지역공동체를 위한 수문/수질 평가 의사결정지원시스템

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Hydrological Impact Evaluation Web-Based DSS for Local Community

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Abstract

의사결정지원시스템은 다양한 분야에 적용되어 왔으며, 그 중 수자원 및 수질 관련 분야에도 다각적으로 적용되어 왔다. 본 연구에서는 미 농무성의 자연자원보전국(NRCS, Natural Resources Conservation Service)에서 개발한 유출곡선법(Curve Number Method)과 EMC(Event Mean Concentration)을 사용한 L-THIA(Long-Term Hydrologic Impact Assessment) 수문/수질 모형을 강우자료 데이터베이스, 웹기반 지리정보시스템, 웹 사용자 편의 시스템과 통합한 수문/수질 L-THIA web 의사결정지원시스템을 개발하였다. L-THIA web은 도시계획가나 지방자치단체, 또는 지방의 공동체가 사용할 수 있도록 쉽고 단순한 사용자 편의 시스템을 제공하고 있으며, 미국의 50개 본토의 주와 카운티(County) 이름으로 기상자료와 수문토양분류(Hydrologic Soil Group)을 인터넷 지리정보시스템을 이용하여 제공하고 있다. 본 연구는 지방자치단체 및 지역공동체의 실무자를 사용자로 수문/수질 평가 및 관리를 위한 시스템으로 유용하게 활용될 수 있을 것으로 사료된다.

Keywords : 의사결정지원시스템, 수문모형, 토지이용변화, 인터넷 GIS

I. Introduction

Application of information technology is a general approach to solve problems that require significant data processing, and adaptations of the technique to the hydrologic field are no exception. The interdisciplinary and hybrid work between hydrology and information technology has recently made a vivid footprint as a necessarily important approach to make data easy to use with such approaches as geographic information system (GIS), databases and web communication techniques. Advances in information technology involving computer hardware, software and communication networks have overcome most difficulties in use of timely and spatially scattered resources in the decision making processes. One of the biggest benefits of using information technologies in decision-making is the potential to overcome limited resources in terms of time, data and communication.

Urban sprawl and the corresponding land use change from lower intensity uses such as agriculture and forests to higher intensity uses including high density residential and commercial has various long- and short-term environment impacts on ground water recharge, water pollution, and storm water drainage (Bhaduri et al., 2000). Since each land use has a different level of impact, careful physical planning is an ideal tool that can minimize these impacts in initial development stages rather than relying solely on structural solutions after the impact has occurred (Bhaduri et al., 2000). However, many land use planners and city managers, even water resources managers, do not have easy to use tools that provide estimates of the potential hydrologic impacts of land use change and urban sprawl. To fill this need for a user-friendly hydrologic impact evaluation tool, the Long-Term Hydrologic Impact Assessment(L-THIA) model was developed. L-THIA was initially a spreadsheet tool (Harbor, 1994), and more recently was integrated with GIS (Grove, 1997, Bhaduri, 1998). An interdisciplinary team at Purdue University has developed a web-accessible version of L-THIA, overcoming several difficulties related to common data availability, ease-of-use and widespread accessibility with interactive web-based GIS.

This paper explores decision support systems (DSS) and the L-THIA web DSS based on an integration of a daily direct runoff hydrologic model, web-based programs, GIS, and databases. It also introduces DSS features associated with the L-THIA DSS including charts, graphs, suggestions and urban best management practice (BMP) cost estimation.

II. Background

The DSS concept described by Gorry and Scott-Morton (1971) is generally accepted as the original definition. A DSS is regarded as a computer system to help decision makers with a well-structured provision to appropriately analyze or process data in lieu of having the decision maker perform this analysis.

DSS can be developed for nearly any type of problem that uses standard procedures based on data to reach a decision. DSS have proliferated over many application fields during the past decades, fueled by rapid advances in information technologies (Eom and Lee, 1990, Power 2001). Therefore, it is natural that the specific meaning of DSS increasingly depends on the application area or components of systems (Power, 2001).

Since the introduction of DSS in the early 1970s (Gorry and Scott-Morton, 1971), numerous systems have been constructed to support various types of decision procedures (Eom and Lee, 1990). In water resources management and hydrology, DSS have been useful tools for solving a wide range of problems (Reitsma et al., 1994, Reitsma, 1996, Jamieson and Fedra, 1996, Dunn et al., 1996, Andreu et al., 1996, Eschenbach et al., 2001). DSS can be particularly helpful tools in data intensive areas in the water resources engineering field, because research on hydrology and water resources traditionally has required analysis of large amounts of data including weather, stream flow and topographical data. DSS are well suited to applications that require organization and analysis of results from large data sets to determine the best decision (Jamieson and Fedra, 1996). Since the early 1980s, DSS have been applied for various water management purposes (Fedra, 1983) with several DSS applied for the specific purpose of river-basin management(McMahon et al., 1984). Since the 1990s, development of DSS for watershed and water resource management has almost always involved GIS for spatial data manipulation, and GIS is now seen as an essential element to include in DSS tools that support spatial analysis, automated mapping and visualization of results in agricultural decision support(Choi and Lee, 1999). This has prompted new research on the integration of GIS and hydrologic models for decision support dealing with hydrologic problems (Wilson et al., 2001). In creating a DSS to describe the economic and environmental impacts of rural land use change, Dunn et al. (1996) created the NERC-ESRC Land-Use Programme Decision Support System (NELUP DSS) and described the hydrologic models in the NELUP DSS. The NELUP DSS integrates economics, ecology and hydrology models with relational and spatial databases, and supplies a GUI (Graphical User Interface) that can be used for future scenario evaluations. In reviewing DSS capabilities and performa

The first version of L-THIA (Harbor, 1994) was developed as a spreadsheet application that required the user to provide 30 years of local daily precipitation data and to identify the Natural Resources Conservation Service (NRCS) curve number(CN) (based on land use and soils information) within their area of interest. By applying an approach based on standard USDA techniques, LTHIA provided users with information on land use change impacts on hydrology for present and future land use changes over long time periods, and this far exceeded what was available previously in terms of scope and ease of access (Bhaduri et al., 1997, Minner et al., 1998, Leitch and Harbor, 1999). Even though the original L-THIA data requirements were fairly minimal, they still limited the use of L-THIA. To overcome the data requirement difficulties, and to dramatically enhance the evaluation of spatial patterns of impact, 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, and these maps were used within the system to identify CN values and areas represented by each CN. 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 a nonpoint source (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 data sets. Despite considerable improvements to the standard version of L-THIA, it continues to require data that are sometimes difficult to assemble for many users. Although more straightforward than many models, the GIS versions of L-THIA still require significant expertise to operate. Therefore, an interdisciplinary team at Purdue University developed a web-accessible version of L-THIA, overcoming several difficulties related to data availability,

Ⅲ. Web-based Long-Term Hydrologic Impact Assessment (L-THIA)

Web-based DSS

A DSS has complicated internal structures and processing capabilities, and a Graphical User Interface (GUI) to allow the user to interact with the model in a simple, understandable way. During the early stage of developing DSS applications, GUIs were typically developed with Windows toolkits and libraries (Andreu et al., 1996, Jamieson and Fedra, 1996). However, after the introduction and popularization of HTML (Hyper Text Markup Language) for web and Internet browsers, web pages have become typical user interfaces for web-based DSS. In using the HTML protocol, the GUI can support not only the standalone platform but also Internet network applications. On the other hand, the HTML protocol has several limitations for use over networks. The main limitations come from network speed, security and over simplification, producing barriers in applying sophisticated models, data intensive applications and time consuming jobs. Power (1999) presented a web-based DSS definition in terms of operational aspect. A web-based DSS is as a computerized system that delivers decision support information or decision support tools to a manager or business analyst using a "thin-client" Web browser like Netscape NavigatorTM or Internet ExplorerTM. The computer server that hosts the DSS application is linked to the user's computer by a network with the Transmissions Control Protocol/ Internet Protocol (TCP/IP) protocol. In many companies, a web-based DSS is synonymous with an enterprise-wide DSS that supports large groups of managers in a networked client-server environment with a specialized data warehouse as part of the DSS architecture (Power, 1999).

System Components

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. The web also provides a convenient way to reach people who are potential users. Although complex programs are still difficult to integrate within the Internet environment, various techniques have been applied to enable web-based DSS. A comparison of DSS systems with the applicable techniques (Table 1, Choi and Lee, 1999) shows that the GIS-web-based system has several advantages in terms of data resources, potential users, visualizations and remote access, but includes limitations due to network communication. In the following sections, the information technologies approaches used in the development of the L-THIA web DSS are described.

Most DSS typically have three main components (Ariav and Ginzberg, 1985) including a model system, data system, and user interface. The L-THIA web system also satisfies the general DSS structure. The structural components of L-THIA were diagrammed by following Ariav and Ginzbergs (1985) DSS structure and are described in Fig. 1. However, a DSS that is targeted to novice users should provide additional functionalities to help users understand the results. Such functionality can make the results more helpful and can assist users in analyzing and understanding results. In the L-THIA web DSS, several useful functions were integrated as shown in Fig. 1.

long-term average impact, rather than an extreme year or storm event impact. L-THIA results do not

Table 1 DSS Specifications Comparison (Adapted from Choi and Lee (1999))

Items		Conventional	DSS with DBMS	DSS with GIS	DSS with Web, GIS and DBMS
System	Hardware	-	Computer	Computer	Computer
	Software	Model	Model, DBMS, GUI	Model, DBMS, GUI, GIS	Model, HTML, JAVA-application, GIS, D/B
	Construction time	-	Less than the rights	Much	Much
Data	Category	-	Text	Text, map, image	Text, map, picture
	Resources	Little	More than the left	More than the left	More than the left
	Supportability	Limited	Limited by database	Limited by GIS	Limited by network speed, DB, GIS
	Quality	Low	Not spatial	High(spatial)	Depends on network speed
	Type	-	Includes database table	Includes digitalized spatial data	All electrical types
Inter-face	With model	Manual	Possible	Possible	Possible
	With users	-	Simple	Graphical	Graphical
	User numbers	Strictly limited	Limited	Limited	Potentially unlimited
Remote opera-tion	Possibility	-	Optional	Optional	Basic
	Skill	-	Difficult	Difficult	Comparably easy
	Links others	-	Difficult	Difficult	Easy
Report	Speed	Slow	Faster than conventional	Faster than conventional	Faster than conventional
	Feedback	Difficult	Easy	Easy	Easy
	Sub/objective (Based on data)	Subjective	Objective	Objective	Objective

Model System

Runoff Model

The web-based L-THIA DSS contains a hydrologic model, L-THIA, to simulate direct runoff. The L-THIA estimates long-term average annual runoff for land use types in a watershed based on long-term climate data, soils and land use data for that area. By using more than 30 years of daily precipitation data in the direct runoff calculation with the NRCS CN method, L-THIA produces the predict what will happen in a specific year, but the results provide insight into the relative long-term hydrologic impacts of different land use scenarios (Bhaduri et al., 1997). It also provides comparative impact assessments of land use change in terms of annual average non-point source pollution loadings. The model is quick and easy to use with readily available data, in contrast to other models that require considerable additional data collection to use, but which provide results suitable for detailed engineering design(Bhaduri et al., 2001). The L-THIA model was re-written in the "C" programming language and an executable L-THIA created to run within the web-based L-THIA system by Common Gateway Interface (CGI).

Probability of Exceedance

To help users understanding of the probability of runoff and non-point source pollution loading from a watershed on a yearly basis, a probability of exceedance program was developed. The program calculates probability of exceedance a 30 year annual series of runoff and non-point source pollution loading. The probability of exceedance is the percentage of time that a runoff or nonpoint source pollution value is exceeded that is computed by the rank divided by total number of years used for computation. The rank is the number in descending order of runoff and non-point source pollution loading for each year in the series. This capability can provide information about extreme and normal values of runoff and non-point source pollution loading, which can help users understand annual variability of runoff and pollutant loadings. The results from the program are presented as charts in a users browser.

Data System

Weather Data Manipulation

The location data provided by the user is used within a CGI script written in Practical Extraction and Report Language (PERL) to query an ORACLETM database on the web server 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 US are stored within the L-THIA web-based system.

Web-GIS for Soil Map

Hydrologic soil group maps can be requested from the interface for each of the 48 states in the continental US. NRCS State Soil Geographic Database (STATSGO) soil maps are served using MapServer internet-GIS technology. The hydrologic soil group maps along with counties and major roads appear in a second web browser window. The user can interactively zoom to the location of interest and determine the appropriate hydrologic soil group(s) to use in the analysis.

Dialog System

In L-THIA web, 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 hydrologic soil group combination within the area of interest. 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 and land use data and CN values as input. The L-THIA generated runoff and NPS pollution loading output are processed with CGI scripts, Javascript and Java to provide web-based tabular and graphical representations of the model output.

In the L-THIA web 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 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 past time period, as they are at present and as they might be at some time in the future. Once the user has provided the information required by L-THIA, they select the Run L-THIA button to run the model. L-THIA runs on the web server and generates a series of tables, bar charts, and pie charts for runoff and NPS pollution.

land use change. To minimize runoff increases from urban/urbanizing areas, for example, construction and management cost to build an appropriate storm water basin might be required. A cost estimation step might be the last stage in decision support procedures, and if a DSS can support the function, it would be helpful. Exact cost estimation is very difficult with computerized algorithms and requires large amounts of data, such as the physical dimensions of Best Management Practices (BMPs),

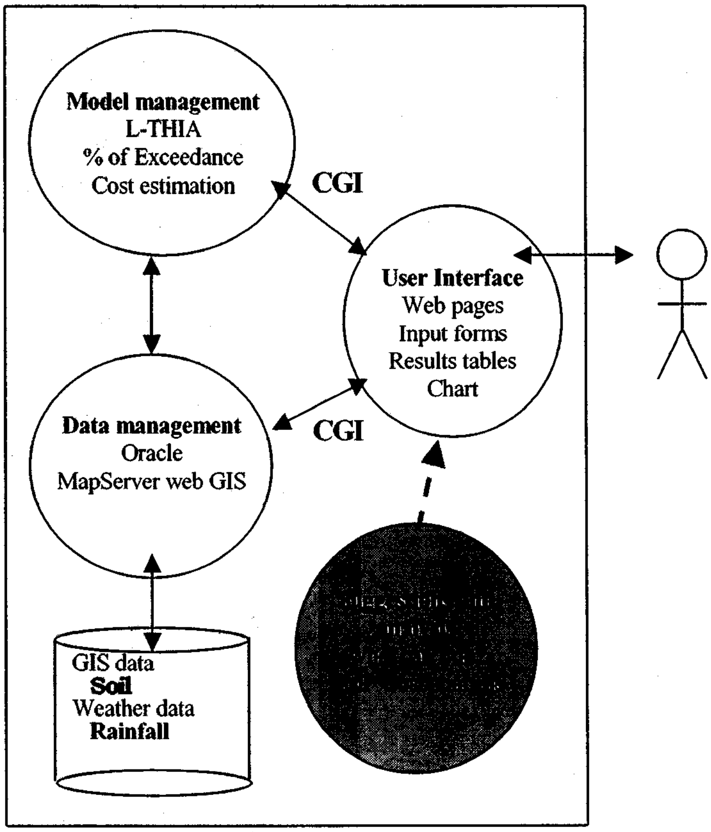

Figure 1. Description of L-THIA web components as a DSS.

Analysis and Suggestion System

BMP Cost Analysis

In general, decision makers want to include information in their decision-making on the cost to mitigate increased runoff and pollution loadings from interest rates, unit prices of items, and labor charges. Moreover, some data and dimensions depend on site-specific conditions and require professional experience to evaluate. Nevertheless, using experience and historical construction cost data, an estimated cost range can be provided to support decision makers. The USEPA (1999) recommended empirical cost estimation methods for seven urban BMPs on the basis of several historical reviews, and these methods have been incorporated into the DSS.

Urban BMP cost analysis needs several inputs, including watershed name, area of the watershed, rainfall zone, and percent impervious area through a web input form. The CGI for the cost estimation runs the computation program, and finally the costs for BMPs are displayed in tabular form. Although the urban BMP cost analysis system was programmed from simple empirical equations and a unit price approach, it can support decision makers within appropriate error ranges. In the cost analysis web page, users can also access a wide variety of information about urban BMPs, and thus can increase their understanding and knowledge in support of sound decision making.

What can I do Section

If the DSS targets novice users, the system should include useful functionalities to help such users understand the results. Numeric output of hydrologic models is hard to understand for many users. If users can understand the effect of land use change with cause-and-effect relationships, the decision they make will more likely be the best decision. Hence, functionalities to assist with understanding the output can make the results helpful in analyzing and understanding output. In L-THIA web, several useful functions were created and integrated, including BMP categories, results analysis, and examples (Fig. 1). This section was prepared to increase users comprehension of the effects of land use change and to suggest methodologies that can be used to mitigate runoff and non-point source pollutant increases.

IV. Web-based L-THIA Decision Support

Steps in Using the DSS

This section introduces the DSS features following the user work flow, rather than from the perspective of the hydrologic analysis. The recommended L-THIA web work flow suggests appropriate use of the decision support for water quality management of land use change. When users first enter the DSS, they select a study area (watershed) and enter their own land use change scenarios. The user can also examine soils maps that are linked to the input form. After basic input data are entered, the user selects the RUN L-THIA button to generate results. Users can examine the results as both tables and figures. If two or three land use scenarios were input, users can compare the results with visual-aids like bar and pie charts. During the comparison phase of analysis, users can obtain help from the What can I do menu to improve comprehension of the results. If users have acceptable results, they can go into the results report preparation section. The L-THIA web DSS is available at http://www.ecn.purdue.edu/runoff/.

Preparation of Data

The analysis was conducted using present land use and two hypothetical land use change scenarios. This process illustrates the types of results produced by this method and demonstrates how the impacts of present and proposed land uses on the amount of runoff generated by different land uses can be easily estimated. Seven existing land use types were used for this analysis: commercial, industrial, residential, forest, grass, agriculture and the wetland. Based on the tendency for urban sprawl and loss of farm land in this area, for the first scenario it is assumed that the agricultural area will be changed to low-density residential use, and for the second scenario that the agricultural area will be changed to commercial use. The prepared data input with the L-THIA form is shown in Fig. 2. While the users are preparing input data, they can refer to soil and land use data within the web-GIS as shown in Fig. 2.

Results and Analysis Aids

for output results and the tabular form of runoff. Fig. 3 (b) shows the input land use as the pie charts, and Fig. 3 (c) shows the runoff in the form of bar charts, facilitating comparison of the runoff increase from the land use change from agricultural to commercial in scenario 3. Fig. 3 (d) shows the probability of exceedance of annual series for runoff and the charts help users understanding about the land use change impact on runoff probability.

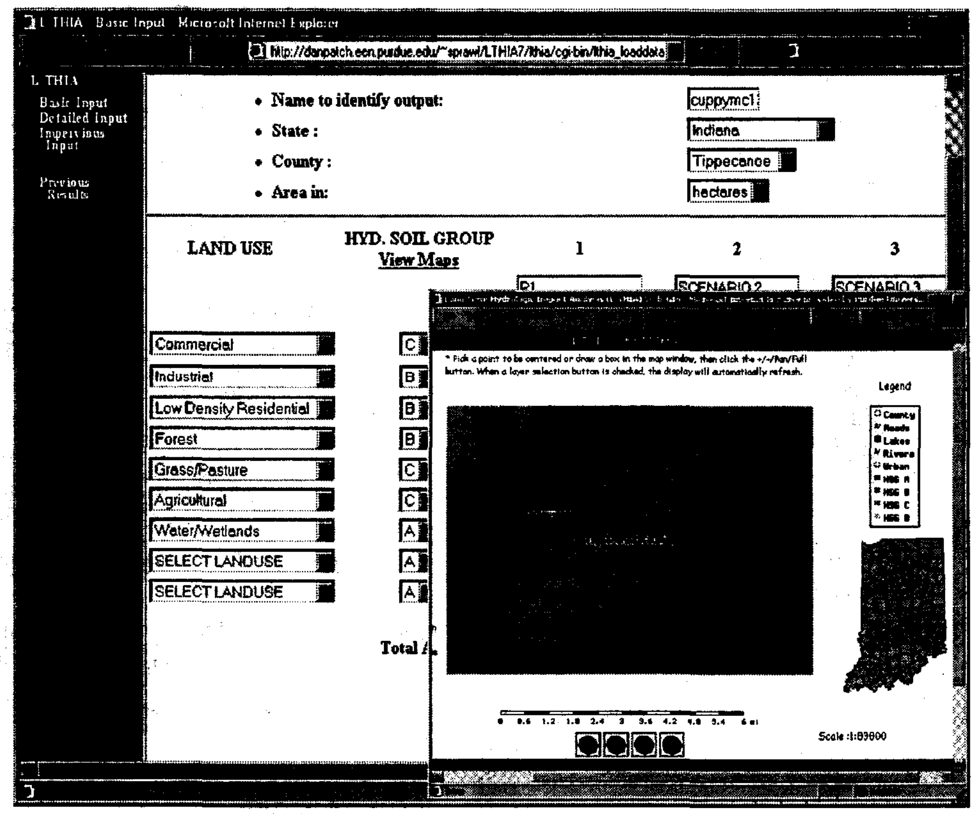

Figure 2. Input form and web-GIS contents.

After running the L-THIA hydrologic model engine, users can obtain results in terms of runoff quantity and NPS pollutant loading. To help with comprehension of the hydrologic simulation results and comparison of hydrologic impact, the DSS presents the output in table, bar, pie and series charts for runoff and 12 NPS pollutants. Fig. 3 (a) shows the menus

Solution Tools

The goal of using a DSS is to determine the best solution under several conditions, and this should include the possibility of mitigating undesirable impacts associated with some land use options. Thus, the DSS should provide information on ways to mitigate runoff changes and pollutant loadings

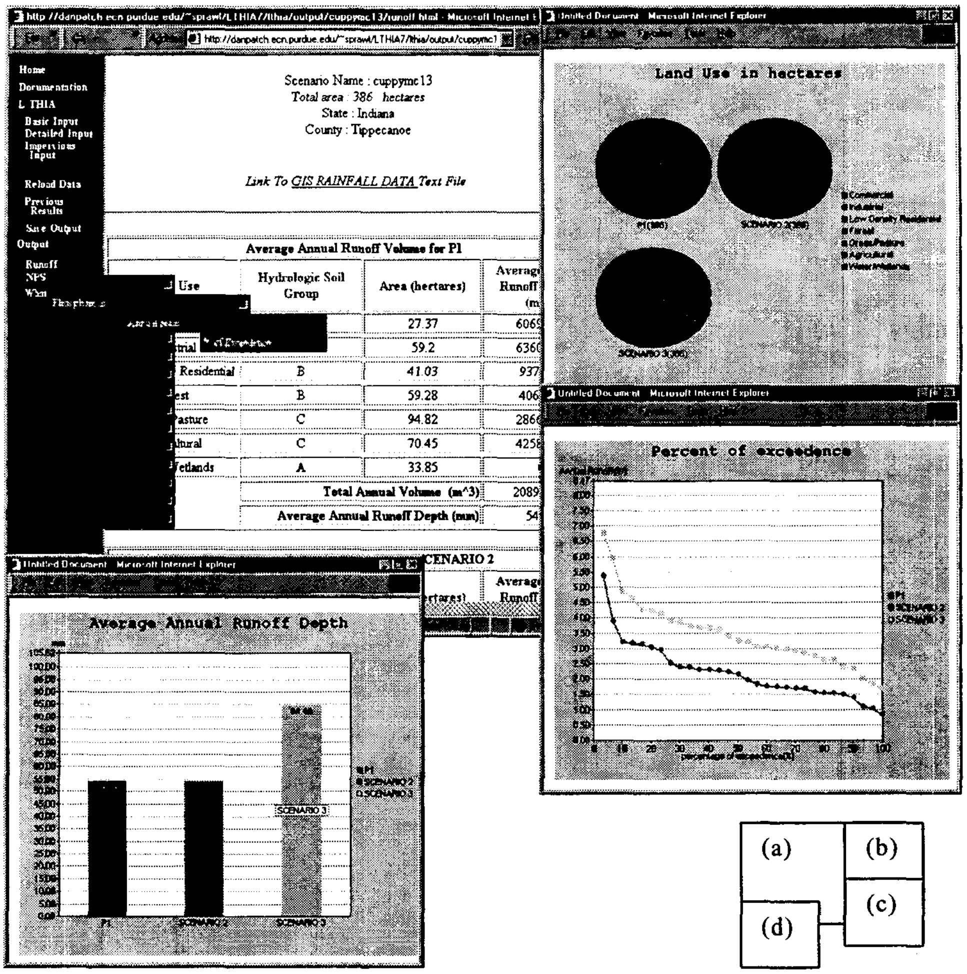

Figure 3. Output table and charts.

(a) tabular results and hierarchical side bar menu system for results selecting to be shown. (b) pie charts of land use input for each scenarios. (c) bar charts of average annual runoff depth for each scenarios. (d) line charts for percent of exceedance of annual runoff that can assist understanding of annual variation of runoff.

from an area undergoing land use change. In the L-THIA web DSS (Fig. 4), the What can I do feature provides strategies to manage the impact, and discusses how to analyze results and conduct BMP cost estimation. Using cost estimation programs in the DSS as shown Fig. 4, users can estimate the approximate cost to control, for example, the pollutants caused by urban area expansion.

V. Conclusions

Decision support systems have been applied in many areas of water resources management and hydrology and typically are based on a similar fundamental structure. The L-THIA web, a DSS based on an integration of webbased programs, a runoff and NPS estimation model, internet-GIS and an ORACLE-based weather database, has been constructed to support decision makers and provide information about the

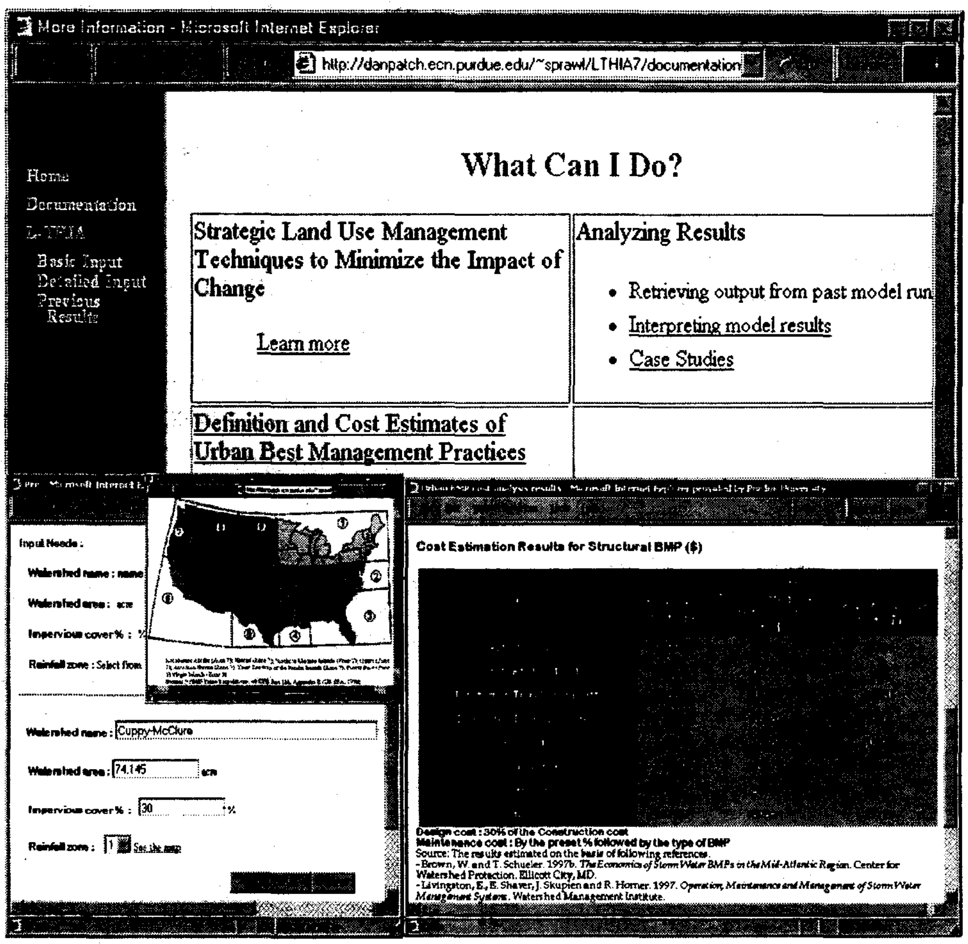

Fig. 4 Suggestion section and BMP cost estimation results.

hydrologic impacts of water quantity and quality of land use change. The approaches used to solve problems that arise in integrating databases, decision support, and server-provided GIS capabilities may help others involved in DSS development to find new ways to solve the challenges they face (see also Pandey et al., 2001). The L-THIA web DSS has unique features that were prepared for novice users who are targeted as potential users of the L-THIA web and who may have limited hydrology knowledge. The L-THIA web DSS enhancement features include impact evaluation, treatment suggestions and urban best management practices (BMP) cost estimation. These enhancement features can help and guide users to the best decision, and increase users comprehension of the effects of land use change on water quantity and quality.

Typically, scientists and engineers who are experts in technical areas develop DSS that are technically excellent, but which are not used extensively because the DSS are not matched to the capabilities, information access and needs of decision makers. Using an interdisciplinary team composed of staff in technical, programming, and user areas, as well as extensive feedback from a wide range of users, DSS can be developed that are both technically sophisticated and that provide users with easily accessible information geared towards the decisions they need to make.

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