN was also predicted to decrease by 2030 to 71% (49500kg/yr) and 70% (49100kg/yr) (Base 2030 and High 2030 respectively), and that to TP decrease to 73~76% (14600~14500kg/yr). The decreases in TN and TP loads from Ag are offset by the increases in TN and TP loads from C/I/I and LR. For example, C/I/I contribution to TN was 9% (6450kg/yr) in 2000, but was predicted to increase to 13% (8890~9020kg/yr) in 2030. LR contribution to TN was predicted to increase from 2% (1320kg/yr) to 5% (3830kr/yr) or 6% (4010kg/yr) in 2030. Therefore, there would be little change in TN and TP loads by 2030 for the region.

When it comes to TSP, Ag is still a dominant source, but the contribution from C/I/I was more than 10% in 2000, and it would increase to more than 20% by 2030. EMC value of C/I/I is almost 60% of that of Ag, and slightly higher than that of UOS (Table 1). Substantial amount of particles build up on urban areas during dry periods and are washed away by direct runoff. That is why C/I/I is an important source of TSP and there will be a greater percent increase of TSP (Figure 6) than TN and TP. Contribution from LR is also predicted to almost triple.

Changes in Direct Runoff and NPS Loads by Subbasin

When the changes are examined for each subbasin, runoff is predicted to increase in Subbasin 1 by 11.7 or 12.5% but around 4% or less in other subbasins (Table 4). Such a noticeable increase in runoff in Subbasin 1 can be attributed to the fact that most of the increases in C/I/I and LR are projected to occur in Subbasin 1 (Figure 5). Other subbasins are projected to have more LR and C/I/I lands in the future by large percentage, but the absolute increases in LR and C/I/I in those subbasins cannot even compare to those in Subbasin 1.

Table 4. Calculated runoff (liter/ha/yr) and NPS loading (kg/ha/yr) in each subbasin for 2000, Base 2030 and High 2030 scenarios along with their percent changes (in parenthesis) with respect to the values in 2000

	1	2	3	4	5	6	7
Runoff							
2000	845331	947259	754327	714429	700071	878081	579802
Base 2030	943841 (11.7)	985892 (4.1)	775952 (2.9)	741370 (3.8)	723035 (3.3)	908078 (3.4)	598498 (3.2)
High 2030	951389 (12.5)	985251 (4.0)	776593 (3.0)	741396 (3.8)	723458 (3.3)	908053 (3.4)	598402 (3.2)
TN							
2000	1.96	2.50	2.33	2.01	2.28	2.34	1.90
Base 2030	1.97 (0.1)	2.53 (1.0)	2.33 (–0.3)	2.03 (0.9)	2.29 (0.3)	2.37 (1.0)	1.91 (0.6)
High 2030	1.96 (0.0)	2.52 (0.7)	2.32 (–0.4)	2.02 (0.6)	2.31 (1.3)	2.36 (1.0)	1.91 (0.6)
TP							
2000	0.54	0.67	0.64	0.56	0.64	0.62	0.53
Base 2030	0.54 (–0.3)	0.68 (1.3)	0.64 (–0.4)	0.56 (1.0)	0.64 (0.2)	0.63 (1.1)	0.54 (0.3)
High 2030	0.54 (–0.4)	0.68 (1.1)	0.64 (–0.5)	0.56 (0.7)	0.64 (0.1)	0.63 (1.1)	0.54 (0.3)
TSP							
2000	53.84	60.87	55.66	50.02	56.18	55.95	47.49
Base 2030	56.99 (5.8)	62.67 (3.0)	56.40 (1.3)	51.12 (2.2)	57.18 (1.8)	57.61 (3.0)	48.46 (2.1)
High 2030	57.23 (6.3)	62.48 (2.7)	56.34 (1.2)	51.01 (2.0)	57.18 (1.8)	57.59 (2.9)	48.44 (2.0)

Note: percent changes were calculated before rounding runoff and NPS loading values and were rounded thereafter.

With regard to TN and TP, there is little variation by subbasin. Some subbasins show negative changes, but the percentage is too small to be meaningful. It is interesting to note that Subbasin 1 is not unique regarding the changes in TN and TP loads. However, it showed a much higher increase in runoff than the others. Subbasin 1 shows the largest decrease in Ag and the largest increase in C/I/I (Figure 5). Therefore, the amount of runoff increase from C/I/I and LR (LR is also projected to substantially increase) is larger than that of runoff decrease from Ag in Subbasin 1. With regard to TN and TP, since they are far more sensitive to changes in Ag than other land-uses, the amount of decreases in TN and TP loads from Ag is roughly equal to that of increases from LR and C/I/I. TSP is somewhere in the middle between runoff and TN/TP, therefore Subbasin 1 shows more increases in TSP loading than the others, but the difference is not as large as in runoff.

The results from this study indicate that Subbasin 1 should be given the most attention for mitigation of land-use change impacts. Subbasin 1 is currently the most developed one, and is expected to undergo the greatest increase in development, especially in terms of C/I/I. As runoff is expected to increase by around 12% in Subbasin 1, some necessary steps need to be taken for mitigating negative impacts such as more frequent flood events. Suspended solids also deserve attention for water quality management. However, more detailed studies are needed to determine the total maximum daily loads (TMDL) of nutrients and what needs to be done to control nutrient loads below the TMDL under future land-use conditions.

Discussion

It has been projected by the dynamic land-use change model LEAM, that the Richland Creek basin will have far more urbanized land than now at the expense of mostly agricultural lands. The accompanying results projected by L-THIA include noticeable increases in direct runoff volume and TSP loading, and negligible changes in TN and TP loads. The increases in runoff and TSP loads are the largest in Subbasin 1, while changes in TN and TP loads show little spatial variation.

The results for the entire basin are in general agreement with several other studies. Chang (2004) performed subbasin analysis for a basin in Pennsylvania, USA and found both negative and positive changes in N loads and only negative changes in P loads with urban growth. The magnitude of change in that study is generally greater than that in the present study. Some reasons for the difference include groundwater source, which was simulated by a dynamic model but is not considered in this study, and different magnitude of urban growth. Bhaduri et al. (2000) and Tang et al. (2005) used L-THIA as well, and found small increases or even decreases in TN and TP, but large increases in other pollutants such as nickel, lead, and oil and grease. Especially, Tang et al. (2005) present similar results for runoff and nutrients in terms of the magnitudes of percent changes. The difference is that in their “2040 sprawl” scenario, each urban land-use type is projected to increase with similar percentage (134~178.8%), while LR is projected to increase much more (by 147~155%) than C/I/I (by 36~38%) in this study. The land-use change model utilized by Tang et al. (2005) has a single urban land-use unlike LEAM. This study reveals that even though subbasins experience enormous per cent increases (by up to 1000%) in LR, the impacts are not remarkable when its portion in the subbasin is much smaller than Ag. This finding is in line with that of Wang et al. (2005) from their temporal analyses. Soranno et al. (1996) also predicted modest increases in annual P loading with a substantial increase (80%) in urbanized lands in the future, and found that the changes in P loading would be largest when natural vegetation covers are replaced by either urban or agricultural lands.

The merit of this study is that it presents the effect of different urban land-use types on direct runoff and NPS pollutant loads in subbasins. Analyzing absolute and percent changes for each land-use type in each subbasin lead to a reasonable explanation of the behavior of runoff and NPS loads in subbasins. It suggests that even though urbanized lands increase, impacts on runoff and TSP loading may not be significant if most of the new development is low-density residential or the percentage of low-density residential in the subbasin is still negligible. As can be figured out from Table 2 and Figure 5, LR is projected to increase tremendously within a wide range of percentage (69~1046%) in subbasins other than Subbasin 1, but those subbasins show similar responses regarding runoff and TSP loading (Table 4). On the other hand, changes in Ag and C/I/I are much larger in Subbasin 1 than in other subbasins, and runoff and TSP loading responses in Subbasin 1 are distinguished from those in other subbasins.

The limitations of the study also need to be mentioned. First, the difference in impact between Base 2030 and High 2030 does not look substantial. The biggest reason is that the anticipated urban growth based on the population growth in the region is not large and the weight of population projection given to the High 2030 scenario did not create substantial urban growth. I could try another scenario with more severe urban growth in the future, but practically, such a scenario is not likely to happen. Secondly, even though LEAMluc was developed with credible logic and the simulation results look reasonable, it still has substantial uncertainty as it models human activities. Therefore, the land-use scenarios need to be understood as only some of many potential future land-uses in the region. Thirdly, EMC, which L-THIA is based on, is site-specific (Tang et al. 2005). We used the estimates suggested by Baird and Jennings (1996), which were used as default values in L-THIA.

Summary and Conclusions

The anticipated changes in direct runoff and non-point source pollutant loads were assessed regarding the future land-use change in the Richland Creek basin located in the Metropolitan St. Louis region. An export-coefficient based model L-THIA and land-use scenarios generated by a dynamic land-use change model, LEAM, were used for the work. L-THIA was selected from many different models for its simplicity and timely assessment capability at the subbasin scale.

Under the given land-use scenarios, direct runoff and total suspended particles loading (TSP) are predicted to increase by about 7% and 4% respectively by 2030, while total nitrogen (TN) and total phosphorus (TP) loads will change little. TN and TP mostly come from Ag, and no other land-use types contribute more than 10% of total load. However, C/I/I and LR play stronger roles in producing direct runoff and TSP than TN and TP, and the main trend of land-use change in the region is from Ag to C/I/I or LR. As a result, while the loss of Ag source of TN and TP is offset by the gain of C/I/I and LR sources, the loss of Ag sources of direct runoff and TSP is moderately overcompensated by the gain of C/I/I and LR sources.

At the subbasin scale, the changes in runoff and TSP loading in Subbasin 1, which is currently the most developed one, are exceptionally notable, while the changes in TN and TP loading are similar in all the seven subbasins. It is because runoff and TSP load are more sensitive to changes in C/I/I than TN and TP loads and Subbasin 1 is subject to the greatest decrease in Ag and increase in C/I/I both in terms of absolute and per cent values. TN and TP could even be projected to decrease if more Ag is converted to other land-uses such as forest rather than LR or C/I/I.

In a hydrological perspective, this article reveals the effect of different urban land-use types on runoff and NPS pollutant loads. The effect is more visible when the analysis is conducted for different sub-units. In a regional planning perspective, it is suggested that careful planning of development types and locations can help minimize negative environmental impacts.

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