This paper was peer-reviewed for scientific content.
Pages 1018-1023. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Development of the Long Term Hydrologic Impact Assessment (LTHIA) WWW Systems

Kyoung Jae Lim, Bernard A. Engel, Youngsug Kim, Budhendra Bhaduri and Jon Harbor*

ABSTRACT

In urbanizing watersheds, conversion from non-urban to urban land uses leads to increased imperviousness and consequently increased runoff. Urban areas have also been recognized as a significant source of Non-Point Source (NPS) pollution. Several models have been developed to predict event-specific NPS loading from urban areas. Long Term Hydrologic Impact Analysis/Non-Point Source (LTHIA/NPS) is an easy to use Curve Number (CN) based model, which can be used to predict long-term runoff and NPS pollution from urbanizing watersheds.

A user-friendly LTHIA/NPS WWW interface was developed using Java/Java Script, HTML, and CGI Scripts. Land use and soil maps are provided on the WWW, and precipitation data are provided for approximately 500 weather stations in the US. This interface provides easy access to the model and improves understanding of the results through graphical representation. The LTHIA/NPS WWW GIS system allows the user to select their area of interest directly from a map using a WWW browser and run LTHIA/NPS. Users can simulate the impacts of land use changes on runoff and NPS pollution and examine the results via a WWW browser. Users ranging from students to land use planners and other environmental professionals can use these WWW-based tools to assess long-term hydrologic impacts of land use change.

INTRODUCTION

More than two – thirds of the US population lives in urban areas and these areas are continuing to expand (Chinitz, 1991). Ongoing urbanization increases impervious areas and results in increased runoff and NPS pollution. Urban NPS pollution is generated by deposition and accumulation of pollutants on land surfaces, followed by washoff in stormwater runoff. Urban NPS pollution typically includes suspended and dissolved solids, bacteria, heavy metals, oxygen-demanding substances, nutrients, oil and grease, and pesticides (Novotny el al., 1994). The main sources of these pollutants are vehicles, fertilizer and pesticide application, animal wastes, construction activities, erosion, and atmospheric deposition (Baird, 1996). Since agricultural areas have often been thought of as primary sources of NPS pollution, many of the hydrologic/water quality models primarily focus on agricultural pollutants which may be transported in solution with runoff water, suspended in runoff water, or adsorbed on eroded soil particles (Bhaduri, 1998). Thus there is considerable need for NPS models that addresses urban areas.

For decision makers, such as land use planners and other environmental professionals, it is important to assess the effects of land use changes on environmental problems - especially on surface runoff and groundwater recharge. Hydrology should be part of the overall analysis of the effects of land use change. Neglecting hydrology associated with land use change may result in flooding, stream degradation, erosion, and loss of groundwater supply (Burke et al., 1988). Land use changes to urban areas usually increase impervious areas and alter spatial and temporal patterns of surface runoff (Bhaduri, 1998). Increased runoff results in more soil erosion and sediment load to streams and lakes, spoils wildlife habitat, and increases non-point source pollution with runoff and chemicals attached to sediment (Verma et al., 1996).

The Long Term Hydrologic Impact Assessment (LTHIA) tool was developed to assess long-term effects of land use changes (Harbor, 1994). Many models, including LTHIA, compute runoff using the Curve Number (CN) method (USDA, 1986), which is based on precipitation, land use, hydrologic soil group, and management practices. Recently a NPS pollution assessment module was incorporated into LTHIA, and integrated with GIS for spatial data analysis (Bhaduri, 1998). However, the NPS module is limited to a small number of pollutants and land uses (Bhaduri, 1998).

The primary objectives of this project were:

1. To extend the GIS integrated LTHIA to predict NPS pollution, and
2. To develop a WWW-based LTHIA/NPS system and LTHIA/NPS WWW GIS system.

METHODOLOGY

The original LTHIA/NPS GIS approach (Bhaduri, 1998) uses land use and hydrologic soil group data in vector format to compute the composite attributes of these two inputs. Eight land use classifications – Water, Commercial, Agricultural, High Density Residential, Low Density

*Kyoung Jae Lim and Bernard A. Engel, Dep. Agricultural and Biological Engineering, Purdue University, 1146 ABE Bldg, West Lafayette IN 47907-1146; Youngsug Kim, Korea Institute of Construction Technology (KICT), Seoul, Korea; Budhendra Bhaduri, Oak Ridge National Laboratory, Oak Ridge, TN; Jon Harbor, Department of Earth and Atmospheric Engineering, Purdue University, 1397 CIVL Bldg, West Lafayette IN 47907-1397. *Corresponding author: kjlim@ecn.purdue.edu

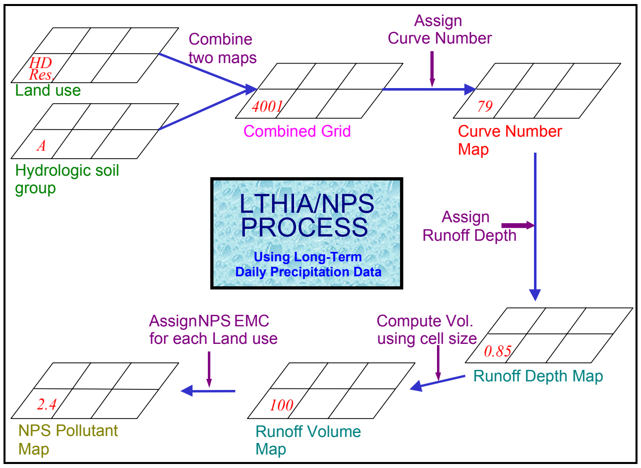

Figure 1. LTHIA/NPS GIS Overview

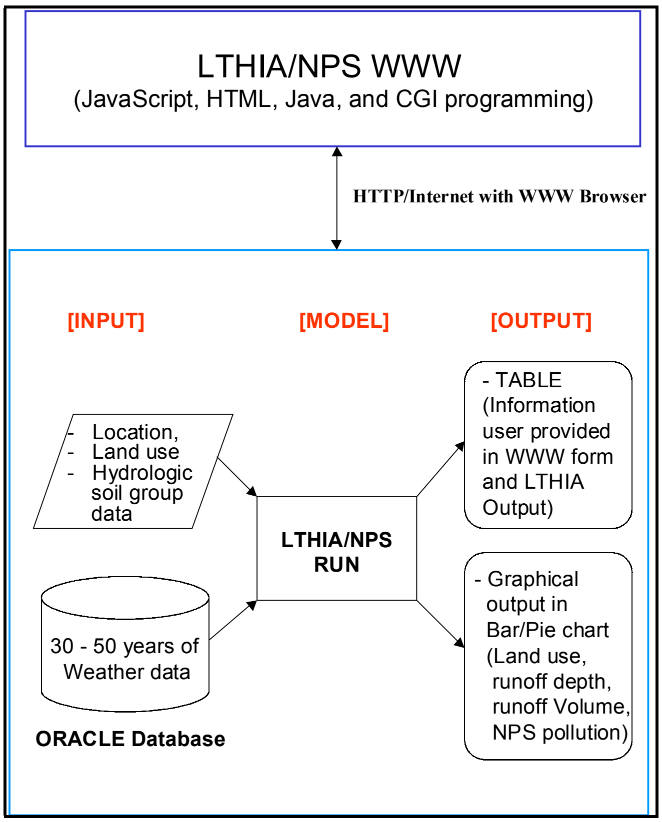

Figure 2. LTHIA/NPS WWW Overview.

Residential, Grass/Pasture, Forest, Industrial - are considered within the LTHIA/NPS GIS although no Event Mean Concentration (EMC) data are assigned to the land use "Water", and an average Curve Number is assigned to each polygon. Precipitation data are used to estimate Antecedent Moisture Conditions (AMC) in the soil, and the Curve Number is adjusted according to AMC conditions. LTHIA is run using long-term daily precipitation data to predict average annual runoff for each Curve Number, which are then assigned to corresponding land uses. Dust and dirt accumulation in urban areas and its washoff are used to estimate NPS pollution, and equivalent loadings values are used for agricultural areas.

After assessing the performance of the LTHIA/NPS GIS (Bhaduri, 1998), we used ArcView Avenue scripts to make use of ArcView GRID format to improve manipulation of spatial data and analysis. Many of the spatial data, such as land use maps obtained from remote sensing and classification processing, are already in raster format, and computations using the raster format are faster than those using the vector format in the LTHIA/NPS GIS. Thus, the raster approach was adopted. Figure 1 shows how the LTHIA/NPS GIS works with the raster approach. Avenue scripts were modified to use grid layers for all analyses.

Two runoff computation types are provided in the new LTHIA/NPS GIS. One is the ArcView SCS CN method for single runoff events (Engel, 1997), and the second is the LTHIA method to estimate average annual runoff. The ArcView SCS CN method developed by Engel (1997) assists the user in editing land use and hydrologic soil group maps if these input data don't have the required classification for LTHIA. Runoff volume is computed by runoff depth multiplied by cell area. Cell size is read directly from the runoff depth grid.

The NPS module in the original LTHIA/NPS GIS did not predict NPS pollutants for non-urban areas. Event Mean Concentration (EMC) data (Baird and Jennings, 1996) were used in the new model version to predict NPS pollutants for non-urban areas as well as urban areas. The EMC data used (Table 1) were compiled by the Texas Natural Resource Conservation Commission (Baird and Jennings, 1996). Numerous published sources and existing water quality data were reviewed by Baird and Jennings (1996) with respect to eight categories of land: (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 for land use.

However, some pollutant concentrations vary with time for rainfall events, so flow-averaged sample values were used as Event Mean Concentrations in these cases. Therefore, EMCs should be reliable for determining average concentrations and calculating constituent loads.

Two WWW-based versions of LTHIA/NPS were developed. One is a spreadsheet-like version for simple analyses and the other is GIS-based for more advanced analyses. Figure 2 shows how LTHIA/NPS WWW (http://danpatch. ecn.purdue.edu/~sprawl/LTHIA2) works. With land use and hydrologic soil group information provided by the user and long-term daily precipitation data queried from an ORACLE database, LTHIA/NPS is run and generates runoff and NPS pollution output in tabular and graphical forms – bar and pie chart formats.

Figure 3 shows how the LTHIA/NPS WWW GIS system communicates with the ArcView GIS tool. Java, JavaScript, ArcView Internet Map Server (IMS), Netscape Server and Avenue scripts in ArcView are used. First, a Java applet sends a URL request to the ArcView Internet Map Server

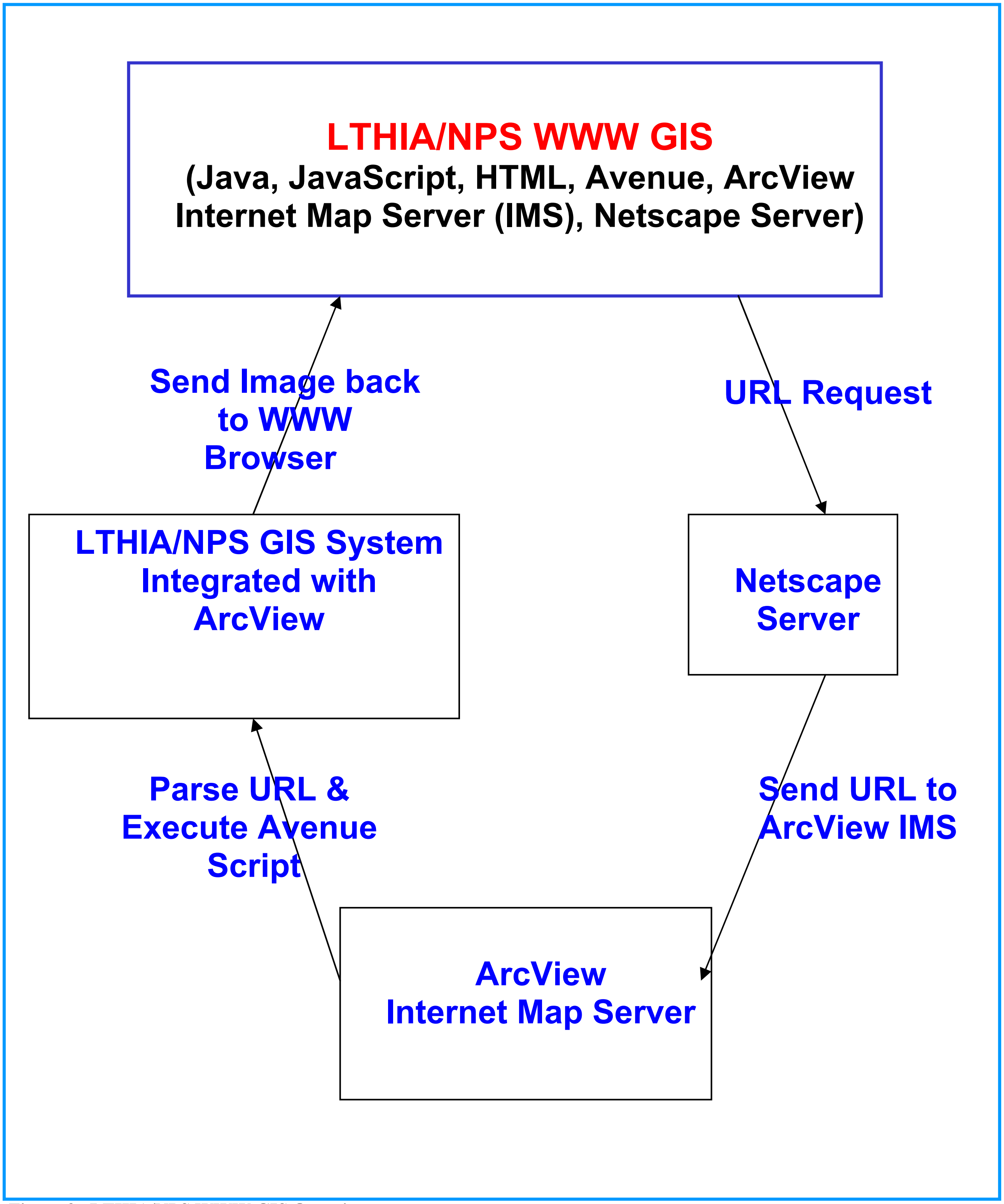

Figure 3. LTHIA/NPS WWW GIS Overview.

Table 1. Event Mean Concentration for Each Land Use Classification (EMC data were reclassificed in 7 major land use classes, Baird and Jennings, 1996)

NPS Pollutant	Land use classification						
	Residential	Comm-ercial	Industry	Transition	Mixed	Agri-cultural	Range
Total Nitrogen (mg/L)	1.82	1.34	1.26	1.86	1.57	4.4	0.7
Total Kjeldahl Nitrogen (mg/L as N)	1.5	1.1	1.0	1.5	1.25	1.7	0.2
Nitrate+Nitrite (mg/L)	0.23	0.26	0.3	0.56	0.34	1.6	0.4
Total Phosphorus (mg/L)	0.57	0.32	0.28	0.22	0.35	1.3	0.01
Dissolved Phosphorus (mg/L)	0.48	0.11	0.22	0.1	0.23	---	---
Suspended Solids (mg/L)	41	55.5	60.5	73.5	57.9	107	1
Dissolved Solids (mg/L)	134	185	116	194	157	1225	245
Total Lead (µg/L)	9	13	15	11	12	1.5	5.0
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
Total Cadmium (µg/L)	0.75	0.96	2	1	1.05	1	1
Total Chromium (µg/L)	2.1	10	7	3	5.5	10	7.5
Total Nickel (µg/L)	10	11.8	8.3	4	7.3	---	---
BOD (mg/L)	25.5	23	14	6.4	17.2	4.0	0.5
COD (mg/L)	49.5	116	45.5	59	67.5	---	---
Oil and Grease (mg/L)	1.7	9	3	0.4	3.5	---	---

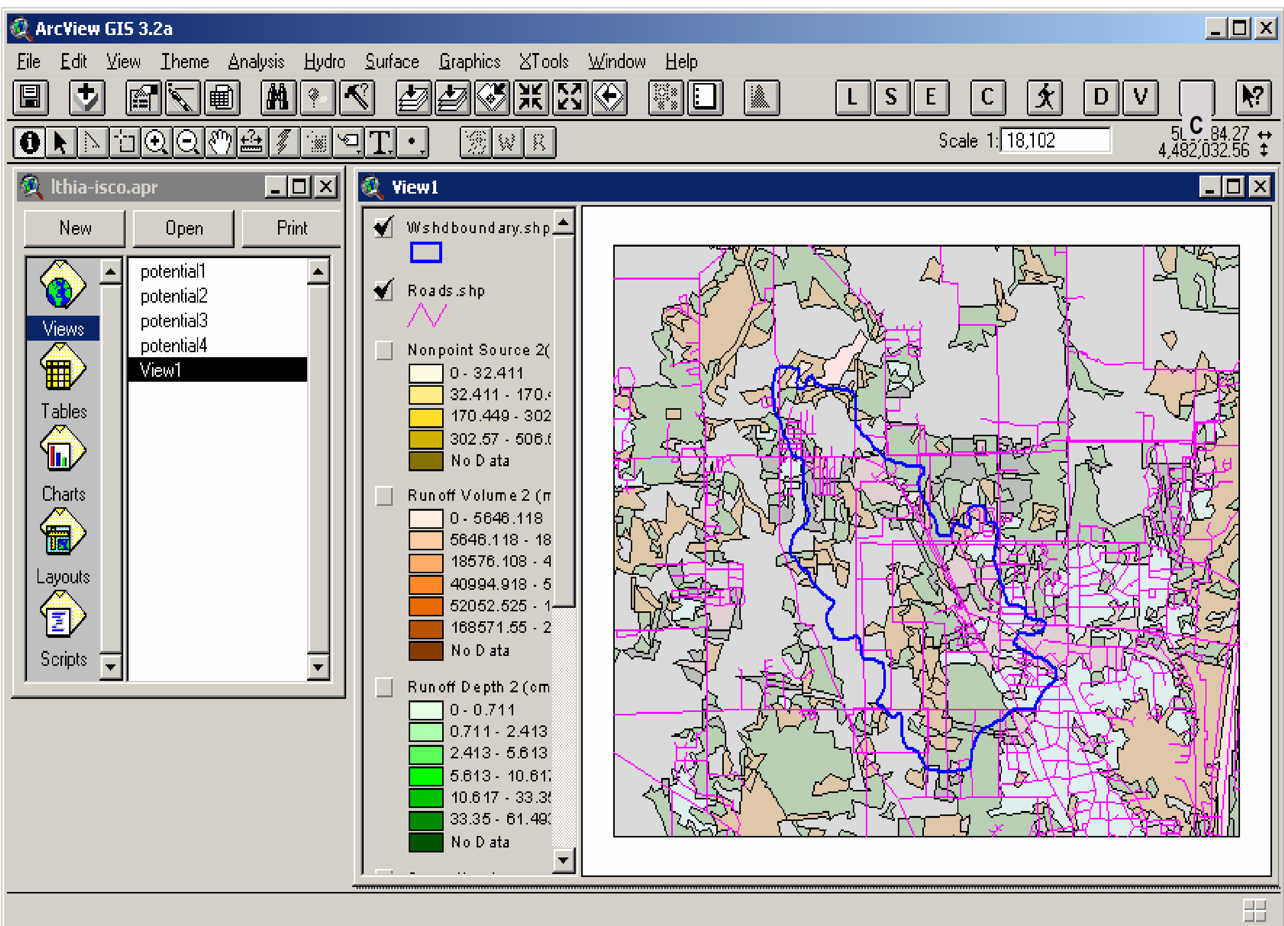

Figure 4. ArcView Interface of the LTHIA/NPS GIS.

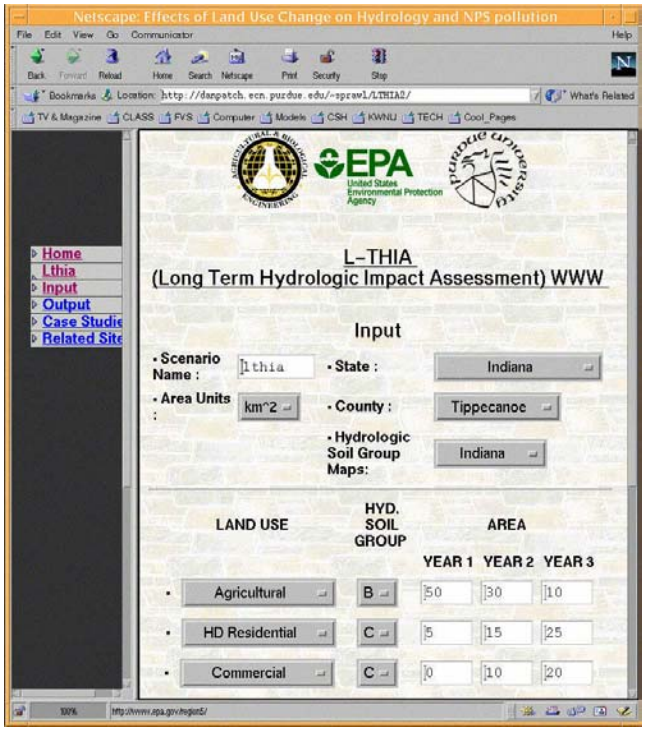

Figure 5. LTHIA/NPS WWW Interface.

(IMS) through the Netscape Server. ArcView IMS parses the URL from the WWW browser and executes corresponding Avenue scripts in the LTHIA/NPS GIS. Once it runs, it creates a snapshot of the View and sends the image with other necessary information, such as current extent of the View and current status of maps on the View, to the WWW browser. Before the WWW browser reads the snapshot of the View, it waits for a message from ArcView IMS to see whether the action is completed.

RESULTS

Figure 4 shows the ArcView interface of the LTHIA/NPS GIS. The user runs the LTHIA/NPS GIS using 8 buttons that were added to the ArcView GIS toolbar. The "L" button assigns values to each land use for CN determination. The "S" button assigns values to each hydrologic soil group for CN determination. The "E" button helps the user edit the land use or hydrologic soil group maps. The "C" button combines land use with the hydrologic soil group data and assigns Curve Numbers for each of the combinations. The icon with the running person executes the LTHIA/NPS program. The "D" button reads LTHIA/NPS results and creates a runoff depth map. The "V" button computes runoff volume for each cell. The second "MC" button assigns Event Mean Concentration (EMC) based NPS pollutant values to each land use to create NPS pollutant runoff maps.

Figure 5 shows the LTHIA/NPS WWW interface. The user can determine the effects of land use changes for their local area. Based on the location the user selects, weather data for the nearest weather station are queried from the database and reformatted for the LTHIA run. The user selects one of the eight land use classifications, hydrologic soil group information and provides area for each land use classification for this combination for each time step the LTHIA/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, and average runoff depth information. Pie charts provide land use and runoff volume for each time of interest.

Figures 6 (a) and (b) show the LTHIA/NPS WWW GIS interface. LTHIA/NPS WWW GIS receives all necessary information from the ArcView GIS, creates maps and displays them in the WWW browser. Buttons are provided to zoom, pan, and identify features. Using the LTHIA/NPS WWW GIS, the user can zoom to a location of interest by selecting pull down menus with county names for each state as shown in Figure 6 (a). The user can continue to zoom and

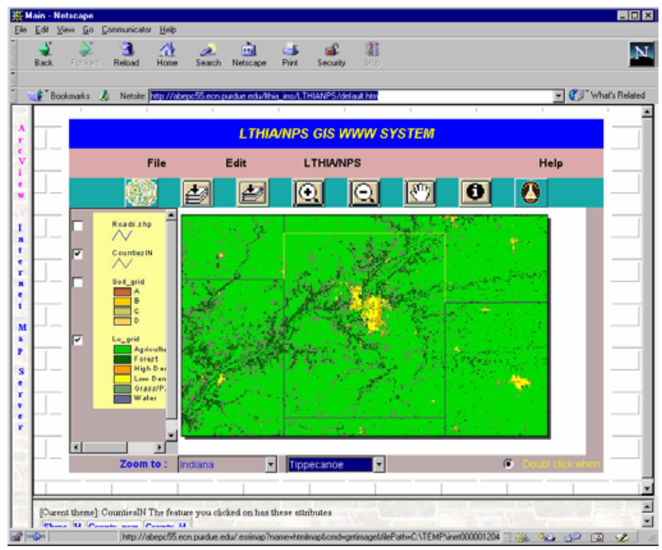

Figure 6 (a). LTHIA/NPS WWW GIS Interface with Land Use for Tippecanoe County, Indiana

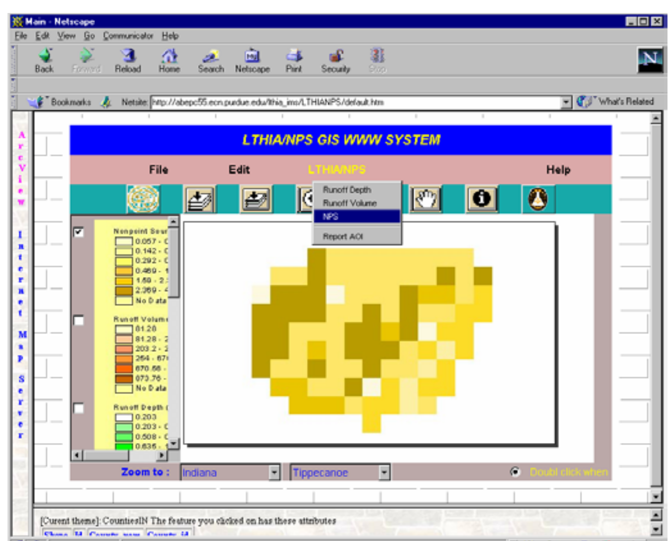

Figure 6 (b). LTHIA/NPS WWW GIS Interface with Nitrate NPS Pollution Map for Area of Interest.

then digitize the area of interest for LTHIA NPS simulation using the mouse. The runoff depth function in the LTHIA/NPS pulldown menu creates the Curve Number map and runoff depth map using the land use and hydrologic soil group data identified as the area of interest. From this same pull down menu, runoff volume and NPS pollution maps are generated. Figure 6 (b) shows runoff depth, runoff volume, and NPS pollution maps for the area selected through on-screen digitizing by the user.

LTHIA/NPS WWW and LTHIA/NPS WWW GIS have several advantages over the traditional 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 (Lim, 1998).

SUMMARY AND CONCLUSIONS

The LTHIA/NPS GIS was enhanced by adding an Event Mean Concentration (EMC) approach to predict NPS pollution for both urban and non-urban areas. Average annual NPS pollution is now estimated for 15 pollutants. The system was further modified so that runoff can be estimated for single events.

A spreadsheet-like LTHIA/NPS WWW system (http://danpatch.ecn.purdue.edu/~sprawl/ LTHIA2) was developed. Users are able to simulate the impacts of land use changes on runoff and NPS pollution and examine the results via their WWW browser. This interface provides easy access to the LTHIA/NPS model and improves understanding of the results, since results are represented in tables, bar charts and pie charts.

A LTHIA/NPS WWW GIS prototype was developed but it is not yet publicly available on the WWW. Within this system, the user can zoom into an area of interest, digitize the area of interest directly on the WWW browser, complete LTHIA/NPS model runs and view model results. The WWW browser communicates with ArcView installed on the server through the Netscape server and ArcView Internet Map Server (IMS). Using the LTHIA/NPS WWW GIS system, a decision maker can obtain information to assist in making decisions related to hydrologic and environmental issues in their local area. Even decision makers or members of the general public with limited knowledge of hydrology and environmental issues can easily utilize the LTHIA/NPS WWW GIS system for their local area in Indiana.

REFERENCES

Bhaduri, B. 1998. A Geographic Information System-based Model of the Long-Term Impact of Land Use Change on Non-Point Source Pollution at Watershed Scale, Ph. D. thesis, Purdue University.

Burke, D., E. Meyers, R. Tiner and H. Gorma. 1988. Protecting nontidal wetlands.American Planning Association, Planning Advisory Service, Report No. 412/413.

Baird, C., and M. Jennings. 1996. Characterization of Nonpoint Sources and Loadings to the Corpus Christi Bay National Estuary Program Study Area, Texas Natural Resource Conservation Commission.

Chinitz, B. 1991. A Frameworkfor Speculating about Future Urban Growth Patterns in the US. Urban Studies. Vol. 28 No. 6, pp. 939-956.

Engel, B.A. 1997. GIS-based CN Runoff Estimation, Agricultural and Biological Engineering Departmental Report, Purue University.

Grove, M. 1997. Development and Application of a GIS-based Model for Assessing the Long-Term Hydrologic Impacts of Land-use Change. MS thesis, Purdue University.

Harbor, J.M. 1994. A practical method for estimating the impact of land-use change on surface runoff, groundwater recharge and wetland hydrology, Journal of the American Planning Association, Vol. 60, No. 1, pp. 95-108.

Hughes, J. 1999. Urban Sprawl Major Culprit In Degraded Rivers, American Rivers Web Site (http://www.amrivers.org/).

Lim, K.J. 1998. An extension of the national agricultural pesticide risk analysis (NAPRA) approach to include nutrients. M.S. Thesis, Ag. and Biological Engineering, Purdue University.

Novotny, V. and H. Olem. 1994. Water Quality. Van Nostrand Reinold. New York, pp. 1054.

United States Department of Agriculture, 1986. Soil Conservation Service, Urban hydrology for small watersheds, Technical Release 55.

Verma, A., R. Cooke and L. Wendte. Mapping subsurface drainage system with Color Infrared Aerial Photographs", http://umbc7.umbc.edu/~tbenjal/vermal/verma.html.