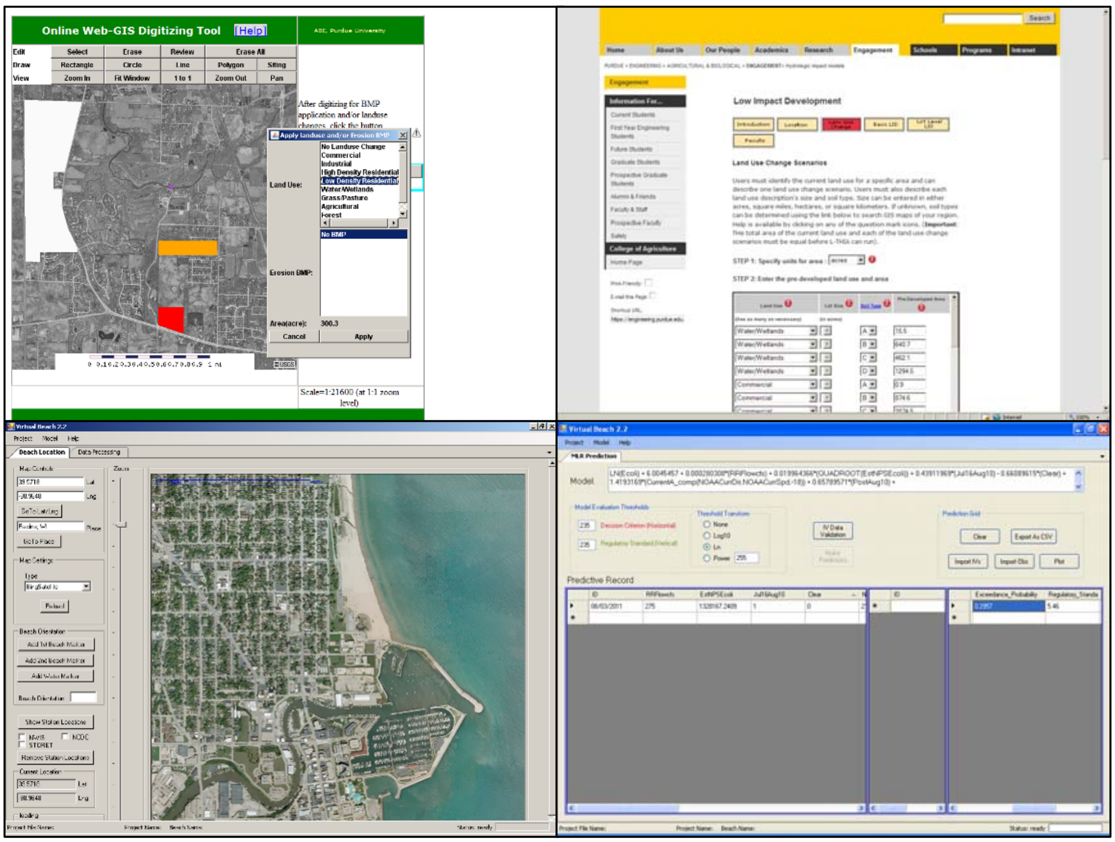
Development of a Tool for Predicting and Reducing Bacterial Contamination at Great Lakes Beaches



WISCONSIN DEPT. OF NATURAL RESOURCES

Bureau of Science Services
Wisconsin Department of Natural Resources
P.O. Box 7921
Madison, WI 53707-7921

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Summary: This report describes grant-funded work undertaken by the Wisconsin Department of Natural Resources in collaboration with the Racine Health Department, the Department of Agricultural and Biological Engineering at Purdue University, and the U.S. Environmental Protection Agency's Office of Research and Development. We developed an integrated, decision-support tool for predicting microbial water quality at Great Lakes beaches based on real-time environmental parameters, as well as land use and development practices in contributing watersheds. This new tool combines a real-time hydrologic impact assessment tool (a modified version of Purdue University's Long-Term Hydrologic Impact Assessment tool) with the U.S. EPA's Virtual Beach water-quality predictive tool. The new system represents the first attempt to operationally link a real-time watershed model, including land use and low impact development scenario-building capabilities, with a beach water-quality "nowcast" system. The pilot site for this system was the lower Root River watershed in southeastern Wisconsin. This report describes the work we undertook, documents the deliverables produced, presents lessons learned, and makes recommendations to improve future beach modeling and nowcasting efforts. This document also fulfills final reporting requirements for our grant agreement.

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Cover Illustrations: Screen captures of web-based tools developed as part of the grant-funded work.

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Adam C. Mednick
Natural Resources Research Scientist

Bureau of Science Services
Wisconsin Department of Natural Resources
P.O. Box 7921
Madison, WI 53707-7921

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Abbreviations and Acronyms

CFU – colony-forming units

DNR – Department of Natural Resources

EMC – event-mean concentration

EPA – Environmental Protection Agency

GIS – geographic information system

km – kilometer

LID – low impact development

L-THIA – Long-Term Hydrologic Assessment tool

mL – milliliter

NLCD – National Land Cover Dataset

NOAA – National Oceanic and Atmospheric Administration

NPS – non-point source pollution (polluted runoff)

ORD/NERL/ERD – U.S. EPA Office of Research and Development/National Environmental Research Lab/Ecosystem Research Division

qPCR – quantitative polymerase chain reaction

RHD – Racine Health Department

SEWRPC – Southeast Wisconsin Regional Planning Commission

WHAT – Web-based Hydrograph Analysis Tool

Executive Summary

Working in collaboration with the Racine Health Department (RHD), the Department of Agricultural and Biological Engineering at Purdue University, and the U.S. Environmental Protection Agency's Office of Research and Development/National Environmental Research Lab/Ecosystem Research Division (ORD/NERL/ERD), the Wisconsin Department of Natural Resources (Wisconsin DNR) oversaw the development of an integrated, decision-support tool for predicting microbial water quality at Great Lakes beaches, based on real-time environmental parameters, as well as land use and development practices in contributing watersheds. The "L-THIA/VB" tool combined a real-time hydrologic impact assessment tool (a modified version of Purdue University's Long-Term Hydrologic Impact Assessment [L-THIA] tool) with the U.S. EPA's Virtual Beach (VB) water quality predictive tool. The system represented the first attempt to operationally link a real-time watershed model, including land use and low impact development (LID) scenario-building capabilities, with a beach water quality "nowcast" system. The pilot site for this system was the lower Root River watershed in southeastern Wisconsin, which discharges just south of North Beach in the City of Racine.

As part of this project, RHD collected weekly water quality samples at 34 sites along the lower Root River. Using these data, along with previously-collected samples and baseflow-separated gauge data from the U.S. Geological Survey, project staff estimated point versus non-point source (NPS) *E. coli* concentrations at 25 open water sampling points. Flow-weighted mean NPS *E. coli* concentrations were regressed on the percentage of different land uses within each sample location's drainage area in an attempt to develop watershed-specific, event-mean concentration (EMC) coefficients. The analysis confirmed that higher proportions of urban and agricultural land correspond to higher *E. coli* concentrations; however, the resulting coefficients were not suitable for use as EMCs, based on validation data and in comparison to EMCs developed for previous studies, which were identified through an initial literature review. The desktop L-THIA component was programmed to allow for the substitution of EMC coefficients, as well as rainfall-runoff curve numbers, making it more transferable to other watersheds and flexible to changes in the quality of data and available parameters in the future.

The various L-THIA components (web-mapping interface, LID component, and real-time L-THIA component) were developed by Purdue, as part of an existing collaboration through the Midwest Spatial Decision-Support System Partnership. Changes and enhancements to Virtual Beach were similarly carried out by ORD/NERL/ERD. Project staff maintained regular contact with both teams to guide and coordinate development and enhancement of each component. Staff also consulted with RHD and the Alliance for the Great Lakes to obtain feedback on which features and capabilities would be most useful to local officials and volunteer users. Once all system components were completed, project staff conducted an on-site demonstration, after which final changes were made by Purdue. Project staff developed step-by-step learning modules for the different system components and recorded accompanying training videos for web-posting.

Development of the L-THIA/VB system addresses two coastal management issues. The first is coastal beach monitoring. Past research has shown that the current system of monitoring recreational water quality at Great Lakes (as well as marine) beaches, relying principally on lab-culturing fecal indicator bacteria, results in frequent false exceedances and non-exceedances of water quality standards, and in turn unnecessary advisories and increased public health risk. At North Beach and other beaches potentially influenced by urban and/or agricultural runoff in river

plumes, the inclusion of daily estimated bacteria loads as an additional explanatory variable for predicting beach water quality, can improve the predictive power of beach water quality "nowcasts."

The second coastal management issue addressed by the development of this system is NPS pollution control through land use planning and LID practices. The L-THIA/VB system includes a web-mapping interface for the Lower Root River watershed, through which users can modify existing land use using an on-screen digitizing tool, to create alternative land use scenarios. The system also includes a LID component, through which users can select optional lot-level LID practices to apply to user-determined proportions of all high- and low-density residential and commercial land. The scenarios created using these two on-line components can be input into a desktop, real-time L-THIA application, which estimates daily loads of fecal indicator bacteria from on-line rainfall totals, based on the land use or LID scenario selected. Daily outputs can be copied into Virtual Beach to generate a water quality nowcast that can be modified to reflect changes in land use or development practices.

1. Introduction

Elevated concentrations of the fecal indicator bacteria *Escherichia coli* at Great Lakes beaches is a concern for Wisconsin's coastal communities due to both public health risks and economic impacts. In order to better protect beach visitors, and to reduce the number of unnecessary closures and swim advisories, local health officials need access to tools for the rapid detection and/or real-time prediction of bacterial contamination. Similarly, planners, stakeholders, and decision-makers in watersheds that contribute to beach water quality conditions can benefit from tools that help them identify those land uses and development practices that generate non-point source (NPS) contamination and estimate the potential impact that alternative scenarios could have on beach conditions.

Currently, the standard approach to water quality monitoring at Great Lakes beaches entails collecting samples, transporting them to a laboratory, and measuring or estimating the concentration of *E. coli* colony-forming units (CFU) per 100 mL of water. *E. coli* concentrations exceeding the federal standard of 235 CFU/100 mL result in a swim advisory, while concentrations above 1,000 CFU/100 mL result in a beach closure. Because of the time needed for transport and lab analysis, advisories and closures are issued a day after samples have been collected, resulting in numerous *Type I* monitoring errors (unnecessary advisories and closures) and *Type II* errors (non-advisory days when beaches should be posted or closed) (Mednick and Watermolen 2009).

In response to this problem, and in anticipation of future requirements for the deployment of rapid monitoring techniques at high priority beaches, researchers have investigated and applied rapid lab-based methods, such as quantitative polymerase chain reaction (qPCR), as well as real-time multivariate statistical models, or "nowcasts." Beach nowcast models regress the concentration of *E. coli* or other pathogen indicators on readily-measurable meteorological variables (e.g., antecedent rainfall, temperature, and sky conditions), nearshore conditions (e.g., wave height, turbidity, and longshore currents), and time variables (e.g., "stage," or quarter, of the beach season). Although results vary from beach to beach, nowcast models have proven to be more accurate than standard approaches (e.g., Nevers and Whitman 2005, Francy 2009, Olyphant and Phister 2009).

Typically, nowcast models do not include among their multiple input variables, bacteria loads discharging from nearby coastal tributaries (since river samples take the same 18 to 24 hours to analyze as beach samples). The absence of real-time data on bacteria loads discharging from coastal tributaries limits the predictive power of nowcasts in locations where NPS bacterial pollution within river plumes is a likely contributor to nearshore water quality conditions at the beach. Additionally, statistical nowcast models provide no information on the relative contribution of NPS *E. coli* from different upstream land uses or development practices, or information on the potential impacts that could be expected in response to altering those land uses or practices. To date, nowcasts have treated watershed conditions such as imperviousness, land use, and development practices as fixed and exogenous (i.e. outside the model).

Ensemble models that link real-time estimates of bacteria loads discharging from a coastal tributary with beach water quality nowcasts have been conceptualized in the environmental health literature with some preliminary models developed in the United Kingdom (Kay et al. 2005). These models, however, have yet to be implemented in an operational capacity and are not geared towards testing the impacts of alternative development scenarios. Available watershed modeling systems like the Soil and Water Assessment Tool (SWAT; Arnold and Fohrer 2005) could be used to predict *E. coli* associated with urban and agricultural runoff; however, the process of building, calibrating, and operating such models falls beyond the technical capabilities of most local health officials, beach managers, and community planners.

Working with the Racine Health Department (RHD), the Department of Agricultural and Biological Engineering at Purdue University, and the U.S. EPA's Office of Research and Development/National Environmental Research Lab/Ecosystem Research Division (ORD/NERL/ERD), the Wisconsin Department of Natural Resources (Wisconsin DNR) oversaw the development of an integrated decision-support system for predicting water quality at Great Lakes beaches, based on real-time environmental parameters and land use in contributing watersheds. The resulting "L-THIA/VB" system (Figure 1) represents the first attempt to operationally link a real-time watershed model, including land use and low impact development (LID) scenario-building capabilities, with a beach water quality "nowcast" system. This project is part of a larger effort to refine nowcast methods, tools, and practices in order to implement them on a broader scale in Wisconsin and throughout the Great Lakes basin (Mednick 2011).

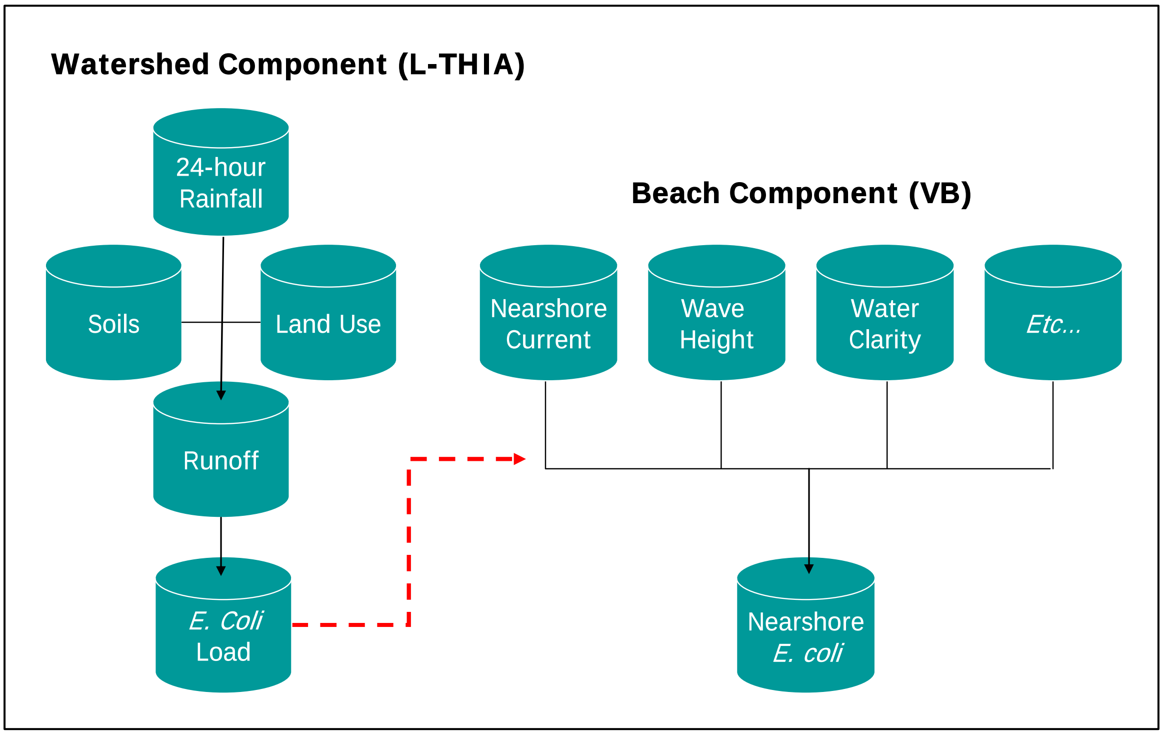

Figure 1. *L-THIA/VB System Framework.*

2. Methods

2.1. Project Area

The project area for the development of the L-THIA/VB system was the 180 km^2 lower Root River watershed in Racine and Milwaukee counties and the nearby North Beach within the City of Racine (Figure 2). The lower Root encompassed a mixed agricultural/urban sub-watershed that discharges into Lake Michigan via Racine Harbor just south of the beach. The project area was selected on account of the existence of an extensive dataset of *E. coli* concentrations measured at monitoring locations along the beach and a number of sampling locations along the river. In addition to daily (5-7 days per week) *E. coli* data for the beach, weekly *E. coli* data existed at fixed locations along the Root River dating back to 2004. Beginning in 2007, river monitoring was expanded to 34 locations (25 open water sites and nine stormwater outfalls). Expanded river monitoring was instituted after engineering improvements to the English Street stormwater outfall, beach re-grading, and improved beach grooming practices successfully mitigated contamination sources outside of the watershed and closer to the beach (Kinzelman and McClellan 2009).

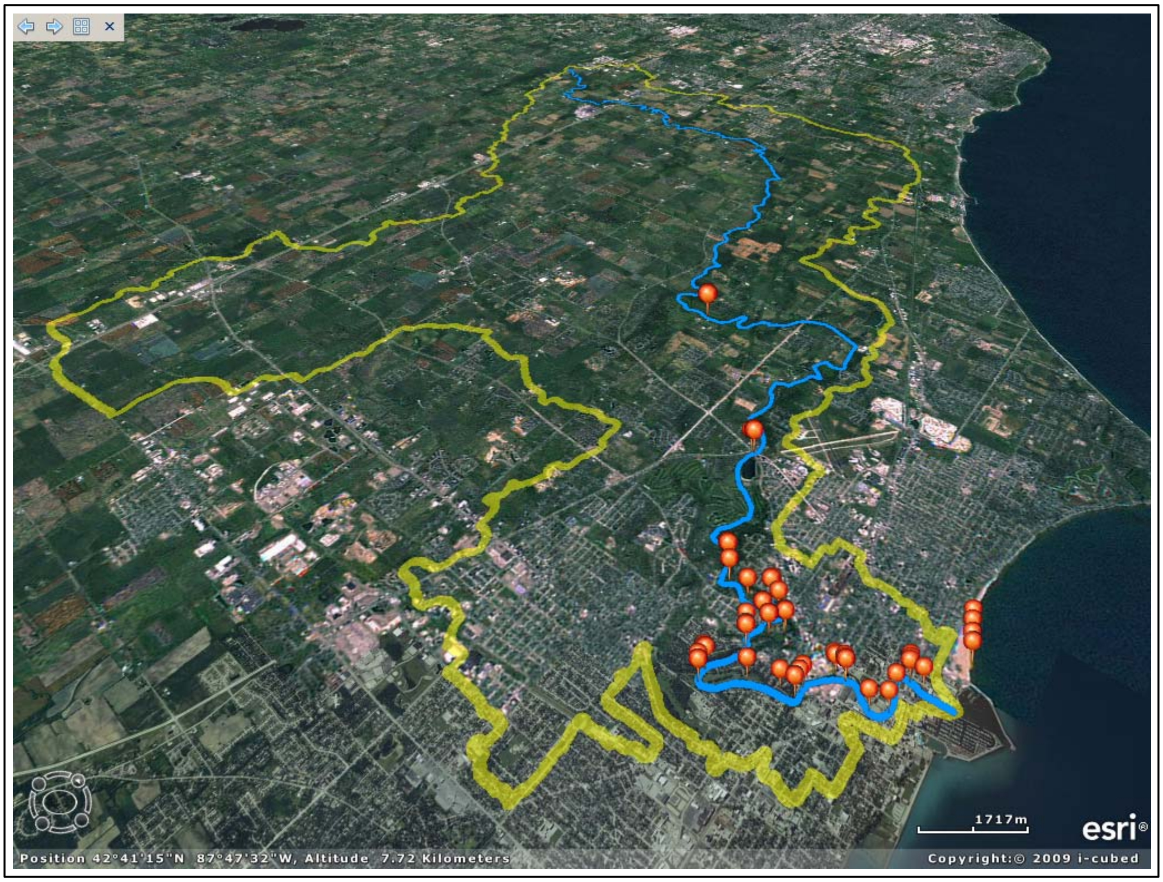

Figure 2. *Lower Root River Watershed and Water quality Monitoring Locations.*

2.2. Water quality Monitoring

The spatiotemporal extent of water quality data available for the project area suggested the possibility of estimating watershed-specific event mean concentration (EMC) coefficients for *E. coli* associated with different land uses, which could then be incorporated into a real-time watershed model to estimate *E. coli* loads discharging from the river on a daily basis. Under contract with the Wisconsin DNR, RHD staff continued the large-scale river sampling that occurred in 2007 and 2008. The goal was to expand the *E. coli* time-series from approximately 35 observations per sampling location (collected over two beach seasons) to approximately 70 observations per sampling location (collected over four beach seasons), thereby capturing as much variability as possible across the river's hydrologic flow regimes (see Figure 3). Grab-samples were collected by field staff on Mondays and Wednesdays, with approximately half of the 34 locations sampled on each day. Samples collected at the beach and along the river were transported to the RHD lab and analyzed using the IDEXX Colilert method (Eaton et al. 2005) to estimate the most probable number of *E. coli* colony-forming units. Samples collected at the four monitoring stations along North Beach were composited prior to analysis, so that there is only one beach most probable number value per day.

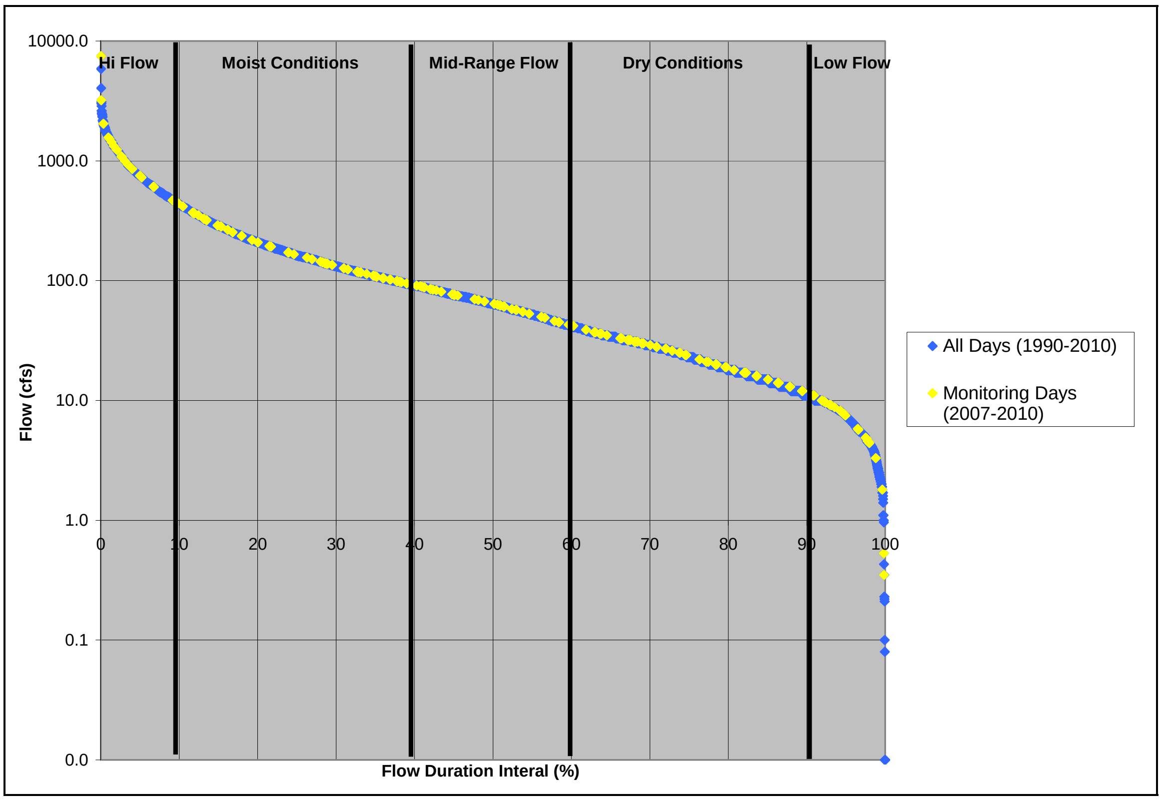

Figure 3. *Distribution of Monitoring Days across the Root River's Five Flow Regimes (Derived Using the Web-based Load Duration Curve Analysis Tool:* http://engineering.purdue.edu/~ldc/JG/duration/main.cgi.

2.3. Estimating Non-Point Source *E. coli* Concentrations

Researchers from Purdue University and the Wisconsin DNR reviewed the water quality literature to identify studies that include EMC coefficients for *E. coli*. Nineteen potentially relevant papers and technical reports were identified. Many of these sources reported EMC values for total fecal coliforms, rather than *E. coli*. Following a procedure used in several of the studies, *E. coli* concentrations were estimated from total fecal coliforms using the formula *EC* = total *FC* * 0.63, based on the ratio of the two U.S. EPA geometric mean standards for recreational water quality using the two different indicator classes (126/200). Following this adjustment, EMC values from the various studies were organized by land use class and analyzed for their mean, median, and standard deviation per land use. Four studies were selected for the purpose of deriving "generic" EMC coefficients (Table 1). Generic coefficients serve as an alternative to the standard L-THIA default values, which are derived from Baird et al. (1996). Those studies that were not selected had fewer land use categories, were conducted in sites considered unreflective of the project area or larger region, or otherwise had anomalous or outlier values for one or more land use classes.

Table 1. *Event-Mean Concentrations of* E. coli* *from Selected Studies.*

Land Use Classes	Baird et al. (1996) †	Cave et al. (1995)	U.S. EPA (2001)	Maestre & Pitt (2005)
Low-Medium Density Residential (>1/4 acre)	12,500	15,626	5,438	5,216
High Density Residential (<1/4 acre)	12,500	10,563	5,438	5,216
Urban Open Space	12,500	4,500	4,500	4,500
Agricultural	16,250	3,125	3,125 ‡	3,125 ‡
Industrial	6,063	375	1,438	1,563
Commercial	4,313	1,625	875	2,688
Grass/Pasture	125	3,125	3,125 ‡	3,125 ‡
Forest/Grassland	125	188	313	188 ‡
Water/Wetland	0	188	313	188 ‡

* Derived from total fecal coliform values.

† Default values in the L-THIA system.

‡ Where EMC values do not exist for other studies, values from Cave et al. (1995) were used as a "conservative" and regionally-appropriate value. These were derived in the Rouge River watershed in southeastern Michigan.

To estimate Root River-specific EMC coefficients it was necessary to first estimate NPS *E. coli* concentrations versus point-source (or ambient) concentrations at each of the 25 open water sampling points using the water quality data collected by RHD staff along with contemporaneous daily flow rates recorded by the U.S. Geological Survey river gauge at Horlick Dam. The Web-based Hydrograph Analysis Tool (WHAT) system (Lim et al. 2005) was used to separate 10 years of daily Root River flow data (2001-2010) into estimated baseflow and direct runoff (total flow minus baseflow). *E. coli* concentrations measured for baseflow-only days were averaged into location-specific, point-source (or ambient) concentrations, typically on the order of 100-400 CFU/100 mL. Using the point-source concentration for a given location, together with the proportion of direct runoff to baseflow on a given day, it was possible to algebraically estimate

NPS *E. coli* concentrations from the measured (sample) concentration. This procedure was applied to all samples collected on days with direct runoff in addition to baseflow. Next, the flow-weighted average NPS concentration was calculated for each of the 25 open water monitoring locations (depending on the location, n = 18 or 19 samples collected during runoff conditions between 2007 and 2010).

In order to estimate EMC coefficients for specific land uses it was necessary to delineate the drainage area of each of the 25 open water sampling locations (Figure 4). This entailed a combination of elevation-based delineation and the interpretation of digital stormwater facility maps provided by the engineering departments of the City of Racine and the villages of Mt. Pleasant and Caledonia. Using the ArcHydro Tools software extension for ESRI's ArcGIS, 10-meter digital elevation data were converted to flow direction and accumulation grids. From these grids, we generated drainage areas for each location. Immediately adjacent sampling points at the same upstream-downstream location (such as opposite river banks) ended-up with identical drainage areas.

Figure 4. *Drainage Areas Delineated for Open Water Monitoring Locations.*

Because urban stormwater systems do not conform exactly to natural drainage patterns it was necessary to review and edit the elevation-based areas against stormwater facility maps provided by the local engineering departments. Apparent conflicts between the stormwater facility maps and the elevation-based areas were resolved on a case-by-case basis, in consultation with the local engineers, using high-resolution aerial imagery wherever this provided supporting information.

Once delineated, monitoring location drainage areas were intersected with land use data layers using ArcGIS software. Initially, the selected land use data layer was 2006 parcel-level data from the Southeast Wisconsin Regional Planning Commission (SEWRPC). The only alternative available at the time was 30-meter National Land Cover Data (NLCD) from 2001. During the course of the project, however, a 2006 NLCD update became available and project staff processed the national image file into an ArcGIS compatible grid layer for the state. Because the NLCD update constitutes a statewide (i.e. geographically-transferable) data layer and the SEWRPC layer included a considerable amount of unnecessary categorical and spatial detail, the NLCD update was selected as the primary land use layer. The NLCD categories were combined into six land use classes (Table 2), plus water/wetlands. We then used ArcGIS to calculate the percent aerial coverage of each of these classes within the 25 drainage areas.

Finally, flow-weighted mean concentration values were regressed on the percent aerial coverage of the different land uses within each drainage area (n = 25), controlling for sampling day and whether or not a monitoring location is within 30 meters (downstream) of a storm sewer outfall. The unadjusted and adjusted R-square values were 0.81 and 0.75, respectively. As shown in Table 2, the regression results confirm that higher proportions of urban land (low-density residential land in particular) and agricultural land correspond with higher *E. coli* concentrations. The regression-estimated coefficients, however, were two orders of magnitude higher than the "generic" EMCs derived from previous studies and were not statistically significant. As such, it was determined that these coefficients would not be valid for use as EMC coefficients within the L-THIA model.

Table 2. *Estimated* E. coli *EMC Coefficients by Land Use*.

	Low-Density Residential	High-Density Residential	Urban Open Space	Crops/ Pasture	Comm.	Forest/ Grassland
Regression Coefficients (Root River)	1,025,385	657,369	690,450	763,121	730,668	231,546
L-THIA Default EMC Coefficients	12,500	12,500	12,500	16,250	4,313	125
"Generic" EMC Coefficients	9,695	8,429	6,500	6,406	2,375	203

2.4. Developing the L-THIA/VB System

The L-THIA/VB decision-support system was developed from two separate modeling systems: Purdue University's L-THIA system (Grove 1997, Engel et al. 2003) and U.S. EPA's Virtual Beach system (Frick et al. 2008, Parmar et al. 2010). L-THIA is a spatially-distributed automation of the SCS Curve Number method (SCS 1986, Mishra and Singh 2003) coupled with a series of EMC coefficients for calculating NPS pollutant loads, including fecal coliforms. L-THIA enables users to modify land use and development practices in a selected watershed or study area and generate alternative runoff and NPS pollution estimates. Virtual Beach guides users through the process of building, evaluating, and/or operating multiple-linear regression models for real-time predictions of recreational water quality at coastal beaches.

In order to link L-THIA to real-time, beach water quality models, computer programmers at Purdue University developed an enhanced L-THIA system that enables users to predict daily NPS bacteria loads based on downloaded 24-hour rainfall totals, user-provided rainfall-runoff curve numbers, and default or user-specified EMC coefficients. The fundamental component of this system is a Real-Time L-THIA desktop application (Figure 5.A), which allows users to download the most recent 24-hour rainfall total for a user-specified location and make a prediction based on watershed-specific curve number values under baseline and/or alternative land use scenarios. A web-mapping interface (Figure 5.B) and a web-based "low impact development" (LID) component (Figure 5.C) were developed to enable users without access to GIS or watershed modeling software to estimate curve number values for their area of interest based on existing or alternative future land use, as well as the adoption of LID practices. The three L-THIA components are described in greater detail in illustrated learning modules (Appendices B-D).

Wisconsin DNR staff worked closely with the programmers to ensure that each of the three L-THIA components met the needs of targeted users, based on guidance provided during consultations with RHD staff and the Alliance for the Great Lakes. In addition, Wisconsin DNR staff communicated routinely with the developers of Virtual Beach in ORD/NERL/ERD to ensure that that system meets the operational needs of local heath department officials and beach managers. Considerable effort went into making sure that the "prediction tab" within Virtual Beach (Figure 5.D) and transferable model files enabled users to more easily enter routine data, such as measured wave height, as well as real-time model outputs, including *E. coli* load estimates from the real-time L-THIA desktop application. This work was guided by previous system evaluation and capacity-building work conducted by the Wisconsin DNR (Watermolen 2009) as part of the Midwest Spatial Decision-Support System Partnership (www.epa.gov/waterspace).

During the process of system development, Wisconsin DNR staff consulted with RHD and Alliance for the Great Lakes staff to better determine and refine the required elements of the eventual L-THIA/VB system. In April 2010, DNR staff participated in an Alliance for the Great Lakes "Adopt-a-Beach" volunteer workshop at Racine's North Beach to better understand whether and how the system might be used by beach volunteer groups. In May 2011, the pilot L-THIA/VB system was introduced to public health officials and beach managers from southeastern Wisconsin and elsewhere as part of a hands-on Virtual Beach workshop conducted at the Lake Michigan Beach Health meeting in Racine. In August 2011, Wisconsin DNR staff conducted a live demonstration of the system to RHD and Alliance for the Great Lakes staff members at Racine City Hall and received final feedback and suggestions. In September 2011, final changes were made to the three L-THIA components in response to the feedback and suggestions. Also in

September, U.S. EPA completed and provided Wisconsin DNR a revamped Virtual Beach (version 2.2) that includes an enhanced predictions tab and file management capability, which enables users to save, share, and operate nowcast models.

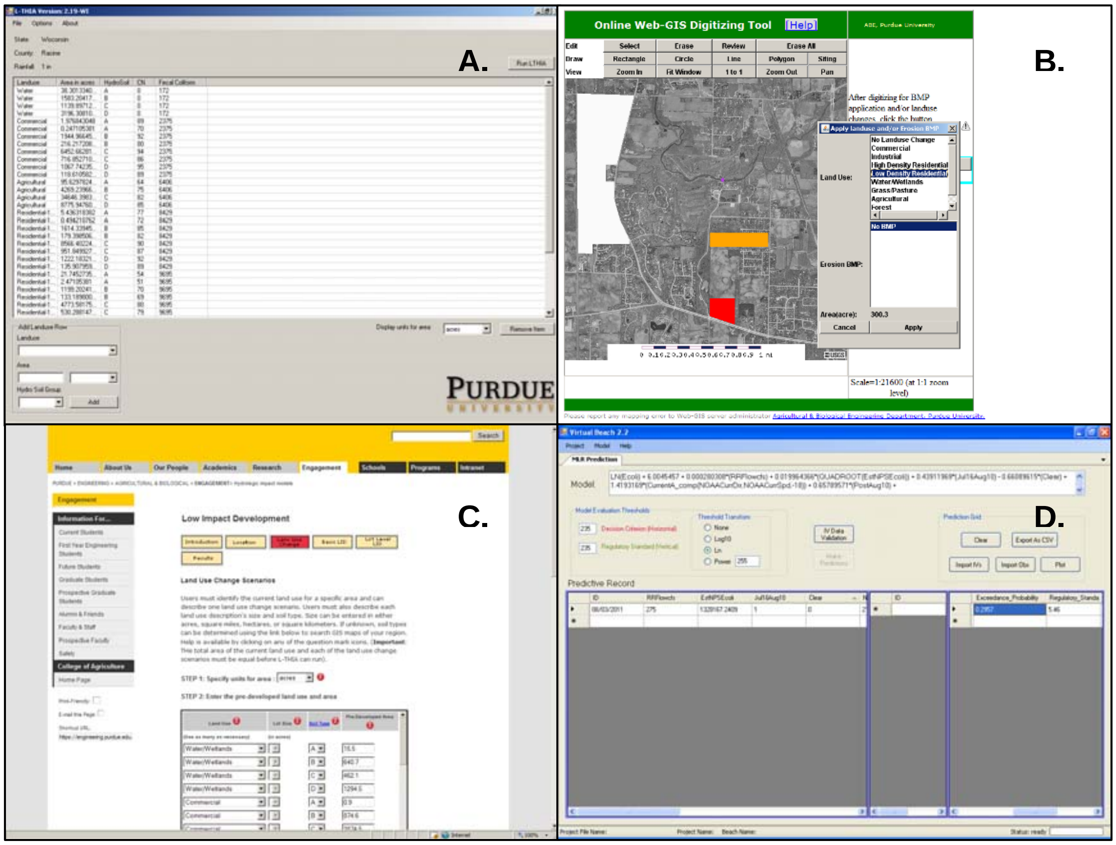

Figure 5. *Components of the L-THIA/VB System: (A) Real-Time L-THIA, (B) Web-Mapping Interface, (C) LID Component, and (D) Virtual Beach Prediction Tab.*

3. Conclusions and Future Directions

The development of the L-THIA/VB system is an important step in the process of creating an integrated monitoring, early-warning, and planning-support system that will enable not only the prediction of water quality conditions at recreational beaches, but will simultaneously allow planners, decision makers, and the interested public to evaluate the potential impacts of land use change and the adoption of LID practices in contributing watersheds. In piloting this system at North Beach in Racine, we sought to estimate and incorporate *E. coli* EMC coefficients based on long-term, water quality data collected along the lower Root River. Although the data and regression-estimated coefficients proved inadequate for this purpose, we were able to use generic EMC coefficients derived from previous studies to demonstrate that the system predicts *E. coli* concentrations with reasonable accuracy and is sensitive to changes in land use and LID applications. In response to guidance and feedback from RHD and Alliance for the Great Lakes staff, the final L-THIA/VB system was modified to enable the easy substitution of EMC coefficients, should additional data or enhanced coefficients from other sources become available. The use of updated national land cover data (NLCD) in place of regional (SEWRPC) data additionally enables the system to be transferred to coastal watersheds anywhere in the Great Lakes basin.

Future directions could include the creation of web-mapping interfaces for additional coastal watersheds in Wisconsin, combining the separate L-THIA components into a single web-based system and/or directly incorporating the desktop Real-Time L-THIA software application into Virtual Beach; i.e. as a new tab, in addition to the Data Input, Modeling, Residuals, and Prediction tabs. Separate enhancements also could be made to the individual components, including an alternative format for Real-Time L-THIA outputs (e.g., cumulatively updated data files in place of one-time HTML's), as well as improved, on-line digitizing and/or data-exchange capabilities within the web-mapping interface. This latter enhancement would enable users to digitize, upload, or "stream-in" more comprehensive and detailed land use features than they currently are able to digitize by hand. Lastly, the desktop software could be enhanced by incorporating a means of estimated variable antecedent moisture conditions based, for example, on the previous five days of rainfall (Mishra and Singh 2003). This modeling change could improve the accuracy of estimated *E. coli* loads by accounting for variable watershed conditions not otherwise related to land use or LID.

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5. Acknowledgments

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Appendix A. Project Presentations, Outreach, and Education

The following presentations and outreach efforts were undertaken during the grant period.

12/8/2009. "On Public-Health" Seminar conducted by Julie Kinzelman (Racine Health Department) and Adam Mednick. University of Wisconsin-Milwaukee School of Public Health, Milwaukee, WI. Title: "Integrating urban planning into municipal water quality monitoring programs."

3/5/2010. Presentation given by Adam Mednick at the 34th Annual Meeting of American Water Resources Association–Wisconsin Section. Madison Marriott West, Middleton, WI. Title: "Linking Great Lakes beach water quality to land use."

3/11/2010. Science Seminar conducted by Adam Mednick. Wisconsin DNR, Madison, WI. Title: "Using real-time statistical models to 'nowcast' Great Lakes beach water quality."

7/19/2010. Presentation given by Adam Mednick at the Annual Meeting of the Midwest Spatial Decision-Support System Partnership. U.S. EPA Region 5, Chicago, IL. Title: "Nowcasting water quality at Great Lakes beaches."

10/9/2010. Presentation given by Adam Mednick at the Association of Collegiate Schools of Planning Conference. Minneapolis, MN. Title: "Linking Great Lakes beach water quality to land use: Developing a novel planning-support system."

11/4/2010. Presentation given by Adam Mednick at the Wisconsin Association of Floodplain, Stormwater, and Coastal Management Conference. Kalahari Resort, Wisconsin Dells, WI. Title: "Linking Great Lakes beach water quality to land use."

11/17/2010. Presentation given by Adam Mednick at the 18th National Nonpoint Source Monitoring Workshop. Milwaukee, WI. Title: "Linking nearshore beach water quality to land use and NPS pollution."

3/16/2011. Poster presented by Julie Kinzelman (Racine Health Department) at the National Beaches Conference. Miami, FL. Co-authored by Adam Mednick (lead), Kyle Minks, and Dan Ziegler (Ozaukee County Public Health Department. Title: "Implementing predictive models on a broader scale: Current efforts in Wisconsin."

5/5/2011. Water quality modeling presentation and hands-on workshop conducted by Adam Mednick and Kyle Minks at the Wisconsin Beach Health Lake Michigan Meeting. Wingspread/Johnson Foundation, Racine, WI.

7/18/2011. Presentation given by Adam Mednick at the Coastal Zone 2011 Conference. Hyatt Regency, Chicago, IL. Title: "Predicting beach water quality: Operational 'nowcasts' and long-term impact assessments."

8/11/2011. Live demonstration of the L-THIA/VB Decision-Support System conducted by Adam Mednick for staff of the Racine Health Department and Alliance for the Great Lakes. Racine City Hall, Racine, WI.

Appendix B. Illustrated Instructions for Using the Web Mapping Component

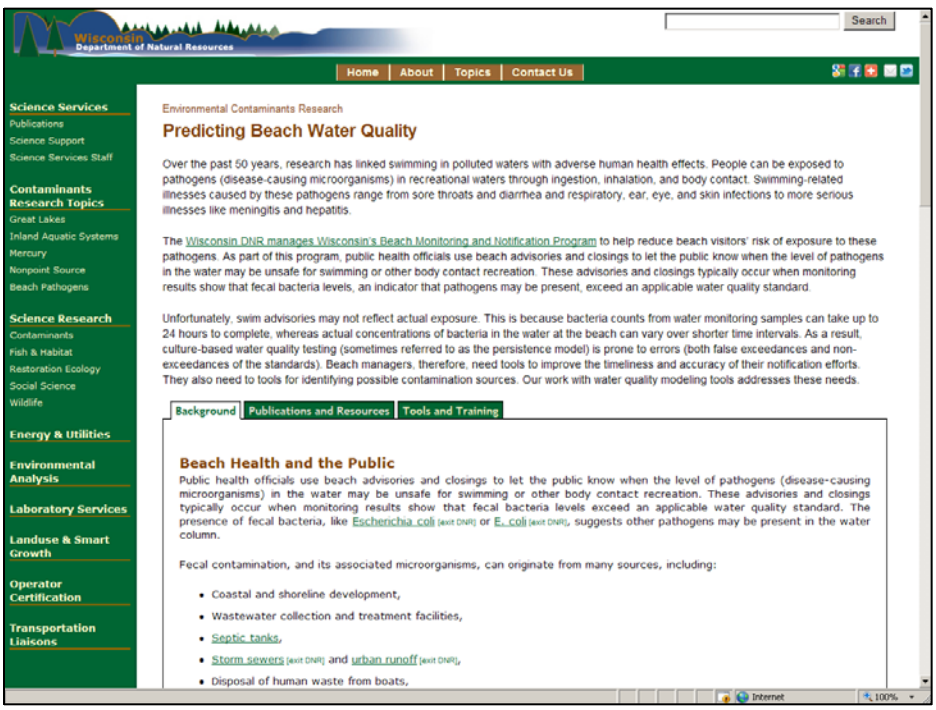
L-THIA/VB Decision-Support System
Learning Module I – *Web-Mapping Interface*

In this module you will learn how to:

A. Create alternative land use scenarios using the online digitizing tool
B. Save "before" and "after" model data for use in Real-Time L-THIA

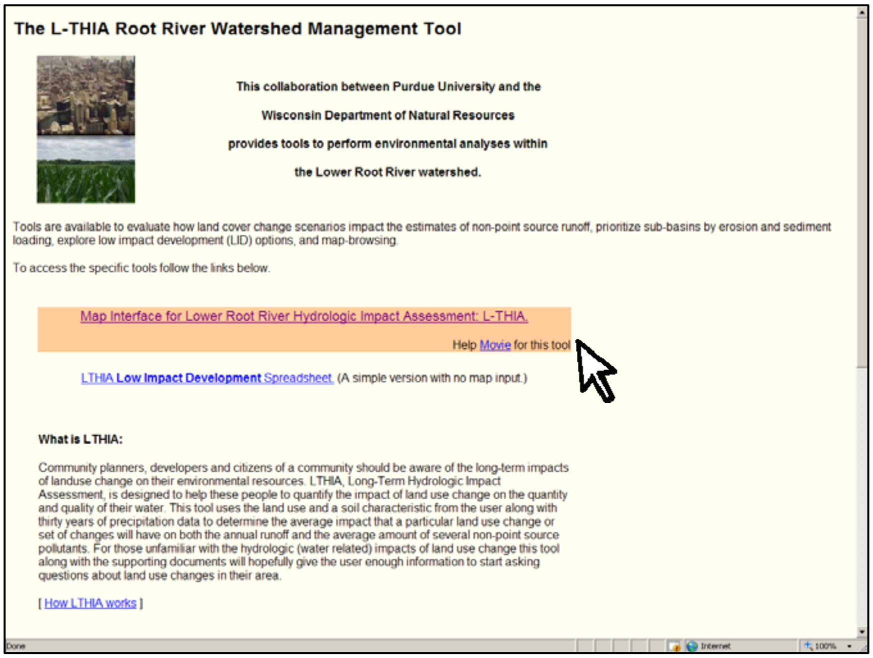
A. Create alternative land use scenarios using the online digitizing tool

A.1. Link to the L-THIA Web Mapping Interface for the Lower Root River from the Wisconsin DNR "Predicting Beach Water Quality" web page (http://dnr.wi.gov/org/es/science/contaminants/beach.htm) or open the system directly at: http://engineering.purdue.edu/mapserve/root_river/

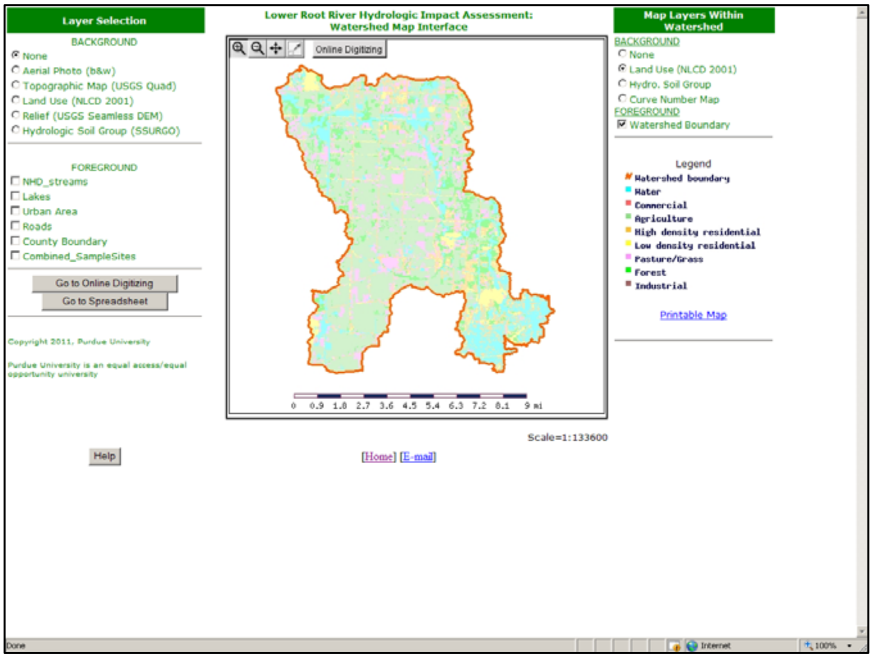


The L-THIA Web Mapping Interface provides a means for users without geographic information system (GIS) software to begin to evaluate the potential hydrologic and water quality impacts of proposed or potential land use changes. Different map "layers" can be viewed in the interface: land use, soil hydrologic group ratings, water quality monitoring points, aerial imagery, and various other reference layers. Users can digitize (draw) alternative land uses on-screen, and save the altered data to model input files that can later be used to predict water quality impacts using the desktop Real-time L-THIA software.

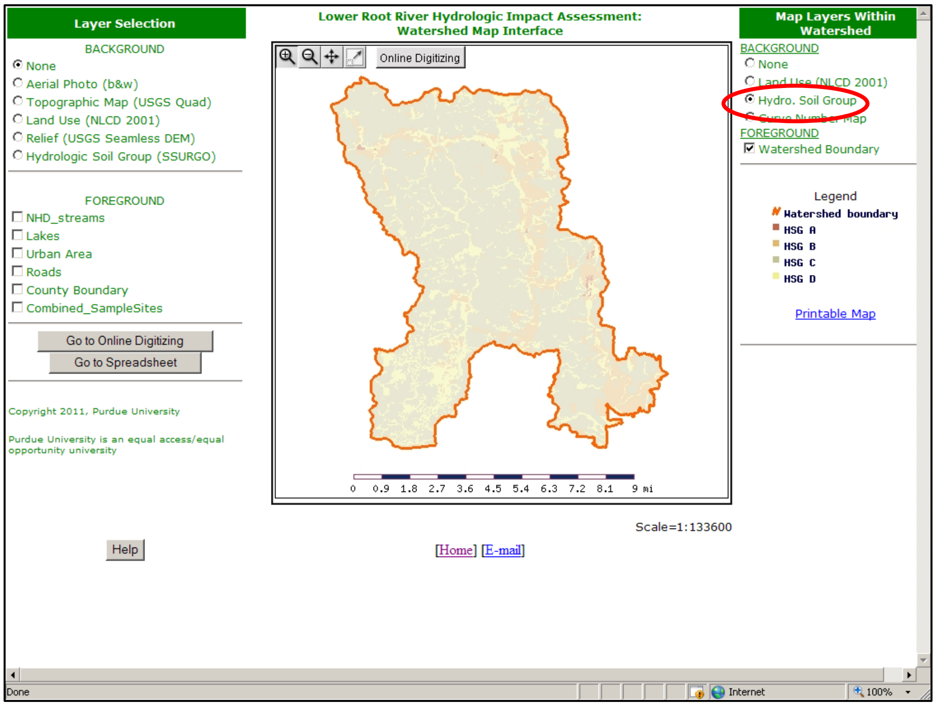
A.2. In the page that opens click on the link to "Map Interface for Lower Root River Hydrologic Impact Assessment: L-THIA."



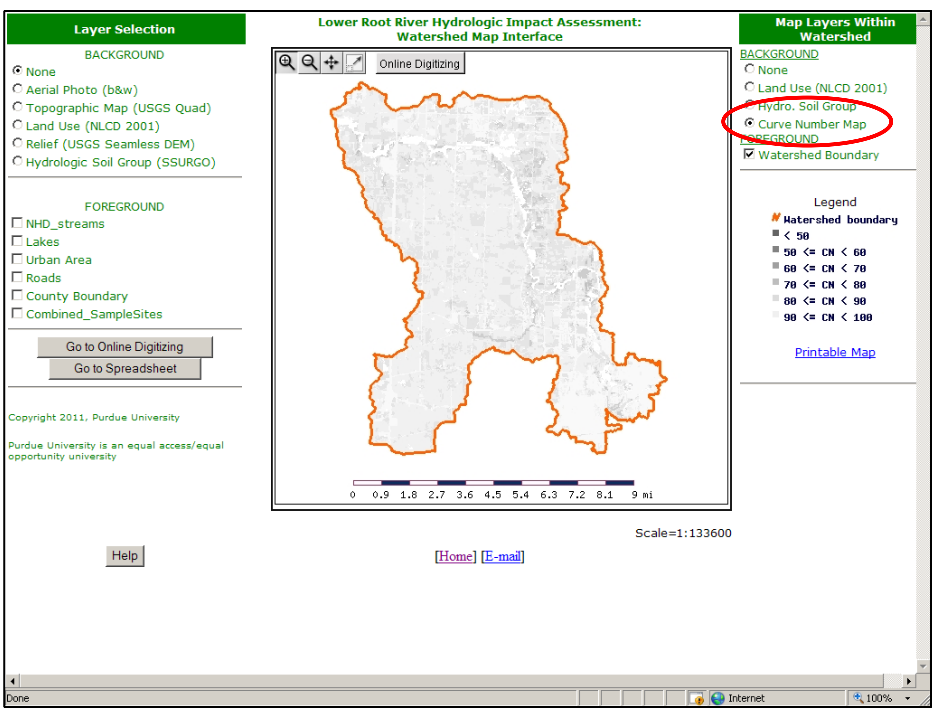
A.3. The Web Mapping Interface will open. Note that there are different Map Layers that can be displayed in the "Background" and in the "Foreground," both within the watershed (right-side checklist) and across the map window (left-side checklist). The default view is of land use within the Lower Root River.



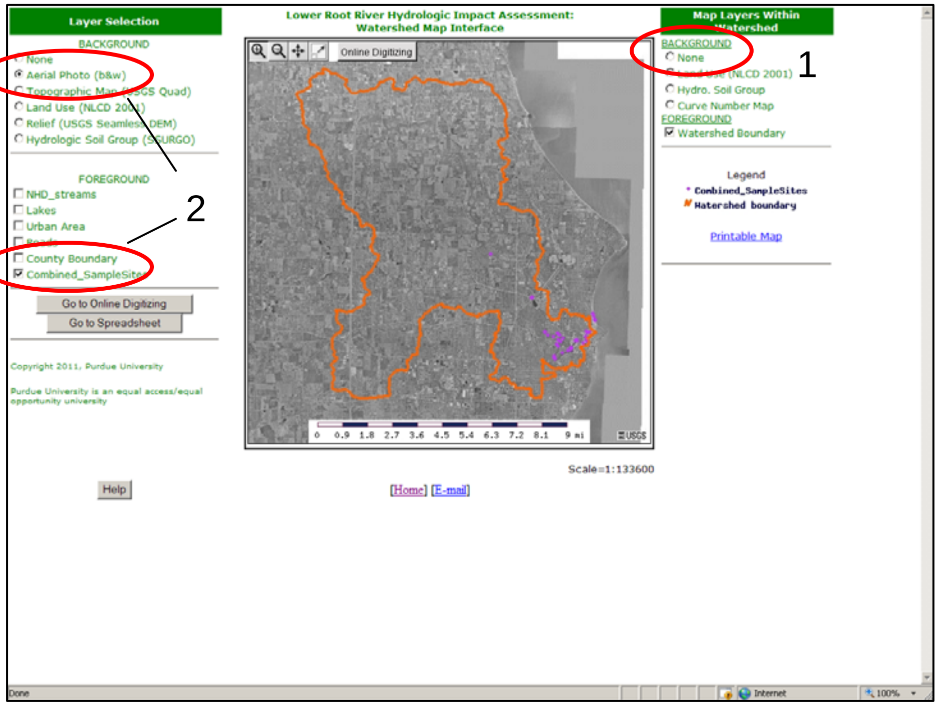
A.4. Check the radio button for "Hydro. Soil Group" to display hydrologic soil group rankings: A = well-drained soils; D = poorly drained soils.



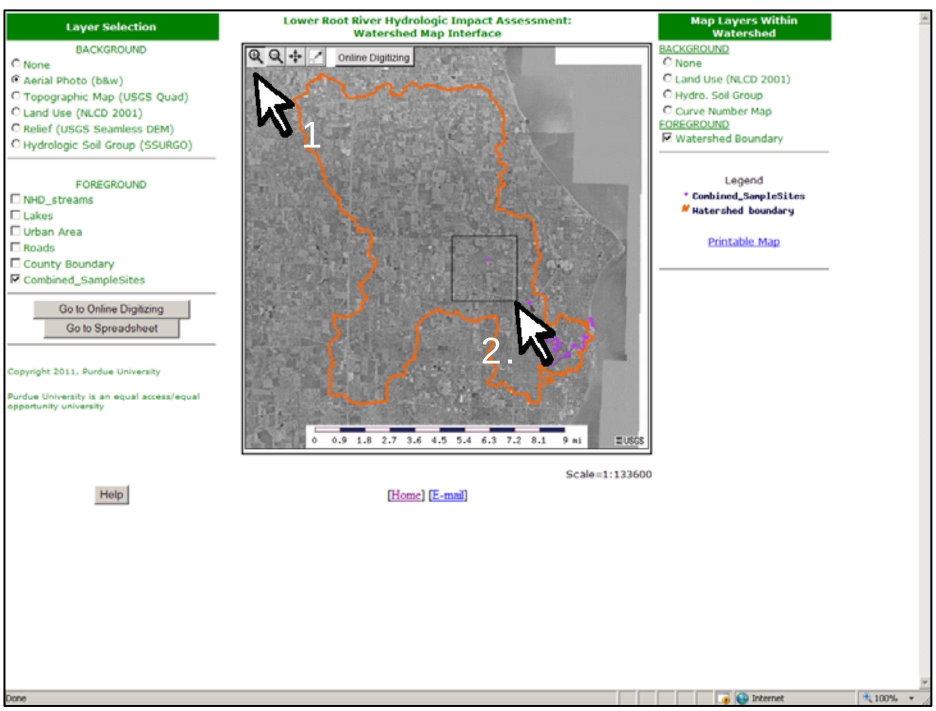
A.5. Check the radio button for "Curve Number Map" to view rainfall-runoff curve numbers (CN's), based on the combination of land use and underlying soil hydrologic group: lower CN's = lower runoff/higher infiltration potential.



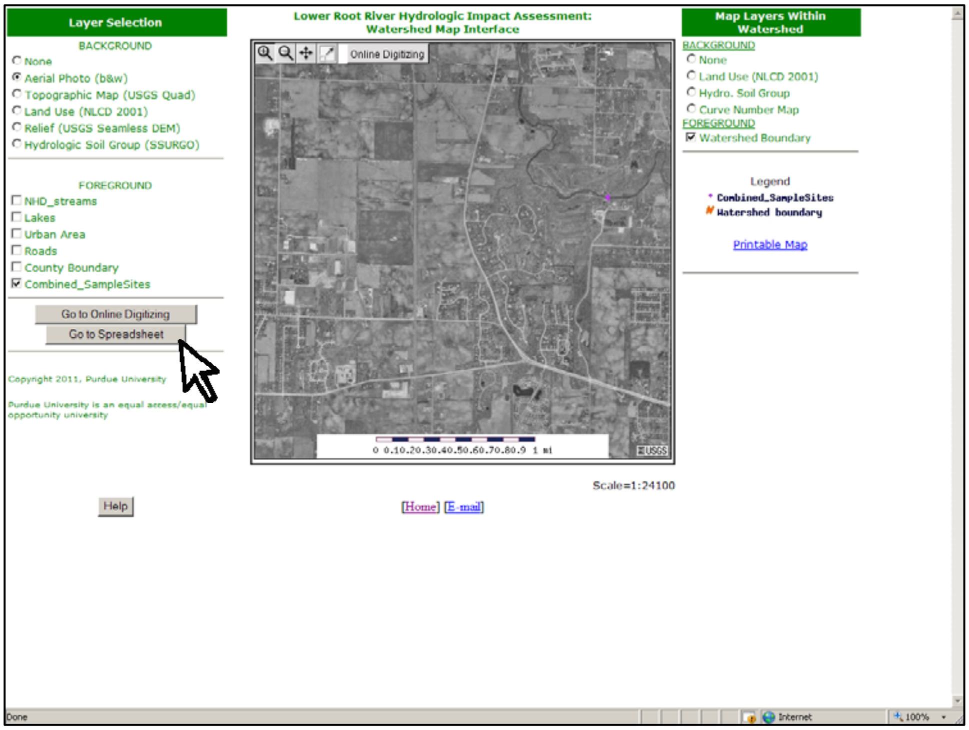
A.6. Under BACKGROUND on the right side check "None," then check "Aerial Photo" and "Combined_SampleSites": Racine Health Department's water quality monitoring sites on the Lower Root River plus North Beach.



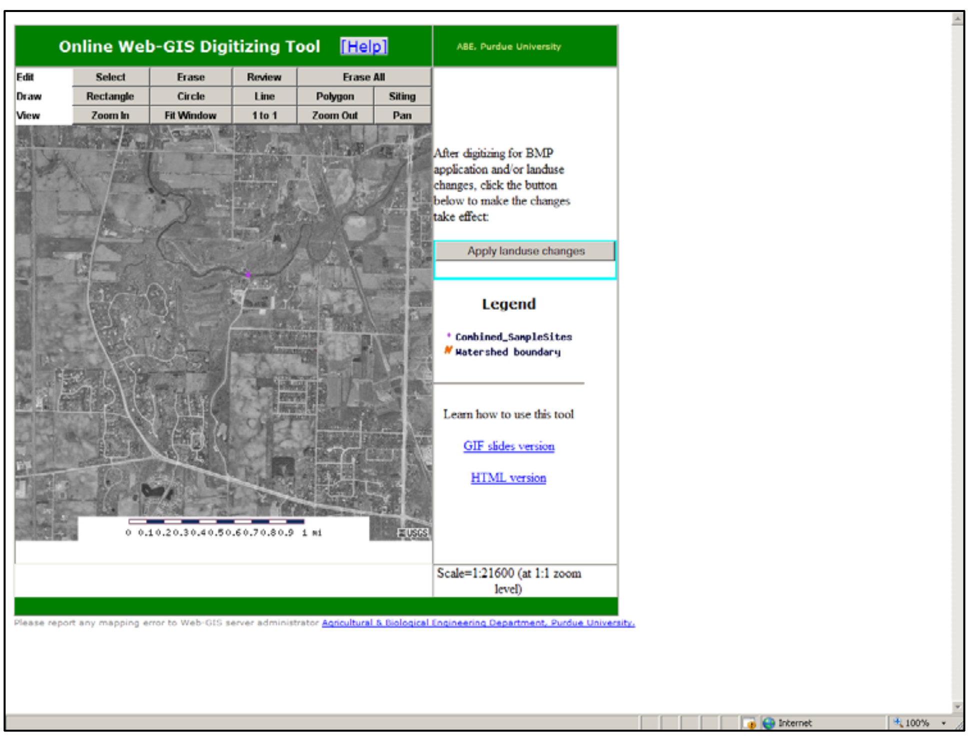
A.7. To zoom-in, first click the Zoom (magnifying glass) button in the map window, then drag a box around the area you wish to enlarge.



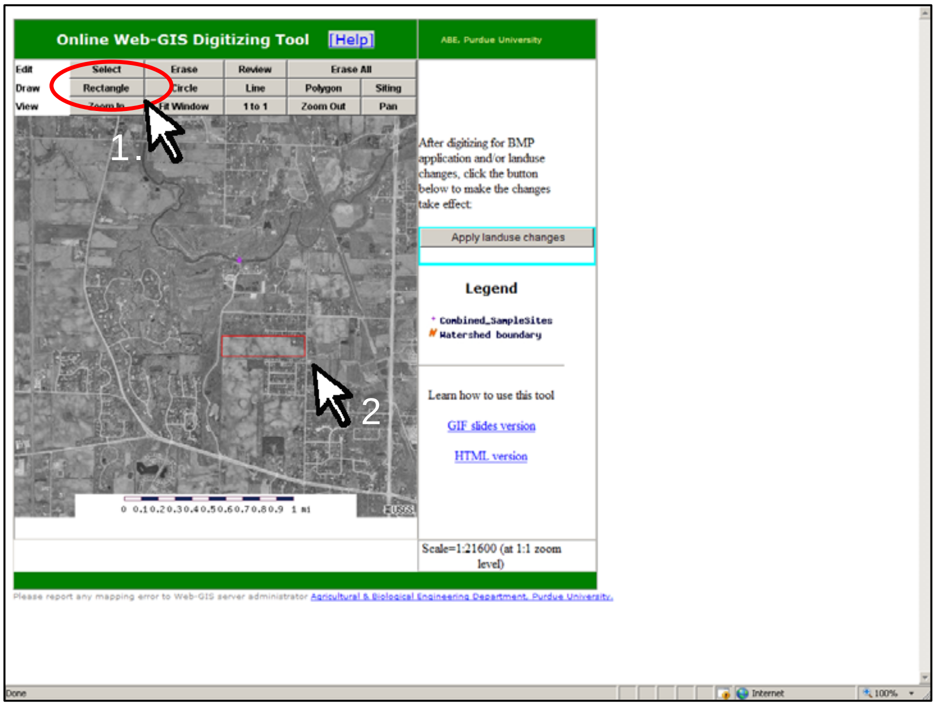
A.8. When you have zoomed to your area of interest and are ready to use the online digitizing tools to create alternative land use scenarios, click the “Go to Online Digitizing” button.



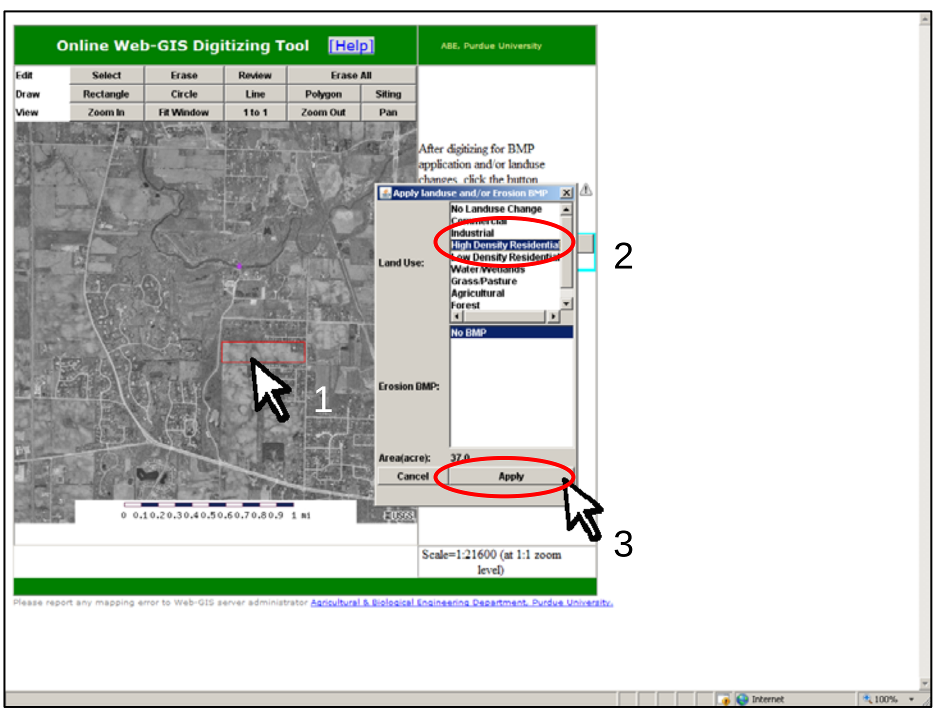
A.9. A new window will open with a series of “Edit,” “Draw,” and “View” tools.



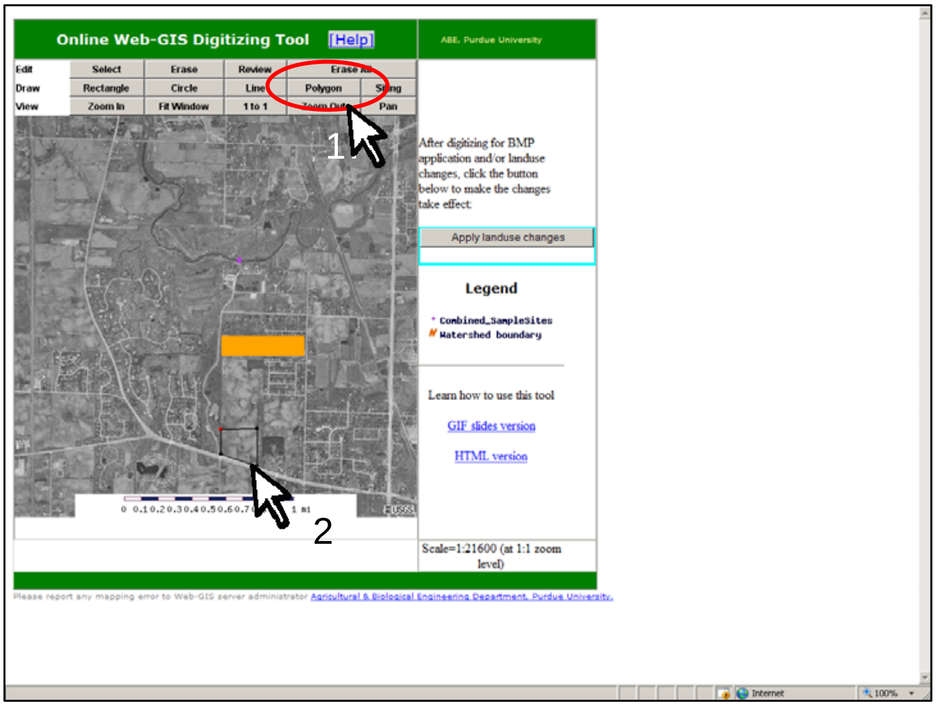
A.10. To digitize a simple, rectangular change in land use, click the “Rectangle” button and use the mouse to outline the area you wish to alter.



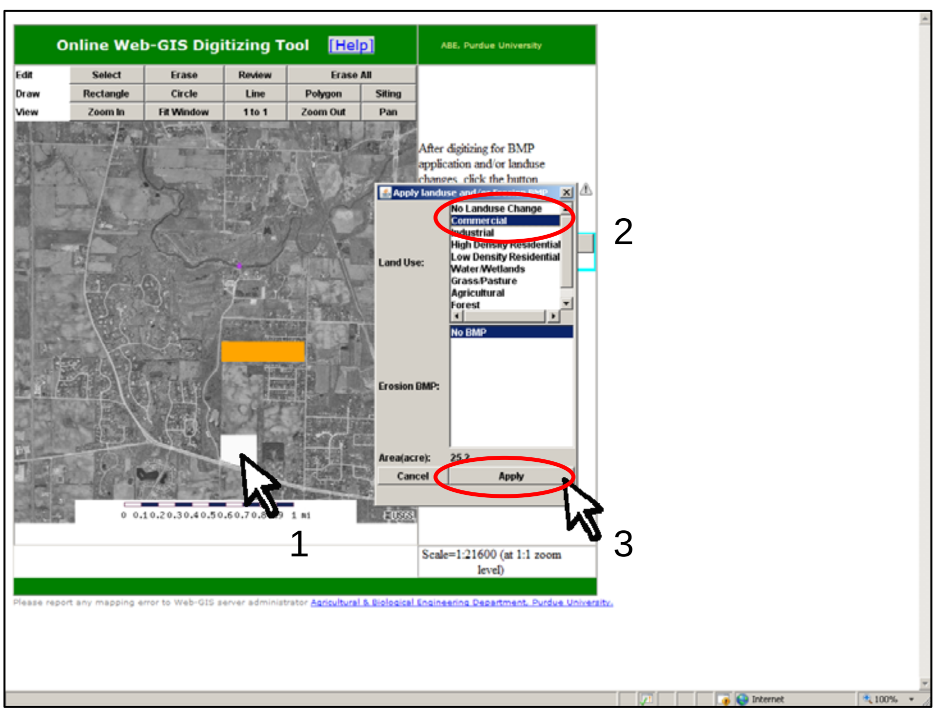
A.11. (1) Right-click inside the rectangle you digitized to open a list of land uses. (2) From the list that appears, select “High-Density Residential.” (3) Click Apply. The rectangle will turn orange signifying the new land use (A.12 below).



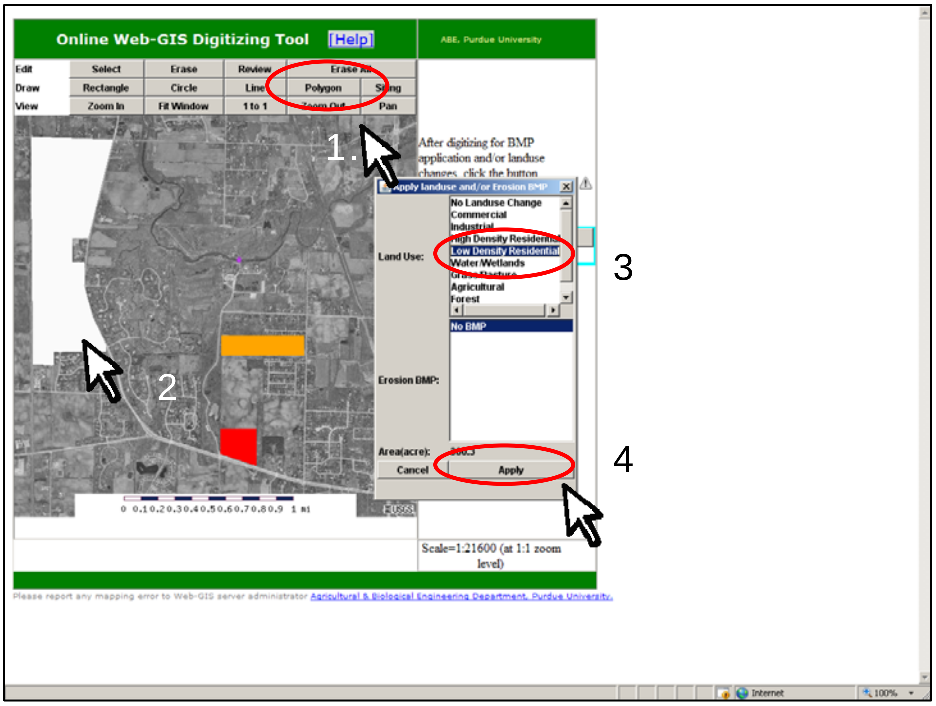
A.12. To digitize a more detailed shape, click the "Polygon" button and use the mouse to draw the outline by clicking vertices (points) around which the outline of the area will be joined. The first point clicked will be red. Double-click on this point when you have finished drawing the outline of the shape.



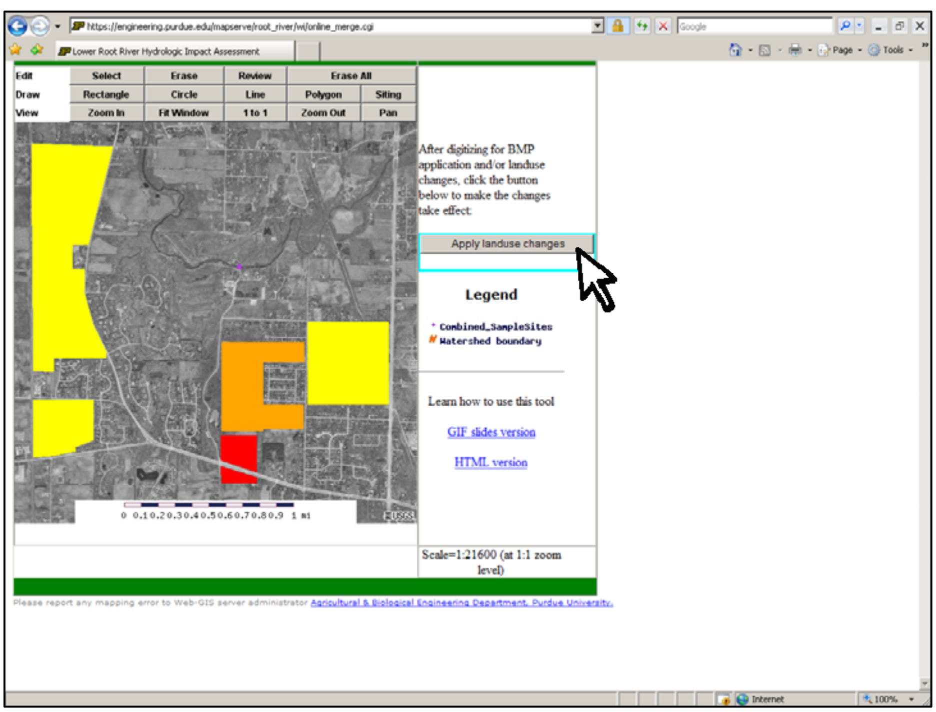
A.13. Repeat the steps from A.11 (above), setting "Commercial" as the new land use.



A.14. Repeat the steps from A.12-A.13 (above) to digitize a polygon and set the new land use as "Commercial." The shape will turn yellow to signify the change (A.15 below).

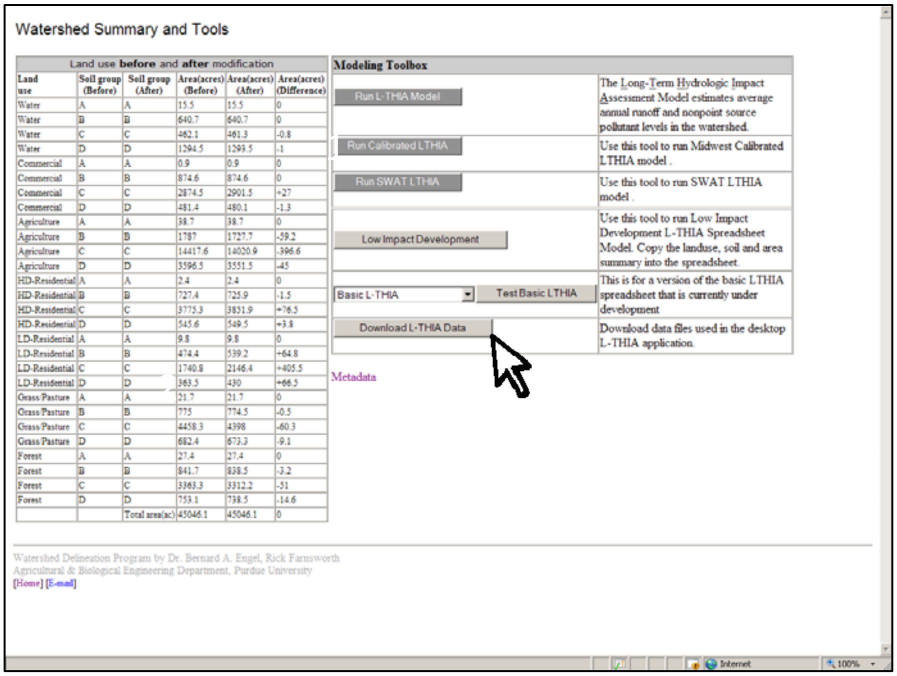


A.15. When you have completed all of your land use changes, click the "Apply Land Use Changes" button.

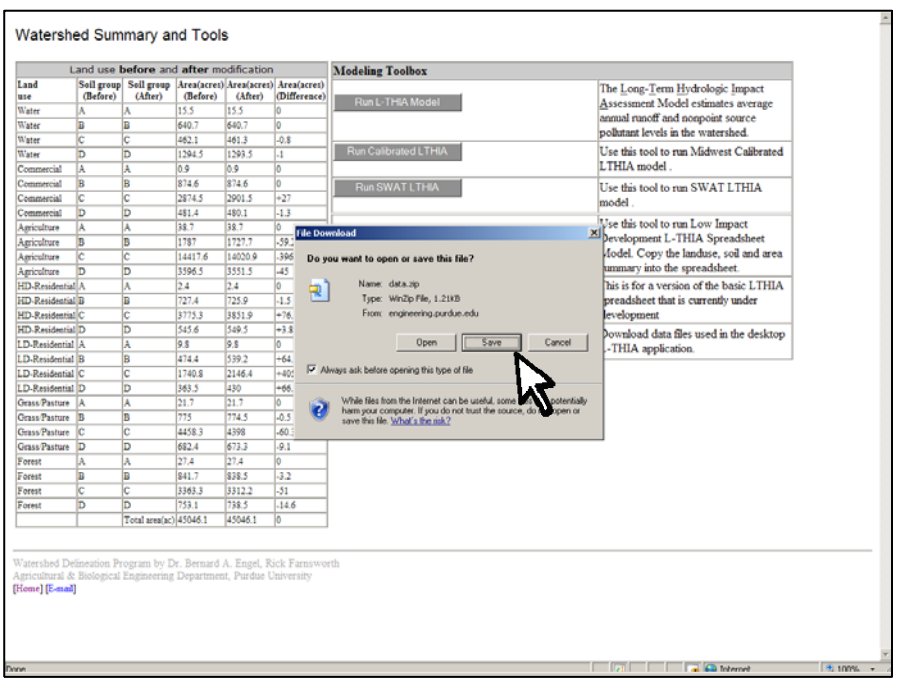


B. Save "before" and "after" model data for use in Real-Time L-THIA

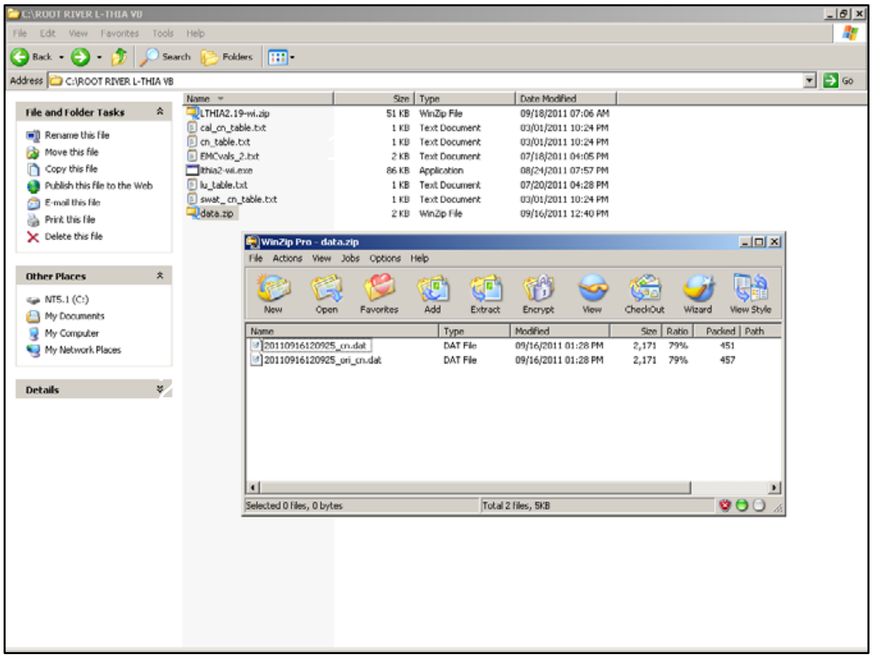
B.1. After applying land use changes, a "Watershed Summary and Tools" window will open, listing "before" and "after" acreages of different land uses and underlying soil groups. To save model data, click the "Download L-THIA Data" button.



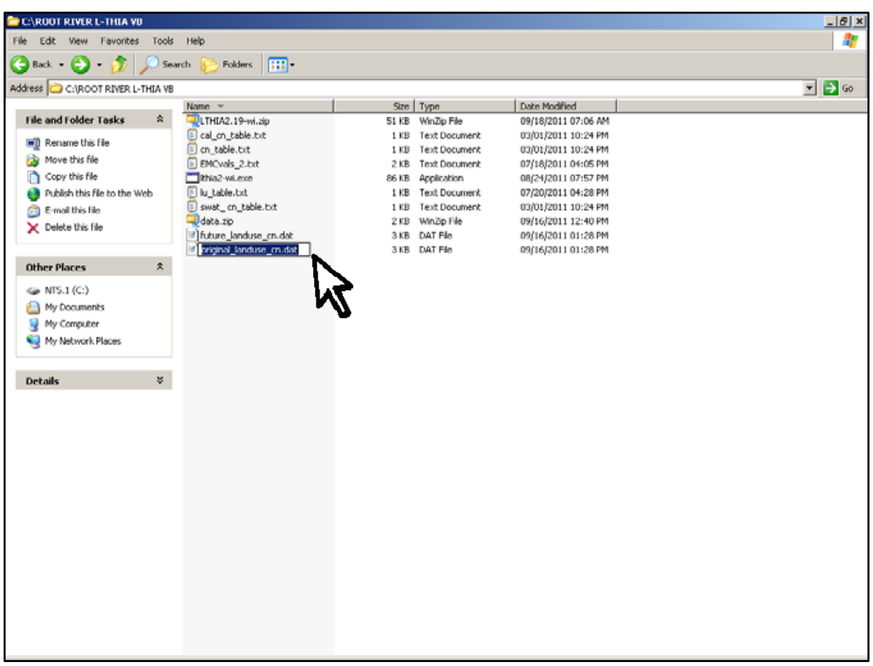
B.2. In the pop-up window click Save.



B.3. The “before” and “after” data are recorded in two .dat files bundled in a zipfile: data.zip. Extract these files into a directory of your choosing. (Note: It will be convenient later on if these files are saved in the same directory as the Real-time L-THIA desktop software [lthia2-wi.exe] and supporting files.)



B.4. By default, the “before” and “after” .dat files are named according to the date on which they were generated followed by “_cn_ori” (for rainfall-runoff curve numbers under the original land use) and just “_cn” for new curve numbers). Rename these files to something that makes sense to you; e.g., “future_” and “original_landuse_cn.”



Appendix C. Illustrated Instructions for Using the L-THIA Component

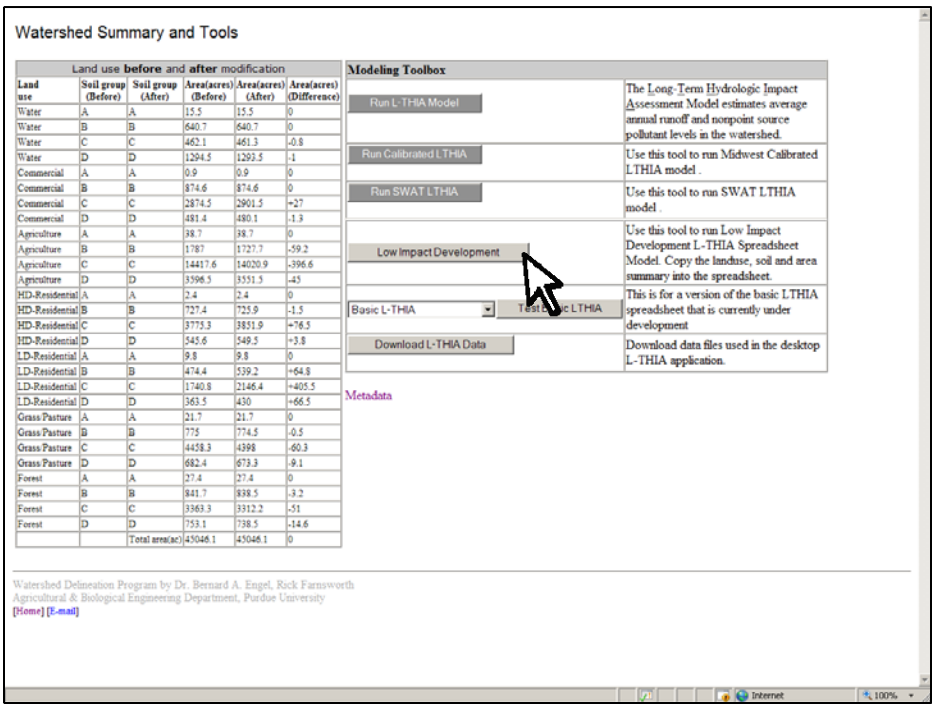
L-THIA/VB Decision-Support System
Learning Module II – *Low Impact Development (LID)*

In this module you will learn how to:

A. Create alternative LID scenarios based on “Lot-Level Screening”
B. Save “before” and “after” model data for use in Real-Time L-THIA

A. Create alternative LID scenarios based on “Lot-Level Screening”

A.1. Return to the “Watershed Summary and Tools” window (see Learning Module I, step B.1 [Appendix B]) and click the button for “Low Impact Development.”

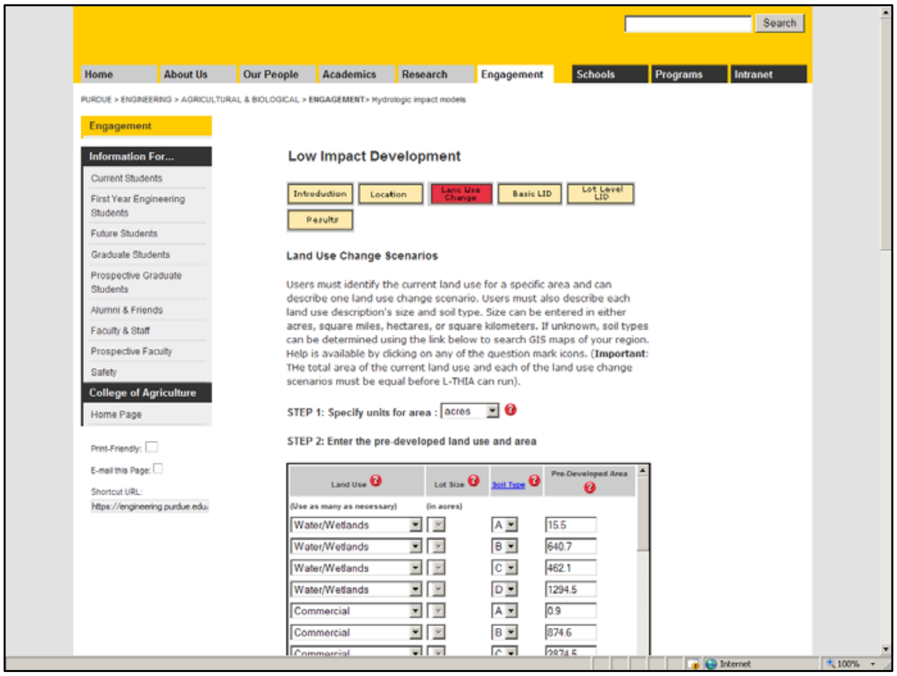


Land use	Soil group (Before)	Soil group (After)	Area(acres) (Before)	Area(acres) (After)	Area(acres) (Difference)
Water	A	A	15.5	15.5	0
Water	B	B	640.7	640.7	0
Water	C	C	462.1	461.3	-0.8
Water	D	D	1294.5	1293.5	-1
Commercial	A	A	0.9	0.9	0
Commercial	B	B	874.6	874.6	0
Commercial	C	C	2874.5	2901.5	+27
Commercial	D	D	481.4	480.1	-1.3
Agriculture	A	A	38.7	38.7	0
Agriculture	B	B	1787	1727.7	-59.2
Agriculture	C	C	14417.6	14020.9	-396.6
Agriculture	D	D	3596.5	3551.5	-45
HD-Residential	A	A	2.4	2.4	0
HD-Residential	B	B	727.4	725.9	-1.5
HD-Residential	C	C	3775.3	3851.9	+76.5
HD-Residential	D	D	545.6	549.5	+3.8
LD-Residential	A	A	9.8	9.8	0
LD-Residential	B	B	474.4	539.2	+64.8
LD-Residential	C	C	1740.8	2146.4	+405.5
LD-Residential	D	D	363.5	430	+66.5
Grass/Pasture	A	A	21.7	21.7	0
Grass/Pasture	B	B	775	774.5	-0.5
Grass/Pasture	C	C	4458.3	4398	-60.3
Grass/Pasture	D	D	682.4	673.3	-9.1
Forest	A	A	27.4	27.4	0
Forest	B	B	841.7	838.5	-3.2
Forest	C	C	3363.3	3312.2	-51
Forest	D	D	753.1	738.5	-14.6
		Total area(ac)	45046.1	45046.1	0

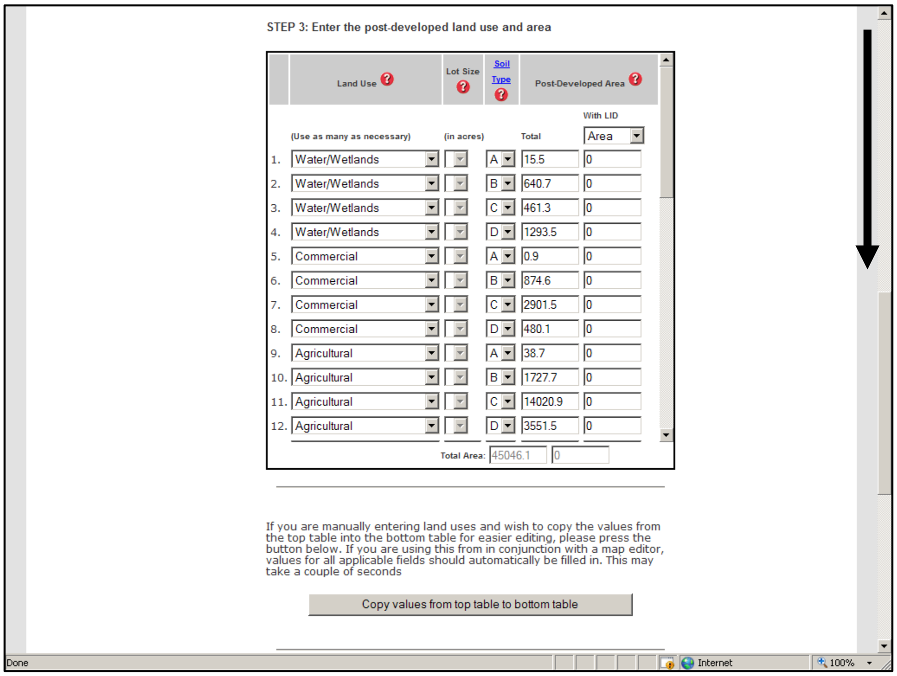
ⓘ “Low Impact Development” (LID) practices include features such as bioswales, perveous pavement, rain barrels, and green roofs, which can reduce the hydrologic impacts of land development.

⚠ In the L-THIA modeling framework, LID practices reduce the effective impervious coverage of residential and commercial land areas and thereby lower rainfall-runoff curve numbers. Only stormwater runoff, however, is altered by LID practices within the model. Event mean concentrations (EMCs) of different pollutants are not adjusted. Future versions of L-THIA may include LID-based reductions in pollutant concentrations in addition to changes in runoff.

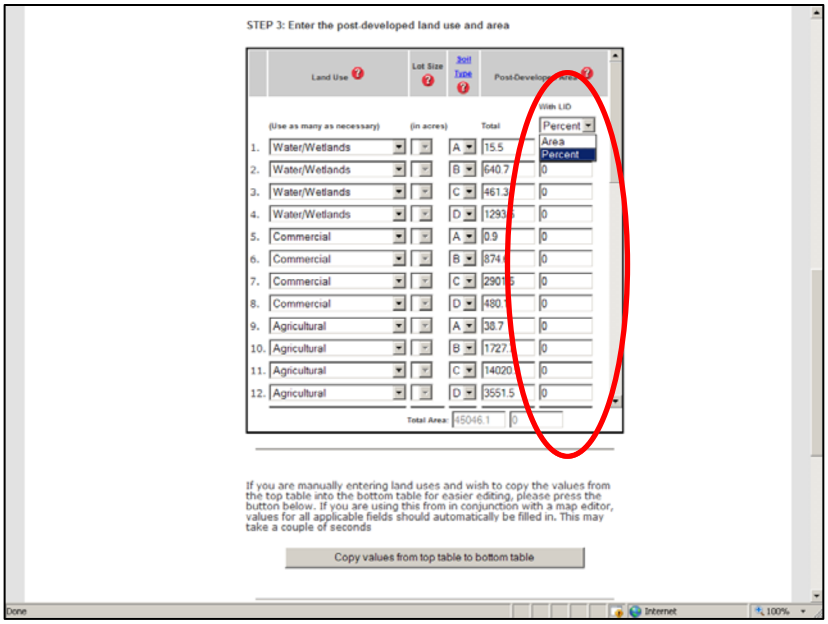
A.2. A new "Low Impact Development" page will open with a table of "pre-developed" (before) land use and soil group acreages.



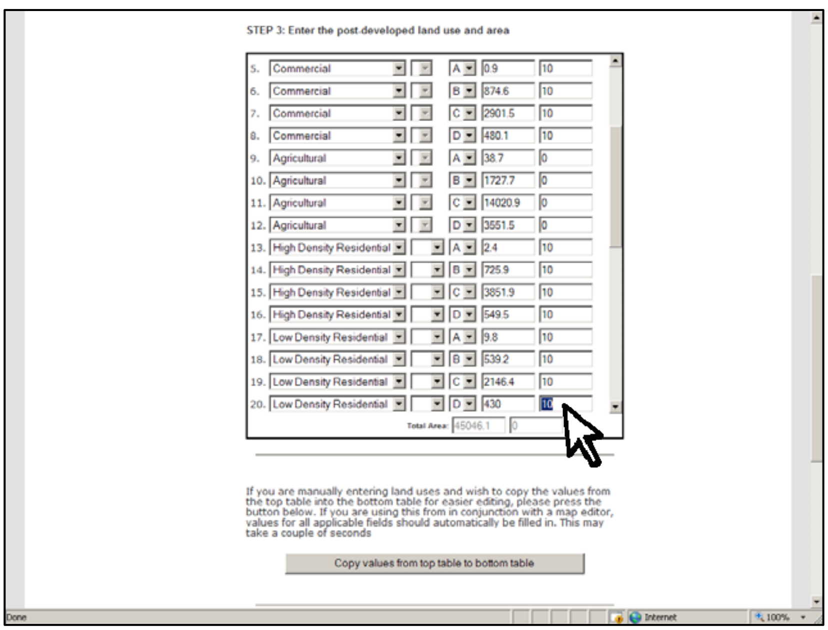
A.3. Scroll down to the "post-developed" (after) land use table, under "STEP 3…" The acreages are based on your on-line digitizing. (If you wish to create a LID-only scenario, you can click the "Copy values from top" button below the table. In this example, however, we are creating a land use change/LID scenario.)



A.4. Note the right-hand column with all zero-values. This represents the amount of each land use/soil class to which you will apply LID practices; e.g., 20%. Change the pull-down menu under the column heading from "Area" to "Precent".

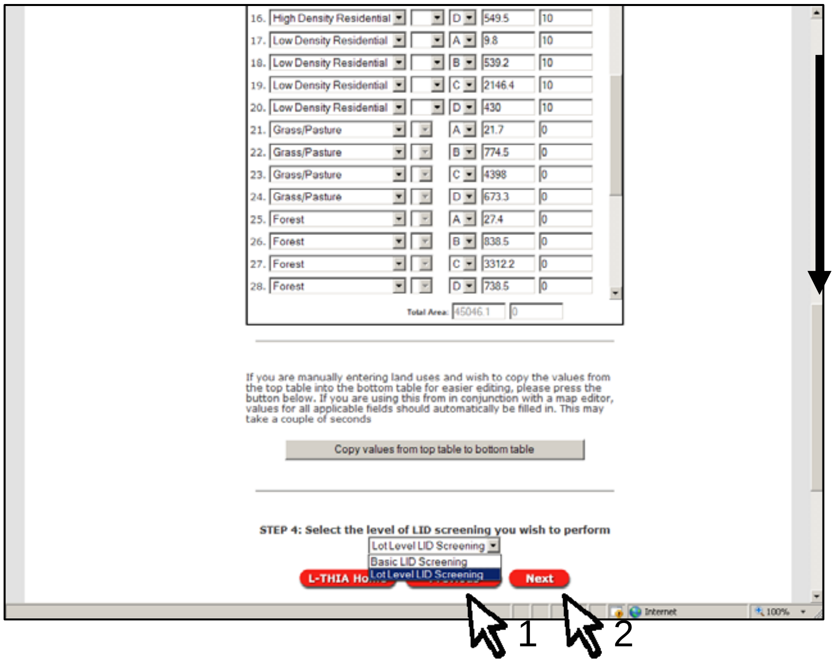


A.5. Type-in "10" next to all Commercial, High-, and Low-Density Residential areas; i.e. ten percent of all these lands will have some form of LID practice in place in your LID scenario.

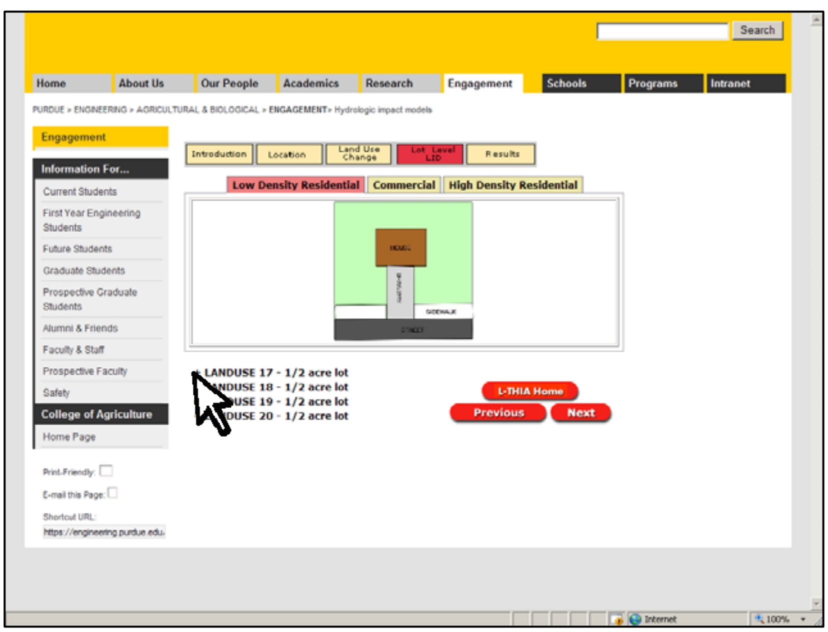


Note: In the current L-THIA modeling framework, the location of LID practices does not determine their impact. The proportion of a given land use with LID practices and the particular mix of practices applied are the determining factors.

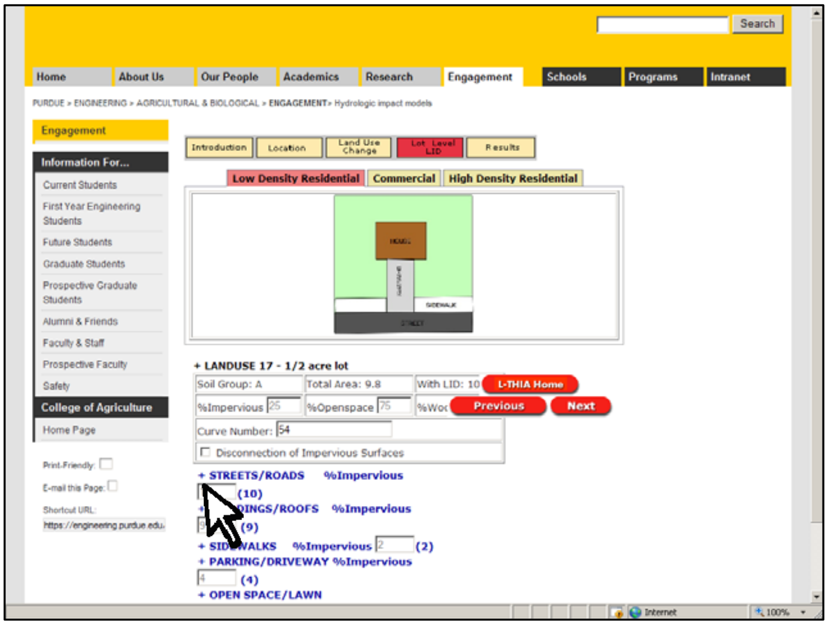
A.6. Scroll to the bottom of the page to "STEP 4". (1) Select "Lot Level LID Screening" from the pull-down. (2) Click "Next." A new window will open showing a schematic of a residential lot (see A.7 below).



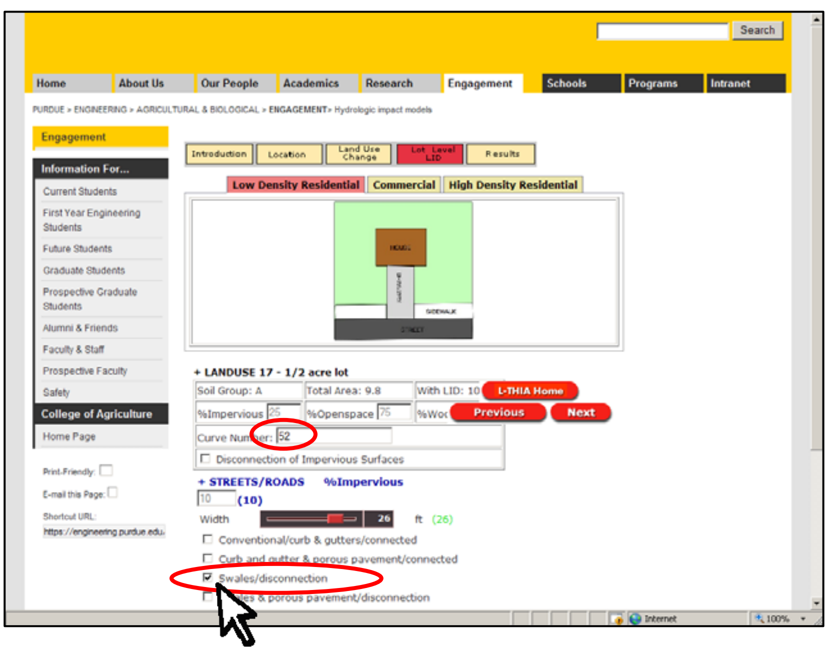
A.7. Each of the four numbered land uses (e.g., LANDUSE 17) represents low-density residential land with different underlying soil hydrologic groups: A-D. Click the "+" sign next to the first land use to see the different LID options. A set of general LID categories will appear below the land use in blue text (see A.8).



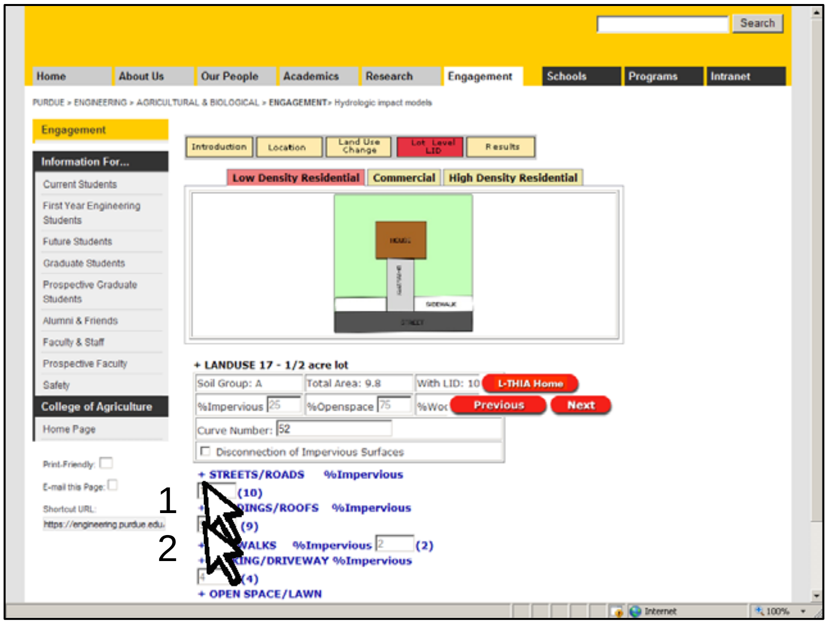
A.8. Click on the blue "+" next to STREETS/ROADS. A set of specific LID options will appear below the category (see A.9).



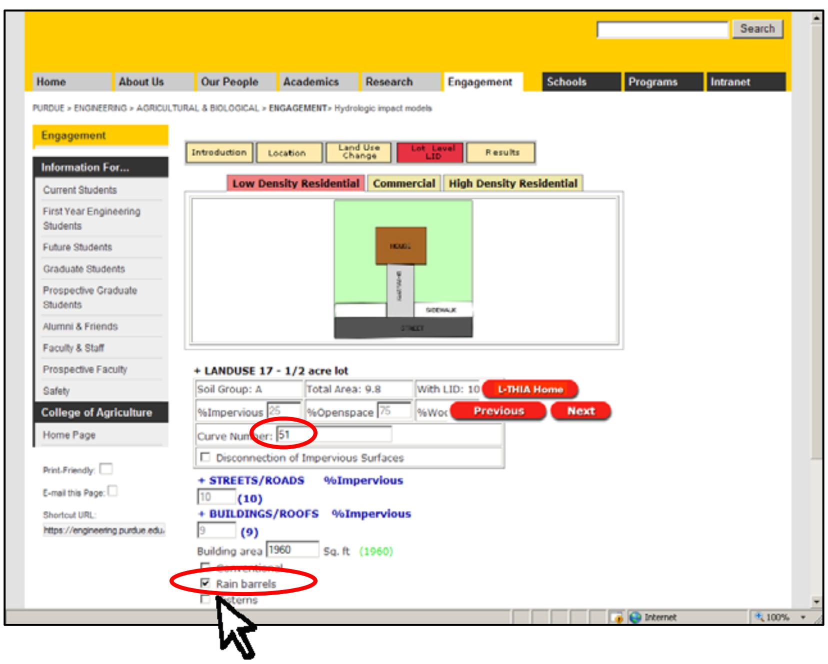
A.9. Check the box next to "Swales/Disconnection." Note that the rainfall-runoff curve number automatically changes from 54 to 52 in response to this selection.



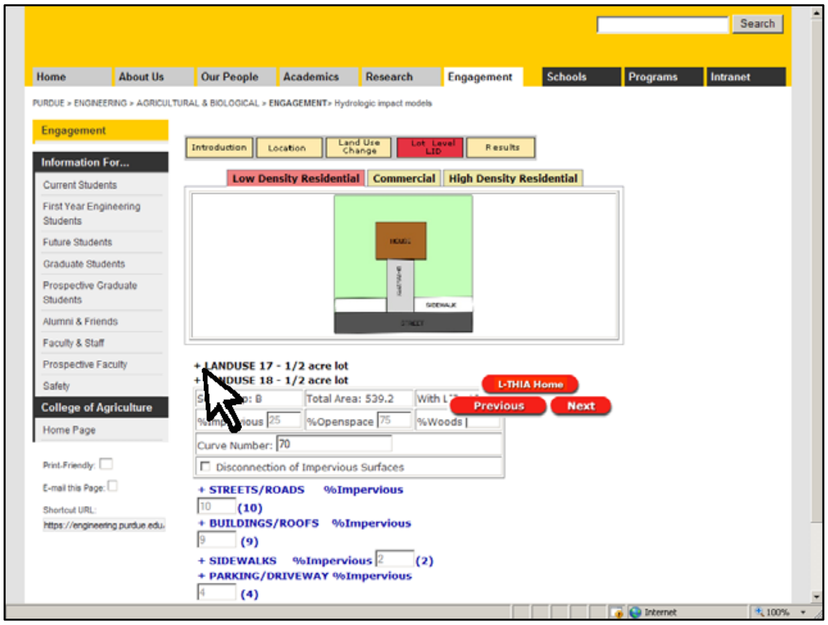
A.10. Click on the blue "+" next to STREETS/ROADS, to minimize this category. Then click on the blue "+" next to BUILDING/ROOFS to open the specific LID options under that category (see A.11).



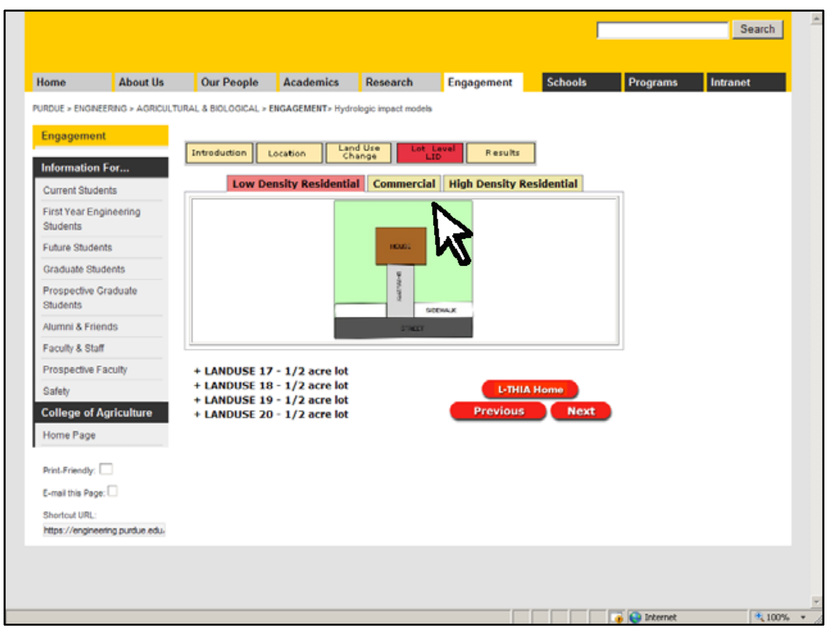
A.11. Check the box next to "Rain Barrels." Note that the rainfall-runoff curve number automatically changes from 52 to 51 in response to this selection.



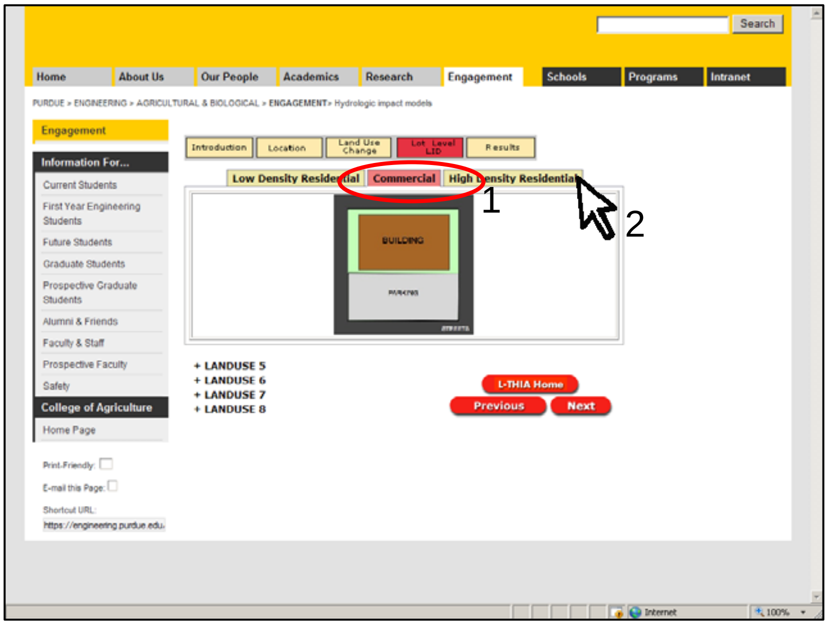
A.12. Click on the black "+" next to LANDUSE 17, to minimize this land use. Repeat steps A.7 through A.11 for LANDUSE 18 through LANDUSE 20 -- so that each has the same LID options: STREETS/ROADS = "Swales/Disconnection" and BUILDINGS/ROOFS = "Rain Barrels."



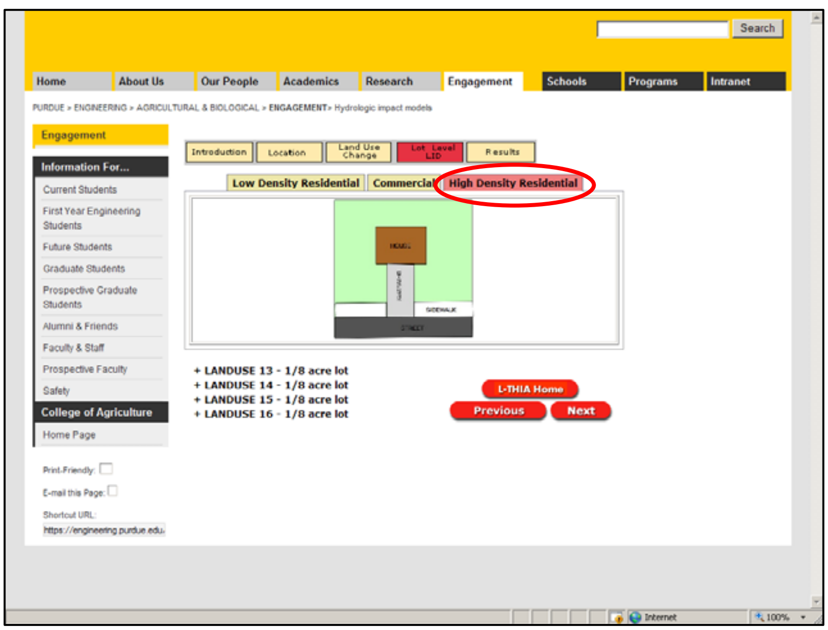
A.13. When you have finished selecting the LID options for low density residential click the tab for "Commercial." A new design schematic will appear (see A.14).



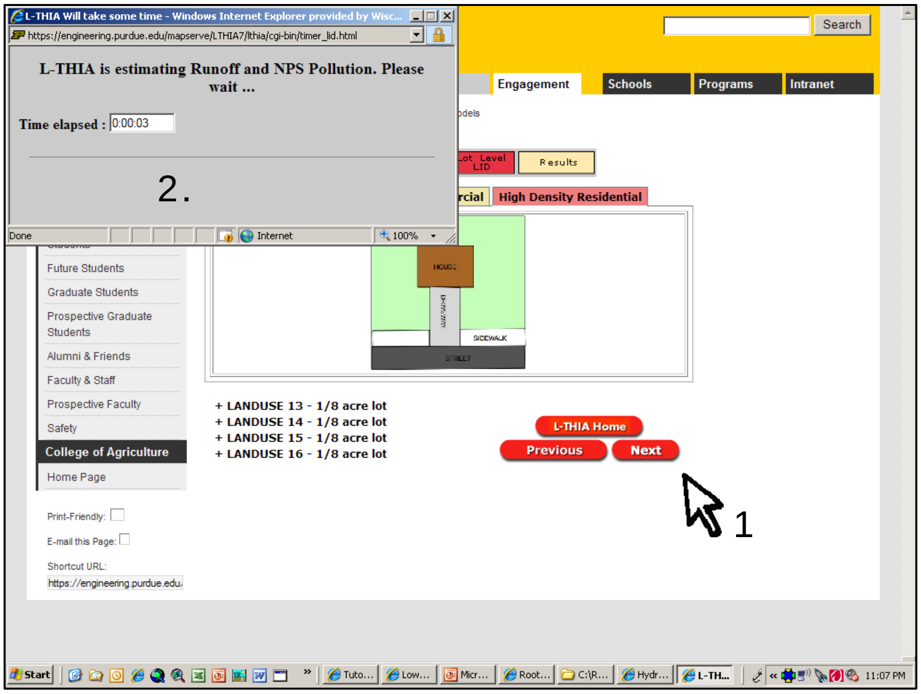
A.14. Repeat steps A.7 –A.11 for the four commercial land use/soil classes, starting with LAND USE 5. Select these LID options: STREETS/ROADS = "Swales/Disconnection"; and PARKING/DRIVEWAY = "Porous Pavement (low)." When you are finished, click the "High Density Residential" tab.



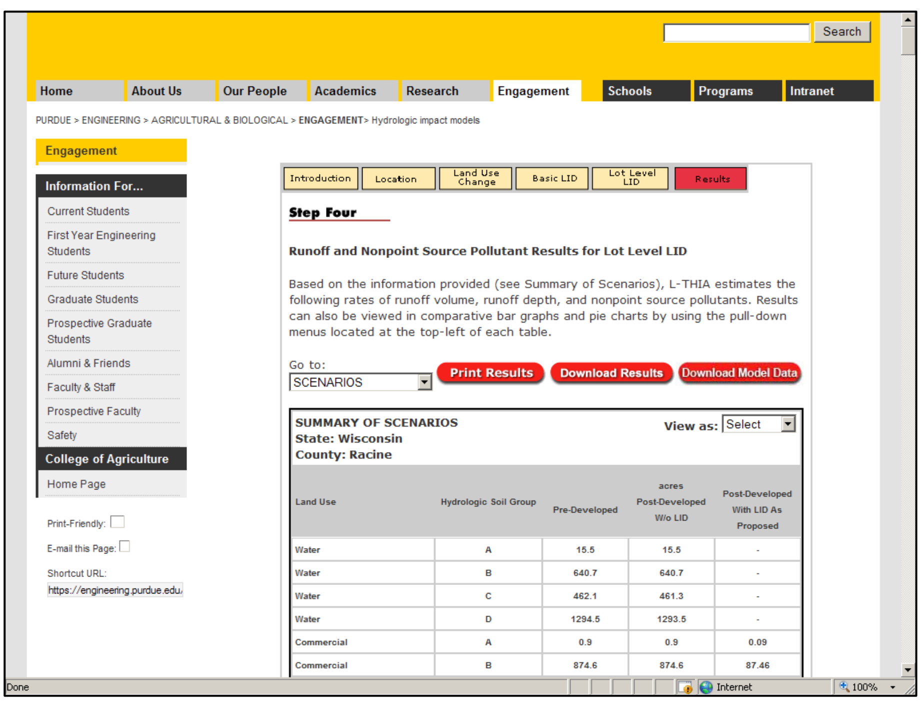
A.15. Repeat steps A.7 –A.11 for the four high density residential land use/soil classes, starting with LAND USE 13. Select the following LID options: STREETS/ROADS = "Swales/Disconnection"; and BUILDING/ROOFS = "Rain Barrels."



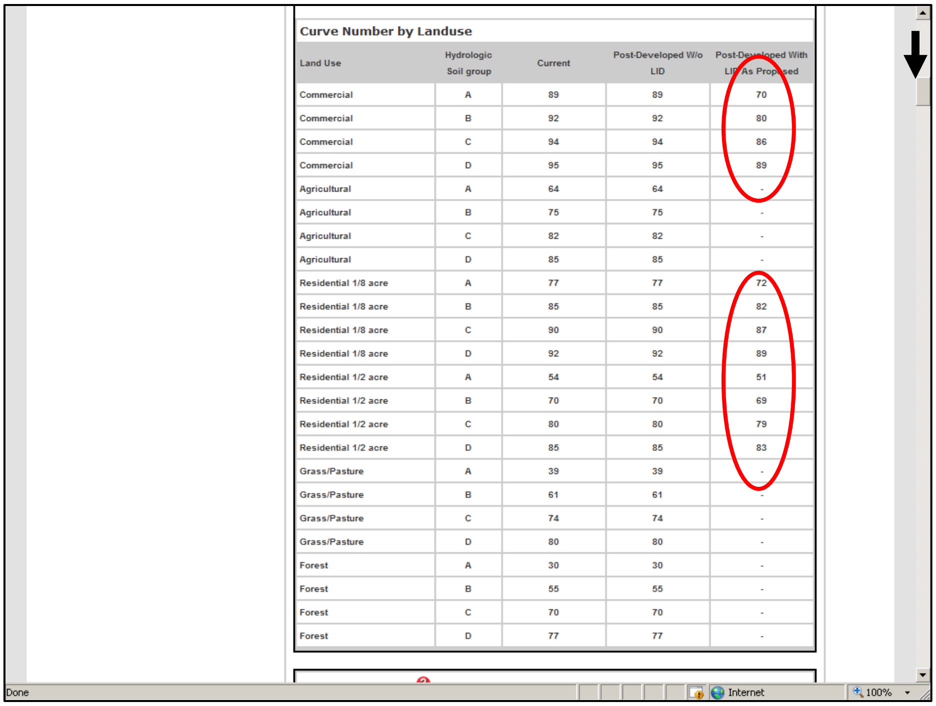
A.16. When you have finished selecting LID options for all of the lands uses click “Next”. A pop-up window will open showing Time elapsed, while L-THIA adjusts the rainfall-runoff curve numbers for each land use.



A.17. A new window will open showing the “Runoff and Nonpoint Source Pollutant Results for Lot Level LID” including a summary table of the pre- and post-development land use scenarios, as well as post-development with LID.



A.18. Scroll down to the table “Curve Number by Landuse” and note the altered rainfall-runoff curve numbers estimated based on the application of the LID practices and changes in effective impervious area.

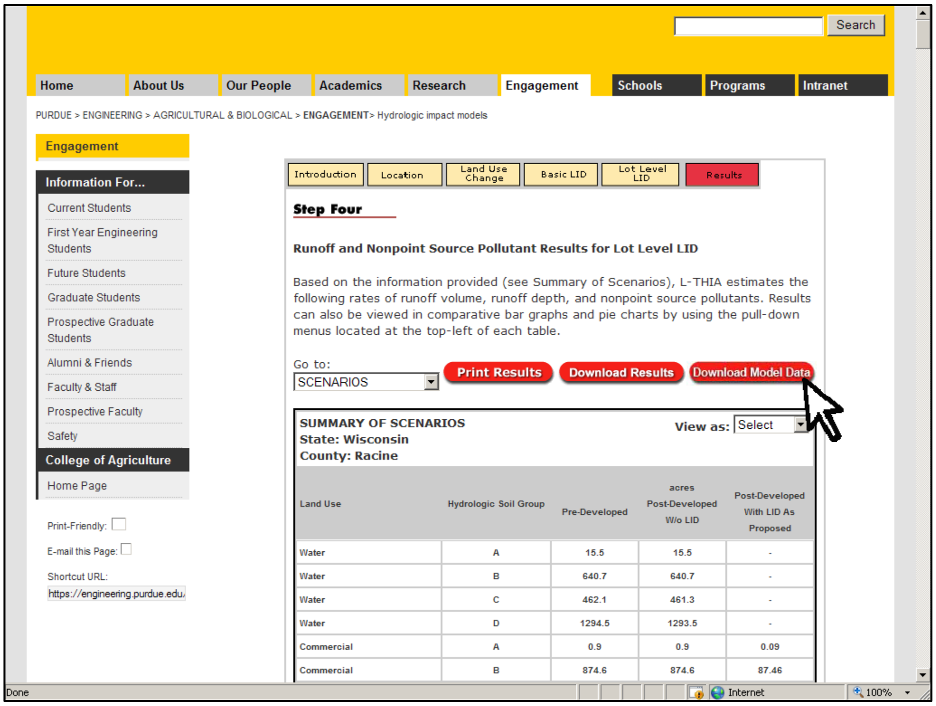


Curve Number by Landuse

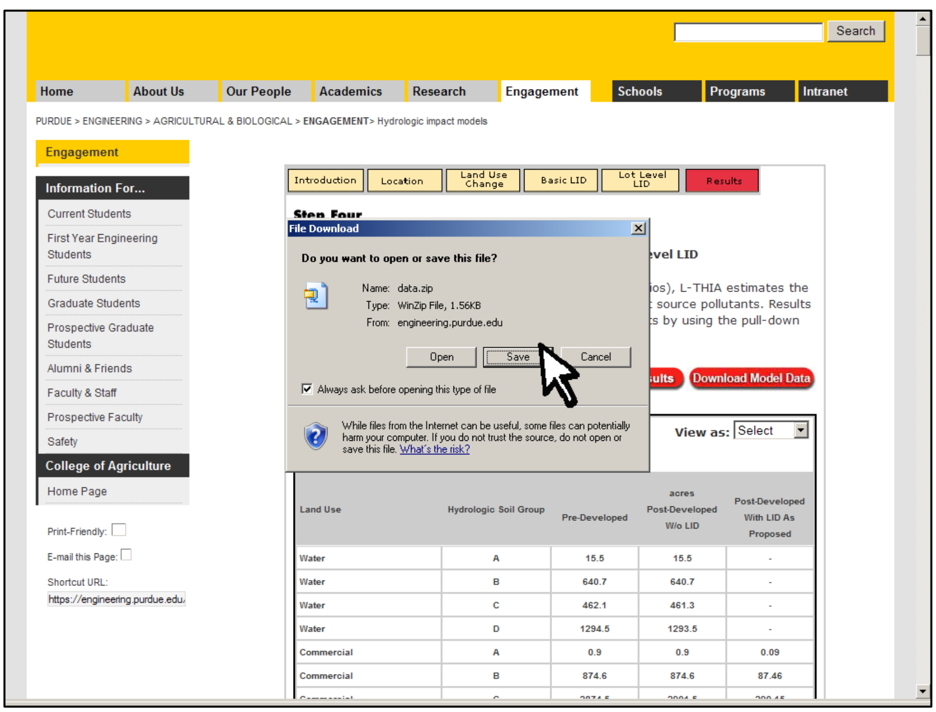
Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Commercial	A	89	89	70
Commercial	B	92	92	80
Commercial	C	94	94	86
Commercial	D	95	95	89
Agricultural	A	64	64	-
Agricultural	B	75	75	-
Agricultural	C	82	82	-
Agricultural	D	85	85	-
Residential 1/8 acre	A	77	77	72
Residential 1/8 acre	B	85	85	82
Residential 1/8 acre	C	90	90	87
Residential 1/8 acre	D	92	92	89
Residential 1/2 acre	A	54	54	51
Residential 1/2 acre	B	70	70	69
Residential 1/2 acre	C	80	80	79
Residential 1/2 acre	D	85	85	83
Grass/Pasture	A	39	39	-
Grass/Pasture	B	61	61	-
Grass/Pasture	C	74	74	-
Grass/Pasture	D	80	80	-
Forest	A	30	30	-
Forest	B	55	55	-
Forest	C	70	70	-
Forest	D	77	77	-

B. Save "before" and "after" model data for use in Real-Time L-THIA

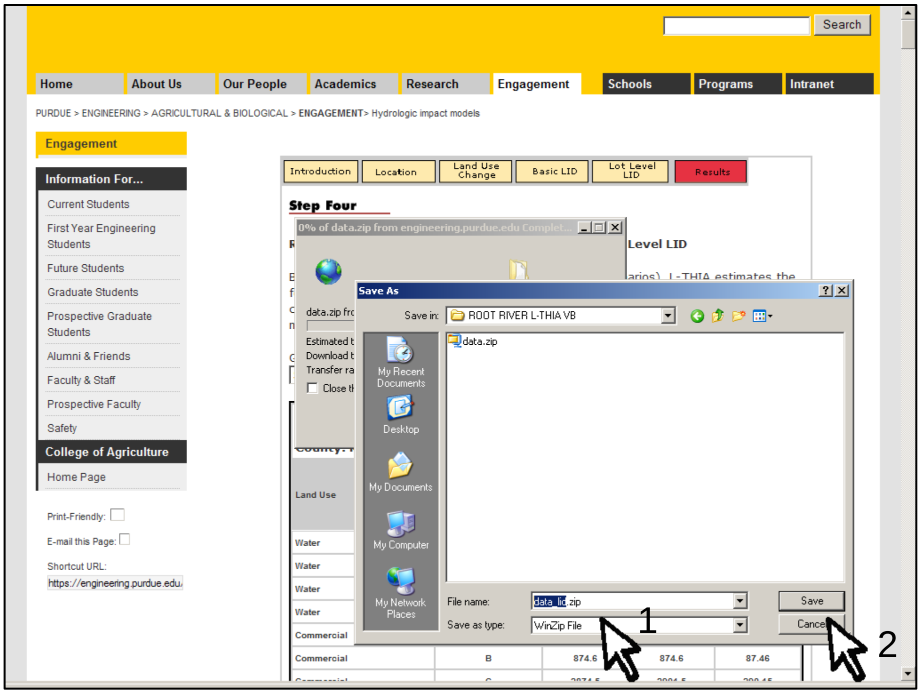
B1. Click "Download Model Data."



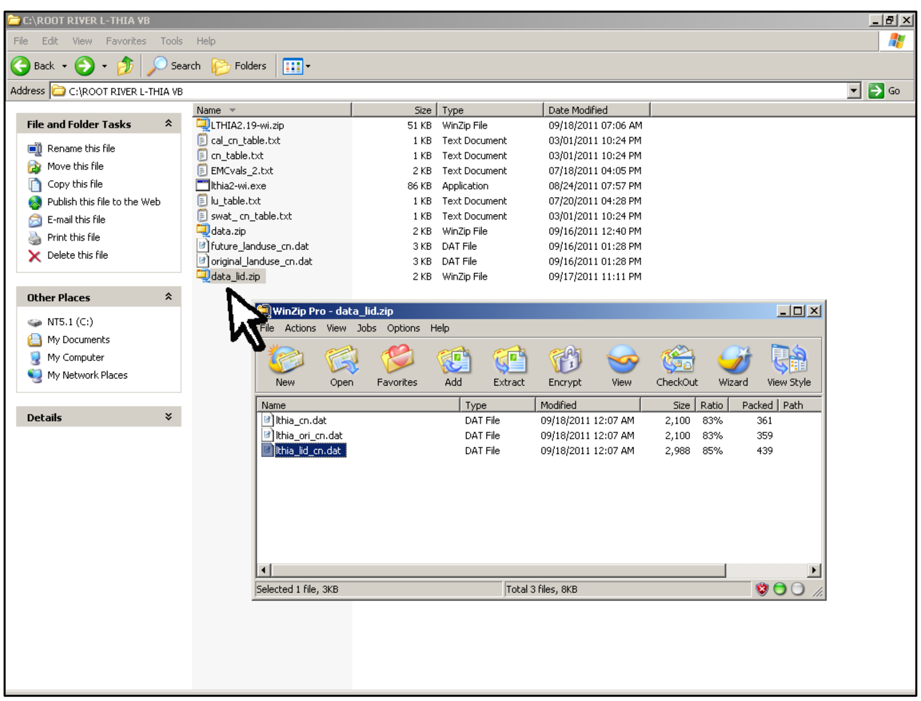
B2. In the pop-up window, click "Save".



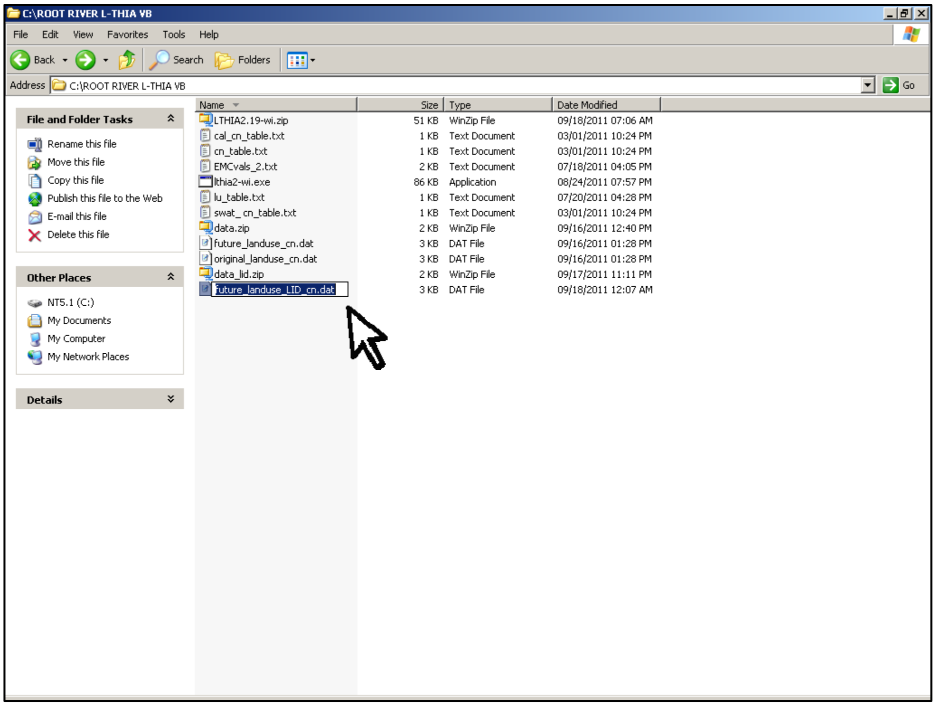
B.3. ID-adjusted model data are recorded in two .dat files bundled in a zipfile: data.zip. To avoid overwriting data downloaded previously (from the Web-Mapping Interface), give the new file a different name (e.g., "data_lid") and click Save.



B.4. Extract the post-development LID file ("lthia_lid_cn.dat") into the directory where you previously saved the land use change scenarios downloaded from the Web-Mapping Interface.



B.5. Once extracted, rename the .dat file to "future_landuse_LID_cn". You should now have three .dat files, representing pre- and post-development land use, and post-development land use with LID.



Appendix D. Illustrated Instructions for Using the Virtual Beach Component

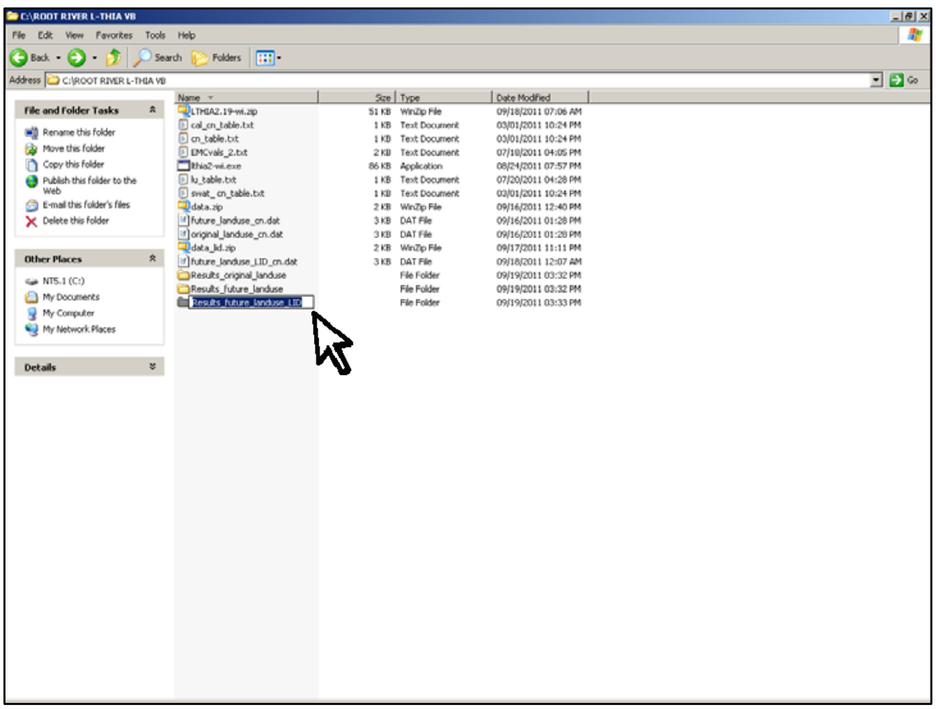
L-THIA/VB Decision-Support System
Learning Module III – *Real-time L-THIA*

In this module you will learn how to:

A. Import "before" and "after" land use and LID model data
B. Substitute default water quality coefficients
C. Estimate daily loads and concentrations of fecal-indicator bacteria

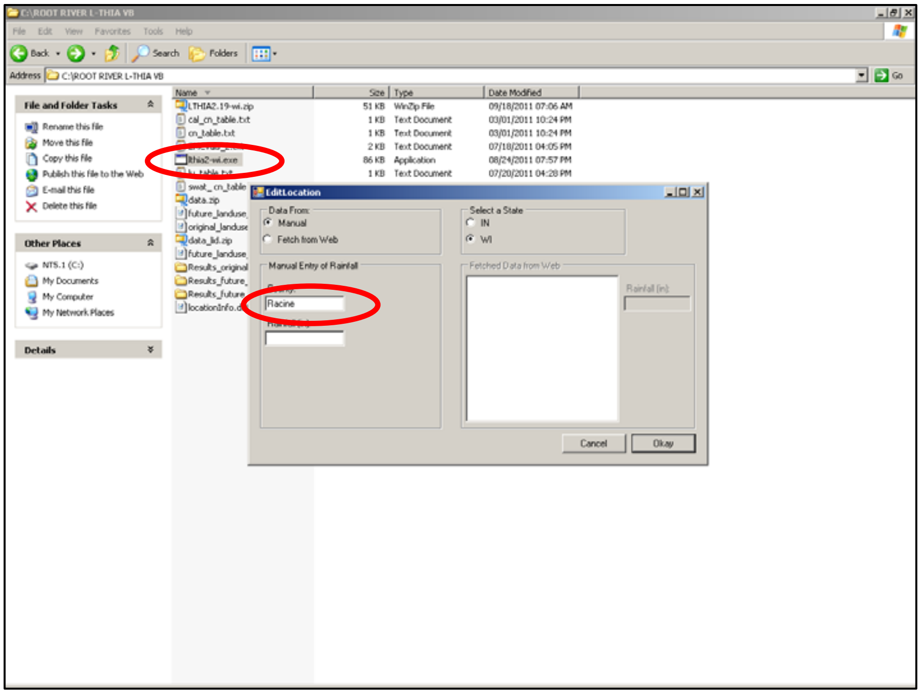
A. Import "before" and "after" land use and LID model data

A.1. For file-management purposes, create three new folders: one file folder for each of the land use/LID scenarios you created in Modules I and II. Give these folders names that will identify the scenarios; for example: "Results_original_landuse," "Results_future_landuse," and "Results_future_landuse_LID."

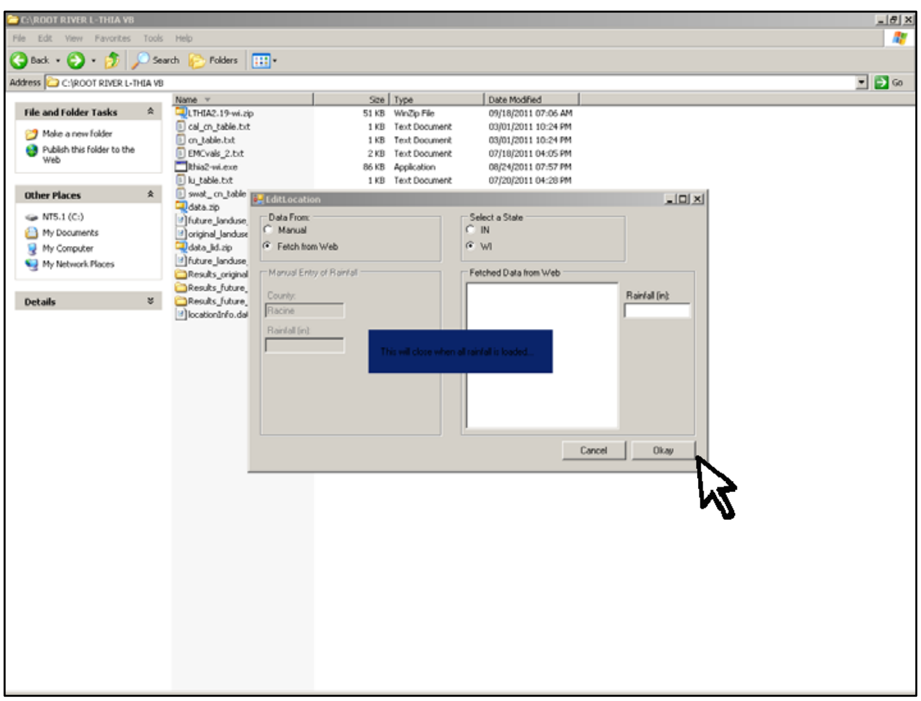


⚠ Real-time L-THIA outputs (predictions) are in the format of separate HTML files for each model run. Over time, this can generate many output files. For the purpose of managing, organizing, and archiving these files, it is a good idea to create separate file folders for the outputs of different land use/LID scenarios (see A.1 above).

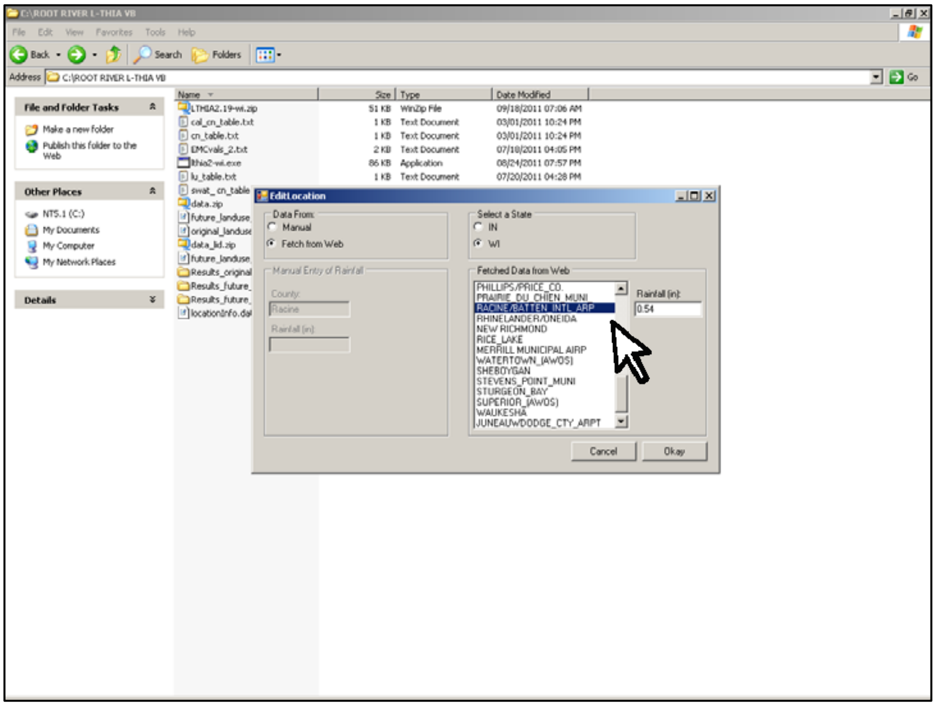
A.2. Open Real-Time L-THIA (lthia2-wi.exe). An Edit Location box will open. The system defaults to "Manual," by which you enter the 24-hour rainfall total. Under "County" the default should be Racine.



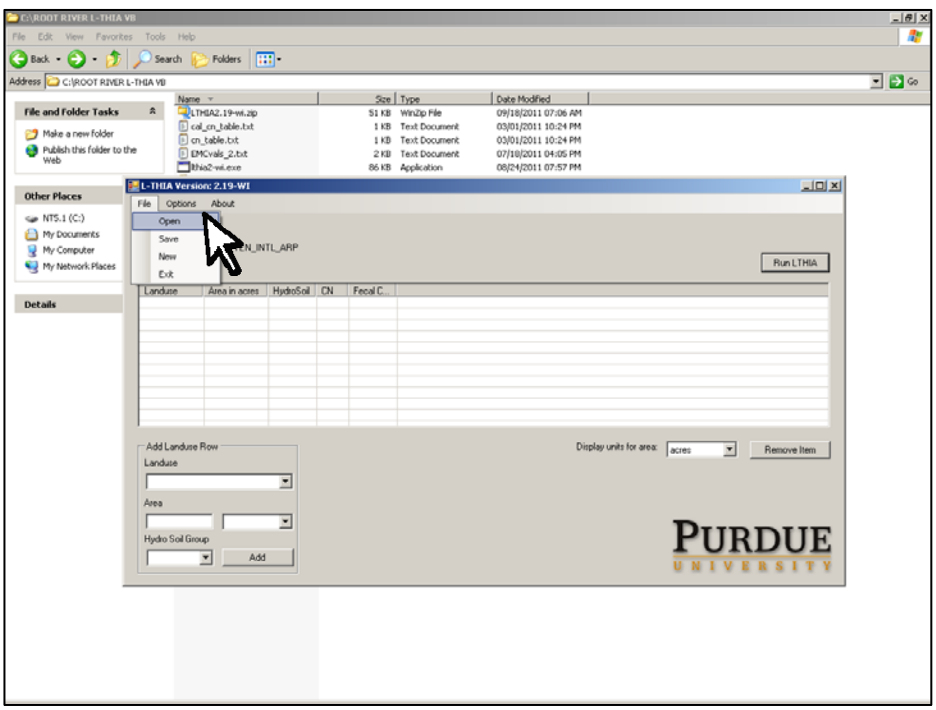
A.3. Another option is to select "Fetch from Web," whereby the system will access the latest 24-hour rainfall total from a NOAA web service. If you choose this option, make sure the radio-button for "WI" (Wisconsin) is selected. Click "Okay".



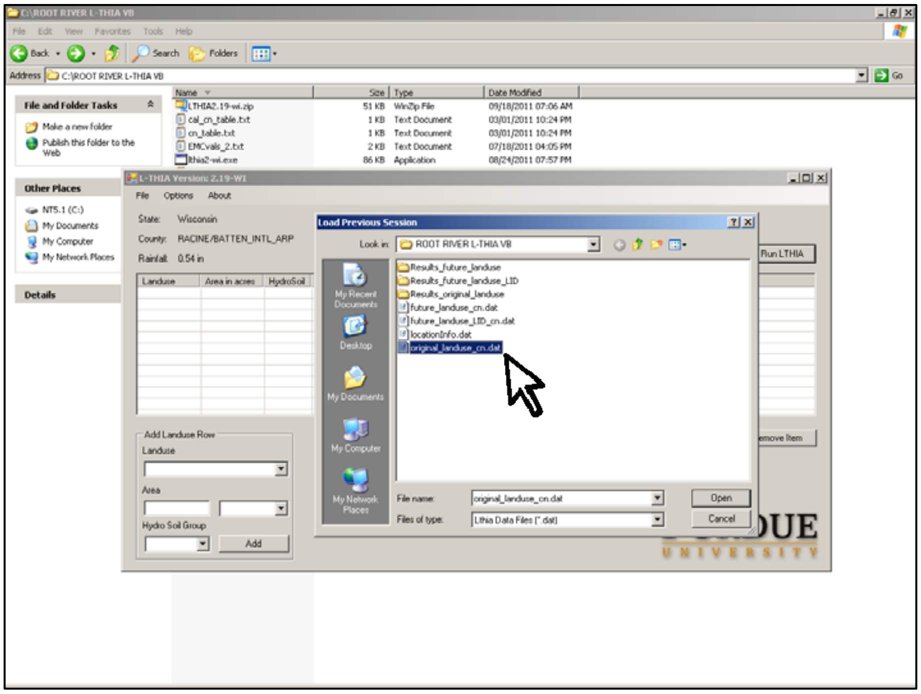
A.4. A statewide, alphabetical list of weather stations will appear. Scroll to "RACINE/BATTEN_INTL_ARP." The Rainfall (in.) box will fill-in with the most recent value. Click "Okay". This will open a new window with an empty table for L-THIA model inputs (see A.5).



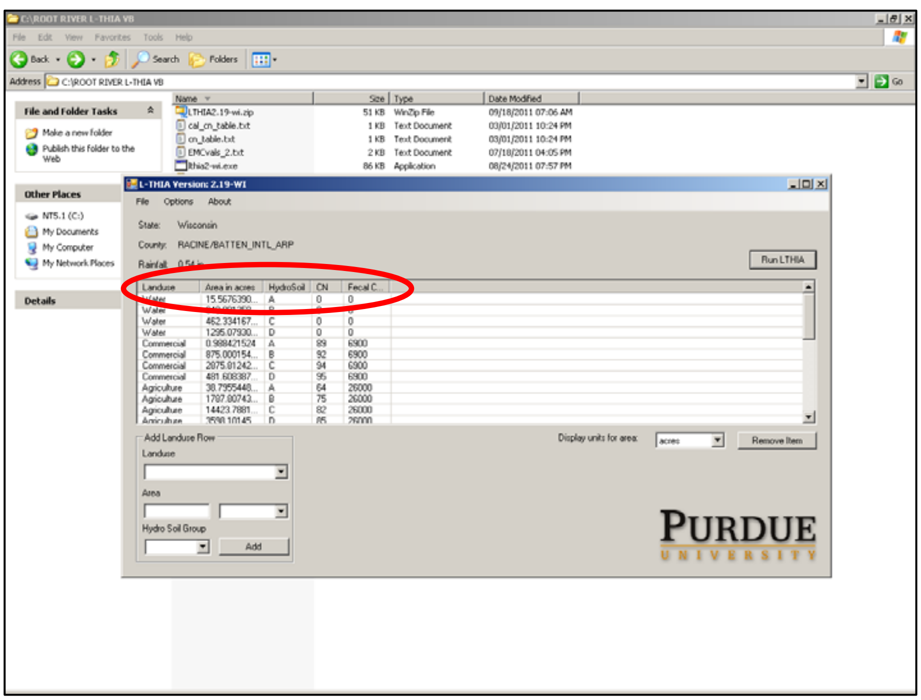
A.5. From the menu bar, select "File > Open."



A.6. Navigate to the directory where you saved the model input data (.dat) files that you generated in Learning Modules I and II [Appendices B and C] using the web-mapping interface or LID system. Select and open the file "original_landuse_cn.dat".

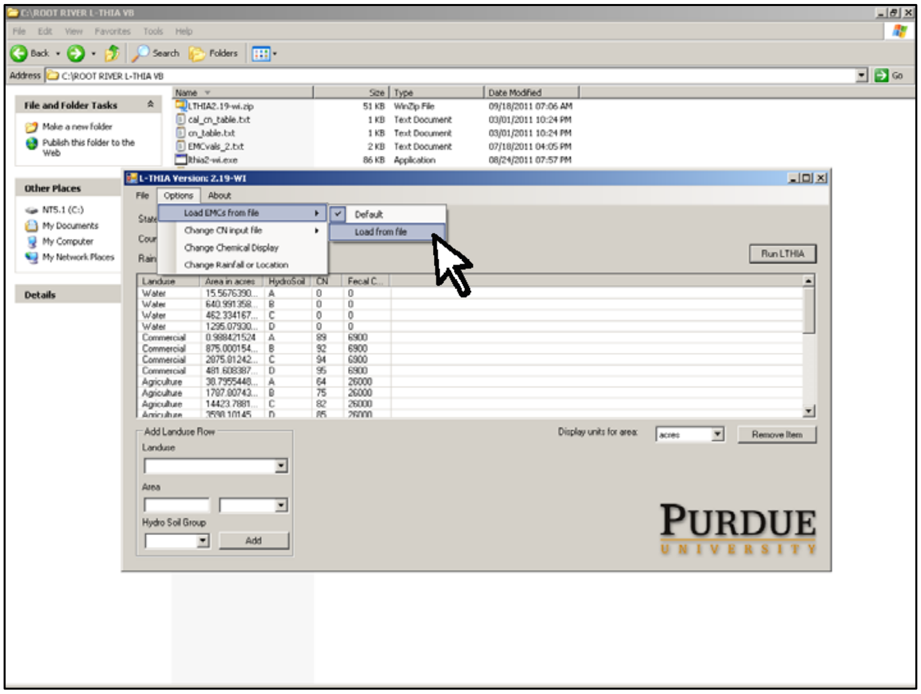


A.7. The data input table will be populated with the model data generated using the web-mapping interface: Land Use, Area, Hydrologic Soil Group, Curve Number, and Fecal Coliform Concentration.

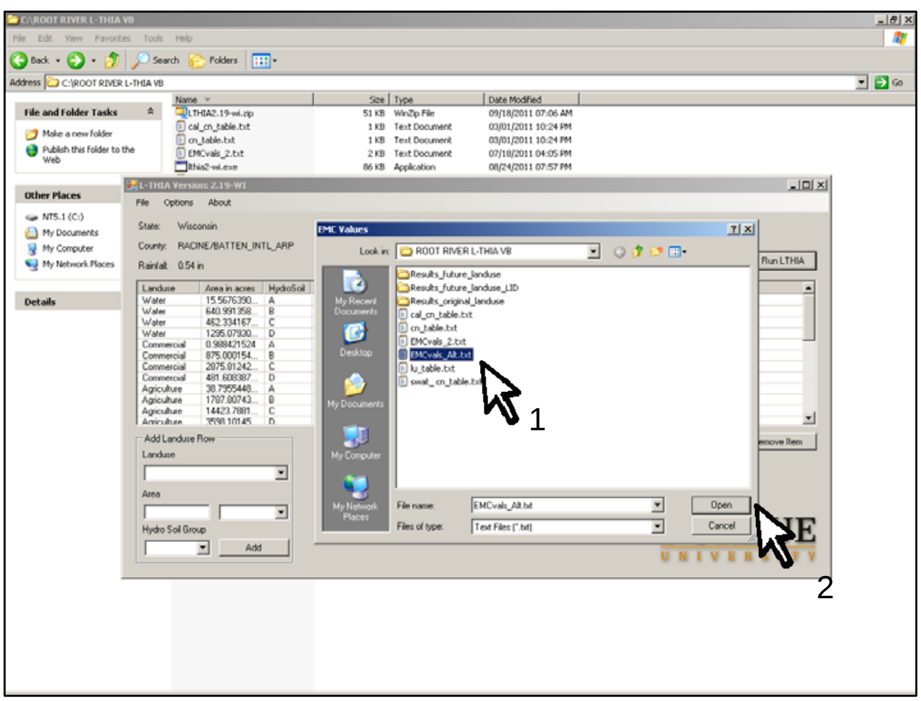


B. Substitute default water quality coefficients

B.1. In the menu bar, select "Options > Load EMCs from file > Load from file."

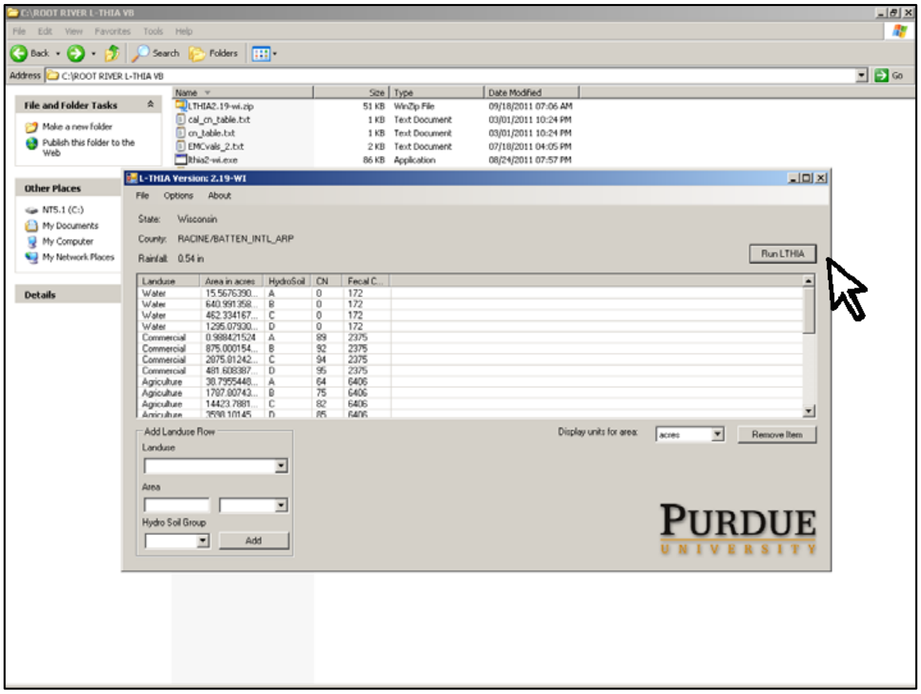


B.2. Select an alternative EMC file. The default is "EMCVals_2.txt." In this example, select "EMCVals_2.alt." These are *E. coli* EMCs from previous studies. Click Open. The new EMC values will appear in the L-THIA table (C.1 below).

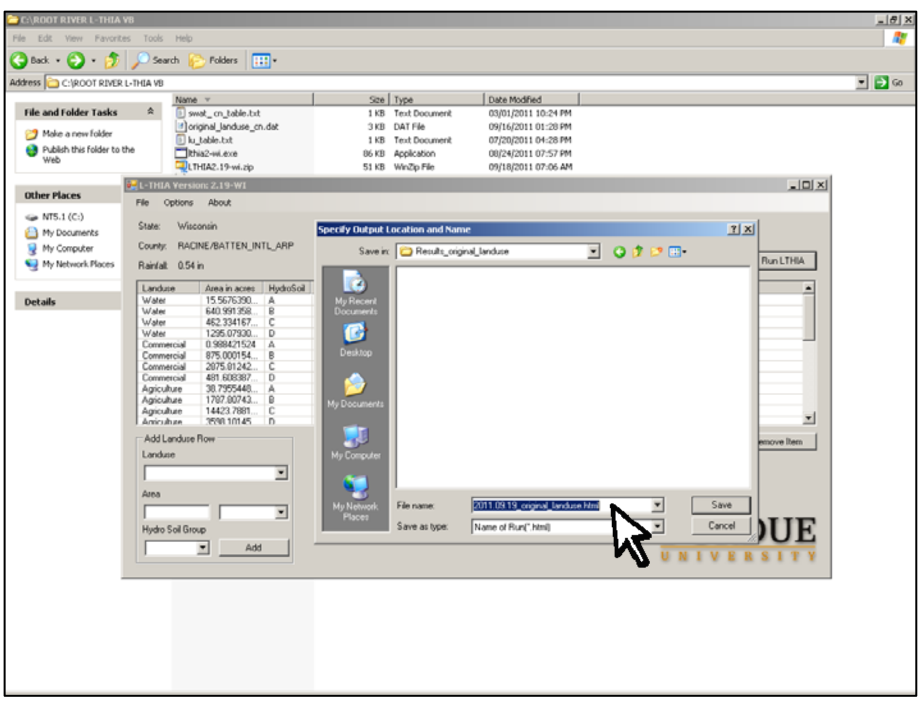


C. Estimate daily loads and concentrations of fecal-indicator bacteria

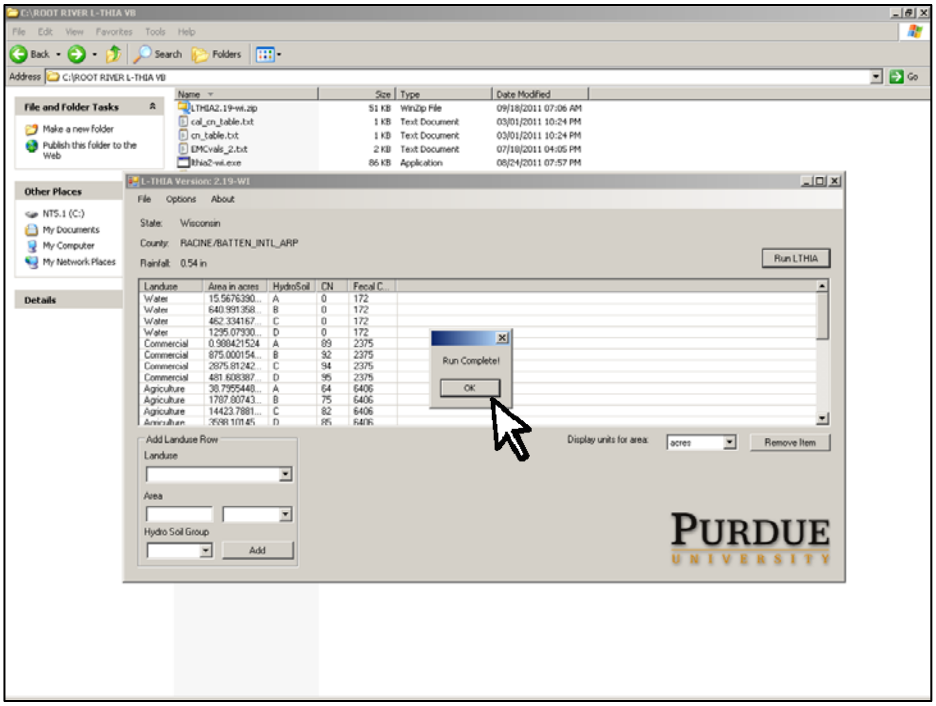
C.1. When you are ready to make a real-time prediction, click “Run L-THIA.”



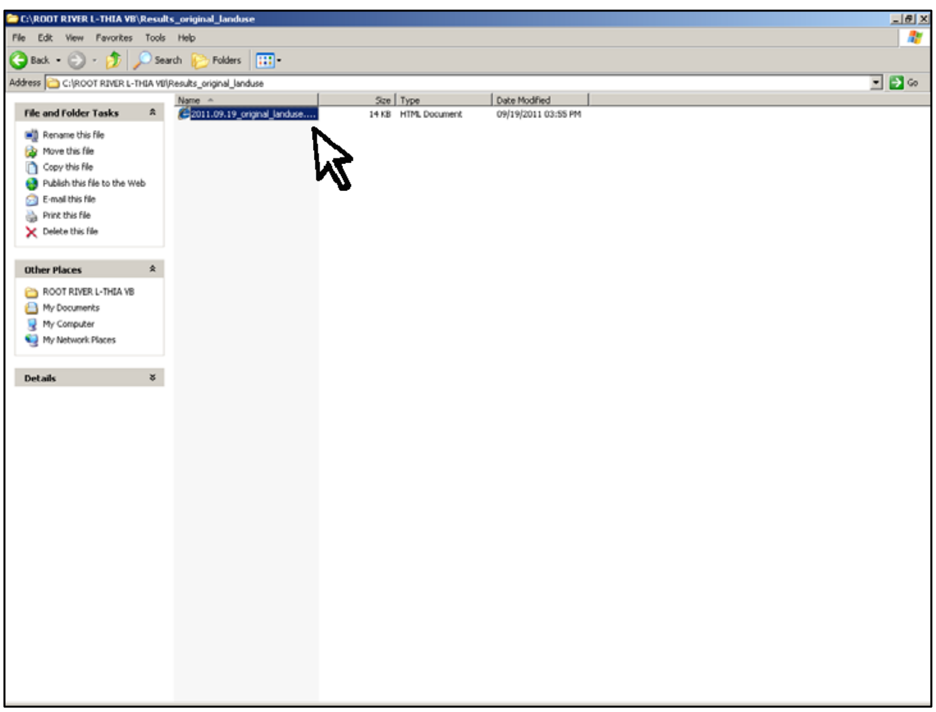
C.2. Navigate to the “Results_original_landuse” folder and name the output file according to the date, starting with the year and month; e.g., “2011.09.20_ original_landuse.html.” This will help you to sort and organize files later.



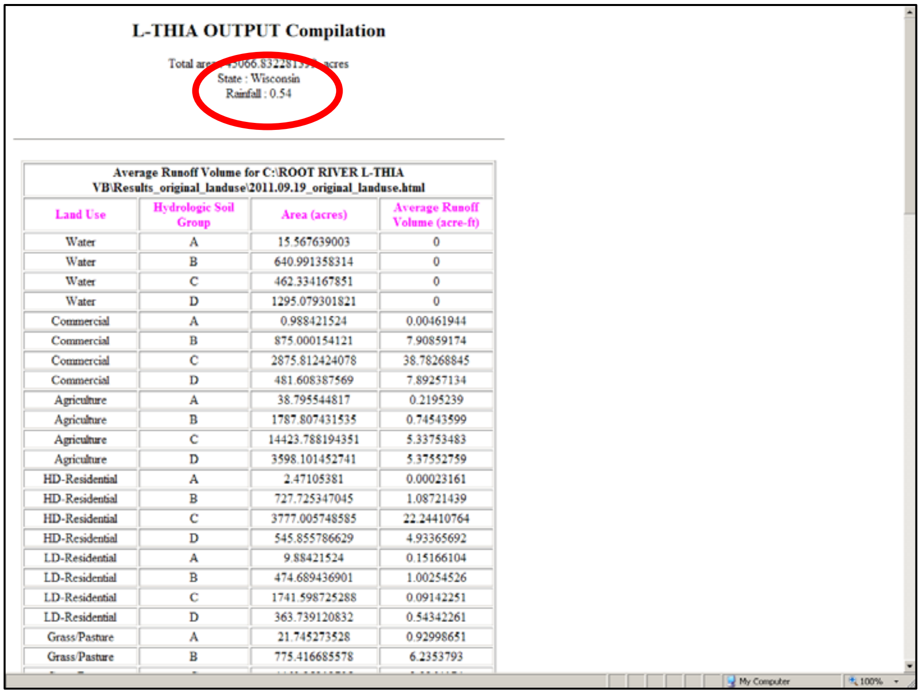
C.3. A "Run Complete!" pop-up will open. Click "OK."



C.4. In your file management system (e.g., Windows Explorer) navigate to the output file and open it. Since the output file is an HTML, the results table will open in your web browser (see C.5 below).



C.5. The results table is a compilation of L-THIA outputs, by land use/soil combination and totaled over the watershed, in response to the input 24-hour rainfall total (in this example 0.54 inches).

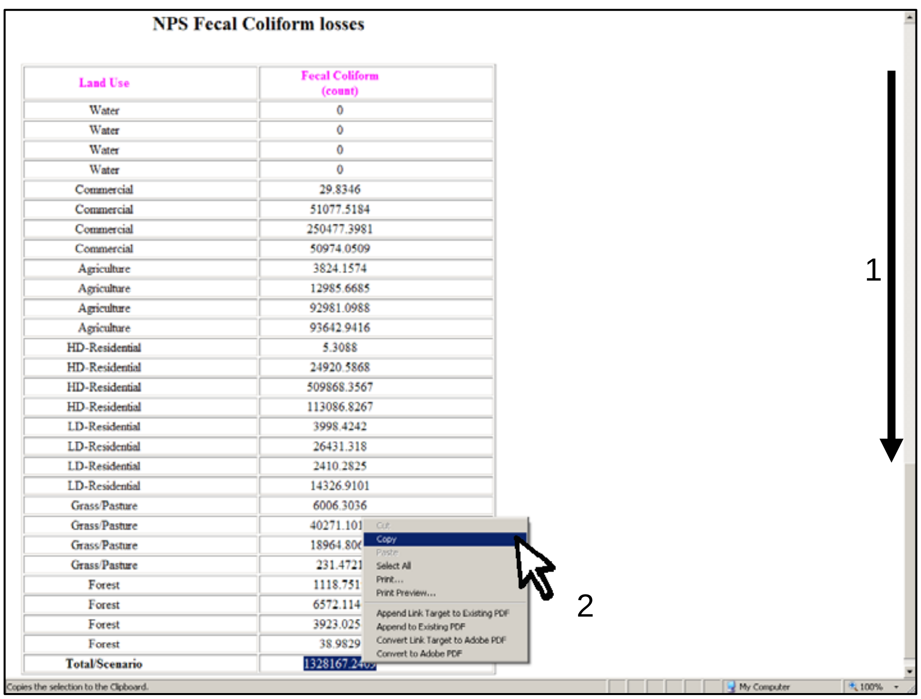


L-THIA OUTPUT Compilation

Total are[illegible]5066.832281[illegible] acres
State : Wisconsin
Rainfall : 0.54

Average Runoff Volume for C:\ROOT RIVER L-THIA VB\Results_original_landuse\2011.09.19_original_landuse.html			
Land Use	**Hydrologic Soil Group**	**Area (acres)**	**Average Runoff Volume (acre-ft)**
Water	A	15.567639003	0
Water	B	640.991358314	0
Water	C	462.334167851	0
Water	D	1295.079301821	0
Commercial	A	0.988421524	0.00461944
Commercial	B	875.000154121	7.90859174
Commercial	C	2875.812424078	38.78268845
Commercial	D	481.608387569	7.89257134
Agriculture	A	38.795544817	0.2195239
Agriculture	B	1787.807431535	0.74543599
Agriculture	C	14423.788194351	5.33753483
Agriculture	D	3598.101452741	5.37552759
HD-Residential	A	2.47105381	0.00023161
HD-Residential	B	727.725347045	1.08721439
HD-Residential	C	3777.005748585	22.24410764
HD-Residential	D	545.855786629	4.93365692
LD-Residential	A	9.88421524	0.15166104
LD-Residential	B	474.689436901	1.00254526
LD-Residential	C	1741.598725288	0.09142251
LD-Residential	D	363.739120832	0.54342261
Grass/Pasture	A	21.745273528	0.92998651
Grass/Pasture	B	775.416685578	6.2353793

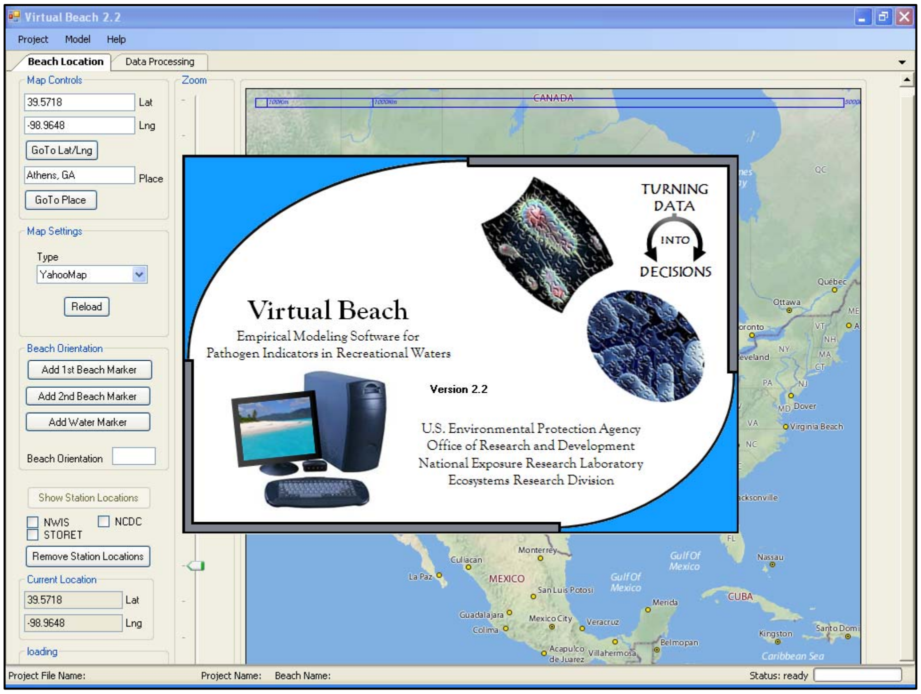
C.6. Scroll to the end of the table. The total NPS bacteria load for the previous 24-hour period is the final value in the table. Highlight this value with your cursor and copy it.



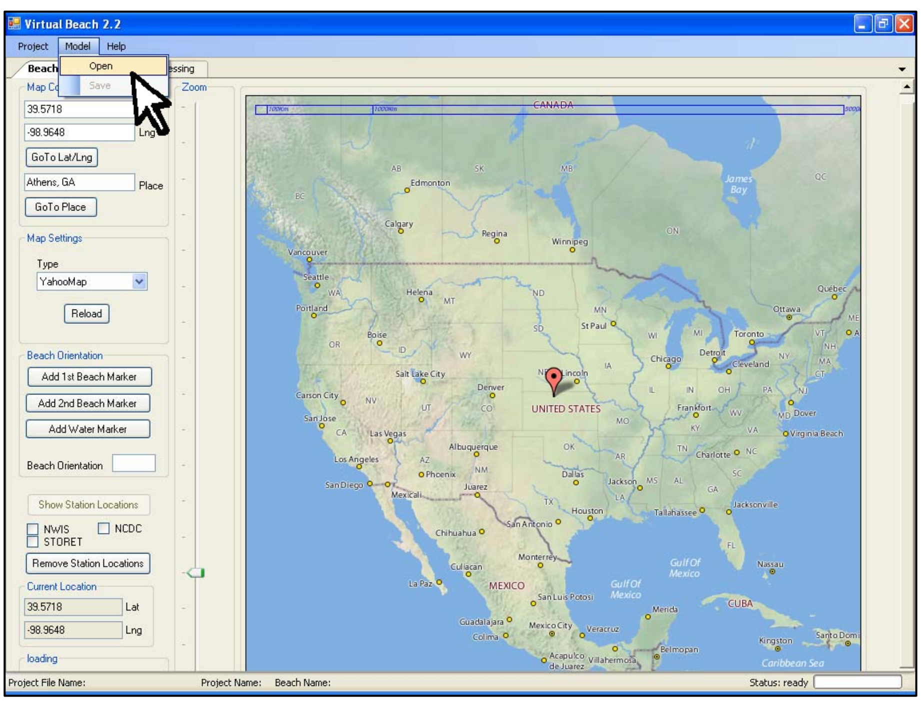
NPS Fecal Coliform losses

Land Use	Fecal Coliform (count)
Water	0
Water	0
Water	0
Water	0
Commercial	29.8346
Commercial	51077.5184
Commercial	250477.3981
Commercial	50974.0509
Agriculture	3824.1574
Agriculture	12985.6685
Agriculture	92981.0988
Agriculture	93642.9416
HD-Residential	5.3088
HD-Residential	24920.5868
HD-Residential	509868.3567
HD-Residential	113086.8267
LD-Residential	3998.4242
LD-Residential	26431.318
LD-Residential	2410.2825
LD-Residential	14326.9101
Grass/Pasture	6006.3036
Grass/Pasture	40271.101
Grass/Pasture	18964.80
Grass/Pasture	231.4721
Forest	1118.751
Forest	6572.114
Forest	3923.025
Forest	38.9829
Total/Scenario	1328167.24

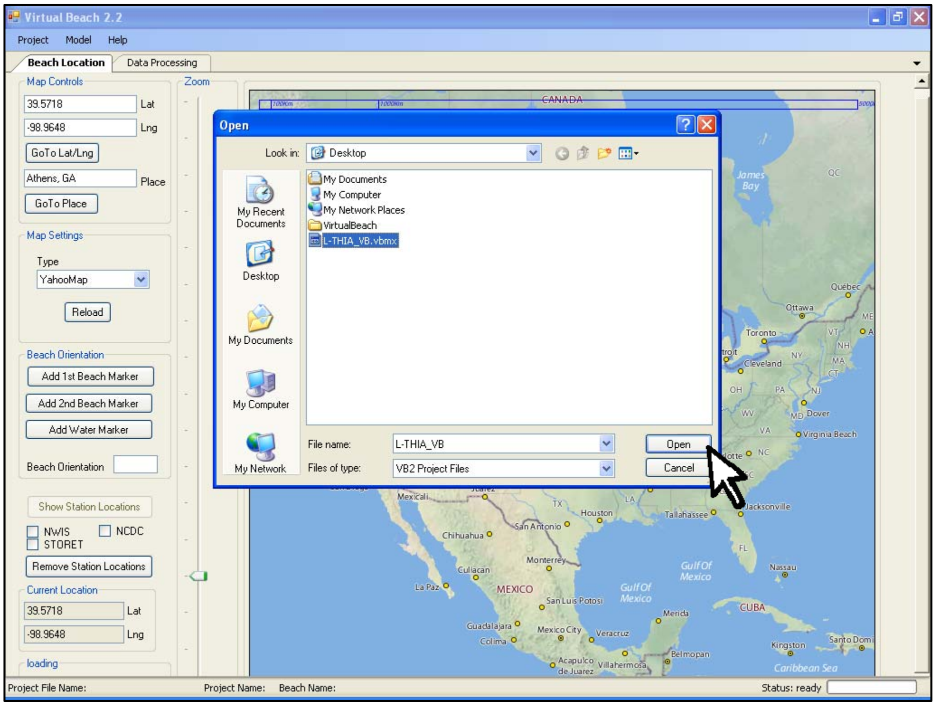
C.7. Open Virtual Beach. (Note: To incorporate the real-time L-THIA results into a beach water quality "nowcast" you will need to have created – or been provided with – a Virtual Beach model file that includes estimated NPS bacteria as an explanatory variable. See Wisconsin DNR's *Predicting Beach Water Quality* website, *Tools and Training* tab: http://dnr.wi.gov/org/es/science/contaminants/beachtools.htm#tab.)



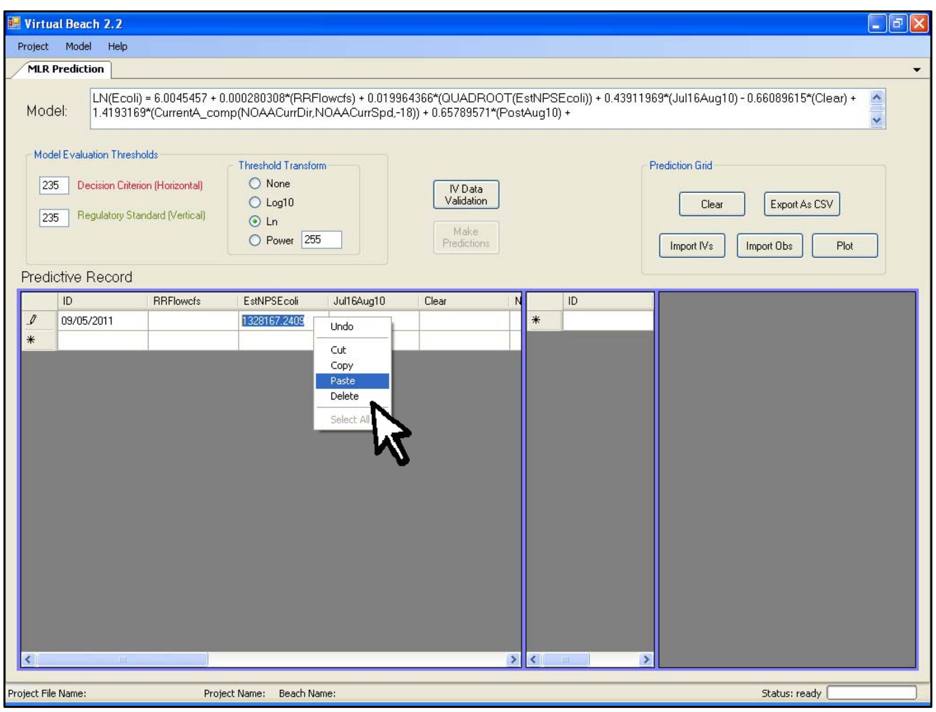
C.8. In the menu bar, select "Model > Open".



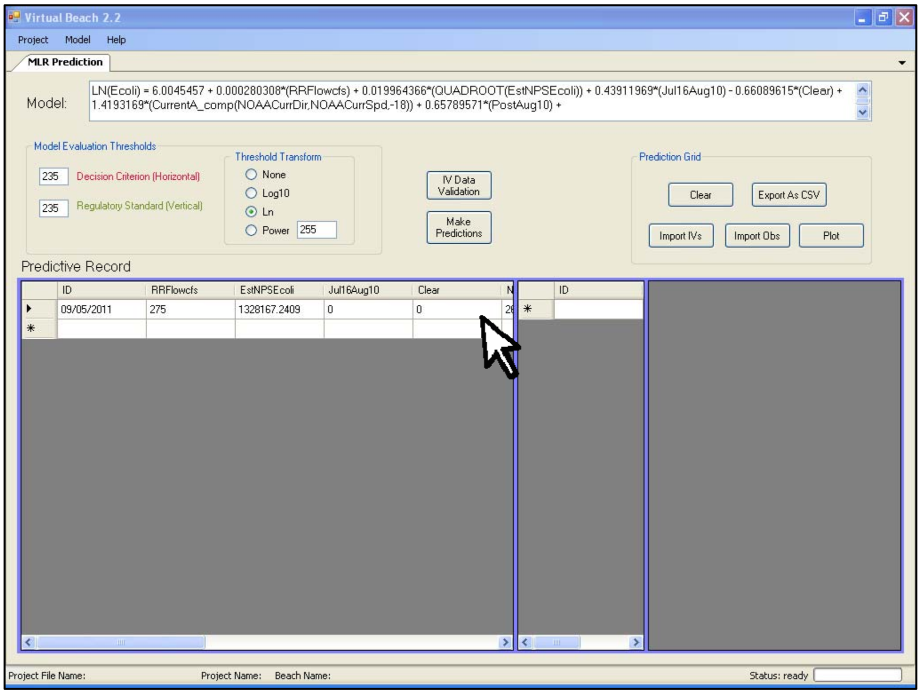
C.9. Navigate to the Virtual Beach model file and click Open.



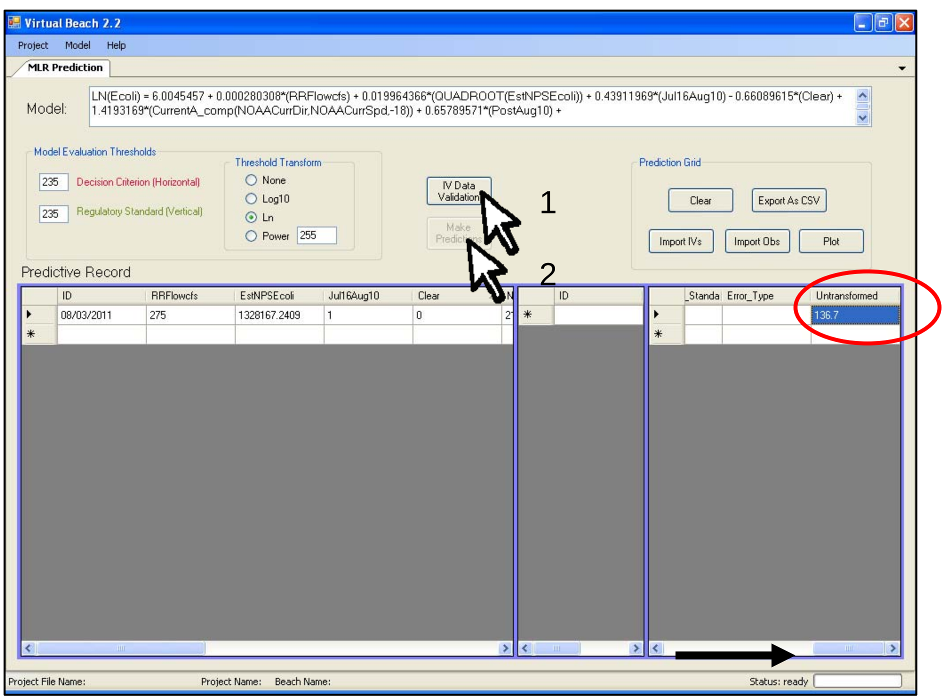
C.10. Enter the current date (under "ID") and paste (right click or CLTRL-V) the value that you copied from the L-THIA results table (see C.6. above).



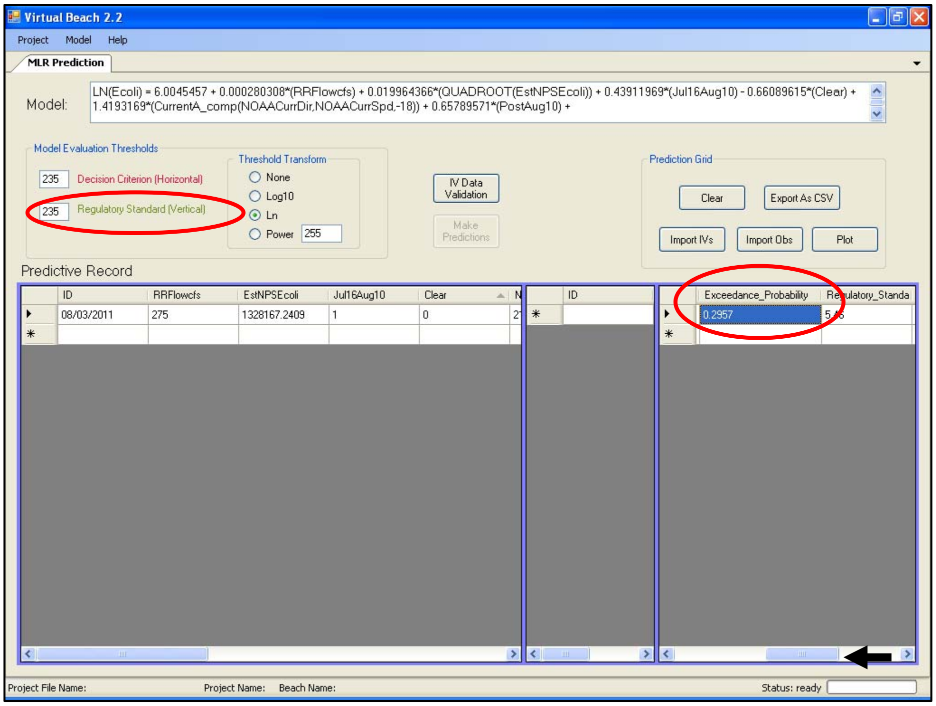
C.11. Enter the values of the other explanatory variables that are included in the beach "nowcast" model.



C.12. When you've finished entering in all of the input data, click "Data Validation" to confirm that there are no missing or anomalous data. Next, click the "Make Prediction" button. Scrolling all the way to the far right, you will see the "Untransformed" (native units) prediction for the beach bacteria concentration.



C.13. Scrolling back, part way to the left, you will see the “Exceedance_Probability.” This is the statistical probability of exceeding the selected regulatory standard. By default, the standard is the federal freshwater standard of 235 CFU per 100 mL.



Note that the beach water quality prediction is based, in part, on the NPS load of *E. coli* estimated by the real-time L-THIA component, which in this example is based on original (i.e. “before”) land use in the lower Root River watershed. Substituting alternative land use- or LID-based (i.e. “after”) results in step C.10 allows you to predict how water quality conditions at the beach might change in response to those changes.

Notes

Notes

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- synthesizing information for policy and management decisions.
- applying the scientific method to the solution of environmental and natural resources problems.
- providing science-based support services for management programs department-wide.
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