Assessing the Long-Term Hydrologic Impact of Land Use Change Using a GIS-NPS Model and the World Wide Web[*]

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ABSTRACT:

Assessment of the long-term hydrologic impacts of land use change is important for optimizing management practices to control runoff and non-point source (NPS) pollution associated with watershed development. Land use change, dominated by an increase in urban/impervious areas, can have a significant impact on water resources. Non-point source (NPS) pollution is the leading cause of degraded water quality in the US and urban areas are an important source of NPS pollution. Despite widespread concern over the environmental impacts of land use changes such as urban sprawl, most planners, government agencies and consultants lack access to simple impact-assessment tools that can be used with readily available data. Before investing in sophisticated analyses and customized data collection, it is desirable to be able to run initial screening analyses using data that are already available. In response to this need, we developed a long-term hydrologic impact assessment technique (L-THIA) using the popular Curve Number (CN) method that makes use of basic land use, soils and long-term rainfall data. Initially developed as a spreadsheet application, the technique allows a user to compare the hydrologic impacts of past, present and any future land use change. Consequently, a NPS pollution module was incorporated to develop the L-THIA/NPS model.

Long-term daily rainfall records are used in combination with soils and land use information to calculate average annual runoff and NPS pollution at a watershed scale. Because of the geospatial nature of land use and soils data, and the increasingly widespread use of GIS by planners, government agencies and consultants, the model is linked to a Geographic Information System (GIS) that allows convenient generation and management of model input and output data, and provides advanced visualization of the model results. Manipulation of the land use layer, or provision of multiple land use layers (for different scenarios), allows for rapid and simple comparison of impacts. To increase access to L-THIA,

we have begun development of a WWW-accessible version of the method. Using databases housed on our computers, the user can select any location in the US and perform L-THIA/NPS analyses.

In this paper we present applications of the WWW-based L-THIA/NPS and L-THIA/NPS GIS model on the Little Eagle Creek (LEC) watershed near Indianapolis, Indiana. Three historical land use scenarios for 1973, 1984, and 1991 were analyzed to track land use change in the watershed and to assess the impacts of land use change on annual average runoff and NPS pollution from the watershed and its five sub-basins. Comparison of the two methods highlights the effectiveness of the L-THIA approach in assessing the long-term hydrologic impact of urban sprawl. The L-THIA/NPS GIS model is a powerful tool for identifying environmentally sensitive areas in terms of NPS pollution potential and for evaluating alternative land use scenarios to enhance NPS pollution management. Access to the model via the WWW enhances the usability and effectiveness of the technique significantly. Recommendations can be made to community decision makers, based on this analysis, concerning how development can be controlled within the watershed to minimize the long-term impacts of increased stormwater runoff and NPS pollution for better management of water resources.

INTRODUCTION:

For decision makers, such as land use planners and watershed managers, it is important to assess the effects of land use changes on watershed hydrology. At present numerous hydrologic models are available that focus on event-specific assessment and management of hydrologic impacts of land use change. Traditionally the focus of these urban surface water management models has been on the control of peak discharges from individual, high magnitude storm events that cause flooding. Models such as those developed by the US Army Corps of engineers (HEC-1, 1974), the US Department of Agriculture (TR-20, 1983; TR-55, 1986), and the US Environmental Protection Agency (Huber and Dickinson, 1988) are routinely

used in assessing how proposed land use changes will affect runoff quantity. Although hydrologic impact assessment based on individual, high magnitude storm events is an appropriate approach for designing runoff control facilities for reducing local flooding and improving water quality, it is of limited use for attempts to understand the long-term hydrologic impacts of land use change. However, it has been increasingly realized that there is a long-term hydrologic impact associated with land use change, and that this is dominated by runoff generated from frequently occurring, smaller storm events rather than extreme, high magnitude storms (Harbor, 1994; McClinktock et al., 1995).

Realizing the importance of NPS pollution, over the last 25 years, models including SWMM (Huber and Dickinson, 1988), AGNPS (Young et al., 1989), and WEPP (Nearing et al., 1989, Flanagan and Nearing, 1995) have been created with capabilities to assess the impacts of NPS pollution on runoff quality in addition to standard assessments of peak discharges. Because NPS pollution from agricultural areas was originally identified as the major cause of water quality degradation, most NPS pollution models focus on typical agricultural pollutants such as sediment, nutrients (nitrogen and phosphorus), and organic compounds (pesticides and herbicides). However, heavy metal pollution from urban areas has recently been identified as a leading cause of NPS pollution problems (Novotny and Olem, 1994) but estimation of heavy metal pollution from urban areas with existing hydrologic/NPS pollution models is quite limited.

In assessing the long-term hydrologic impacts of land use change, planners, developers, and community decision makers usually avoid using the existing hydrologic models because these models are too complex, data intensive, time consuming, expensive, and requires considerable user expertise (Harbor, 1994). To overcome the limitations of traditional hydrologic models, the Long-Term Hydrologic Impact Assessment (L-THIA) model was developed as a user-friendly tool for long-term runoff estimation (Harbor, 1994). L-THIA is built around the Natural Resources Conservation Service's Curve Number (CN) technique that is the core component of many sophisticated hydrologic models (Williams et al., 1984; Young et al.,

1989). Curve numbers or CN values represent surface characteristics of a soil-land use complex. In L-THIA a long-term (typically 30 years) daily precipitation record is used along with soil and land use information to compute daily runoff for estimating annual average runoff. The model was initially developed as a simple spreadsheet application (Harbor, 1994; Bhaduri et al., 1997). Subsequently a C program was developed for the model to facilitate input data handling and model application. The L-THIA model was further expanded to L-THIA/NPS by adding a NPS pollution assessment module. To enhance spatial data management, spatial analyses, and advanced visualization of model results, Geographic Information Systems (GIS) have been utilized. L-THIA GIS (Grove, 1997) and L-THIA/NPS GIS have been developed as customized applications of commercial GIS software. Recently, a WWW-based version of the L-THIA/NPS model has been developed. In the WWW-based implementation of the L-THIA/NPS model, the user provides land use and hydrologic soil group information and L-THIA/NPS is run using long-term daily precipitation data queried from an ORACLE database. By determining and comparing the average annual runoff depths and NPS pollutant loads for land use scenarios from different time periods, it is possible to assess the absolute and relative changes in runoff and NPS pollution due to land use change.

METHODOLOGY

Structure of L-THIA and L-THIA/NPS Model

The L-THIA model was originally developed as a preliminary hydrologic impact assessment tool that focused on predicting the percent increase in annual average runoff from a watershed due to some land use change represented by a change in the CN value for the watershed. The model utilizes a lumped parameter design to minimize model complexity and to reduce the expense and time involved in data collection. For a watershed with multiple land use

categories and/or sub-watersheds, the model can be applied as a lumped (composite CN) as well as a distributed (distributed CN) approach (Grove, 1997, Grove et al., 1998).

Runoff Calculation

Daily runoff is calculated using the USDA NRCS Curve Number (CN) method for a daily precipitation data set spanning many years (typically 30 years). The CN method is an empirical set of relationships between rainfall, land use characteristics, and runoff depth. CN values, ranging from 25 to 98, represent land-surface conditions and are a function of land use, hydrologic soil group (or soil permeability), and antecedent moisture condition (USDA SCS, 1986). The basic equations used in the CN method for standard or average conditions are:

$$R = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad R = 0 \text{ for } P \le 0.2\ S \qquad (1)$$

$$S = \left(\frac{1000}{CN}\right) - 10 \qquad (2)$$

where:

R = runoff depth (inches)

P = precipitation depth (inches)

S = potential maximum retention (inches)

CN = Curve Number

Antecedent Moisture Condition (AMC) and CN Variation

The effect of antecedent rainfall and associated soil moisture conditions has long been recognized as a primary source of variability in runoff determination. To account for this, the

Natural Resources Conservation Services (NRCS) introduced the concept of an antecedent moisture condition (AMC), also referred to as antecedent runoff condition (ARC).

Three AMCs are defined as a step function of 5-day antecedent rainfall, and an AMC remains constant for the specific range of antecedent rainfall values. Definitions of growing and dormant seasons are not easily available and to keep calculations simple and consistent, growing and dormant seasons were assumed to begin on April 15 and on October 15 of any year, respectively. CN values for AMC 1 and 3 are determined by the following relationship as described in NEH-4 (USDA SCS, 1985).

$$CN_1 = \frac{4.2CN_2}{10-0.058CN_2} \quad \text{and} \quad CN_3 = \frac{23CN_2}{10+0.13CN_2}$$

[where, CN_1, CN_2, and CN_3 represent CN values for AMC 1, 2, and 3 respectively.]

Runoff analyses were performed with the CN values for AMC 1, 2, and 3 where AMC is a step function of 5-day antecedent rainfall (Table 1).

AMC	5-day Antecedent Rainfall (mm)	
	Dormant Season	Growing Season
1	< 13	< 36
2	13 -38	36 - 53
3	> 28	> 53

Table 1: Criteria for determination of Antecedent Moisture Conditions (SCS, 1972).

NPS Pollution Calculation:

L-THIA/NPS GIS: Pollutant Build-up and Washoff

The most common urban NPS pollutant estimation technique in current deterministic water quality models including STORM and SWMM is the pollutant "buildup-washoff" function

(Huber, 1986; Barbé et al., 1996). "Buildup" refers to all dry-weather processes that lead to accumulation of solids and associated pollutants on a watershed surface which are "washed off" during subsequent storm events. In developing a NPS pollution sub-model for L-THIA, it was assumed that pollutants accumulate on a land surface as a linear function of time.

$$M_i = (\text{number of days}) \times (L_i)$$

$$[L_i = \text{accumulation rate for pollutant i (mass/area/day)};$$

$$M_i = \text{Ultimate pollutant accumulation (mass/area)};]$$

For this study, daily accumulation rates of solid particles (dust and dirt) for urban land uses (low and high density residential, industrial, and commercial) were adopted from the SWMM manual. Daily dust and dirt accumulation values are reported as a function of curb (road) density, and thus road densities for the urban land uses were required to produce dust and dirt accumulation values as mass/area. Although road density values for different urban areas have been reported in the literature, for this study values of road density for Tulsa, Oklahoma (Heany et al., 1977) were chosen as representative of the Indianapolis, Indiana area where the model was applied. Daily build up values of pollutants on non-urban land uses (agricultural, grass/pasture, and forest) could not be found in literature and were not included in the daily simulations of NPS pollution analyses. However, annual average loading rates for non-urban land uses were taken from literature and used to calculate NPS pollution in the GIS analysis. The NPS pollutant loading values are reported in Table 2.

Pollutant	Annual average loading rate (kg/ha/year)					
	Agricultural	Grass/Pasture	Forest	Low-density Residential	High-density Residential	Commercial
Total N	26.00	6.20	6.20	0.86	1.92	2.30
Total P	1.05	0.50	0.50	0.09	0.20	0.33
Lead	0.10	0.10	0.10	2.90	6.93	12.80
Copper	0.02	0.02	0.02	0.17	0.25	0.52
Zinc	0.08	0.08	0.08	0.58	0.98	3.78

Table 2. Annual average pollutant loading values used in L-THIA/NPS GIS simulations.

For the washoff function, a non-linear washoff equation was used. The washoff relationship is an exponential function of the runoff depth. This approach has been successfully used in numerous studies (Haith and Shoemaker, 1987; Dikshit and Loucks, 1996) and was utilized in the NPS simulation for the L-THIA model because daily runoff depths are calculated in the runoff sub-model which then can be used in the washoff function. The washoff function is expressed as:

$$w_{k,t} = 1 - \exp(-1.81\ Q_{kt})$$

where:

$w_{k,t}$ = fraction of the pollutant mass removed from the land use k on day t;

Q_{kt} = runoff from land use k on day t (cm);

WWW-based L-THIA/NPS: Event Mean Concentration (EMC)

In the Web-based version of L-THIA/NPS, Event Mean Concentration (EMC) data were introduced to predict NPS pollutants for non-urban areas as well as urban areas (Baird and Jennings, 1996). The EMC data used were compiled by the Texas Natural Resource Conservation Commission (Baird and Jennings, 1996). Numerous literature and existing water quality data were reviewed by Baird and Jennings (1996) with respect to eight categories of land

use and several parameters. Land use categories defined were (1) industrial; (2) transportation; (3) commercial; (4) residential; (5) agricultural cropland (dry land and irrigated); (6) range land; (7) undeveloped/open; and (8) marinas. The total pollutant load for a NPS pollutant divided by runoff volume during a runoff event yielded the Event Mean Concentration for that pollutant. EMCs should be reliable for determining average concentrations and calculating constituent loads (Table 3).

NPS Pollutant	Land use classification						
	Residen-tial	Comm-ercial	Indus -trial	Transt-ion	Mixed	Agricu-ltural	Range
Total Nitrogen (mg/L)	1.82	1.34	1.26	1.86	1.57	4.4	0.7
Total Phosphorus (mg/L)	0.57	0.32	0.28	0.22	0.35	1.3	0.01
Total Lead (µg/L)	9	13	15	11	12	1.5	5
Total Copper (µg/L)	15	14.5	15	11	13.9	1.5	10
Total Zinc (µg/L)	80	180	245	60	141	16	6

Table 3. Event Mean Concentration for each land use classification (Baird and Jennings, 1996)

L-THIA/NPS GIS Setup

The L-THIA model has been linked with Arc/INFO® GIS software as a GIS application (Grove, 1997). The ArcView® GIS software was chosen for L-THIA/NPS GIS application because ArcView® is the dominant desktop GIS, and it has a friendlier graphical user interface than Arc/INFO®. The GIS application is implemented through a linked-model approach that utilizes both the graphical and spatial data handling capabilities of a GIS as well as the speed and flexibility offered by a standard executable program. The required input data are initially selected in the GIS before the L-THIA/NPS executable is called by the GIS. The executable calculates the annual average runoff depths for all land uses and annual average dust and dirt amounts (kg/km^2) for all CN values for urban land uses (low density residential, high density residential, industrial, and commercial). These calculations are based on daily rainfall data

spanning many years. The output file created by the L-THIA/NPS executable is then read back into the GIS and used to produce final results.

WWW-Based L-THIA/NPS Setup

A user-friendly L-THIA WWW interface was developed using Java/Java Script, HTML, and CGI scripts (http://pasture.ecn.purdue.edu/~sprawl/lthia2). The interface is a joint effort between Purdue University and the US Environmental Protection Agency, Region 5. This interface provides easy access to the model and potentially improves understanding of the results through graphical representation. Figure 1 shows the L-THIA/NPS WWW interface.

Figure 1. LTHIA/NPS WWW Interface.

Depending on the location the user selects, weather data for the nearest weather station are queried from the database and reformatted for the L-THIA run. The user selects one of the eight land use classifications, hydrologic soil group information and provides the area for this combination for each time step the L-THIA/NPS WWW system is to be run. Tables, bar charts, and pie charts for runoff and NPS pollution are generated on the fly for display in the user's WWW browser. The tabular output provides all information the user provided in the input interface, the Curve Number, runoff depth, and runoff volume for each time step. Bar graphs provide runoff depth, runoff volume, total volume, average runoff depth, and NPS pollution information. Pie charts provide land use and runoff volume for each time of interest. LTHIA/NPS WWW has several advantages over the traditional model and decision support system approach: 1) It is accessible through the Internet using only a WWW browser, 2) Database and GIS data are maintained at a single location, 3) All model users access the same version of the model, and 4) All data are verified by the model maintainer so errors due to input data can be minimized.

STUDY AREA

The L-THIA/NPS model was applied to the Little Eagle Creek (LEC) watershed, a rapidly urbanizing watershed in the northwest section of Indianapolis, Indiana and its suburbs. The LEC watershed is 70.5 km^2 in size and consists of five smaller sub-basins (Figure 2). This watershed has experienced extensive urbanization over the past three decades. Land uses ranging from non-urban natural grass and forested areas and agricultural areas to typical urban residential, commercial, and industrial categories exist in the LEC watershed.

As part of a long-term hydrologic impact assessment study (Grove, 1997), digital land use data were generated from LANDSAT satellite imagery (80m resolution Landsat Multi-Spectral Scanner imagery) for 1973, 1984, and 1991 and these three images represented temporal changes in land use in the watershed. In this study, these land use coverages along

with the Soil Survey Geographic (SSURGO) soils data (1:20,000) were used to analyze the long-term impact of land use change on runoff and non-point source pollution. Only hydrologic soil groups B and C are present in the watershed. The watershed and sub-watershed boundaries were delineated from a Digital Elevation Model (DEM) using the Arc/INFO GRID module (Grove, 1997). Curve Numbers ranged from approximately 60 to 97 for all sub-basins in the watershed. Six land use categories were delineated using ERDAS Imagine software and were used in L-THIA/NPS GIS simulations. These areas of these land use categories and hydrologic soil B and C groups were used in the WWW L-THIA/NPS simulations.
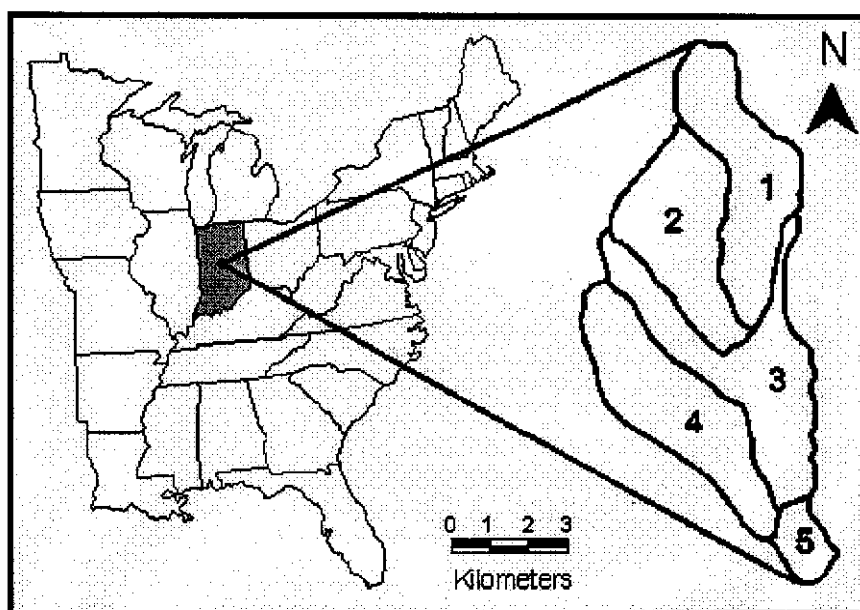

Figure 2. Location of the Little Eagle Creek watershed.

RESULTS AND DISCUSSION

Land Use Change

There is a significant increase in urban land uses between 1973 and 1991 with the majority of the changes taking place between 1973 and 1984 (Table 4). Grouping agricultural, forest, and grass/pasture as non-urban and low density residential, high density residential/industrial, and commercial as urban land uses, 49.3%, 63.5%, and 68.1% area of

LEC watershed was urban in 1973, 1984, and 1991 respectively. Thus, there was a 14.2% increase in urban land uses between 1973 and 1984 and a 4.6% increase in urban areas between 1984 and 1991. The increase in urban land uses is not uniformly reflected in all the urban land use categories.

Land Use	Area (km^2)			% Change in Individual Category		
	1973	1984	1991	1973-1984	1984-1991	1973-1991
Agricultural	10.82	10.21	9.23	-5.66%	-9.58%	-14.70%
Commercial	5.82	10.56	11.31	81.40%	7.12%	94.32%
Forest	13.74	5.72	5.14	-58.37%	-10.19%	-62.61%
Grass/Pasture	10.90	9.64	7.76	-11.62%	-19.47%	-28.83%
HD Residential / Industrial	8.12	19.25	21.44	137.21%	11.34%	164.10%
LD Residential	20.83	14.91	15.30	-28.42%	2.63%	-26.53%
Water	0.27	0.21	0.32	-21.84%	52.73%	19.38%

Table 4. Land use distributions in Little Eagle Creek watershed for 1973, 1984, and 1991.

For individual land use categories, high density residential and commercial areas show tremendous increase in the watershed while low density residential areas show a 28.4% decrease between 1973 and 1984 and a 2.6% increase between 1984 and 1991. The initial decrease in low density residential areas is possible conversion of low density residential to high density residential areas. The increase in urban areas is followed by an equivalent decrease in non-urban areas. However, all the non-urban land uses decrease at the same rate. Forested areas show the greatest loss with a 62.6% decrease, followed by grass/pasture with a 28.8% decrease between 1973 and 1991. Agricultural areas show minimum change (14.7% decrease) during the same time period.

Impact of Urbanization on Annual Average Runoff and NPS Pollution

L-THIA/NPS analyses were performed to assess the impact of land use change on average annual runoff and NPS pollution for the LEC watershed. There are significant changes

in average annual runoff volumes and NPS pollution loads from the LEC watershed as a result of land use change. The results from L-THIA/NPS GIS and L-THIA/NPS web-versions are presented in Table 5 and Table 6 respectively. However, changes in runoff volume or NPS pollution do not have a simple or linear relationship with land use change.

Change in runoff and NPS pollution using L-THIA/NPS GIS simulation:						
	Year			% Change		
Pollutant	1973	1984	1991	1973 to 1984	1984 to 1991	1973 to 1991
Runoff (m³)	2547736	4255457	4581833	67.03%	7.67%	79.84%
Nitrogen (kg)	47848.90	43183.45	39722.04	-9.75%	-8.02%	-16.98%
Phosphorus (kg)	2887.40	2682.04	2526.83	-7.11%	-5.79%	-12.49%
Lead (kg)	18608.45	30374.48	32855.31	63.23%	8.17%	76.56%
Copper (kg)	888.21	1296.23	1387.92	45.94%	7.07%	56.26%
Zinc (kg)	4313.06	6756.24	7238.03	56.65%	7.13%	67.82%

Table 5. Average annual runoff volume and NPS pollution from LEC watershed using L-THIA/NPS GIS that uses daily pollutant build-up and washoff functions for pollution calculation.

Change in Runoff and NPS pollution using WWW L-THIA/NPS simulation:						
	Year			% Change		
Pollutant	1973	1984	1991	1973 to 1984	1984 to 1991	1973 to 1991
Runoff (m³)	5012456	7926728	8379366	58.14%	5.71%	67.17%
Nitrogen (kg)	8599	13051	13684	51.77%	4.85%	59.13%
Phosphorus (kg)	2307	3530	3713	53.01%	5.18%	60.94%
Lead (kg)	46	81	87	76.09%	7.41%	89.13%
Copper (kg)	50	89	95	78.00%	6.74%	90.00%
Zinc (kg)	581	1032	1104	77.62%	6.98%	90.02%

Table 6. Average annual runoff volume and NPS pollution from LEC watershed using web-based L-THIA/NPS that uses Event Mean Concentrations (EMC) for pollution calculation.

The annual average runoff volumes predicted by L-THIA/NPS GIS are approximately half of those predicted by the web-version of the model. This is primarily because two different sets of daily precipitation data were used for the two simulations and the one used for the web version had several large storm events that produced significantly more runoff. However, considering the relative change in runoff volume, very similar results were obtained from both simulations. The amounts of urban or impervious areas dominantly control the volume of runoff

produced from a watershed. For example, in LEC watershed, 87% of the total runoff volume (81% with web-based L-THIA/NPS) was produced from urban areas that occupied only 49% of the total watershed area in 1973. In 1984 and 1991, urban areas occupied less than 70% of the total watershed area but contributed over 93% of the annual average runoff volume (over 90% with web-based L-THIA/NPS). Percent increase in average annual runoff volume is greater between 1973 and 1984 than between 1984 and 1991 because a greater percentage of non-urban land use is changed to urban (more impervious) land use during the former time interval (Figure 3).
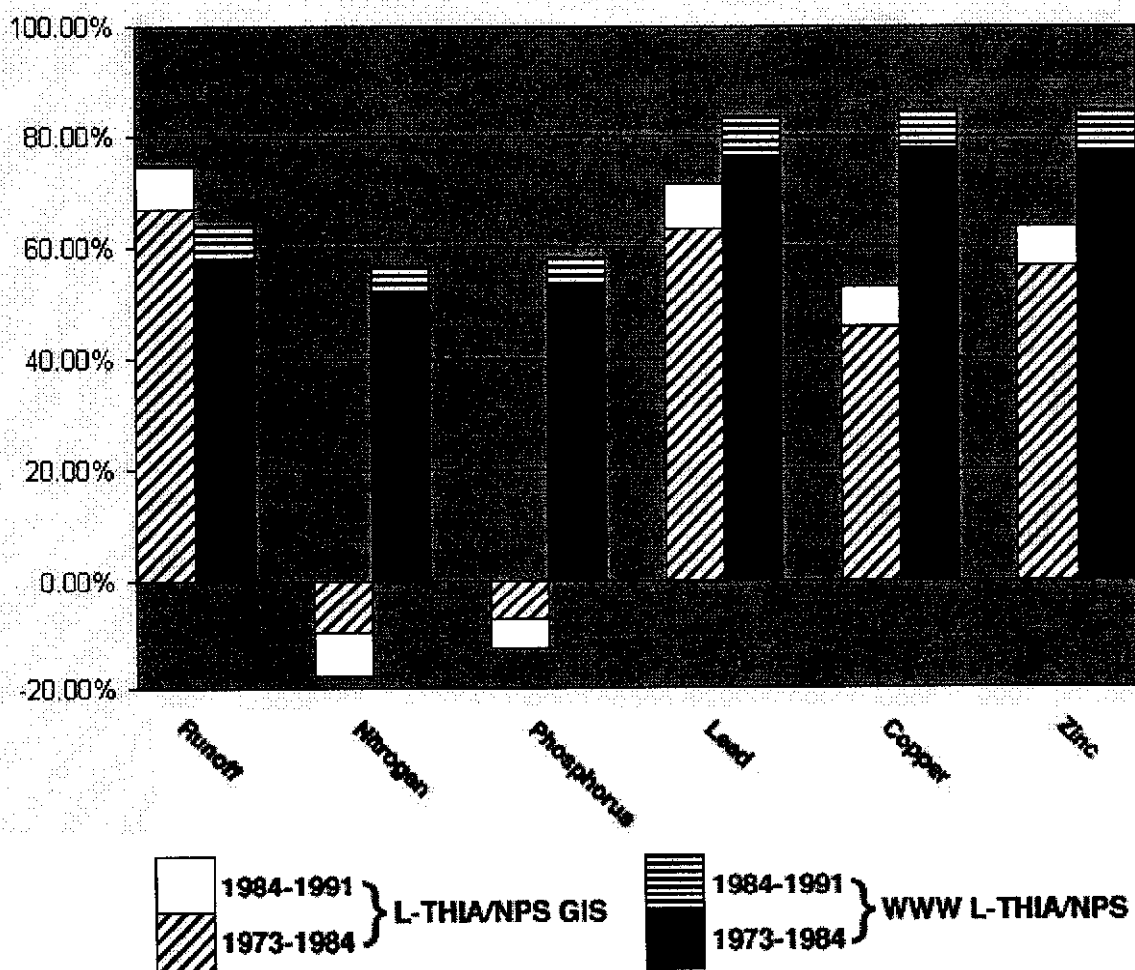

Figure 3. Changes in annual average runoff and NPS pollution from the Little Eagle Creek watershed.

For the NPS pollutants, the relative change in annual average NPS pollution from LEC watershed is not only controlled by the nature of land use change but also by the nature of the pollutants. The time period between 1973 and 1984 experienced a much greater amount of urbanization than the time period between 1984 and 1991. This pattern of land use change is also reflected in changes in average annual runoff volume and metal pollution from the LEC watershed. However, total pollutant loads predicted by web-based L-THIA/NPS are roughly higher by an order of magnitude than those predicted by the L-THIA/NPS GIS model. This difference can be attributed primarily to the different methods of pollution calculations by the two simulations and also the different concentration values of the pollutants used. Using EMC values in the web-version of the model, two different days with the same amount of runoff will produce the same pollutant loads. In the GIS version, that uses pollutant build-up and washoff functions, two similar runoff events can produce significantly different pollutant loads depending upon masses of pollutants that accumulated before those two runoff events. Moreover, Bhaduri (1998) showed that more than 90% of the days in the study area are dry (AMC 1), and thus before any runoff event there will be a significant amount of pollutant accumulated on the watershed.

One significant difference between the two approaches of pollution calculations can be observed in the predicted changes in nutrient pollution. L-THIA/NPS GIS predicts decreasing nutrient pollution with increasing urbanization in the watershed. Nitrogen and phosphorus are dominantly produced from agricultural areas. Moreover, the other non-urban land uses (forest and grass/pasture) show significant decrease between 1973 and 1984. Thus, this small change is nutrient loading between 1973 and 1984 is most plausibly related to the small reduction in agricultural area in the watershed. On the contrary, the web-version of L-THIA/NPS predicts changes in nitrogen and phosphorus loads that conform to the increasing trend in urbanization. Because nitrogen and phosphorus are typically identified as non-urban pollutants, it might be assumed that conversion of non-urban land uses to urban areas would significantly reduce

nutrient pollution from a watershed. Our analyses on LEC watershed indicate that, between 1973 and 1991, a conversion of 19% areas from non-urban to urban land uses results in annual average nitrogen and phosphorus loads being increased by about 60%. This is primarily because there is only a small reduction of agricultural area and a large increase in urban areas in the watershed. Although urban areas produce nutrients at a much lower rate than non-urban areas, but increases in urban land uses produce runoff at a significantly higher rate and thus, the web-version predicts very high nutrient loads.

Heavy metals, such as lead, copper, and zinc, are considered "urban" pollutants because urban land uses contribute a major portion of the metal pollution from a watershed. For the LEC watershed using L-THIA/NPS GIS, we found that only 49% of the area had urban land uses but they contributed 98% of total lead load, 92% of total copper load, and 93% of the total zinc load from the watershed in 1973. However, for individual metal pollutants, this 18% increase in urban areas (or an equivalent decrease in non-urban areas) between 1973 and 1991 results in 76.5%, 56.2%, 67.8% increase in lead, copper, and zinc loads from the watershed respectively. Predictions of changes in metal pollution from web-based L-THIA/NPS simulation were similar to those from the GIS version (Figure 3).

CONCLUSIONS

Assessment of the long-term hydrologic impacts of land use change is important for optimizing management practices to control runoff and non-point source (NPS) pollution from urban sprawl. The L-THIA/NPS model uses the popular curve number technique and empirical relationships between land uses and pollutant accumulation and wash off processes to estimate the relative impacts of land use change on annual average runoff and NPS pollution. L-THIA/NPS uses readily available data to overcome the difficulties of long-term modeling by existing hydrologic models because of their complexity and extensive input data requirements.

Moreover, most traditional hydrologic/NPS pollution models do not emphasize the changes in loads of typical urban pollutants such as heavy metals, which can be addressed by L-THIA/NPS. The model is linked to a GIS to enhance input data generation, data management, and advanced visualization of model results. The GIS version computes NPS pollution using daily pollutant build-up and washoff functions. A World Wide Web based version of the model has also been developed that provides easy access to the model through the Internet. This web-based version of the model uses Event Mean Concentrations (EMC) of pollutants for predicting NPS pollution.

L-THIA/NPS was applied to the Little Eagle Creek (LEC) watershed, an urbanizing watershed near Indianapolis, Indiana, to provide estimates of changes in annual average runoff volumes and NPS pollution loads for three time periods: 1973, 1984, and 1991. Increases in urban land uses were much higher between 1973 and 1984 than between 1984 and 1991. Non-urban land uses, particularly agricultural areas, are the dominant sources of nutrient (nitrogen and phosphorus) pollution but the majority of the metal pollution is contributed from urban areas. Overall, increasing urbanization resulted in increases in annual average runoff volume and metal loads. The L-THIA/NPS GIS simulations predicted decreases in nitrogen and phosphorus loads from the LEC watershed. However, the web-based version of the model indicated increases in nutrient pollution with increasing urbanization. This difference can be explained by the two different methods of pollution calculations by the GIS and web-based versions of the model. This difference in pollution calculation is also reflected in the absolute values of pollution predicted by the two versions. However, considering relative change in runoff and NPS pollution from urbanization, both simulations indicate a very similar trend and direction of changes in NPS pollutants for the Little Eagle Creek watershed.

L-THIA/NPS GIS is a simple and user-friendly model that makes it attractive for applications to other watersheds. Although L-THIA/NPS GIS is designed to run with easily available data, such data is often not readily available for most of the watersheds. Thus,

compilation of model input data sets through field experiments for a variety of watersheds characterized by different geography, climate, and land uses will greatly enhance model applications and performance in a wider range of watersheds. These field-measured data sets should be used to calibrate the L-THIA/NPS model and validate the model predictions. Future work should also explore the sensitivity of the L-THIA/NPS model to the spatial and temporal scales of input data. Work in progress is aimed at allowing a user to access a modified web-based L-THIA/NPS model that will take advantage of GIS functionality in the analysis. In this modified web-version, the users will not only be able to access the model through a web-browser, but will also be able to select or define a watershed using system-supplied maps, and then run L-THIA/NPS analyses run using land use, soils and climate databases stored on our server. The user will then be able to manipulate the GIS land use data in the browser environment or on a remote computer, and run multiple L-THIA analyses to compare hydrologic impacts from different land use scenarios.

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