Developing a Web-enabled Tool to Assess Long-term Hydrologic Impacts of Land-use Change: Information Technology Issues and a Case Study

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Abstract: *In recent years, concern over changes in uses of land and the impact on the environment has grown significantly. However, planners and decision-makers have had difficulty obtaining access to user-friendly tools that consider the impacts of land-use changes on hydrology and the environment, that make use of readily available data, and that are matched to planning concerns and needs. This paper describes a simple computer-based modeling tool, L-THIA (Long-Term Hydrologic Impact Assessment), that is designed to assist land-use decision-makers and urban and regional planners with the assessment of how land-use changes impact long-term hydrology and nonpoint source pollution in a watershed. It also illustrates information technology issues involved in making such a tool Geographic Information System (GIS)-based and web-accessible. A case study using the web-based and the GIS version of L-THIA demonstrates the ease of use of the tool and some potential applications of the model. Information technologies, including the World Wide Web, have been used to overcome difficulties with data, expertise, and access initially associated with L-THIA. With the growing numbers of Internet users in the United States and elsewhere, the web presents a means to supply large numbers of tools, databases, and information to planners and other potential users. In addition, this approach provides opportunities to increase involvement of stakeholders in the decision-making and planning process by providing them with knowledge and data through accessible, easy-to-use tools.*

Introduction

When planning, it is important to consider the long-term effects that land-use changes will have on surface runoff, streamflow, and groundwater recharge. Expansion of urban areas can significantly impact the environment in terms of reduced groundwater recharge and increased water pollution and stormwater drainage. Urbanization leads to the creation of impervious surfaces, which in turn increases surface runoff volumes by contributing to downstream flooding and a net loss in groundwater recharge. Eventually, the loss of recharge can affect residential and municipal water supplies. Increased runoff may also transport nonpoint source (NPS) pollutants to receiving surface waters such as rivers, lakes, and nearshore areas.

Assessment of the hydrologic impacts of urban land-use change traditionally includes the application of models that evaluate how land-use change alters peak runoff rates. These results are then used in the design of drainage and water-detention systems. Such methods are a critical component of an engineering design to reduce risks of flood damage; however, they typically do not address the long-term hydrologic impacts of urban land-use change and often do not consider the different pollutants that wash off from changed land uses. These additional impacts of urbanization also need to be considered if the goal of planning is to produce sustainable communities.

Minimizing and carefully organizing land-use changes in an urbanizing watershed are ways of reducing long- and short-term hydrologic impacts and ensuring continued water supply. Since each land use and location combination can have a different level of impact, physical planning can be used to minimize total impacts. Although the impacts of urban sprawl on groundwater recharge and surface water quantity and quality are of considerable importance, many planners, city managers and water resource professionals lack the ability to provide estimates of the potential hydrologic impacts of land-use change.

In response to the need expressed by land-use planners for a user-friendly impact assessment tool, the Long-Term Hydrologic Impact Assessment (L-THIA) model was developed, initially as a spreadsheet tool (Harbor 1994), and more recently incorporating Geographic Information Systems (GSIs) (Bhaduri 1998, Grove 1997). However, it has become clear that to reach a large number of potential users, it is necessary to provide such tools in a format that is accessible via the World Wide Web (web). With funding provided by the Environmental Protection Agency (EPA) Region 5, an interdisciplinary team at Purdue University is developing and testing a web-accessible version of L-THIA that will be designed to overcome challenges relating to data availability, ease of use, and access limitations for interactive web-based GIS. This article discusses the steps involved in the implementation of this project and demonstrates its use.

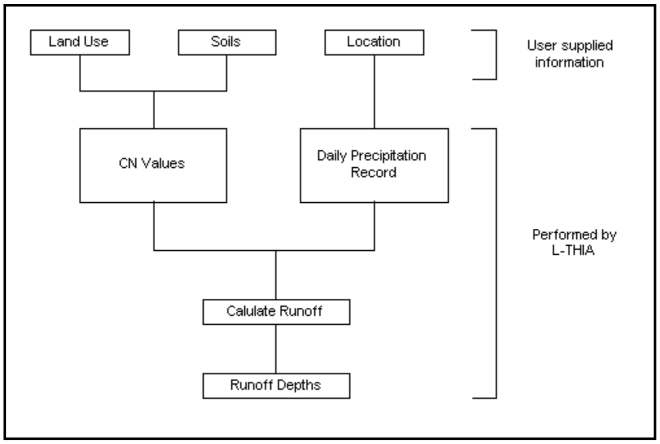


Figure 1. Basic Data Requirements and Components for Analysis in the L-THIA Model

Long-term Hydrologic Impact Assessment Model Concepts

There is considerable need for a site suitability analysis tool for planners and decision-makers which is easy to use and which makes use of information that is readily available from municipal databases. The L-THIA model has been developed as a straightforward assessment tool that provides estimates of changes in runoff, recharge, and NPS pollution resulting from past or proposed land-use changes (Harbor 1994). By making use only of readily available data, the model is quick and easy to use. It provides general, relative assessments of impacts, in contrast to other models that require considerable additional data collection to use, but which provide results suitable for detailed final engineering design.

L-THIA gives long-term average annual runoff for a land-use configuration based on actual long-term climate data, soils, and land-use data for an area (Figure 1). By using many years of climate data in the analysis, L-THIA focuses on the long-term average impact, rather than an extreme year or storm. L-THIA results do not predict what will happen in a specific year, rather the results provide insight into the relative long-term hydrologic impacts of different land-use scenarios (Bhaduri et al. 1997). By applying the method to actual and planned (zoned) urban developments, the long-term effects of past, present, and future land use can be assessed (Leitch and Harbor 1999, Minner et al. 1998, Bhaduri et al. 1997).

L-THIA uses basic data that are readily available to provide general estimates of long-term hydrologic impacts due to land-use change and, therefore, has limitations compared to more sophisticated analyses that require complex data collection and input procedures. In particular, two notable simplifications in the L-THIA curve number (CN) approach are the following: the contribution of snowfall to precipitation is ignored, and the effect of frozen ground in increasing stormwater runoff during cold months is not considered. These simplifications are necessary to keep the technique straightforward and accessible but can be removed when a more sophisticated analysis is required. An additional point to be emphasized is that L-THIA modeling is not an engineering design model or a hydrologic design tool to be used for stormwater drainage design or for addressing peak flow issues and other such urban infrastructure planning concerns.

The original L-THIA (Harbor 1994) was developed as a spreadsheet application that required the user to provide 30 years of daily precipitation data and to identify the CNs within their area of interest. CNs are derived from soil and land-use combinations within an area, using a table to "look up" the CNs. To determine runoff volumes, the area represented by each CN is also required. Even though the data requirements were modest, they limited the use of L-THIA. To overcome some of the data-requirement difficulties associated with L-THIA, Grove (1997) integrated L-THIA with a GIS tool.

The integrated GIS L-THIA system allowed the user to provide land-use and soil GIS maps as the basic input. These maps were used within the system to identify CN values and areas represented by each CN. The L-THIA model was rewritten in the "C" programming language, and an executable L-THIA was created to run within the GIS L-THIA system. After L-THIA was run, runoff depth and volume maps were created within the GIS.

Although the GIS L-THIA system simplified the application of L-THIA, it was still challenging for many potential users. Bhaduri (1998) simplified and extended the GIS L-THIA system by creating a user-friendly interface within ArcView GIS and adding an NPS pollution estimation capability. Lim et al (1999) improved the ArcView GIS L-THIA system so that it considers additional NPS pollutants and runs more quickly for large GIS map layers. Despite the considerable improvements to L-THIA, it continues to require data that are difficult to assemble for many users. Although more straightforward than many models, the GIS versions of L-THIA still require some significant expertise to operate. Therefore, the Purdue University team began the development of simple, web-based versions of the spreadsheet and GIS forms of L-THIA.

Information Technology Approaches to Overcome L-thia Data, Ease-of-use, and Access Limitations

Information technologies and the World Wide Web (WWW) provide opportunities to overcome the data, expertise, and access difficulties associated with L-THIA and many other models and analytical tools. Two WWW-based versions of L-THIA with NPS pollution capabilities were developed. One is a spreadsheet-style version and the second a WWW-based GIS version. The information technologies approaches used in the development of these systems are described in the following sections.

Spreadsheet-Style Version (L-THIA/NPS WWW)

In L-THIA/NPS WWW (Figure 2), the user interacts with a web interface written with HTML, JavaScript, and Java to select the location (state and county) of the site being analyzed and to provide information about the area of each land-use and hydro-

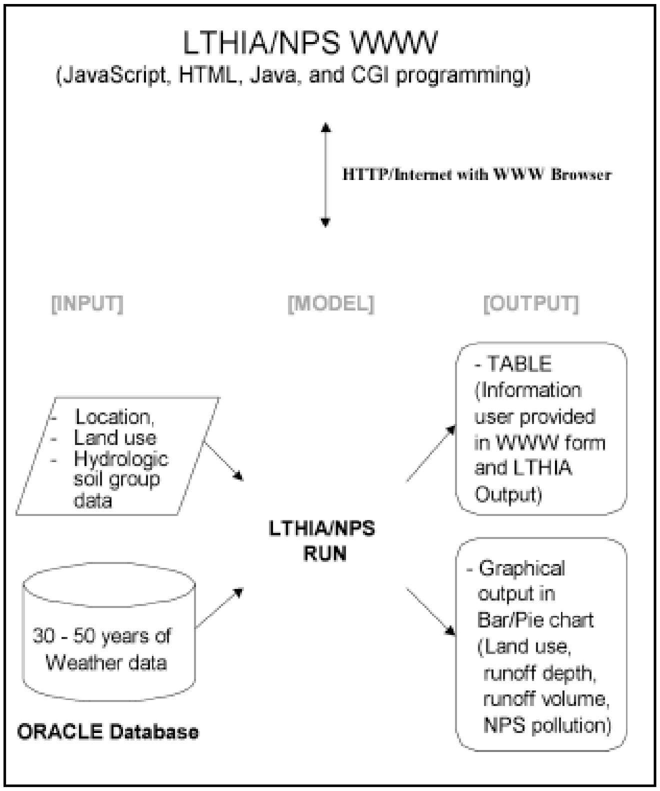
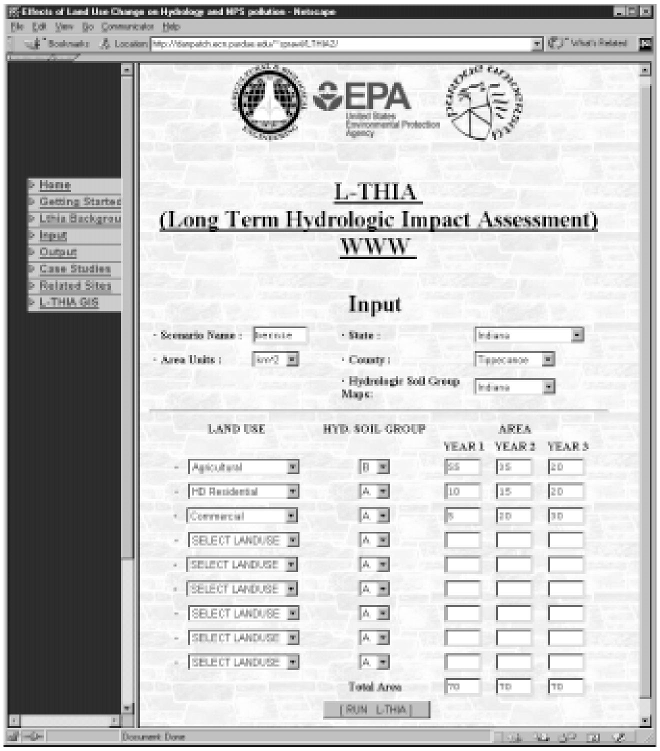


Figure 2. L-THIA/NPS WWW Overview

logic soil group combination within the area of interest (see the interface in Figure 3 or consult the L-THIA web site http://www.ecn.purdue.edu/runoff). The location data provided by the user are used within a CGI script written in Perl to query an ORACLE database on the web server in order to obtain the long-term daily precipitation data needed within L-THIA. Thus, the user need only select the location of interest rather than prepare a rainfall data file. Long-term daily rainfall data for approximately 500 locations within the continental United States are currently stored within the L-THIA web-based systems. A CGI script determines the CN values from the land-use and hydrologic soil information provided by the user. Once the CGI scripts have generated the necessary information, L-THIA is run on the web server using the rainfall data and CN values as input. The L-THIA-generated runoff and NPS pollution output are processed with CGI scripts, JavaScript, and Java to provide web-based tabular and graphical representations of the model outputs. Sample outputs are discussed later.

In the L-THIA/NPS WWW interface (Figure 3), depending on the location that the user selects, weather data for the nearest weather station are queried from the database and reformatted for the L-THIA run. The user provides the area of each land-use and hydrologic soil group for each time of interest. Areas of land-use and soil combinations can be provided for one to three time periods. For example, a user may wish to analyze the effects of historical and future land-use changes. Areas of unique land-use and soil combinations can be provided for a time period in the past, as they are at present, and as they might be at



L-THIA
(Long Term Hydrologic Impact Assessment)
WWW

Input

- Scenario Name : bernie
- State : Indiana
- Area Units : km2
- County : Tippecanoe
- Hydrologic Soil Group Maps: Indiana

LAND USE	HYD. SOIL GROUP	AREA		
		YEAR 1	YEAR 2	YEAR 3
Agricultural	B	55	35	20
HD Residential	A	10	15	20
Commercial	A	5	20	30
SELECT LANDUSE	A			
SELECT LANDUSE	A			
SELECT LANDUSE	A			
SELECT LANDUSE	A			
SELECT LANDUSE	A			
SELECT LANDUSE	A			
Total Area		70	70	70

[RUN L-THIA]

Figure 3. L-THIA/NPS WWW Interface

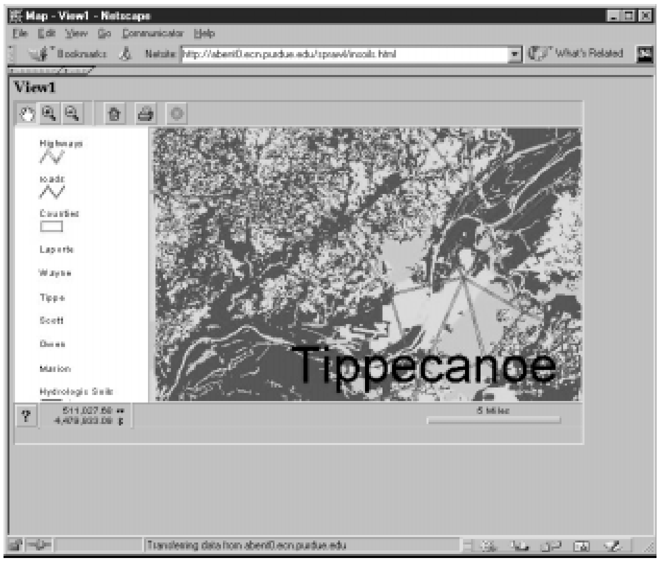
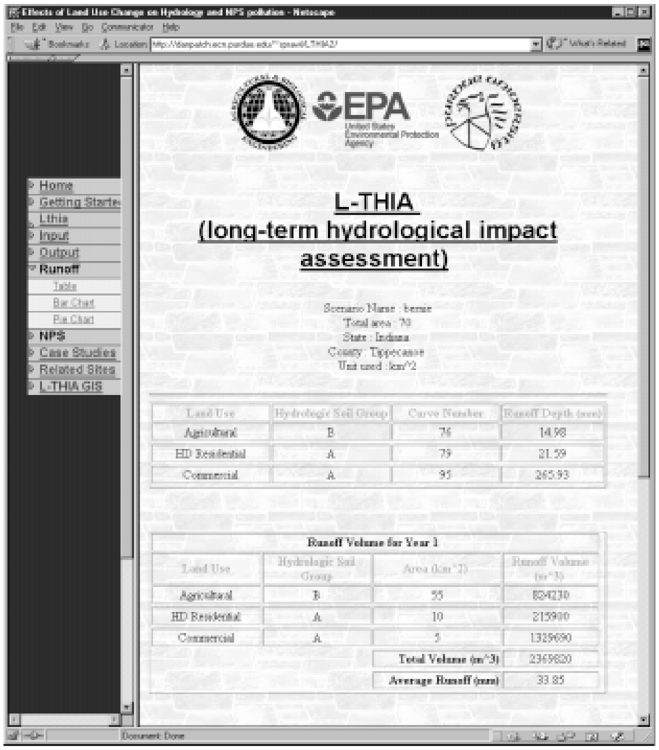


Figure 4. Hydrologic Soil Group WWW Window Interface. Hydrologic Soil Groups for a Portion of Tippecanoe County, Indiana are Displayed.

some time in the future. Hydrologic soil group maps can be requested from the interface for each state in the continental U.S. The hydrologic soil group maps along with counties and major roads appear in a second WWW browser window (Figure 4). The user can interactively zoom to the location of interest and determine the appropriate hydrologic soil group(s) to use in the analysis. Once the user has provided the information required by L-THIA, the Run L-THIA button is used to run the model (Fig-



L-THIA
(long-term hydrological impact assessment)

Scenario Name : bernie
Total area : 70
State : Indiana
County : Tippecanoe
Unit used : km^2

Land Use	Hydrologic Soil Group	Curve Number	Runoff Depth (mm)
Agricultural	B	76	14.98
HD Residential	A	79	21.59
Commercial	A	95	265.93

Runoff Volume for Year 1

Land Use	Hydrologic Soil Group	Area (km^2)	Runoff Volume (m^3)
Agricultural	B	55	824230
HD Residential	A	10	215900
Commercial	A	5	1329690
		Total Volume (m^3)	2369820
		Average Runoff (mm)	33.85

Figure 5. L-THIA/NPS WWW Output Runoff Table

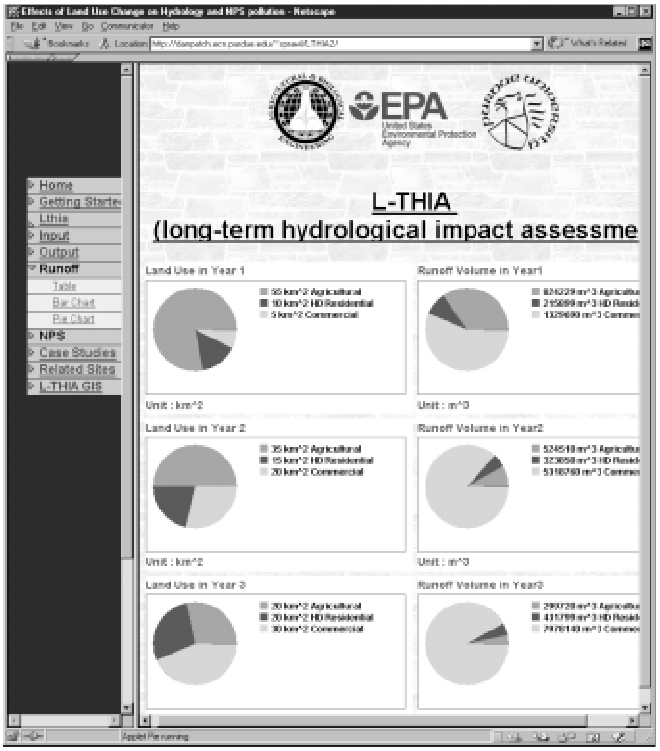


Figure 7. L-THIA/NPS WWW Output Runoff Pie Chart

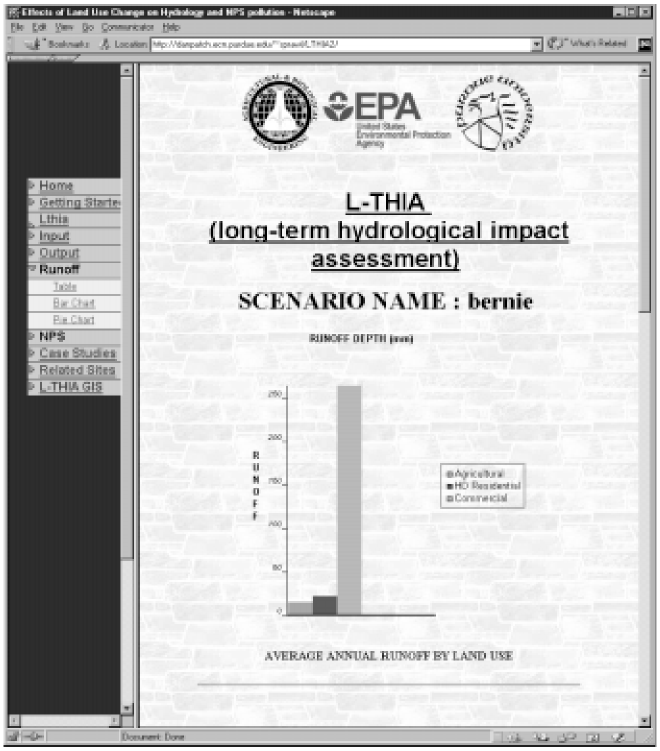


Figure 6. L-THIA/NPS WWW Output Runoff Bar Chart

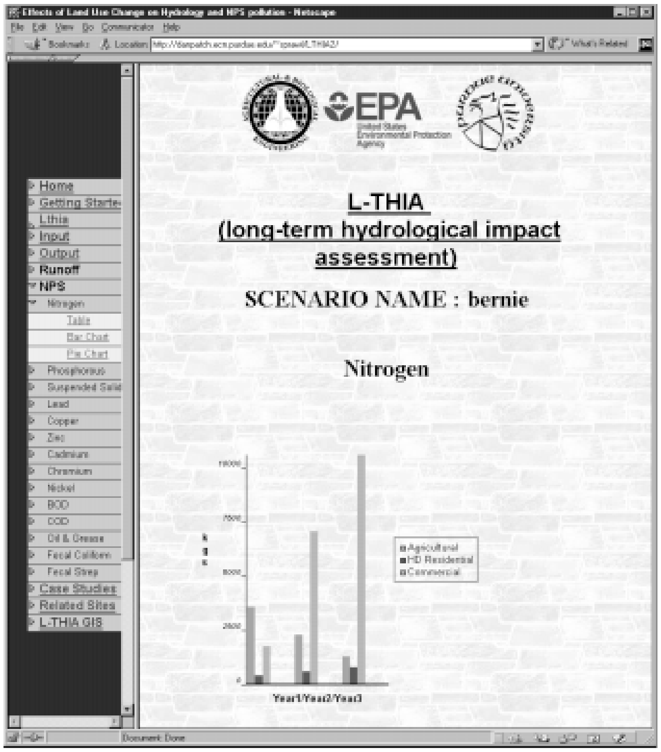


Figure 8. L-THIA NPS Pollution Bar Chart Output for Nitrogen in Runoff

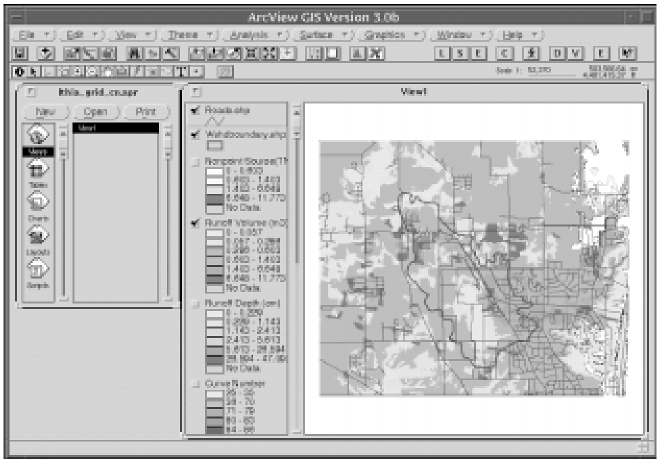


Figure 9. ArcView Interface of the L-THIA/NPS GIS

ure 3). L-THIA runs on the WWW server (approximately 5 seconds) and generates a series of tables, bar charts, and pie charts for runoff and NPS pollution (Figures 5-8). A 3-minute **demonstration** of L-THIA/NPS WWW is available.

In the L-THIA/NPS WWW runoff output table (Figure 5), all information that the user provided in the input interface, in addition to the CN, the runoff depth, and the runoff volume for each time period, is analyzed. Figure 6 shows a portion of the L-THIA/NPS WWW runoff output in bar-graph form. Bar graphs provide runoff depth, runoff volume, total volume, and average runoff depth information. Presentation of the results in this form can often assist the user in more quickly understanding the model results. Figure 7 shows L-THIA/NPS WWW runoff output as pie charts. Land-use and runoff volume for each time of interest are also provided in pie-chart form. Tabular and graphical output is available for each of the 12 NPS pollutants considered. Figure 8 shows the estimated NPS nitrogen masses lost with runoff for each land use for the three periods analyzed.

GIS-Style Version (L-THIA/NPS GIS)

The ArcView GIS version of the L-THIA/NPS system (Figure 9) (Lim et al. 1999) was used as the starting point for implementation of the web-based L-THIA/NPS GIS system. This version was created using a series of Avenue scripts (programming language within ArcView) and an executable version of the L-THIA model (Lim et al. 1999, Bhaduri 1998). The ArcView Internet Map Server (IMS) and Java were used to make the core functionality of this system web-accessible. The user interacts with the Java-based interface in their web browser that sends requests to the ArcView IMS through the web server. The ArcView IMS parses the information and executes corresponding Avenue scripts in the L-THIA/NPS GIS system on the server. Once L-THIA components are run, appropriate maps are passed back to the user's web browser. The GIS, L-THIA, and supporting data are maintained and run on the web server. This has many advantages for the user, but most importantly it means that the user is not required to have a GIS, an L-THIA code, or data on his/her own computer. All of this is maintained on the host server.

As with the spreadsheet-style version, the GIS-style version of L-THIA/NPS is available at http://www.ecn.purdue.edu/runoff. Although not required, the ArcView L-THIA/NPS GIS application may be downloaded from the L-THIA web site for use locally; however, to use the system in that manner, the user must have ArcView and ArcView Spatial Analyst on his/her local machine. Documentation and sample data sets are also available for downloading. The interface for ArcView L-THIA/NPS GIS is shown in Figure 9.

Figures 9 through 12 show the L-THIA/NPS GIS interface and functions. The only software needed by the user is a web browser. The GIS and model components run on the web server. The web interface provides buttons to zoom and identify features within the maps presented in the user's web browser. The user can also zoom to a location of interest by selecting pull-down menus with county names for each state. The user can continue to zoom and then digitize the area of interest for L-THIA simulation using the mouse. The L-THIA/NPS pull-down menu enables users to run the model. The runoff depth function creates a CN map and a runoff depth map using the land-use and hydrologic soil group data for the area identified by the user. Runoff volume and NPS pollution maps are generated with the other menu selections. A 4-minute **demonstration** of the L-THIA/NPS GIS system is available from the web version of this article. Figure 10 displays the land-use map for the area selected through on-screen digitizing by the user. Figures 11 and 12 show the runoff depth, runoff volume, and NPS pollution maps created using L-THIA/NPS GIS.

Information Technology Implications

The approach used in creating and accomplishing web-based applications through L-THIA/NPS WWW and L-THIA/NPS GIS has several significant advantages over more traditional approaches to providing decision-support and analytical tools to users.

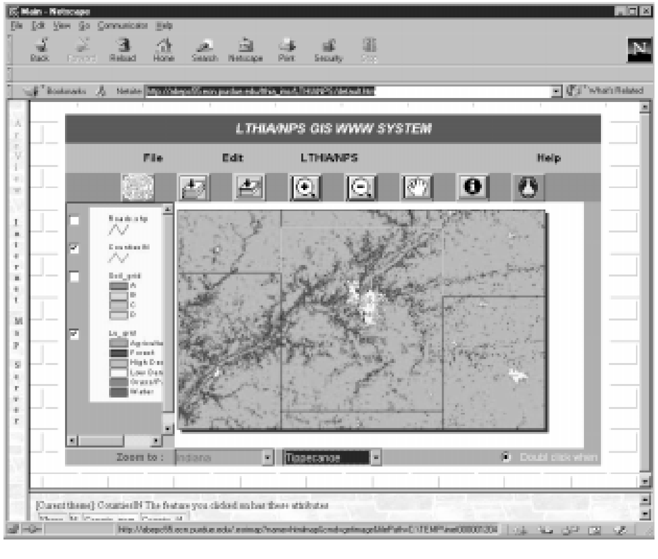


Figure 10. L-THIA/NPS GIS Showing Land Use for Tippecanoe County, Indiana

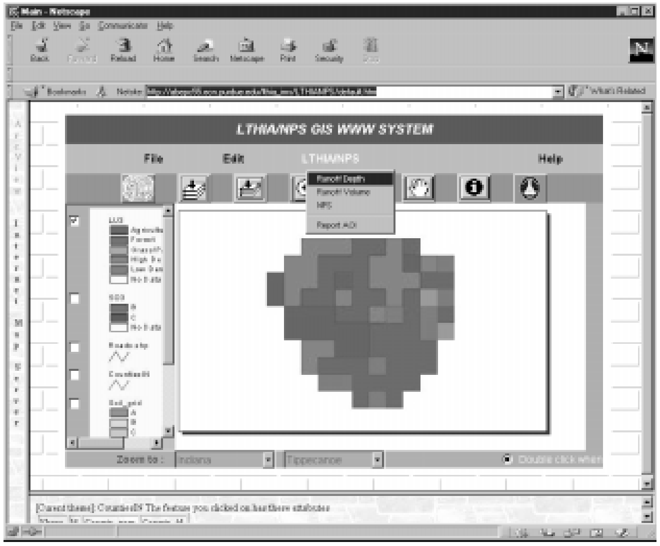


Figure 11. Area of Interest Created by On-Screen Digitizing

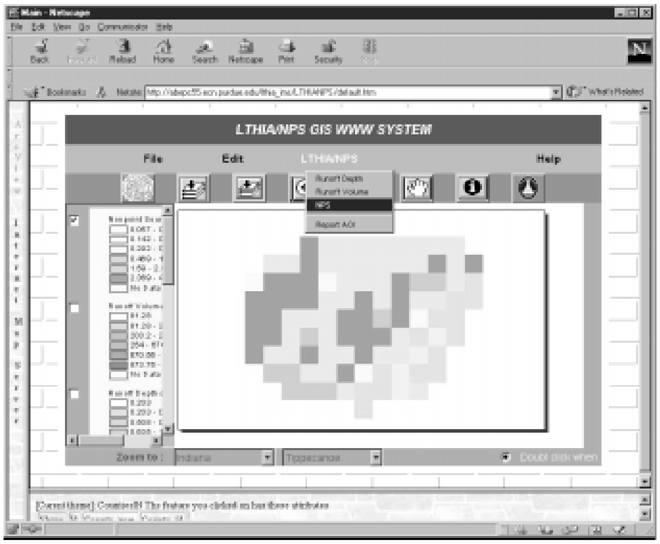


Figure 12. L-THIA/NPS GIS Pollution Map

1) The approach is accessible through the Internet using only a web browser. Therefore, users are not required to have GIS tools, models, and databases on their local computers. This can result in significant financial savings.
2) Database and GIS data are maintained at a single location. Large data sets such as weather and GIS data can be located on a computer such that multiple uses can be made of them. Users are not burdened with preparing the data for use in the model; rather, they use the best available data from the server.
3) All model users access the same version of the model. Maintenance and distribution of models and supporting tools to users are greatly simplified.
4) Data input into the model can be verified if the data are located on a server, thus errors due to input data can be minimized.
5) Computational and data-intensive applications can be run on powerful servers rather than less capable desktop computers.

L-THIA is designed for a wide range of users, from land-use planners to concerned citizens. The user interfaces for both L-THIA/NPS WWW and L-THIA/NPS GIS provide the user with simple, easy-to-use access to the model. L-THIA/NPS WWW features pull-down menus for location, land use, and soil type. The area is typed in corresponding boxes. By opening the project downloaded with L-THIA/NPS GIS in ArcView and adding land-use and soil themes, ArcView becomes the interface for the model. New buttons appear on the toolbar to run the model. Some prior experience with ArcView is helpful; however, users who know how to open a project, edit a table, edit legends, and create layouts should have few difficulties running the model.

Detailed tutorials for both versions of L-THIA/NPS are available on the L-THIA homepage at http://www.ecn.purdue.edu/runoff. For L-THIA/NPS WWW, the "Getting Started" option provides details on using the model. Additional information on the GIS version is available via the "L-THIA GIS" option.

An Application of L-thia: Wildcat Creek, Indiana, Case Study

The ArcView GIS version (L-THIA/NPS GIS) and the web-based spreadsheet version of L-THIA (L-THIA/NPS WWW) have been applied to an Indiana watershed to demonstrate how L-THIA can be used to analyze the effects of land-use change on hydrology and NPS pollution. The GIS version was utilized with past and present land uses obtained from remotely sensed images and aerial photography, while the spreadsheet version was utilized with the present and proposed future land-use changes based on zoning by the local planning authority.

Study Area

The Wildcat Creek Watershed is more than 2000 sq km in area, is located in north central Indiana, and includes the cities of Kokomo, Frankfort, and a portion of Lafayette. A U.S. Geologic Survey (USGS)-defined 14-digit subwatershed (Figure 13) was used for this analysis. This watershed is of particular interest as it

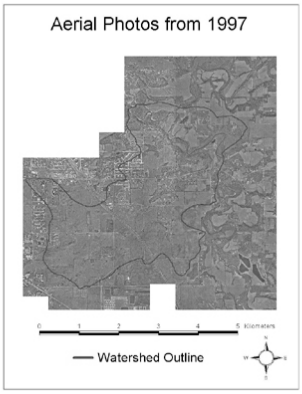


Figure 13. Study Area within the Wildcat Creek Watershed, Northcentral Indiana.

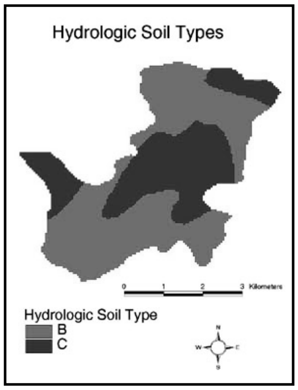


Figure 14. Hydrologic Soil Types

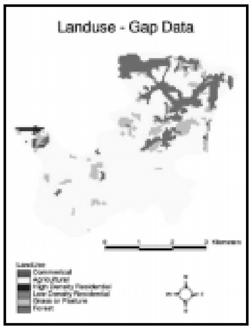


Figure 15. Land Use – Gap Data

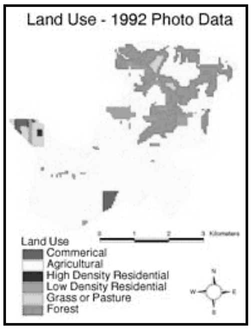


Figure 16. Land Use – 1992

Photo 1. Creation of large impervious surfaces that cause increases in runoff

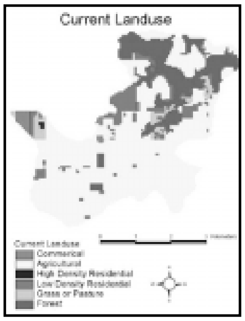


Figure 17. Land Use - 1997

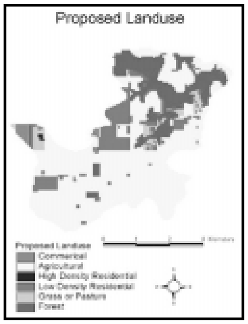


Figure 18. Land Use - Present

adjoins a rapidly urbanizing part of a city and is experiencing significant land-use change. Proximity to major roads has encouraged growth in this area. Indiana Highway 26 runs east and west through the middle of the watershed; running northwest to southeast through the watershed is Interstate 65 connecting Indianapolis to Chicago. Partially due to proximity to the interstate and a new "super store" at the intersection of Interstate 65 and Highway 26, several new subdivisions have been built in the last 10 years near the middle of the watershed. Commercial growth has also occurred along Highway 26 in the far eastern portion of the watershed. To the north, upscale homes have been built in the wooded areas around Wildcat Creek. Although there is currently little development in the southeastern portion of the watershed, the area directly to the east of the watershed has experienced a large amount of commercial growth. The region is expecting more growth as can be seen in the recent widening of a road running north and south slightly outside the watershed (Photo 1). Several areas in the watershed have recently been rezoned by the local planning authority to accommodate increasing demands of housing and commercial space (*Journal and Courier* 1999). At several locations in the watershed, the total maximum daily load of E. coli, dissolved oxygen, polychlorinated biphenyl (PCB), ammonia, lead, and cyanide has been exceeded for the water body (Indiana Department of Health 1997). More than 20 stream segments are unfit for recreational uses or do not support any aquatic life due to pollution. Since 1997, there has been an official advisory in place recommending that fish caught in a significant stretch of Wildcat Creek not be eaten.

Data Used

Land-use data for 4 years were compiled to track changes. Land-use change information, along with the hydrologic soil groups (Figure 14), was used to assess the change in runoff volumes and NPS pollutant loadings in the watershed. Four sets of historical, present, and proposed land-use data were used for the change impact-assessment analysis.

The first set of data is "GAP" data from the U.S. Fish and Wildlife Service. This is the 1990 land-use layer used in the analysis (Figure 15). The second set of data comes from USGS digital ortho quadrant aerial photos shot in late 1992 (Figure 16). The third set of data, the most detailed, was generated by manual photo interpretation of 1997 aerial photos provided by the Tippecanoe County GIS Department. These high-quality images are the most current aerial photos available and clearly show new residential areas and areas where new subdivisions are being developed. To generate the land-use map from the aerial photos, the area for each land use was digitized on screen to produce a GIS file containing the land uses. This was the 1997 land-use layer for the watershed (Figure 17). The lay-use layer for 1999, or the present layer (Figure 18), was extrapolated from the 1997 data based on field visits to the study area. Proposed land-use changes were based on zoning maps from the local planning authority. This information was obtained in paper format. The procedure used to convert these analog data to a digital format to be used in the spreadsheet analysis is described in the following section.

There is a clear progression of land-use changes in the watershed (Figures 15-18; Table 1). The 1990 dataset is most clearly different from the other land-use maps, in part because of the

Land use	1990	1992	1997	1999
Commercial	0.530	0.297	0.305	0.305
Agricultural	15.177	13.334	12.626	11.979
High Density Residential	0.062	0.037	0.032	0.032
Low Density Residential	0.037	0.928	1.469	2.117
Grassland or pasture	1.375	0.469	0.630	0.630
Forest	2.485	3.245	3.270	3.270

Table 1. Land use areas within the watershed (in km^2)

age of the data, but also because of differences in the method of compilation and characterization of land uses. The 1990 dataset (Figure 15) was collected using satellite imagery, whereas the other data were based on aerial photos. Within the 1990 data, some northern parts of the watershed appeared to be forested, but were considered grass, pasture, or agricultural from the aerial photos. Other discrepancies include areas in the southern and western regions that were considered pasture according to the GAP data, but agricultural from the aerial photos. Some of the discrepancy is also due to the timing of the photos. Neither the 1992 or 1997 photos were taken during the growing season. This made it difficult to distinguish between a pasture and a field. Also, the 1992 land-use layer shows a significant commercial area in the southern portion of the watershed. This was a temporary parking lot that was assigned a commercial land use for looking up the CN. For hydrologic purposes, a parking space is treated the same as a commercial space because both are large, impervious surfaces generating large amounts of runoff. This area was changed to agricultural use in the 1997 land-use layer.

Higher quality and printable versions of all of the map layouts are available in pdf format. To download the pdf form, click on the layout. The layouts for the four land-use scenarios are contained in one pdf file.

The hydrologic soil group theme (Figure 14) was combined with each land-use theme (Figures 15 to 18) to produce CN themes.

GIS Version (L-THIA/NPS GIS)

Using the land-use data and local climate data in the L-THIA database, runoff maps for each scenario were generated (Figures 19-22). Runoff depth is a function of both the land use and the soil type, which is clearly visible in the runoff patterns shown in the figures. Areas with hydrologic soil group B produce less runoff than areas with hydrologic soil group C, for the same land uses. The forested areas have low runoff due to the interception of the rain by the trees, large amounts of ground cover, and undisturbed soil in the area. As land use changed, runoff in most areas of change increased due to urbanization, with the exception of agricultural areas converted to low-density residential uses. This is expected, as high-intensity agricultural uses (such as corn) produce more runoff than low-density residential developments with extensive grassed or wooded areas. There is a clearly visible reduction in runoff due to the change in land use from the temporary parking lot assigned as commercial use in 1992 to agricultural use in 1997 (Figures 20 and 21). This is an anomaly based on the input datasets used for the analysis.

Nonpoint Source Pollution

The loss of nitrogen from agricultural fields is a major concern in many areas of the U.S., including the Wildcat Creek watershed (Indiana Department of Health 1997). Soil type has little effect on the nitrogen concentration in runoff, but the land use and specifically what is applied to the land has a large impact. Changes in land use from agricultural to residential reduce the amount of nitrogen leaving the area, because of the higher fertilizer application rate for cropland. This conclusion is based on typical nitrogen runoff levels for different land uses, but would not apply to a case where residential lawns are overfertilized. Forested areas have even less nitrogen loss than residential and agricultural areas. However, commercial areas typically produce high nitrogen loss rates because of both high loadings and very high runoff totals.

Although much has been done in recent years to reduce the amount of lead exposure, especially for children, there are still significant concentrations of lead in many drinking water supplies. Wildcat Creek has been cited for having excessive levels of lead many times in the past few years. Not only does this affect water supplies, but also the number of fish caught and eaten from the Wildcat Creek. Lead in the water comes largely from NPSs such as runoff from commercial areas, parking spaces, and roads. The largest amount of lead is in runoff from commercial sites. Both the commercial areas near Highway 26 and a temporary parking lot in the 1992 data show very high predicted lead loadings.

Summary of Results

While the typical reader may not be interested in the results arrived at when using L-THIA/NPS in a particular geographic location, a detailed summary of the results for a specific instance helps illustrate the extent to which various forms of data may be processed using the system. The following illustration should be viewed as a proof of concept, rather than as an indication that the system and method have been verified as appropriate modeling across all possible applications.

In this specific instance, the model and system show that land-use changes in the Wildcat Creek watershed have resulted in significant changes in the total average runoff that is generated by the different land uses in the watershed. There also have been changes in the quantity and the type of NPS pollutants flowing into the surface water bodies in and around the watershed.

Land Use	**1990**	**1992**	**1997**	**Present**
Commercial	18060	468	105501	105501
Agriculture	285285	267480	250050	234330
High Density Residential	7576	9	3117	3117
Low Density Residential	654	15474	8895	30804
Grass or Pasture	18636	6039	21074	8895
Forest	11914	17614	16496	16496
TOTAL	**342125**	**307084**	**405133**	**399143**

Table 2: Runoff volume changes (m^3)

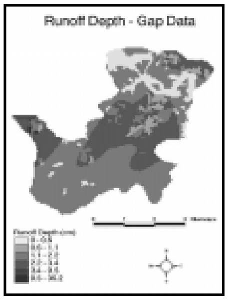


Figure 19. Runoff depth – 1990

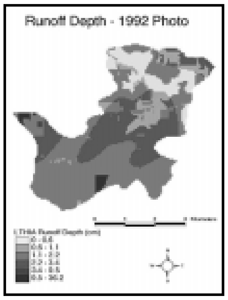


Figure 20. Runoff depth 1992

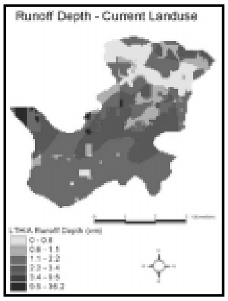


Figure 21. Runoff depth 1997

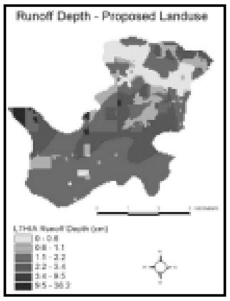


Figure 22. Runoff depth Present

	Nitrogen (kg)	**Lead (g)**	**BOD (kg)**
1990	1316	899	1796
1992	1345	1858	3624
1997	1318	1785	4333
1999	1266	2271	4519

Table 3: Annual non-point source pollution in runoff

The total runoff from 1992 to 1999 increased by 57,000 m^3 (Table 2). This is a significant increase from the original amount. Runoff from commercial areas increased from less than 500 m^3 in 1992 to more than 100,000 m^3 in 1999. The runoff generated by low-density residential areas increased twofold in the same time frame. The reduction in runoff from some land uses, such as agriculture, is due to the dramatic reduction in area covered by such land uses. Moreover, these reductions in runoff from specific land uses are more than offset by increases in runoff from other land uses such as commercial and residential.

This increase in total runoff volumes and increase in runoff generated by specific land uses also affects the type and quantity of pollutants running into the water. Typically, pollutants such as nitrogen decrease in areas of land-use change from agricultural to low-density residential. In the case of the study area, the total nitrogen in the runoff decreased from 1316 kg in 1990 to 1266 kg in 1999 (Figures 23-26; Table 3). This results primarily from the change in use from agricultural land to low-density residential use.

The increase in the amount of lead in the watershed is significant (Figures 27-30). Lead is present in large amounts from runoff due to land uses such as commercial, parking spaces, roads, and highways. Lead, as mentioned earlier, is a major problem in the area. In this case, the lead in the runoff increased from less than 900 g to more than 2000 g (Table 3). This is an increase of almost 150% from the original amount. The presence of lead leads to its absorption by aquatic animals, which in turn can be harmful if consumed by humans. However, it should be noted that data on lead loadings are based on published values that may not adequately reflect declining lead runoff rates with decreasing use of leaded gasoline.

The Biologic Oxygen Demand (BOD) also increased from 1992 to 1997 by approximately 150% (Figures 31-34). The BOD of a water source is a measure of the amount of dissolved oxygen required by microorganisms to oxidize organic compounds. It gives an indication of the amount of organic matter in the water. Although there was a decrease in the runoff depths in the areas converted from agricultural to residential, the BOD of these areas greatly increased. The influx of commercial land use also increased the BOD of the runoff.

These values obtained from the L-THIA NPS analysis must be evaluated remembering that the model does not take into account changes in temporal values due to policy changes. The NPS pollutant loadings, however, are based on standard values obtained from widely available research data published in scientific literature. For further details, refer to Bhaduri (1998).

Web-based Spreadsheet Version

The spreadsheet version of L-THIA was used to analyze the runoff generated by the present land use (1999) of the case study watershed and the runoff that will be generated if land uses within the watershed become the proposed land uses. The proposed informa-

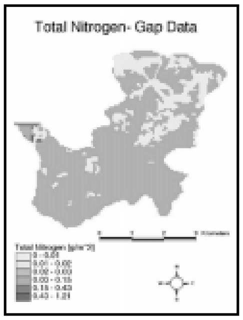


Figure 22. Total Nitrogen – 1990

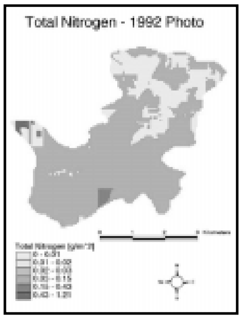


Figure 23. Total Nitrogen – 1992

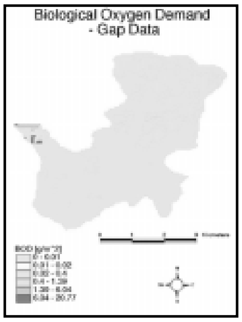


Figure 30. Biological Oxygen Demand - 1990

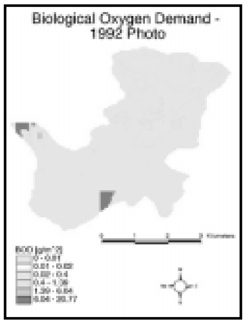


Figure 31. Biological Oxygen Demand - 1992

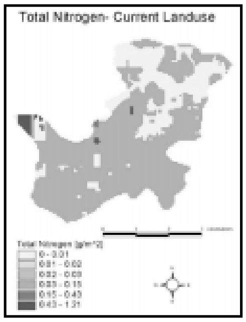


Figure 24. Total Nitrogen – 1997

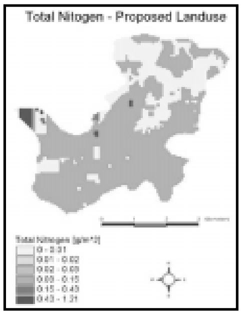


Figure 25. Total Nitrogen – Present

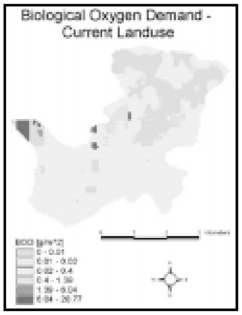


Figure 32. Biological Oxygen Demand - 1997

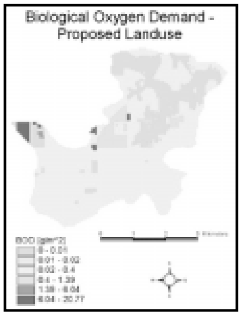


Figure 33. Biological Oxygen Demand - Present

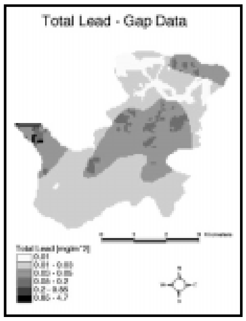


Figure 26. Total lead - 1990

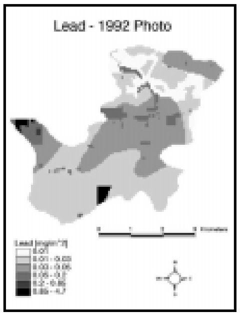


Figure 27. Total lead - 1992

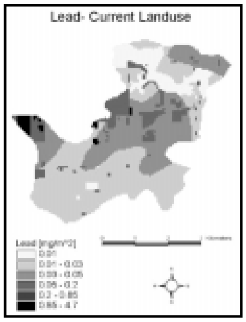


Figure 28. Total lead - 1997

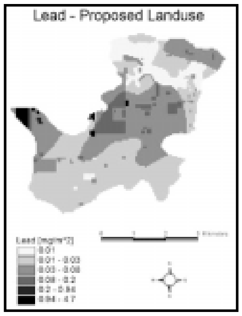


Figure 29. Total lead - Present

tion was obtained from the local planning authority in paper format. The data obtained in paper format posed problems in terms of converting the data into a digital format and the accuracy of the converted data. To complicate matters, the three maps covering the watershed of interest were at three different scales.

Data conversion was performed in three steps. The first step was to transfer the data from the proposed land-use maps to a map made up of a mosaic of the 1997 aerial photographs of the watershed. The next step was to calculate the total area covered by all land uses on the two hydrologic soil types found in the watershed. These two hydrologic soil types are B and C. A map, at the same scale as the photo mosaic map, was obtained from the digital database used for the GIS version of L-THIA. The soil map was then overlaid with the proposed land-use information map produced in an earlier step. A third composite map was produced from the two maps that showed the area covered by different land uses in the watershed according to the two soil groups.

The third step was to calculate the area covered by different land uses according to the soil types. This was done by overlaying the new composite map with a 0.25-km square grid. The number of squares covering each land use were manually counted and multiplied by 0.25 to obtain the area covered by the land use (sq km). The data generated by this method are not as accurate as estimates obtained using GIS. The total area of the watershed using this method comes to 19.25 sq km, whereas the total area of the watershed according to the digital data is 18.11 sq km. Such differences can be expected considering the crudeness of the method used to estimate the area; however, this relatively slight difference in area has a small overall effect on the estimated

	Present		Proposed	
Land Use	Soil C	Soil B	Soil C	Soil B
Low Density Residential	0.77	0.67	0.88	1.69
High Density Residential	0.03	0	1.38	1.06
Commercial	0.26	0.03	0.94	2.31
Industrial	0	0	0.38	2.75
Agricultural	4.19	8.3	3.25	2.63
Forest	0	2.06	1.25	2.19
Grass	0.49	0.13	0.00	0.00
Total	**5.74**	**11.19**	**8.06**	**12.63**

Table 4: Land use according to soil types (all data in km^2)

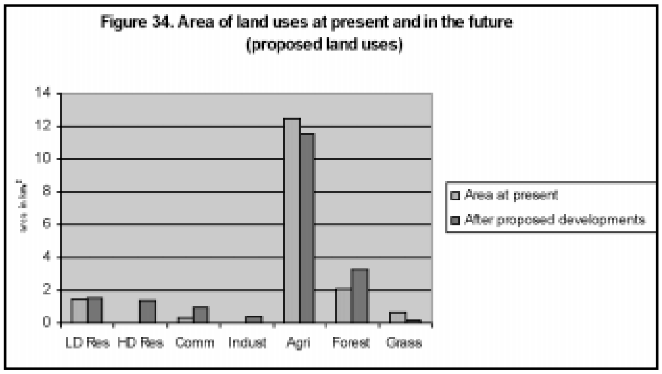


Figure 34. Area of land uses at present and in the future (proposed land uses)

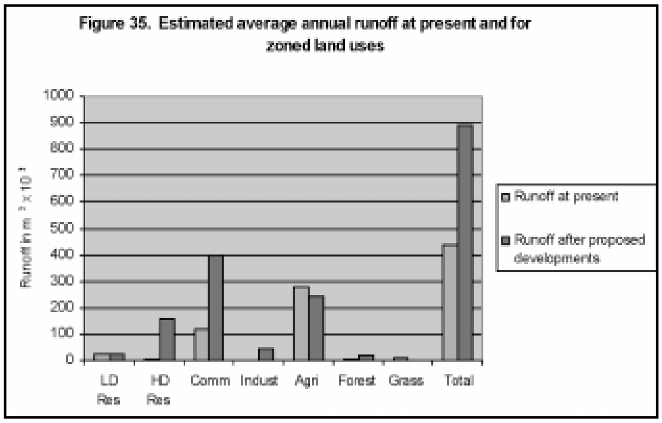


Figure 35. Estimated average annual runoff at present and for zoned land uses

long-term changes in runoff generated by L-THIA. The data generated by the manual method were then used to run the web-based spreadsheet version of L-THIA.

To run the spreadsheet version of L-THIA, the following information is required:

- the location of the area of interest (state and county);
- the land-use areas, which were obtained by the procedure described above; and
- hydrologic soil groups for the land-use areas, which were obtained from the digital database available at Purdue; such data can also be obtained at the local Soil and Water Conservation District office or Natural Resources Conservation Service office.

More information on this can be obtained by accessing the L-THIA section at: http://www.ecn.purdue.edu/runoff.

Figure 35 shows the present and zoned land-use distribution in the watershed. Figure 36 shows the estimated average annual runoff for present and proposed land uses.

The proposed developments in the watershed result in an estimated 100% increase in the average annual runoff generated in the watershed. This could have several long-term impacts on the hydrology of the region. The overall runoff volume of the watershed increases from less than 450,000 cu m to almost 900,000 cu m. At present, the watershed is predominantly agricultural. The conversion of agricultural land to commercial, industrial, and high-density residential uses has drastic consequences on the runoff.

The areas proposed for commercial development in the watershed are the largest contributors to the increase in runoff. An increase of just 0.7 sq km of commercial use results in an increase of 400% in the runoff generated by that particular land use. Other high runoff-generating land uses such as industrial and high-density residential areas are also introduced into the watershed. In addition, they account for the large increase in runoff.

Secondly, land uses such as commercial, industrial, and high-density residential also cause changes in the pollutants that runoff with water into the surrounding water bodies. At present, the watershed is mainly agricultural; it accounts for 73% of the total area and contributes 63% of the total runoff. In the proposed development scenario, commercial land use covers only about 5% of the total area but contributes almost 45% of the total runoff. The increase in land uses such as forests in the riparian buffer zone actually contributes to reducing the total runoff in the watersheds.

Is the proposed land-use plan the best solution for the long-term hydrology of the region? This can be determined by running L-THIA for different scenarios or keeping the same land uses but changing the location of the land use so that the proposed land use is on a different soil type. Since different soil types in combination with different land uses generate different runoffs, an alternative land-use change solution that maintains the same area of each land use as in the current proposed plan can be found using L-THIA that results in a minimum increase in runoff in the watershed. The data to run such an analysis with L-THIA are provided in Table 4. The watershed is located in Indiana in Tippecanoe County. Using the information in Table 4, L-THIA can be used to determine the average annual runoff that would result from this zoning plan. Click here to use L-THIA to generate the runoff for this situation.

Conclusion

There are several advantages to making tools such as L-THIA accessible via the web. In general, putting such models, decision-support tools, and databases on the web gives users access to seemingly vast and diverse options from which to choose. Users of the web-based version of the L-THIA model do not need a GIS package on their local systems. Databases required to run the model are also stored at a central server. This has the twofold advantage of significant savings in cost and time for the users of the model. Secondly, the combination of a spreadsheet and a GIS version covers a larger population of the users, as not all users are familiar with GIS and not all have access to data in a digital format.

The web-based approach of making tools available described in this article also provides an opportunity to involve the large and growing number of Internet users in the U.S. and elsewhere in the world in planning and decision-making processes. “There is no question now that the web offers the promise of public participation broad enough to sustain more competent decision making” (Klein 1999). The use of information technologies to make models, data, and analytical tools accessible on the web will allow stakeholders to gain the knowledge and information necessary to actively participate in decisions that will impact the quality of their lives. These techniques provide access to tools in familiar web-based interfaces, raise the possibility of utilizing authenticated data stored on web servers, and do not require the purchase of specialized hardware or software. These same benefits may also be realized by municipalities and planning offices.

L-THIA is an easy-to-use model that utilizes readily available data from municipal databases. The results generated from L-THIA can be used to generate community awareness of potential long-term problems of urban sprawl. They can also be used to support physical planning aimed at minimizing disturbance of critical areas. Urban and regional planners and land-use decision-makers can use L-THIA to evaluate the potential effects of land-use change on the hydrology of a region and to identify the best location of a particular land use so as to have minimum impact on the natural environment of the area.

L-THIA analyses have been completed for various large and small watersheds within the U.S. and internationally (Leitch and Harbor 1999, Minner et al. 1998, Bhaduri 1998, 1997, Grove 1997, Ogden 1996). Due to the nature of the accessibility of the model, it is not possible at this point to assess the number of planners, professionals, and interested communities that actually use the tool. The number using the web-accessible version is not monitored because of privacy concerns for the users. However, it is possible to determine the number visiting the site for an extended period of time, and this shows that the site has gained considerable popularity.

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