Literature Review and Case Study References for L-THIA and L-THIA LID.

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The L-THIA model has been extensively used for land use impact assessment. The L-THIA model was developed to estimate direct runoff using the CN method (Harbor, 1994). It utilizes daily rainfall depth, land use, and hydrologic soil group data. The model uses the distributed CN approach to compute the contribution of each land use to runoff in the watershed. Grove et al. (1998) compared runoff estimation using composite CN approach and distributed CN approach in L-THIA for the Little Eagle Creek watershed, an urbanizing watershed in the Indianapolis, Indiana area. The Little Eagle Creek watershed is 70.5 km^2 with a wide range of land uses (natural forest, grass, agriculture, high and low density residential, industrial, and commercial). Various precipitation events and land uses (for 1973, 1984, and 1991) generated from LANDSAT satellite imagery were used for the simulations. Model runs were completed without model calibration and the study found that the compositing CN values can result in underestimation of runoff, especially for wide CN ranges such as would typically be found for watersheds with urban development, low CN values and low precipitation depths due to the curvilinear relationship between CN and runoff depth.

The L-THIA model has been used in calibrated and uncalibrated modes, and in case studies to illustrate and inform planners or to mimic real-world conditions. For example, Pandey et al. (2000) discussed how land use changes impact long-term hydrology and nonpoint source pollution with a case study using the computer-based L-THIA model. Datasets corresponding to 1990, 1992, 1997, and 2000 in the Wildcat Creek Watershed in Indiana (more than 2,000 km2) were used for uncalibrated model simulations. Results show that land use changes in the watershed have resulted in significant increase in the total average runoff and pollutant loads that are generated by the different land uses in the watershed. The authors discussed the ease of use of the tool and issues involved in making the tool a GIS-based and Web-base tool. With the web-based tool, users do not need a GIS package on their local systems. The databases required to run the model are also stored at a central server, allowing users to save time and money. The web-based approach provides an opportunity to involve L-THIA users in planning and decision making processes.

Bhaduri et al. (2000) used L-THIA to assess long-term hydrologic impacts of land use change with special attention given to small and low-frequency storms in the Little Eagle Creek in Indianapolis, Indiana (70.5 km2). Daily precipitation from 1966 to 1995, with 1973, 1984, and 1991 land use data were used for the simulations. The study determined that an 18% increase in urban and impervious areas resulted in approximately 80% increase in annual average runoff volume, more than 50% increase in heavy metal loads (lead, copper, and zinc), and 15% increase in nutrient loads (phosphorus and nitrogen).

Kim et al. (2002) evaluated the impact of land use change on runoff. The study was conducted in the Kennedy Space Center (KSC; 9,000 km2), which is located in the Indian River Lagoon, Florida (IRL; 30, 000 km2). Rainfall events of 1-, 5-, 10-, 50-, and 100-year return periods for 24 h, 30 years of daily rainfall, and land use data of 1920, 1943, and 1990, were used for the analysis. The authors found that runoff increases in the study watershed as a result of land use change, especially with increase in urbanization. Between 1920 and 1943, estimated average annual runoff for the KSC increased less than 10%, while average annual runoff for IRL increased nearly 26% due to increased urbanization in that area. Between 1943 and 1990, estimated average annual runoff for the KSC increased 37%, while runoff for the IRL increased 69%. Between 1920 and 1990, estimated average annual runoff for the KSC increased about 49%, while runoff for the IRL increased nearly 113%.

Lim et al. (2006) discussed the importance of calibration in simulating hydrologic and water quality impacts of land use changes with the L-THIA model in the Little Eagle Creek watershed (70.5 km2) near Indianapolis, Indiana. The study developed an automated calibration procedure and shows that calibration will improve the accuracy of the L-THIA model in estimating runoff and pollutant loads. The model was calibrated and validated with one year data for daily simulations. The first six months of data were used for model calibration and the last six month were used for model validation. Calibration predicted that for this watershed estimated average annual direct runoff increase by 34%, 24% for total nitrogen, 22% for total phosphorus, and 43% for total lead.

Muthukrishnan et al. (2006) developed a simple method to calibrate the L-THIA model using linear regression of L-THIA predicted direct runoff and USGS observed direct runoff values derived from hydrograph separation of stream flow data, which includes both direct runoff and baseflow. The model was calibrated and validated using four tests in the Little Eagle Creek watershed, Indiana (58.8 km2). In the first test, data from 1973 to 1982 were used for calibration and data from 1983 to 1991 were used to verify the model. In the second test, data from 1982 to 1991 were used for calibration and 1973 to 1981 were used to verify the model. In the third test, the dataset was divided into odd years and even years and odd years were used for calibration and the even years were used to verify the model. Finally, in the fourth test, calibration based on the whole dataset (1973 to 1991) was performed and compared with the other three calibration models. A comparison of linear and nonlinear regression models used to fit the observed and predicted data showed that a linear model was the best model, suggesting more complex models are not necessary in this case. In general, L-THIA model predictions are found to be approximately 50% lower than actual observed direct runoff for the watershed due to the intrinsic developmental conditions of the CN values which might not be representative of the conditions in this particular watershed. The study sheds some light regarding the factors that control runoff generation and systematic under prediction of direct runoff by the L-THIA model compared to actual observed runoff data.

Lim et al. (2010) highlighted the importance of calibration of both runoff and baseflow when assessing hydrologic and water quality impacts of land use changes with the L-THIA model. The study was conducted in the Little Eagle Creek watershed, Indiana (70.5 km2), and the 2001 NLCD set and precipitation data were used in daily simulations. The L-THIA model was calibrated using the BFLOW and the Eckhardt filtered direct runoff values. The study showed that L-THIA direct runoff estimates can be incorrect by 33% and non point source pollutant loading estimation by more than 20%, if the accuracy of the baseflow separation method is not validated for the study watershed prior to model comparison.

The authors documented the importance of baseflow separation in hydrologic and water quality modeling using the L- THIA model.

Wilson and Weng (2010) assessed the impacts of land use change on runoff and surface water quality using ArcHydro GIS extension and a modified version of the L-THIA model to estimate runoff and nonpoint source pollutant concentration around Lake Calumet between 1992 and 2001. The model was calibrated using split-sample method and the size of the study area was 220.7 km2. The authors reported that surface water quality depends on the extent of LULC change over time and also the spatial extent of hydrologically active areas within the watershed. The model predicts that an increase in runoff volume will contribute to differential increases in concentration among most pollutants. Conversely, biochemical oxygen demand and chemical oxygen demand properties of surface water demonstrated a contrary pattern to the aforementioned one. The study demonstrated that the level of concentration of nonpoint source pollutants in surface water within an urban watershed heavily depends on the spatiotemporal variations in areas that contribute towards runoff compared to the spatial extent of change in major land use/land cover.

Ahiablame et al. (2012) developed a framework to represent, evaluate, and report the effectiveness of low impact development practices using the Long-Term Hydrologic Impact Assessment Low Impact Development (L-THIA LID) model. The modeling procedure was applied to a 71 ha residential subdivision in Lafayette, Indiana (the Brookfield Heights subdivision). Twenty years of daily rainfall data and the 2001 National Landcover Data Set set were used for annual simulations. The effectiveness of LID practices in the study area was examined in 8 simulation scenarios using 6 practices which include bioretention, rain barrels and cisterns, green roof, open wooded space, porous pavement, and permeable patio. Results showed that average annual runoff and pollutant loads increased for post-developed conditions compared to pre-developed conditions, indicating that the construction of the BH subdivision influenced pre-development hydrology and water quality. Simulations of LID scenarios, by reducing the amount of runoff and pollutant loading after the construction of the BH subdivision, showed that LID design principles could be used to bring post-developed hydrology to a level comparable to that of pre-development. This study showed that reduction in runoff is greatly influenced by reduction in impervious surfaces. The authors pointed out that considerations should be given to LID practices in water resources planning and management for the preservation of natural hydrology. This modeling framework builds the foundation for reducing modeler’s biases, providing consistency among various modeling studies for comparing, sharing and distributing research results, promoting thus a wide adoption of low impact development practices.

Gunn et al. (2012) developed two simple metrics to quantify hydrologic impacts of land uses as a result of urbanization. The indices consist of the pre vs. post development index (PPH) and the extent of maximum index (EH). The indices were applied in three case studies of residential subdivisions in Lafayette, Indiana. These subdivisions are Brookfield Heights (50 ha), Meadow Brooks (26 ha), and The Orchards (39 ha), and built with varying styles. The Brookfield Heights was built in the early 1990s, with large houses on small lots and curb and gutter systems. The Meadow Brooks was built in early 1960s with larger lots and swales for drainage. The Orchards was built in 2001 with many water features to minimize environmental impacts of the development. The uncalibrated L-THIA model was used to compute annual runoff volume with daily precipitation data for evaluation of the metrics. The case studies illustrate how to interpret the resulting index values. Results showed that average annual runoff shown by the PPH and the EH methods exhibited increased runoff for Brookfield Heights and Meadow Brook subdivisions and decreased runoff for the Orchards subdivision, while the time of concentration and peak runoff varied for the three subdivisions. The scores for the time of concentration increased for Brookfield Heights and Meadow Brooks, indicating that runoff reaches downstream receiving waters more rapidly with the development. Peak runoff rates increased for Brookfield Heights subdivision but decreased for Meadow Brooks and the Orchard.

Discussion of applied or case study references.

The L-THIA model has also been used in combination or incorporated in other models, and Web- and GIS-based Decision Support Systems. Thus, Choi et al. (2003a) presented an automated watershed delineation tool using MapServer Web-GIS capability. The tool was applied to the Wildcat Creek washed (2,000 km2) with a 30 m cell DEM (Digital Elevation Model). Results show acceptable quality for use as a real-time system for watershed delineation via the web. This capability can be used with L-THIA to characterize watershed size, land use and soil groups.

Choi et al. (2003b) assessed the impact of urbanization on each hydrologic component of streamflow with the Cell Based Long Term Hydrological Model (CELTHYM). The model was used in the Little Eagle Creek watershed (70.5 km2) in the Indianapolis area. This watershed has undergone extensive land use changes over the past three decades due to the expansion of the Indianapolis metropolitan area. The authors reported that the effects of urbanization were greater on direct runoff than on total runoff with annual increase in direct runoff of 14% from 1973 to 1984, and 2% from 1984 to 1991. The study points out also the importance of baseflow in sustaining streamflow.

Engel et al. (2003) presented the long-term hydrological impact assessment (L-THIA) web application as a decision support system (DSS) based on an integration of web-based programs, geographic information system (GIS) capabilities, and databases, intended to support decision makers who need information regarding the hydrologic impacts of water quantity and quality resulting from land use change to assist and guide users in decision-making and increase users' comprehension of the effects of land use changes on water quantity and quality. The tool was demonstrated in two watersheds of 46.1 ha and 55.4 ha in Indiana.

Tang et al. (2004) presented a web-based decision support system named SEDSPEC (Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool) with an illustrative case study. The tool integrates Web GIS technology to help users estimate watershed boundaries and access a spatial database to obtain land use and hydrologic soil group data for the watershed. The tool uses also the Rational Method and TR-55 to simulate short–term peak runoff based on site-specific hydrologic soil groups and land uses. The tool allows the user to estimate dimensions and explore options for implementation and maintenance costs of hydrologic, sediment and erosion control structures.

Shi et al. (2004) discussed the design principles and strategies of a Web GIS-based Hierarchical Watershed Decision Support System for the United States are presented in this paper. The tool incorporates other decision support tools such as the online watershed delineation and L-THIA model. The paper illustrates the system functionality and reports the progress made on the project.

Choi et al. (2005a) described a conceptual web-based spatial decision support systems (SDSS) framework which uses web-GIS for watershed delineation, map interfaces and data preparation routines, a hydrologic model for hydrologic/water quality impact analysis (the L-THIA model), and web communication programs for Internet-based system operation. The authors illustrated how web-based SDSS's can be helpful for watershed management decision-makers and interested stakeholders. The role of GIS and information technologies in creating readily accessible and useable SDSS capabilities is also highlighted in the paper.

Tang et al. (2005) explored the impacts of urbanization on hydrology and water quality. The study used the land use change model (LTM) to predict land use change in the Muskegon River, Michigan watershed (7, 032 km2), and the L-THIA model to estimate hydrologic/water quality changes associated with the estimated land use changes. The LTM was used to predict land use change from 1978 to 2040 and the L-THIA was used in an uncalibrated mode to predict hydrologic changes associated with this time period. Two types of developments were evaluated: sprawl and non-sprawl developments. Results show that increase in urban expansion causes increase in runoff volume and nonpoint source pollution.

Choi et al. (2005b) applied a conceptual web-based spatial decision support systems (SDSS) framework which uses web-GIS for watershed delineation, map interfaces and data preparation routines, a hydrologic model for hydrologic/water quality impact analysis (the L-THIA model), and web communication programs for Internet-based system operation. The paper uses the case study of an urbanizing watershed of 270 ha in Lafayette, Indiana (the Elliot Ditch watershed) to show that the SDSS operates satisfactorily.

The latest version of the L-THIA model has been enhanced to incorporate low impact development (LID) practices. Ahiablame et al. (2012) reviewed the effectiveness of LID practices as reported in the current literature. The authors discussed also how low impact development practices are represented in hydrologic/water quality models used for assessing the effectiveness of low impact development practices. They used three computational models with varying level of complexity to illustrate the discussion. The three models discussed include the SUSTAIN model, SWMM model, and the L-THIA LID model. The authors proposed directions for future research to conclude the paper.

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