On-line Decision Support Tools for Watershed Management:

High Impact Targeting (HIT)
Long-term Hydrologic Impact Assessment and Low Impact Development (LTHIA-LID)
Digital Watershed

A training manual in support of the U.S. Army Corps of Engineers
Great Lakes Tributary Modeling Program

Developed by:

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Introduction

Over the past decade, the U.S. Army Corps of Engineers (USACE) has developed a strong working relationship with the Institute of Water Research at Michigan State University (MSU) and Purdue University's Biological and Agricultural Engineering Department through the Great Lakes Tributary Modeling Program. This relationship has yielded research on sediment loadings at multiple scales, GIS models for erosion and sediment loading risk, new and advanced modeling algorithms, multi-scaled prioritization maps, and on-line decision support systems to help users maintain and restore water quality in watersheds throughout the Great Lakes Basin. These achievements have been published in scientific journals, presented at numerous conferences, and disseminated through hands-on workshops. The on-line decision support systems have been well received by stakeholders and utilized in the development of numerous watershed management plans.

This document is a training manual for three of the most popular of those decision support systems: High Impact Targeting (HIT) for prioritizing sediment reductions from agricultural lands; Long-term Hydrologic Impact Assessment and Low-Impact Development (LTHIA-LID) for evaluating water quality and quantity impacts related to surface run-off; and Digital Watershed, a map portal to watershed scale environmental data across the entire U.S. Each chapter includes sections tracing a particular tool's development, describing scientific bases for underlying models, and walking through each tool's functions. In addition, Appendix A includes step-by-step tutorials for applying each tool to select Great Lake tributaries.

Each chapter is associated with a corresponding author. If you have questions or comments regarding a particular tool, please send them to the appropriate corresponding author. If you have questions or comments regarding this manual, or are interested in participating in a training for these tools, please contact the U.S. Army Corps of Engineers – Detroit District's Great Lakes Tributary Modeling program.

Chapter 1

High Impact Targeting (HIT) Model

[https://www.iwr.msu.edu/hit2]

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Section 1.1: Overview

Sediment and attached nutrients from agricultural run-off pose a major threat to water quality in the Great Lakes region and beyond (Dybas 2005, Trebitz et al. 2007). The annual Lake Erie dead zone can be attributed to the high concentration of agriculture in the western Lake Erie Basin (EPA 1999). There has been marked improvement in reductions of agricultural non-point source pollution to Lake Erie over the past 30 years, through conservation programs such as buffer strips and no-till; however, the problem persists and, in a few areas, is getting worse (Richards et al. 2008).

The Institute of Water Research (IWR) developed the High Impact Targeting (HIT) system/model to prioritize agricultural areas in terms of erosion and sedimentation risk in order to facilitate effective targeting of soil conservation practices. The GIS-based HIT model produces spatially explicit estimates of annual soil erosion and sediment delivery down to 100 m^2 areas, and is accessible for the entire Great Lakes Basin through an on-line mapping interface (www.iwr.msu.edu/hit2).

HIT's development began in 2001, when IWR partnered with the U.S. Army Corps of Engineers (USACE) to help reduce USACE's dredging responsibilities in Great Lakes channels and harbors. IWR combined soil erosion and sediment delivery models to estimate sediment contributions to Great Lakes tributaries, and identify the most likely upland source areas. The principle outcome of this effort was an estimate of annual sediment loading for every 8-digit watershed (hydrologic unit code 8 – HUC8) in the basin (Ouyang et al. 2005). These estimates allowed USACE to begin targeting sediment reduction efforts at a macro-scale. However, to accommodate the broad geographic scope of the analysis, IWR had to generate these sediment estimates at very coarse resolutions of 90m^2. With continued USACE support, and through an NRCS Conservation Innovation Grant (CIG), IWR refined this initial effort and produced basin-wide estimates at minimum 30m^2 resolutions and developed a website to provide decision-support capabilities to users at federal, state, and local scales (O'Neil 2009).

IWR continues to refine HIT by developing finer-resolution models on a watershed-by-watershed project basis, incorporating new and richer model inputs, improving model processing time, and enabling dynamic web-based scenario modeling.

HIT Model Description

Compared to other sediment loading models, HIT is relatively simple. It has a small number of inputs and relatively straightforward variable relationships. This simplicity adds to the overall model uncertainty (discussed later), but has enabled IWR to generate data at scales as broad as the Great Lakes Basin with minimal data input processing.

HIT is the product of two sub-models, the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997) for estimating annual soil erosion, and the Spatially Explicit Delivery Model (SEDMOD) (Fraser 1999) for estimating the percentage of eroded soil from a given area that reaches the nearby stream network (Figure 1.1). For each pixel in a GIS raster representation of a watershed, SEDMOD employs a surface roughness coefficient (Manning's *n*) derived from land cover data, the percentage of soil

composed of clay, and the path of a given pixel to the nearby stream to estimate the percentage of eroded soil from each pixel that reaches the nearby stream each year. RUSLE employs the same inputs to estimate soil loss for each pixel. It uses a digital elevation model (DEM) to estimate the influence of slope (LS factor), a land use raster (with tillage information incorporated if available) to estimate the impact of surface cover (C factor), a soil survey to estimate soil erodibility (K factor), annual rainfall intensity (R factor), and existing conservation practices (P factor). The mathematical product of these factors is annual sheet erosion from each pixel. The combination of the SEDMOD and RUSLE outputs is sediment loading to the nearby stream.

RUSLE is a well tested model that has gone through various improvements since its inception as the Universal Soil Loss Equation in 1978 (Wischmeier and Smith 1978) and is a standard tool for NRCS technicians. SEDMOD is not as well-tested, but has been successfully utilized in a number of studies (Pinney et al. 1998, Brady et al. 2001, Ouyang et al. 2005, Norman and Feller 2008, Norman et al. 2008, O'Neil 2009) and its pixel level estimates of sediment delivery ratio far exceed the resolutions of the catchment-scale outputs of more broadly used sediment models such as the Soil and Water Assessment Tool (SWAT).

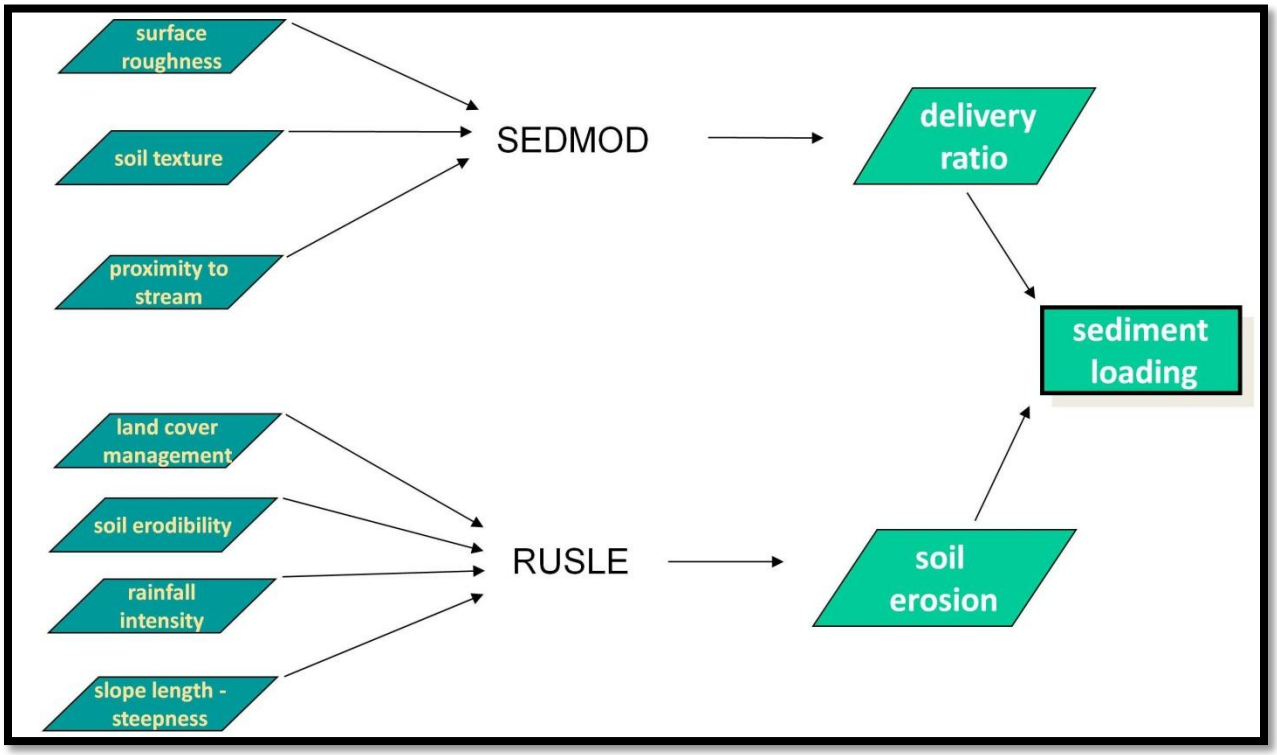

Figure 1.1: The HIT model design.

Most HIT models produced by IWR have been at 30-meter resolutions, as this resolution has been the best available for much of the United States Geological Survey (USGS) National Elevation Dataset (NED) DEMs for Great Lakes Basin. Several Great Lakes Basin watersheds have 10-meter resolution HIT models available, where IWR has had funding for more thorough model pre-processing (including DEM development). The map in Figure 1.2 shows where 10-meter HIT models will be available by the end of 2012 (in yellow), the other areas (in green) currently have 30-meter resolution models available. The other model inputs used to generate HIT outputs in these green areas are also coarser than in the yellow areas. IWR used 1:100K scale STATSGO soil surveys to estimate SEDMOD's clay content and RUSLE's K factor, as opposed to the 1:24K SSURGO soil surveys used in the high resolution areas. Furthermore, for the high resolution areas IWR integrated county-level crop-type data and tillage practice survey results from the Conservation Technology Information Center (CTIC) with multiple years of the USDA's Cropland Data Layer (CDL) satellite imagery to estimate RUSLE C factors that represented specific crop rotations as individual pixels; whereas the coarse resolution areas relied solely on state-wide CTIC survey results to estimate general crop rotations and tillage practices for all agricultural land pixels.

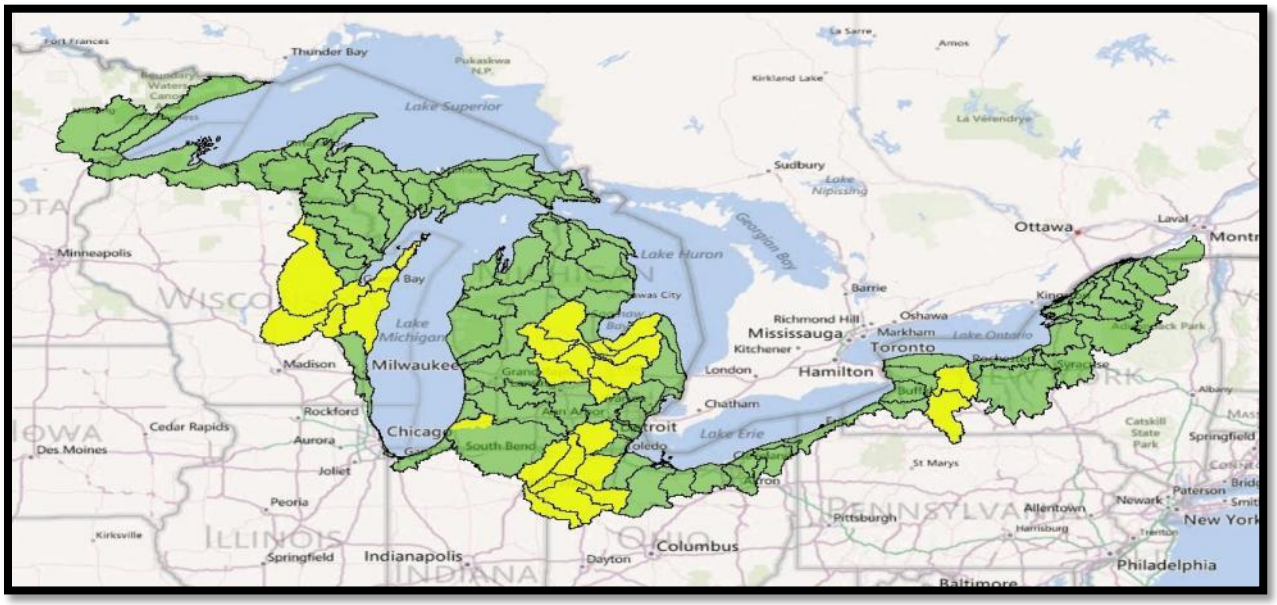

Figure 1.2: 10-meter resolution HIT model availability (yellow) by the end of 2012, 30-meter resolutions (green).

As mentioned earlier, relative to more sophisticated sediment loading models with numerous inputs, such as SWAT and AnnAGNPS, the uncertainty in HIT's estimates of watershed-scale sediment loading is high. RUSLE only accounts for sheet erosion; it does not estimate wind, ephemeral gully, or stream bank erosion, each of which can be severe depending on the region. Furthermore, as an agriculturally based model, HIT is not suitable for estimating sediment loading from urban or sub-urban areas. SEDMOD only reports eroded soil that reaches the stream network, it does not attempt to model in stream sediment transportation or deposition. These limitations make calibration of HIT to observed sediment load results difficult (O'Neil 2009). Therefore, IWR has promoted HIT's watershed-scale estimates of

sediment loading solely for relative prioritization, not for precision estimates of the actual loading or reductions from simulated conservation programs.

HIT's greatest utility as a tool is to identify high-risk sediment loading areas at field scales. Since HIT estimates are produced at pixel levels, users can identify high risk areas within a particular farm field (Figure 1.3). O'Neil (2009) coordinated a thorough field-scale evaluation of HIT's ability to identify these high risk areas. Local conservation district technicians visited over 200 individual sites and assessed whether HIT correctly characterized the sediment loading risk at each location. Results showed that HIT's characterization was correct at roughly 70% of the sites. Return visits to a sample of the 30% of sites where HIT did not accurately represent risk revealed that coarse land cover inputs and relatively flat topographies (which confound surface water flow-routing algorithms) led to the model's poor performance in those areas.

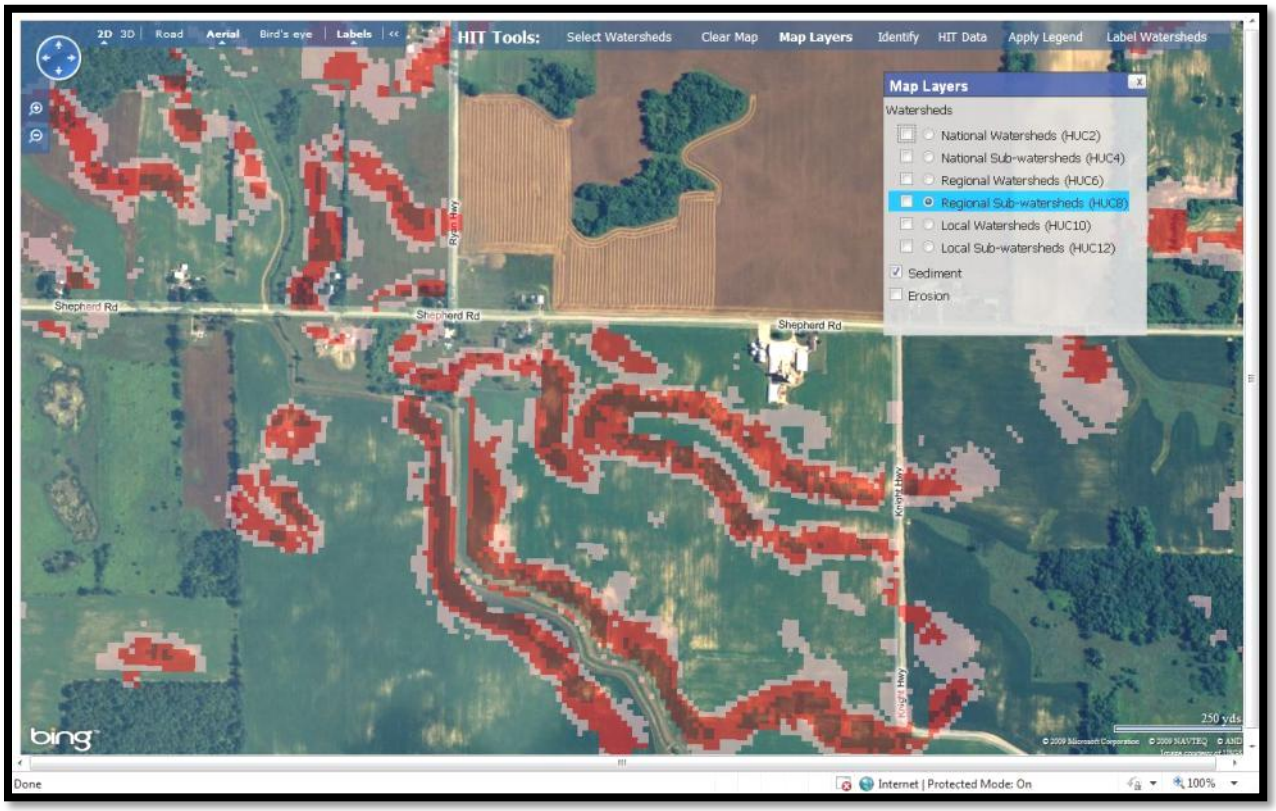

Figure 1.3: Field-scale sediment loading risk in HIT.

These generally positive results, and the broad availability and accessibility of HIT data, encouraged the Michigan Department of Environmental Quality (DEQ) to promote HIT's use in the development of EPA 319 Watershed Management Plans (which need state approval). Several Michigan local conservation districts have utilized HIT in the development of watershed plans, and in day to day operations.

Though it is a relatively simple approach to estimating sediment loading, HIT is a readily accessible tool for effective targeting of sediment reduction activities, mitigating the need for costly time-intensive model development.

Section 1.2: HIT Functionality

I. Navigating the HIT main page

A. HIT homepage

To access the HIT main page, open up a web-browser and type in the following address: www.iwr.msu.edu/hit2

B. "Data Access" tabs

The links under "Data Access" are used to select watersheds. The "By watershed" and "By address" allow a user to select watersheds from the main page. The "Straight to map" tab allows the user to select watersheds on the map. See Part II of this section on page 7 for more detail. The selected method will appear in bold.

C. "Help" tab

This page provides contact information for questions regarding the HIT model, and also includes a link to various instructional documents.

D. "About HIT" tab.

This page provides detailed background information on the HIT model, as well as a tutorial specific to the Swan Creek watershed in northwestern Ohio.

II. Selecting watersheds in the HIT main page

A. By watershed

1. To search for a watershed by HUC or watershed name, type it into the search bar at the top of the page. Hitting the "Find" button presents a list of corresponding HUCs at different scales for the information entered. After selecting the watershed of interest, a user can choose to map the watershed or make a HIT table for that watershed. See Figure 1.5.
2. A user can also search for watersheds using the fields below the search bar. The watersheds in each box can be sorted alphabetically or by HUC, or filtered by selecting a HUC of a larger scale. A user can select multiple watersheds by holding down the "Ctrl" key and clicking on the desired watersheds. See Figure 1.5.

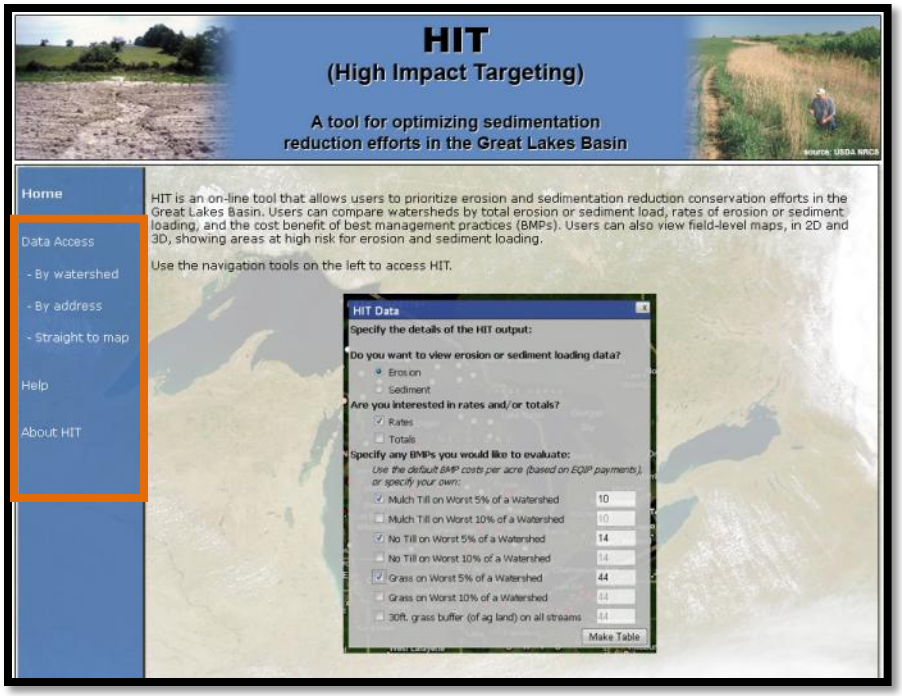

Figure 1.4: HIT Homepage

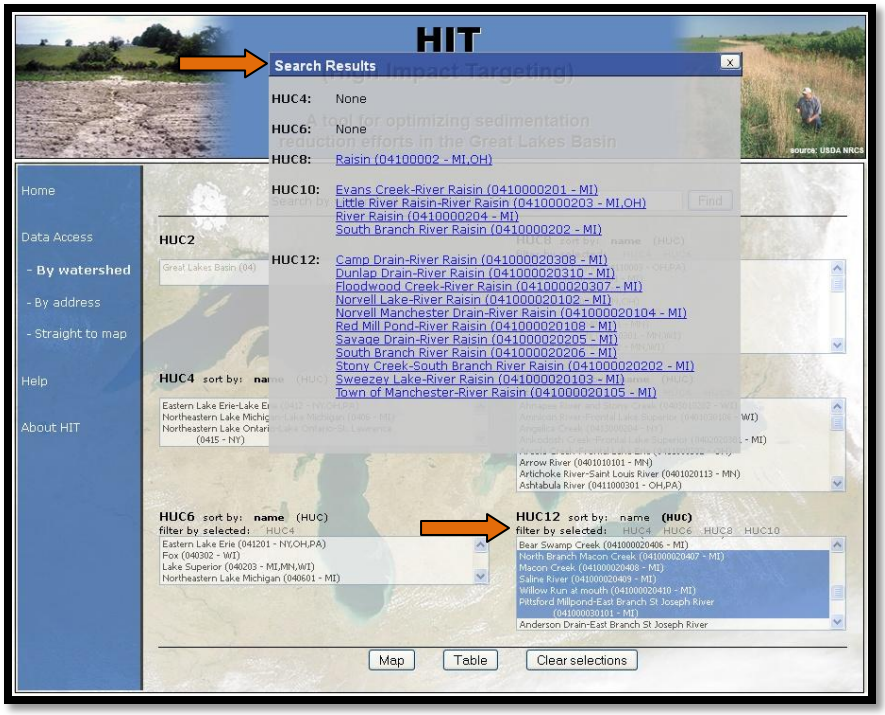

Figure 1.5: "Data Access: By watershed"

B. By address

1. A user can search for watersheds using a specific location. This can be a street address, town, or county.
2. The "Map" button will take the user to a large-scale aerial image of the location.
3. The "Watersheds Here" button displays the watersheds intersecting the center point for the location. At each HUC level, the user can enter the map with that watershed selected, or the user can create a HIT table. See Figure 1.6.

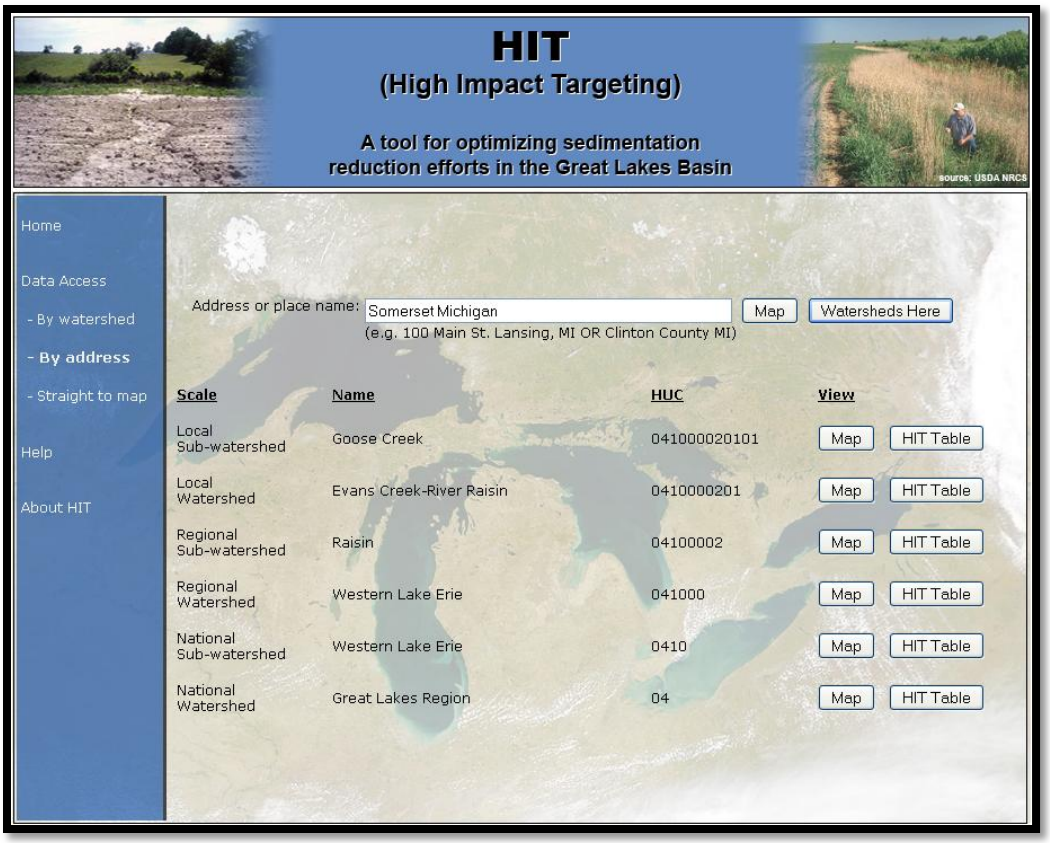

Figure 1.6: "Data Access: By address"

III. Navigating the map page

A. Bing Maps Navigation

HIT's mapping interface is built upon Microsoft Bing Maps. Bing Maps navigation tools are anchored in the top left corner. See Table 1.1 for a description of Bing Maps navigation tools and Figure 1.7 for corresponding icons.

Tool	Description
1. Pan	Clicking on the hand once and dragging allows you to move to a different location on the map.
2. Zoom	To zoom in or out, click on the corresponding magnifying glass. A user can also double click anywhere on the map to zoom in at that location (when active map tool is pan/zoom).
3. Navigate	Clicking on the corresponding arrows within the blue navigation circle will move the map north, south, east or west.
4. Set map dimension	The default map dimension is 2D. 3D is discussed further in Part VIII (p 20).
5. Set map image	The default map image is an aerial photo. Bird's eye view is discussed further in Part VIII (p 19).
6. Toggle labels	Map labels are turned on by default. Turn this off to reduce clutter on the map.

Table 1.1: Bing Maps Navigation Tool Descriptions

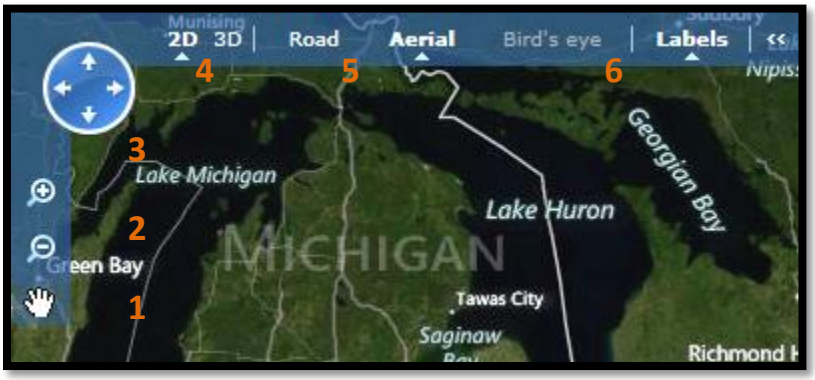

Figure 1.7: Bing Maps Navigation Tools

B. Map Layers

1. Visible and active map layers

All map layers in the HIT model can be drawn on the map. Map layers are drawn on the map by checking the corresponding square box next to a layer's heading. Multiple layers can be drawn on the map at once.

Certain map layers can be activated for use with HIT tools, but only one layer can be active at a time. A layer can be active even when it's not visible on the map. To activate a layer, click on the circle button next to a layer's heading. The map's active layer will be highlighted in blue. Referring to Figure 1.8, the *Regional Sub-watersheds (HUC8)* layer is drawn on the map and is the active layer. All other layers are turned off except for *Sediment* and the *Local Watersheds (HUC10)*. The results of many HIT tools are defined by the selected active layer.

For instance, if the *HUC8* layer is active, then HIT outputs will be based on HUC8 watershed data. With this layer active, only HUC8 watersheds can be searched for and selected on the

map, only *HUC8* layer features will be given when using the "Identify" tool, and only HUC8 watershed features can be labeled on the map, etc.

2. Watershed Layers

The HIT model can display HUC2-HUC12 watershed boundaries. Activate one of these layers before selecting a watershed.

These layers contain several attributes. All of them provide the watershed name and hydrologic unit code (HUC), watershed acreage, baseline annual erosion (erobase) and baseline annual sediment loading (sedbase), as well as erosion/acre/year (ero_acre) and sediment loading/acre/year (sed_acre). Figure 1.10 on page 12 provides an example of what attribute information appears when using the "Identify" tool.

3. HIT Layers

The HIT *Sediment* and *Erosion* layers are rasters that display relative high risk areas for erosion or sediment loading. The "Map Legend" tool informs the user that lighter colors indicate moderate erosion or sediment loading, whereas darker colors can indicate high or highest erosion or sediment loading. Further information on these layers can be found in Part VIII, A on page 19.

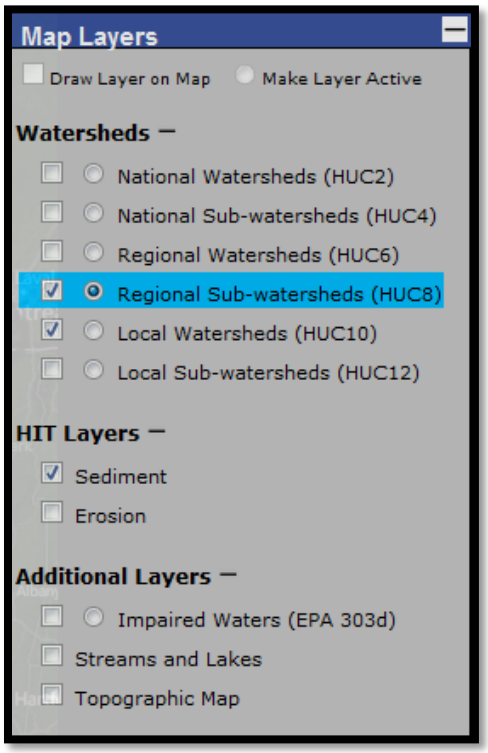

Figure 1.8: Visible and active layers

4. Additional Layers

- Impaired Waters (EPA 303d)

  The EPA, describes impaired waters as those, "…that are too polluted or otherwise degraded to meet the water quality standards set by states, territories, or authorized tribes," (http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm). Specific features of this layer such as the reason for impairment (CAUSE_DESC) can be found by using the "Identify" tool when this layer is active.

- Streams and Lakes

  Streams and lakes from the National Hydrology Dataset (http://nhd.usgs.gov/) can be drawn on the map using this layer.

- Topographic Map

  This layer provides elevation data through topographic maps created by the U.S. Geological Survey.

C. HIT Toolbar Basics

The HIT Toolbar is anchored at the top of the screen and is the access menu for HIT tools. An activated tool will appear in bold in the toolbar.

1. "Map Legend" Tool

A user can display the legend for the layers currently drawn on the map by clicking on "Map Legend." See Figure 1.9.

2. "Identify" Tool

A user can identify the features of the map's active layer by selecting "Identify" and clicking on the map in an area of interest. To view the results, hover over the pushpin. Refer to Figure 1.10 for an example of attributes identified for a HUC8 watershed.

3. "Label Watersheds" Tool

A user can label the active watershed layer by a specified attribute by clicking on "Label Watersheds" and selecting the desired attribute.

4. "Clear Map" Tool

A user can clear the map of any selected watersheds, labels, or identified features by clicking on "Clear Map."

5. HIT Help

A user can access HIT tool descriptions, a detailed presentation on HIT development, and a walk-through HIT tutorial by clicking on the question mark button from the HIT toolbar.

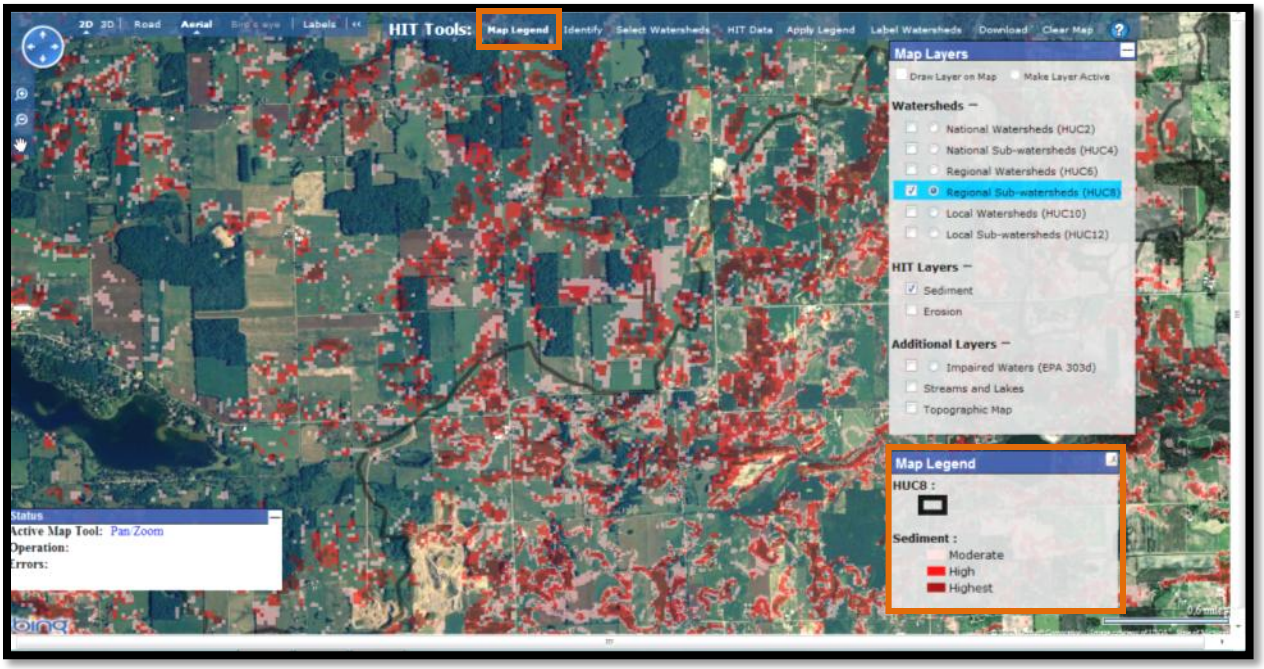

Figure 1.9: "Map Legend" Tool

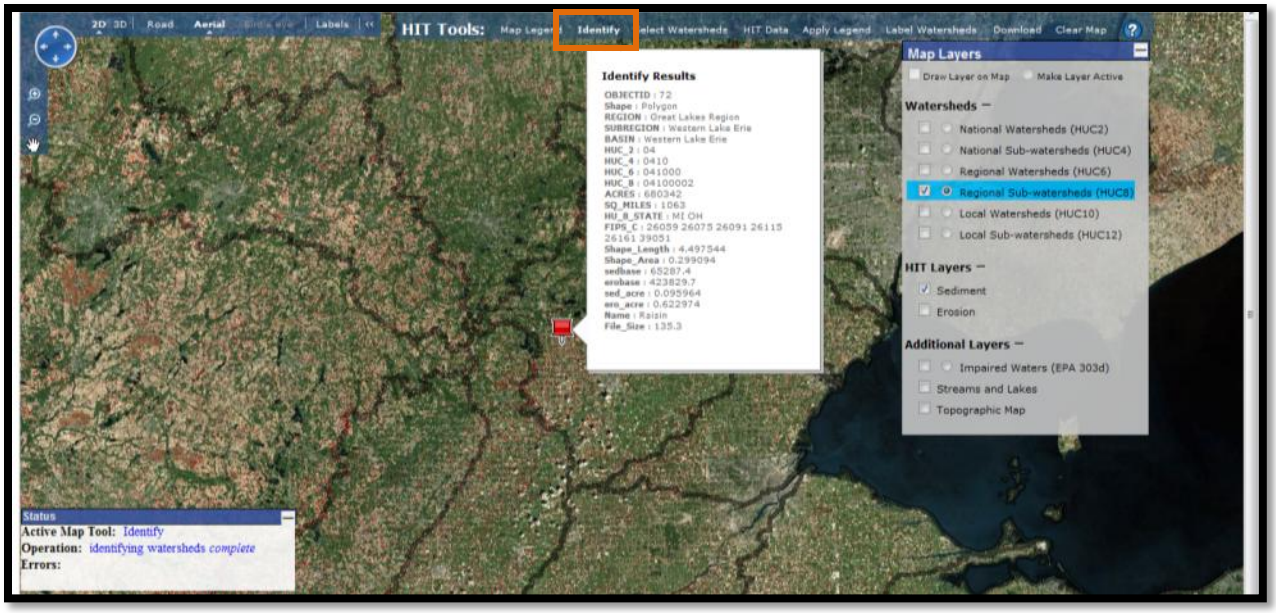

Figure 1.10: "Identify" Tool

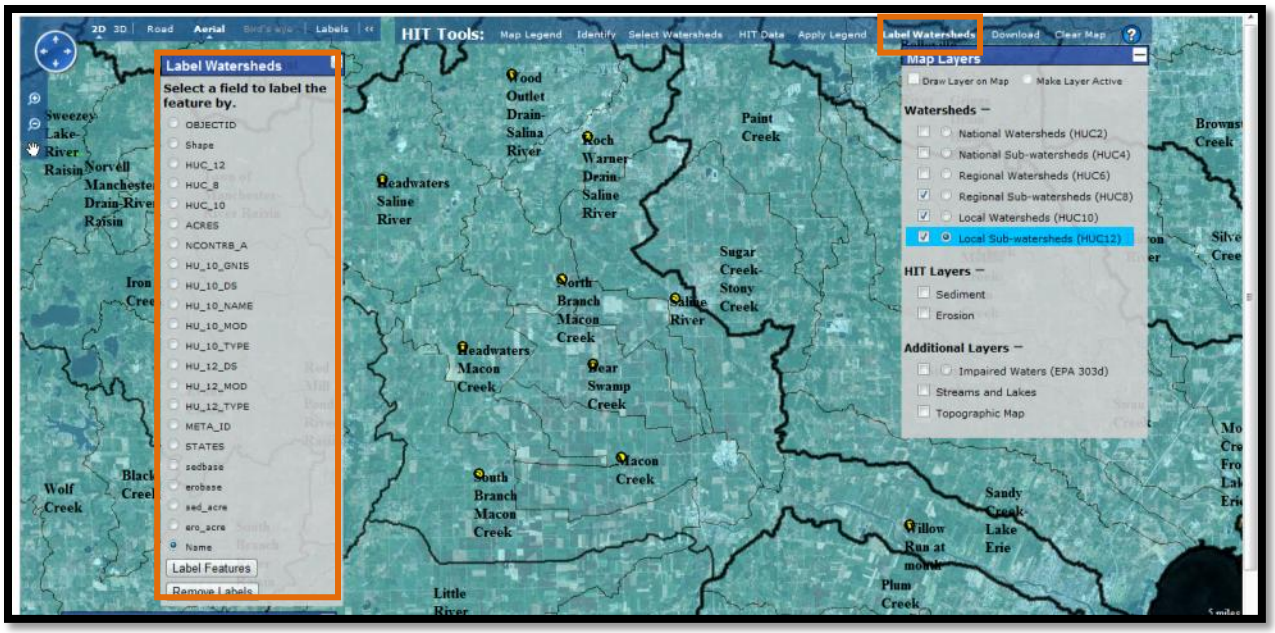

Figure 1.11: "Label Watersheds" Tool

IV. Selecting watershed in the map

There are four ways to select watersheds in the Bing Maps platform. Before selecting a watershed, a user must first activate the desired watershed layer (i.e. the *Local Watersheds HUC 10* layer when searching for a HUC10 watershed) and then choose "Select Watersheds" from the HIT toolbar. The chosen selection method will appear in bold.

A. Manually through "On map"

This option lets a user select watersheds interactively on the map by drawing a box around multiple watersheds or by clicking once on a single watershed (Figure 1.12). Watersheds can be removed from a selection by clicking on an already selected watershed. Once all desired watersheds have been selected, this tool should be deactivated. Disable this tool by clicking again "Select Watersheds" > "On map."

B. "By watershed name or HUC"

A user can specify a watershed name or Hydrologic Unit Code (HUC) for watershed selection (Figure 1.13).

C. "By address"

Choosing this search method allows the user to specify a location (address, town, or county). The map will zoom to that location (Figure 1.14).

D. "What are my watersheds?"

Using this method, the user is given a list of corresponding watersheds (from 4-digit to 12) for a particular location. Watersheds are selected by clicking on one of the results (Figure 1.15).

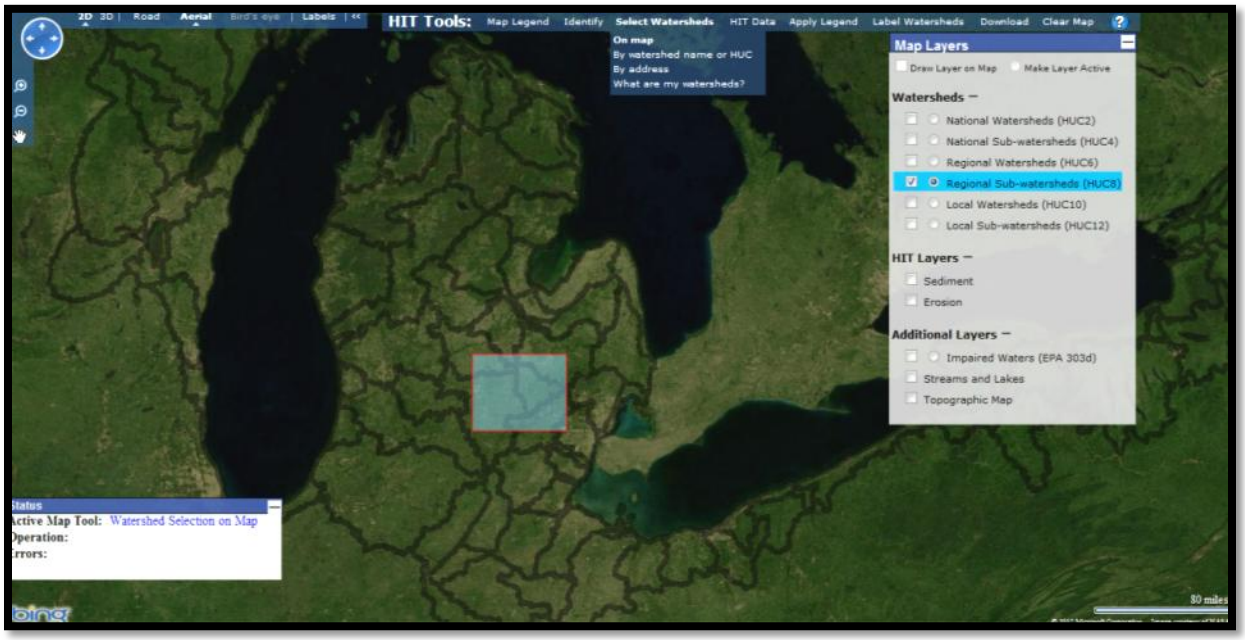

Figure 1.12: "On map" selection method

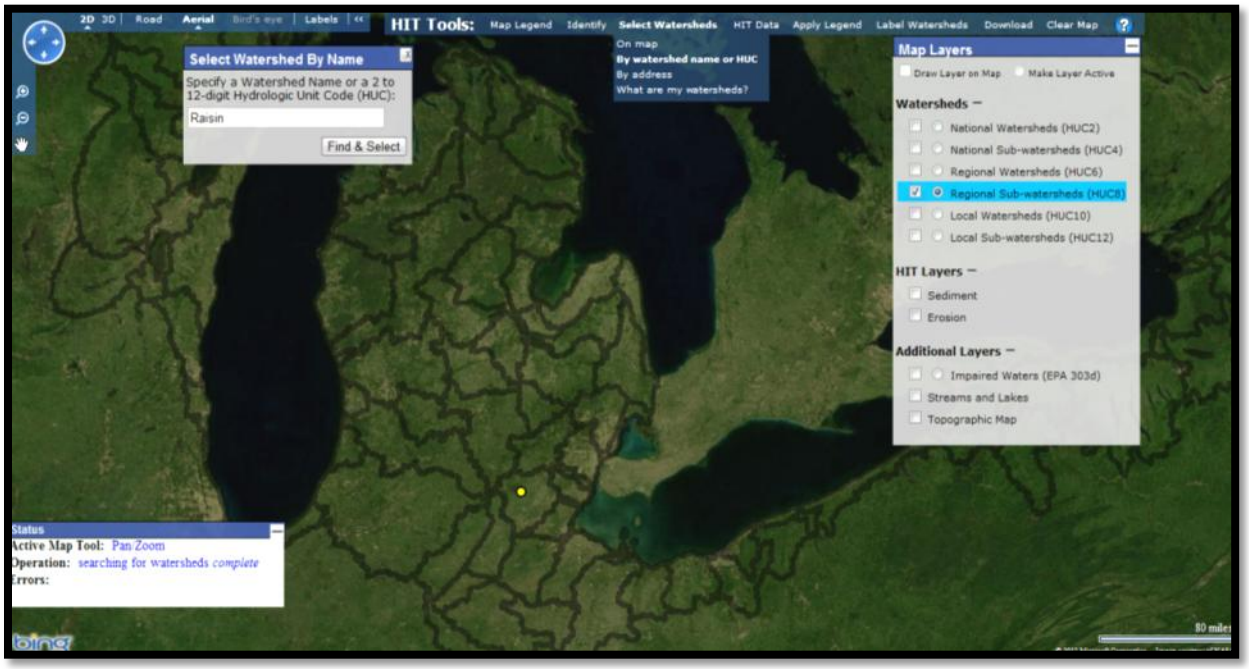

Figure 1.13: "By watershed name or HUC" selection method

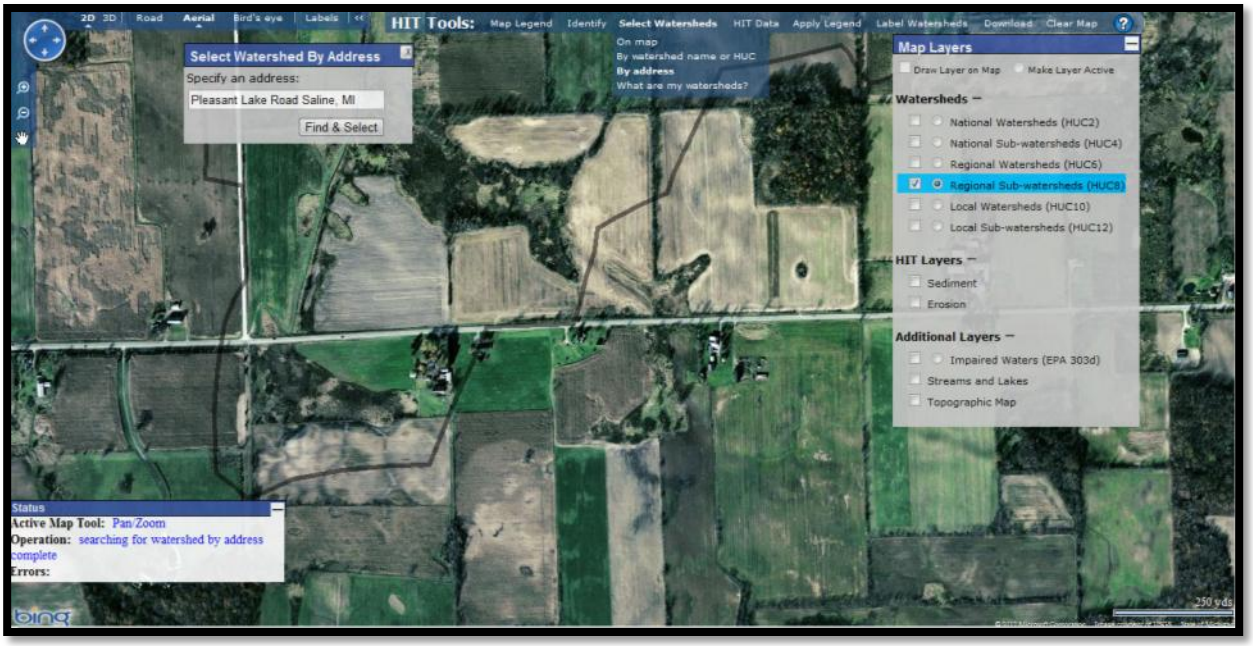

Figure 1.14: "By address" selection method

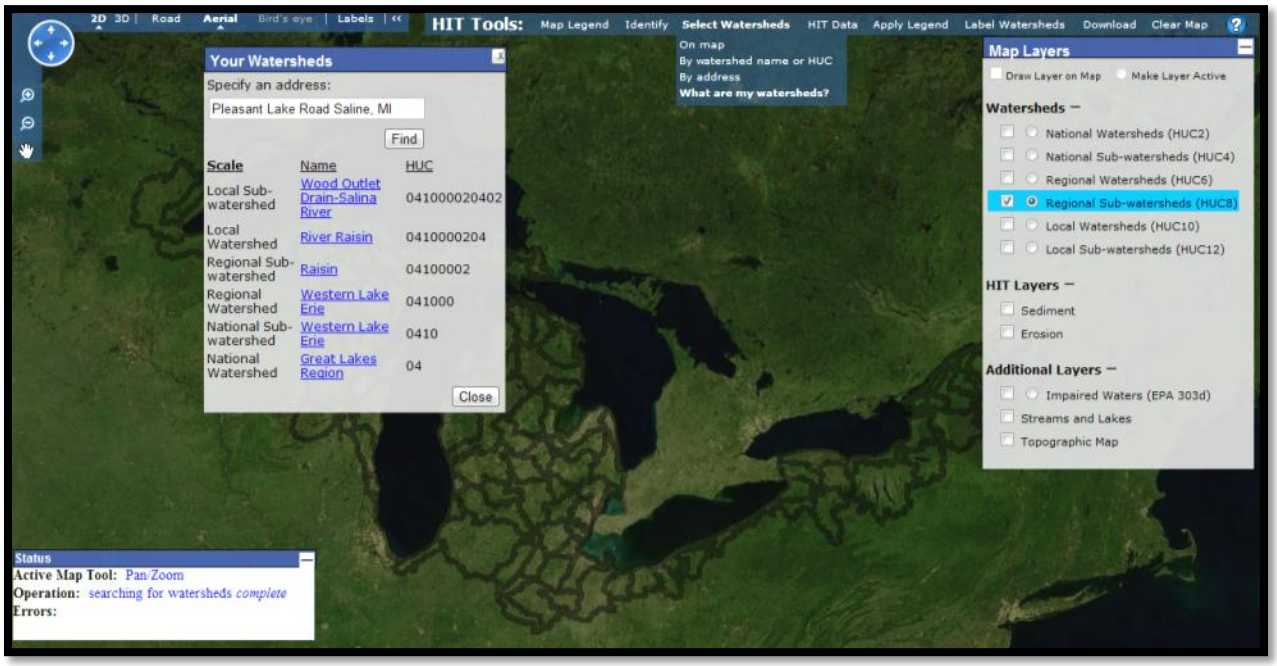

Figure 1.15: "What are my watersheds?" selection method

V. Generating HIT tables

HIT tables provide basic watershed information, sediment loading or erosion data, and cost/benefit estimates from hypothetical BMP scenarios. The generated table will open in a new window. See Figure 1.16 for a detailed view on HIT table parameters. HIT table outputs are discussed in Part VI on the next page.

A. From the homepage

To generate a table from the homepage from the "By watershed" tab, click on the "Table" button at the bottom of the screen. Refer back to Figure 1.4 on page 7.

To generate a table from the "By address" tab, click on "HIT Table" next to the desired HUC. See Figure 1.5 on page 8.

B. From the map page

A user can generate a HIT table for the active HUC layer by clicking on "HIT Data" from the HIT toolbar. The table will open in a new window.

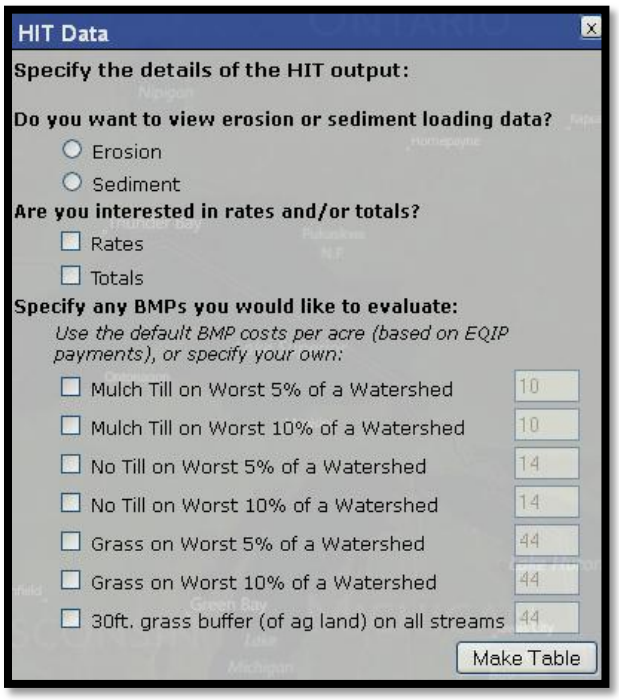

Figure 1.16: HIT Table Parameters

VI. Hypothetical BMP scenarios

Outputs of seven different hypothetical BMP scenarios can be displayed in HIT tables. Refer back to Part V on how to generate HIT tables. See Table 1.2 for a description of each column and Figure 1.17 for an example.

Note that the outputs for these scenarios are not generated dynamically. They were estimated off-line during individual watershed HIT modeling and stored in a database. As with HIT's estimates of sediment loading and erosion, the reductions from these BMP simulations are intended for relative comparisons between watersheds, not for precision. Given HIT's model limitations (not accounting for bank, wind, or ephemeral gully erosion), observed reductions at monitoring stations would likely be greater than those reported here; a relative comparison of reductions across a region's sub-watersheds would be more informative and appropriate.

A. Sorting columns

By default, the table is sorted by the HUC name. To sort by another column, click on the column heading. Note: you can only sort by in ascending order.

B. BMP cost

To adjust BMP costs on the fly, change the dollar amount in the fields at the bottom of the table and hit "Recalculate BMP Cost."

HIT Table Column Name	Description
Name	Watershed name
HUC	Hydrologic Unit Code
Acres	Watershed area in acres
Total (tons/year)	Estimated amount of erosion or sediment loading for the watershed (baseline condition)
Rate (tons/ac/year)	Estimated rate at which erosion or sediment loading is occurring for the watershed
Total Reduction (tons/year)	Estimated amount of erosion or sediment loading that could be reduced by installing the particular BMP in the watershed
Reduction %	Potential amount of reduced erosion or sediment loading in the watershed as a percentage
BMP Cost at $X per acre	Total cost of installing the particular BMP for the watershed, given the user-specified cost per acre of the BMP
BMP Cost Benefit ($/ton reduced)	Cost-benefit for the BMP for the watershed

Table 1.2: HIT Table Column Descriptions

Sediment

Click on a column title to sort ascending.

Name	HUC	Acres	Total(tons/yr)	Rate(tons/ac/yr)	BMP: Mulch Till on Worst 5% of Area				BMP: Mulch Till on Worst 10% of Area			
					Total Reduction (tons/yr)	Reduction %	BMP Cost at $10 per acre	BMP Cost Benefit ($/ton reduced)	Total Reduction (tons/yr)	Reduction %	BMP Cost at $10 per acre	BMP Cost Benefit ($/ton reduced)
South Branch River Raisin	0410000202	121,918	16,415	0.135	1,055	6%	$60,959	$58	1,467	9%	$121,918	$83
Little River Raisin-River Raisin	0410000203	189,769	16,137	0.085	974	6%	$94,885	$97	1,326	8%	$189,769	$143
Evans Creek-River Raisin	0410000201	170,030	14,818	0.087	544	4%	$85,015	$156	749	5%	$170,030	$227
River Raisin	0410000204	198,615	17,918	0.090	299	2%	$99,308	$332	400	2%	$198,615	$497
TABLE TOTALS		680,332	65,287	0.096	2,872	4	$340,166	$118	3,942	6	$680,332	$173
Specify new values to recalculate BMP cost:							$ 10				$ 10	

Recalculate BMP Cost

Institute of Water Research, All rights reserved 2006

Figure 1.17: Example HIT Table. Sediment loading totals and rates for the selected watersheds. Only "Mulch Till" BMPs are selected, the table is sorted by "BMP Cost Benefit for Mulch Till on Worst 5%", and the default BMP costs are used.

VII. Shading selected watersheds

A. "Apply Legend" Tool

A user can shade selected watersheds according to their erosion or sediment loading rates or totals by clicking on "Apply Legend" from the HIT toolbar. Darker colors represent higher sediment loading or erosion relative to the other watersheds. A legend for the colors can be accessed by clicking "Map Legend" on the HIT Toolbar.

B. Parameters

The user can display totals or rates for the erosion or sediment data. The user can also classify the data by Equal Intervals or Quartiles. Equal Intervals defines bins for the watersheds using value ranges of equal size (e.g. 0-2, 2-4, 4-6, 6-8), while Quartiles creates value ranges for the bins so that each bin has roughly the same number of watersheds (Figure 1.18). Quartiles typically produce the more cartographically appealing map, as Equal Intervals can be skewed by very large values relative to the rest of the sample.

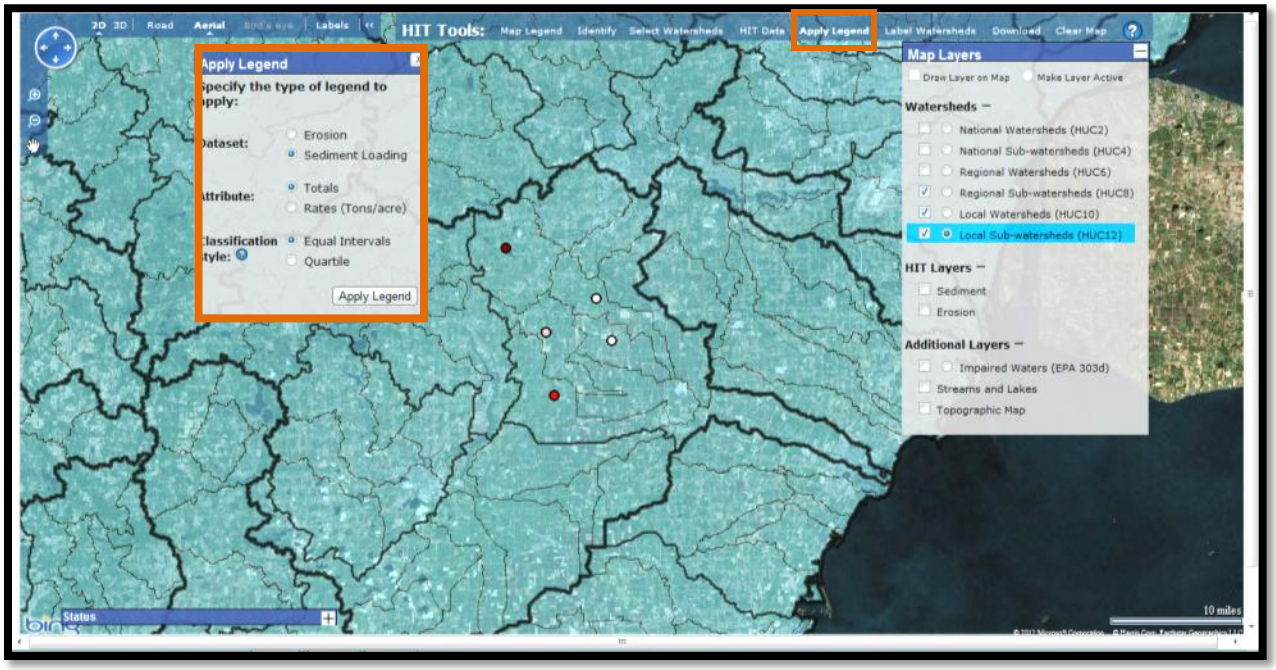

Figure 1.18: "Apply Legend" Tool

VIII. Viewing high risk area at field scales

A. *Sediment* and *Erosion* layers

Users can view high risk cells by selecting the *Sediment* or *Erosion* layer. These raster layers generally have a resolution of 30 meters, though in some areas (where finer digital elevation model resolutions were available) cells are displayed at a 10-meter resolution. Both can be displayed on the map at the same time, but it may be difficult to view all of the data. These layers may not work when zoomed in at very large scales, and will not work in Bird's eye view.

B. "Bird's eye" view

"Bird's eye" view provides close-up aerial imagery at a 45° angle, giving the user a very detailed picture for prioritizing BMP installation at the field level. If "Bird's eye" view is dimmed in gray, this type of aerial imagery is not available for that location.

"Bird's eye" view works differently in 2D and 3D modes. Operating in 2D, "Bird's eye" view may be more cumbersome because of slow panning, limited zooming and missing imagery. "Bird's eye" view in 3D is discussed in Part VIII, C below.

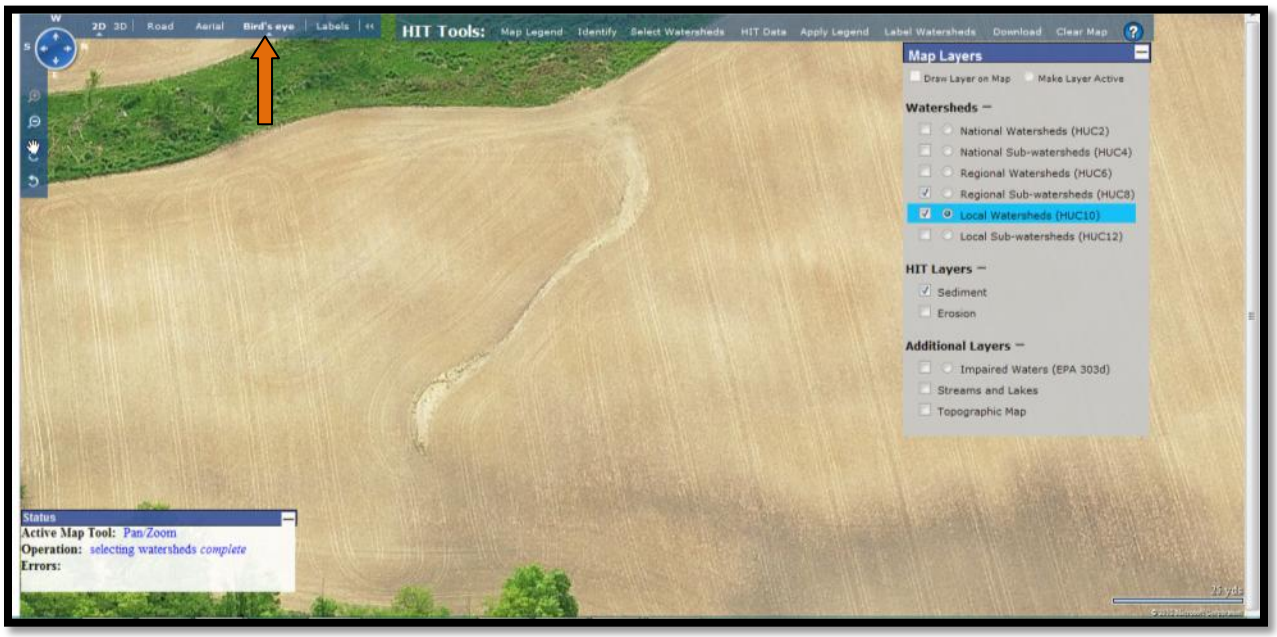

Figure 1.19: "Bird's eye" view 2D mode

C. 3D view

A user can access 3D view from the Bing Maps toolbar. In order to use 3D view, the user's computer must have Bing Maps' 3D software installed (available at http://www.bing.com/maps/Help/VE3DInstall/Default.aspx?action=install&mkt=en-us). 3D is compatible with Internet Explorer 6 and later as well as Mozilla Firefox 3.0 and later. 3D view is helpful in visually examining elevations (Figure 1.20), but often suffers from coarser imagery resolution.

Before clicking on the 3D button, the user must have the desired layers drawn on the map. The HIT toolbar is inaccessible and map layers cannot be adjusted when in 3D mode. Once in 3D mode, the user can adjust altitude and angle in the Bing Maps toolbar on the left of the screen.

3D mode still allows users to access Bird's eye view, which may function better than in 2D mode, as it allows the user to select specific bird's eye aerial images to view (Figure 1.21). The user can zoom in and out of each image and avoid the problems in 2D Bird's eye view.

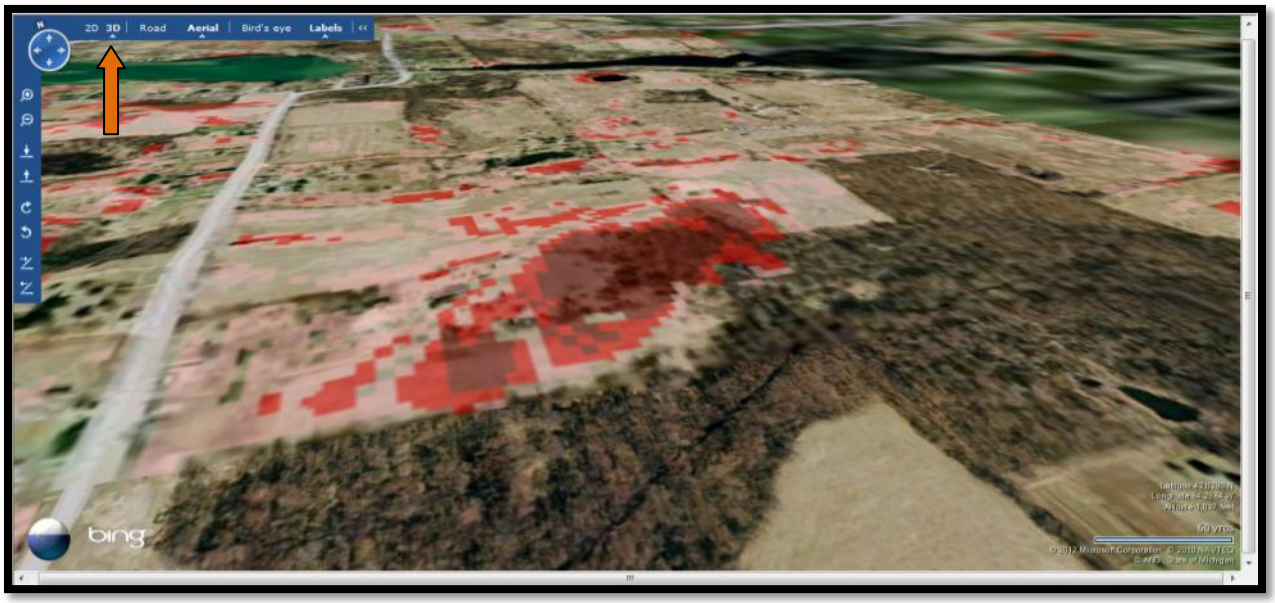

Figure 1.20: 3D view

Figure 1.21: "Bird's eye" view 3D

IX. Viewing metadata

Users can view metadata on any layer by clicking on the layer's name in the "Map Layers" window. A brief description of the layer will appear. Additional details, including detailed FGDC-compliant metadata for the *Sediment* and *Erosion* layers, can be accessed by clicking on the "more" link in each layer's "Layer Info" window (Figure 1.22).

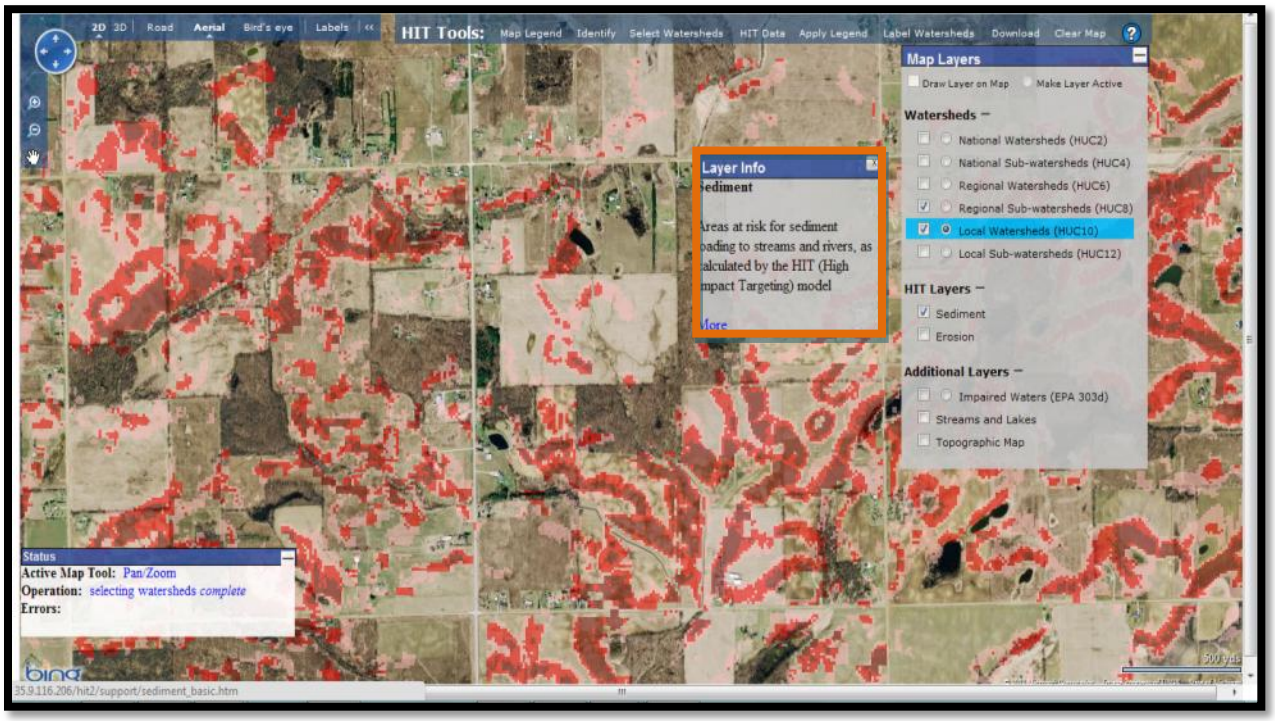

Figure 1.22: Metadata access

X. Downloading HIT models

A. Users can download HIT model data for a selected 8-digit watershed for use in desktop GIS by clicking on "Download" from the HIT toolbar (Figure 1.23).

B. The downloaded data includes shapefiles for HUC8, HUC10, and HUC12 boundaries, with attributes including sediment and erosion estimates, and raster files for annual erosion and sediment (tons /year) and sediment delivery ratios (percentages). There are also two Esri ArcGIS™ layer files for annual erosion and sediment, which will cartographically render the raster layers when applied within Esri's ArcMap™. Figures 1.24 and 1.25 provide examples of HIT model data in Esri's ArcMap™ 10.

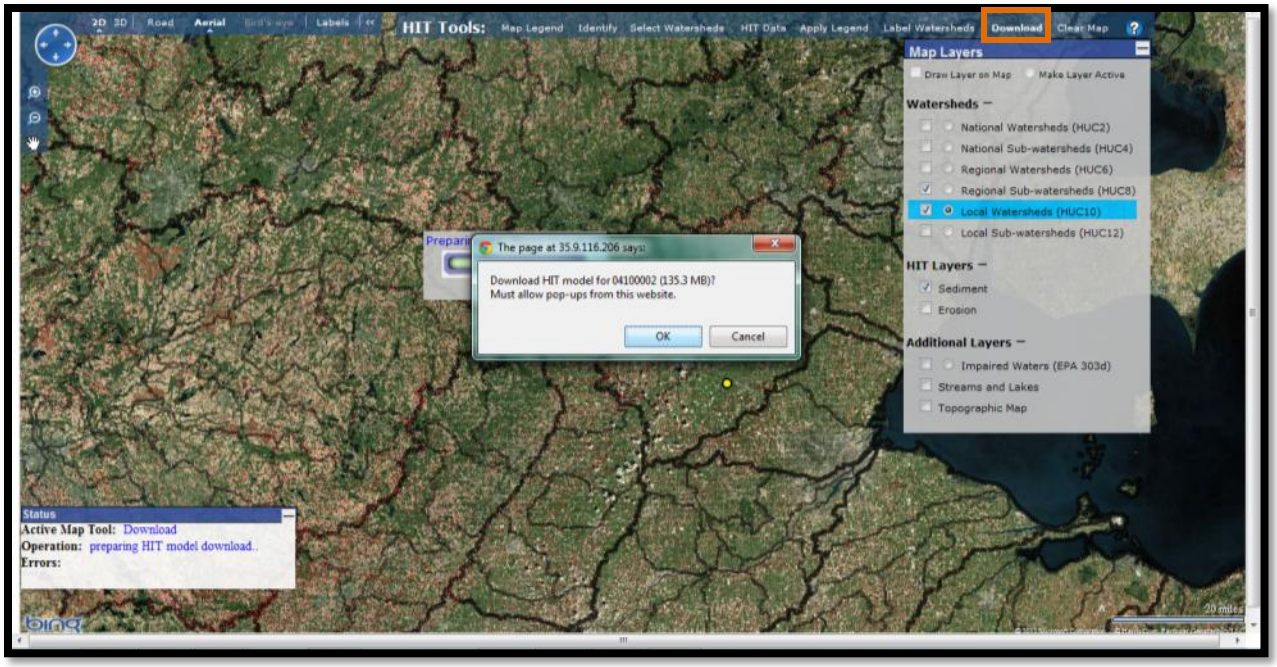

Figure 1.23: Downloading HIT Models

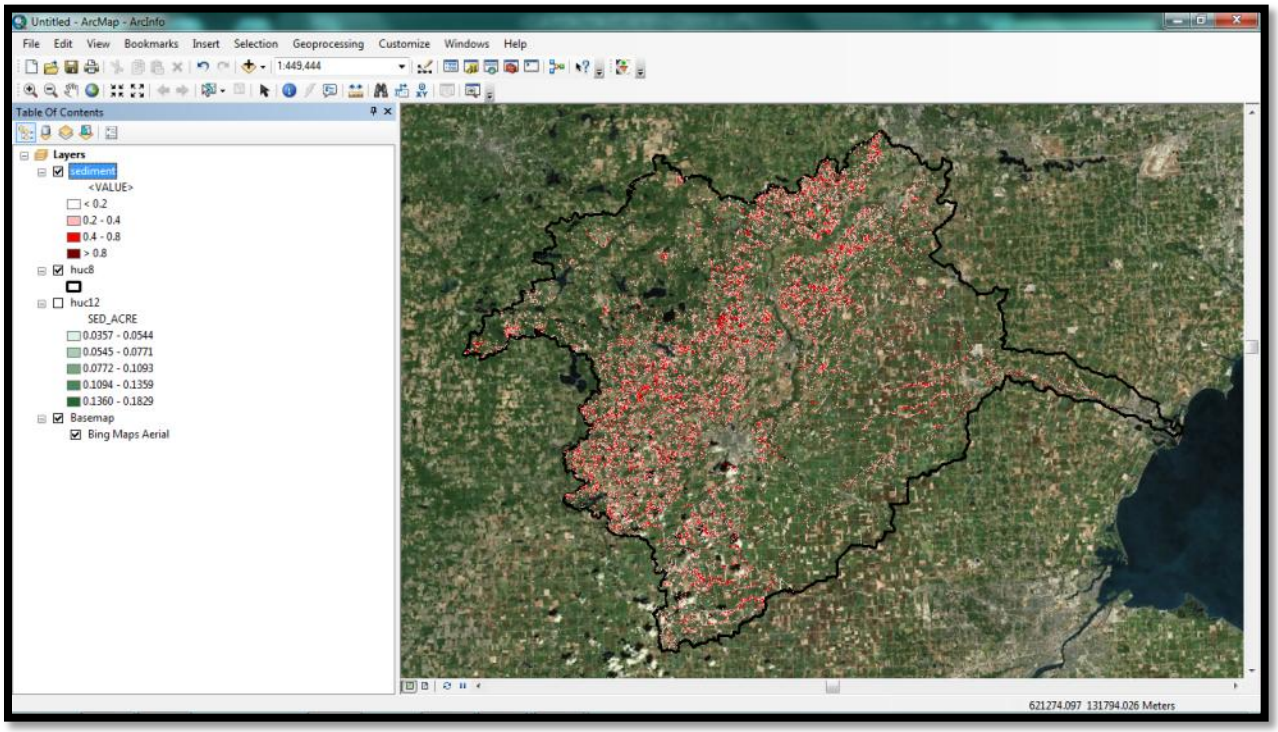

Figure 1.24: High-risk sediment areas with Bing Maps aerial base map

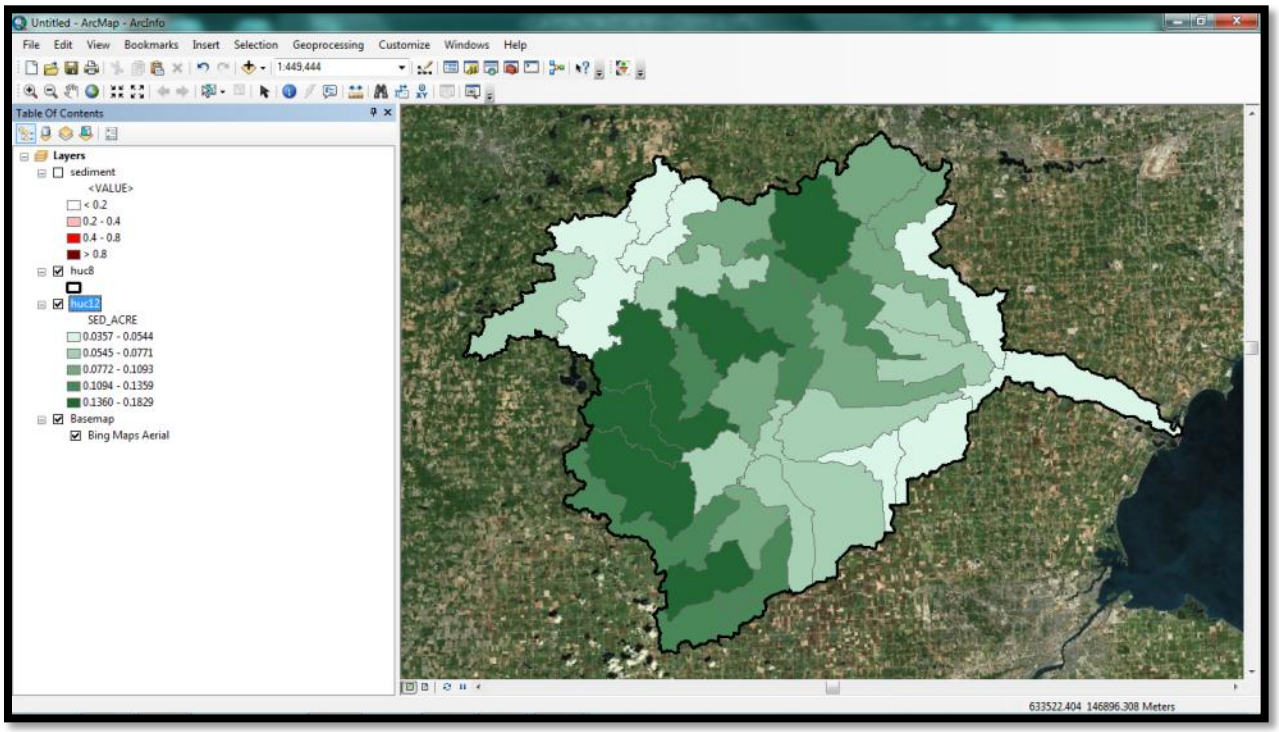

Figure 1.25: Sub-watersheds shaded by annual amount of eroded sediment in tons/acre/year

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Chapter 2

Long-Term Hydrologic Impact Assessment Low Impact Development (L-THIA LID) Model

[https://engineering.purdue.edu/~lthia/LID/]

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Section 2.1: Overview

Increasing urbanization results in conversion of agricultural lands, forests, and wetlands into urban land uses. Urbanization adversely alters watershed hydrology, contributing to the deterioration of water resources and water quality. Examples of this alteration include increased runoff volumes and peaks, decreased time of concentration, decreased base flow and recharge, and increases in nonpoint source (NPS) pollution in runoff including sediment.

Urban NPS pollutants include suspended and dissolved solids, sediment, nutrients, oxygen-demanding organisms, bacteria, pesticides, metals, oil and grease among others. Transport of pollutants in runoff from land areas into water bodies is a natural process; however, urban NPS pollution is intensified by activities associated with urbanization. The most prevalent of these activities include increased impervious surfaces (e.g., roads, parking lots, sidewalks, roofs, compacted areas), increased application of fertilizers and pesticides on municipal lawns and gardens, erosion from land disturbance due to construction activities, and increasing use of vehicles that causes pollutant inputs into the air and subsequent atmospheric deposition transferred to nearby aquatic systems by runoff (Lin et al., 1993; Baird et al., 1996).

In addition, hydraulically connected impervious surfaces can produce high volumes of runoff, causing changes in runoff water chemistry constituents. For example, Ying and Sansalone (2010a) showed that the accumulation and washoff of pollutants from dry deposition on impervious surfaces can increase contaminant loads in runoff during rainfall events.

The impacts of urbanization along with associated socio-economic outcomes have led to a widespread movement for more intelligent and smart planning of urban growth such as smart growth, water sensitivity planning, low impact development (LID) planning, and other alternative ways to mitigate the impacts of urban development on water resources and water quality (USEPA 2000; Coffman 2002).

The use of LID practices to lessen problems associated with urban development has grown in popularity (Coffman 2002). Examples include installation of permeable pavements for stormwater management in Olympia, VA (EPA, 2000), use of bioretention cells for pollutant removal and peak flow mitigation in Charlotte, NC (Hunt et al., 2008), use of vegetated roof tops for runoff mitigation in Philadelphia, PA (Miller, 1998), and the Jordan Cove Urban Watershed LID project in Waterford, CT (Bedan and Clausen, 2009).

Effectiveness of LID practices is typically evaluated through field monitoring and simulation modeling. While the former is necessary for characterizing and identifying changes or trends in the efficiency of the practices; it is generally limited in providing extensive information due to variability in topographic, soil and weather conditions across scales. Simulation modeling is one simple approach to generalize this information.

In recent years, there has been a growing interest in modeling LID practices. Computer models, ranging from computationally intense to simple algorithms, have been used at multiple scales to understand the

processes that govern urban stormwater runoff, and to evaluate the effects of land use changes on hydrology and water quality (Im et al., 2003; Lim et al., 2010). One of the hydrologic/water quality models widely used in the United States to quickly assess hydrologic and water quality impacts of urbanization is the Long-Term Hydrologic Impact Assessment (**L-THIA**) model (Bhaduri et al., 2001; Lim et al., 2001; Harbor, 1994).

The L-THIA model was developed to estimate direct runoff from basic input data, such as daily rainfall, land uses, and hydrologic soil group. [https://engineering.purdue.edu/~lthia/]. The L-THIA model was later enhanced to incorporate LID practices, and referred to as L-THIA Low Impact Development (L-THIA LID).

Located at [https://engineering.purdue.edu/~lthia/LID/], the simple approach of L-THIA LID and its specific implementation of LID practices are discussed further in Section 2.2.

Section 2.2: The L-THIA LID Model Description

[https://engineering.purdue.edu/~lthia/LID/]

Theoretical background

The **L-THIA LID** model presented in this tutorial represents an enhancement to the original model, which can be used to simulate runoff and NPS pollution associated with low impact development (LID) practices at lot to watershed scales, allowing comparison of runoff and pollutants between an initial condition and subsequent LID or conventional development. LID principles are reflected in the use of several practices/techniques in the model to converge toward pre-development conditions being replicated and post-development impacts being reduced (EPA, 2000; Coffman et al., 2004).

The Curve Number (CN) method is widely used to estimate runoff based on the relationship between rainfall, land uses, and hydrologic soil group. This relationship was originally described in the Soil Conservation Service publication "TR-55" (NRCS, 1986) and several modifications have since been proposed. The relationship between rainfall, runoff and CN value is non-linear, meaning that small changes in land use or rainfall can produce large changes in runoff. Although used in simple everyday stormwater management methods, the CN method is also often used in complex models for more sophisticated analyses. The use of the CN equation in L-THIA LID is a simple alternative to more complicated hydrological models that require extensive data inputs which are often not readily available for most areas, or too complex. L-THIA LID allows the user to evaluate the effects of LID strategies on water quantity and quality.

There are two components in the L-THIA model: the **hydrologic component** which estimates direct runoff based on the CN method with daily rainfall data, and the **water quality component** which estimates pollutant loadings using the estimated direct runoff and coefficients associated with land uses (Lim and Engel, 2005).

The hydrologic component of the model

In the hydrologic calculations, the soil component involves the use of four classifications of soil. This system used the classification of "hydrologic soil groups" or HSG which indicate the status of infiltration in the soil. The minimum rate of infiltration obtained for bare soil after a minimum amount of wetting determines the classification. The four groups are denominated as A, B, C, and D. The specific characteristics of the groups are displayed in Table 2.1 below. The soil hydrologic properties for an area are usually available within a standard soil survey, or from websites such as [http://soils.usda.gov/survey/geography/ssurgo/].

Table 2.1 Hydrologic Soil Groups (HSG) and their Properties.

Hydrologic Soil Group	Hydrologic Soil Group Characteristics
Group A	These soils display low runoff potential and high infiltration rates even when thoroughly wetted. Consisting chiefly of *deep*, *well drained* to *excessively drained* sand or gravel. These soils have a **high rate of water transmission** (greater than 0.30 in/hr).
Group B	These soils display moderate infiltration rates when thoroughly wetted. They consist chiefly of *moderately deep* to *deep*, *moderately well drained* to *well drained* soils with *moderately fine* to *moderately coarse* textures. These soils have a **moderate rate of water transmission** (0.15- 0.30 in/hr).
Group C	These soils display low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water, and are soils with *moderately fine* to *fine* texture. These soils have a **low rate of water transmission** (0.05-0.15 in/hr).
Group D	These soils have high runoff potential. They display very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a **very low rate of water transmission** (0-0.05 in/hr).

In the absence of a soil survey, or in the presence of disturbed soil profiles (e.g. native soil profile is mixed, or removed and replaced), there is a method for the modeler to **estimate** the hydrologic soil group from the texture of the surface soil in the area of interest, provided that significant compaction has not occurred. This relationship for determining the HSG classification for disturbed soils from TR-55 is reported below in Table 2.2.

Table 2.2 Estimated HSG from Surface Soil Texture.

Estimated HSG	Surface soil texture
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Some recent research suggests that it is reasonable to assume soils in large dense residential or industrial developments undergo compaction during the construction phase, and so the end result is a B soil transformed into a C soil and C soils may be transformed to D soils (Lim et al., 2006b).

The standard CN values range from 25 to 98, depending on land uses, hydrologic soil group, and antecedent moisture condition (AMC). The use of the Curve Number (CN) equation is a simple alternative to more complicated hydrological models that require inputs of intensive datasets, which are often difficult to obtain or unavailable for areas of interest. The L-THIA LID model uses daily precipitation over 30 years to calculate runoff and pollutant loads on an average annual basis.

The CN method for estimating runoff is a two-parameter (CN and the initial abstraction, S) empirically-based procedure used in simple stormwater management methods as well as in complex watershed models to determine how much of a given rainfall event becomes direct runoff (Mockus, 1972; Garen and Moore, 2005). The initial abstraction, which describes all losses of precipitation before runoff begins (interception, infiltration, surface storage, and evaporation), is a function of the CN and is calculated as (NRCS, 1986):

$$S = \frac{25400}{CN} - 254 \tag{1}$$

Under the condition that precipitation, P (mm) > 0.2S, direct runoff depth, Q_h (mm) is estimated as:

$$Q_h = \frac{P - 0.2S^{\ 2}}{P + 0.8S} \tag{2}$$

$$Q_h = 0 \text{ when } P \leq 0.2S \tag{3}$$

The volume of runoff from an area is determined by:

$$Q_V = Q_h \times A \tag{4}$$

where Q_v is the volume of water; and *A* is the area of interest.
Once runoff **water quantity** is predicted in L-THIA LID, then runoff **water quality** is determined by multiplying simulated runoff against specific coefficients for land use types.

The water quality component of the model

The coefficients or Event Mean Concentration (EMC) data used for the nonpoint source (NPS) water quality calculations was compiled by the Texas Natural Resource Conservation Commission (Baird and Jennings, 1996) from numerous literature and existing water quality data. NPS pollutant masses are computed by multiplying runoff depth for a land use by the area of that land use and the appropriate EMC value and converting units. A complete list of the EMC values used in the L-THIA LID model is available in Appendix B1. The land uses originally proposed by Baird and Jennings have been modified for the Midwest, and consist of the following:

L-THIA LID Land Uses:

Commercial
Industrial
High Density Residential (1/4, 1/8 acre lots)
Low Density Residential (1/2, 1, and 2 acre lots)
Water / wetlands
Grass pasture
Agricultural
Forest

The model output includes a table of Total Average Annual Runoff (volume and depth) and a breakdown of predicted runoff totals for each specific land use type. The output tables also include the estimated Total Average Annual Load (mass) for 11 NPS pollutants and 2 bacterial indicators. The calculations result in average annual NPS load estimates for the following:

L-THIA LID NPS Outputs:

Nitrogen	Chromium
Phosphorous	Nickel
Suspended solids	BOD (Biological Oxygen Demand)
Lead	COD (Chemical Oxygen Demand)
Copper	Oil and Grease
Zinc	Fecal Coliform
Cadmium	Fecal Strep

LID Practices employed in the Model

The **L-THIA LID** model [https://engineering.purdue.edu/~lthia/LID/] currently supports a group of LID practices including:

1) bioretention/rain garden,
2) grass swale,
3) open wooded space,
4) porous pavement,
5) permeable patio,
6) rain barrel/cistern,
7) green roof.

The model simulates the performance of these practices at lot-scale to watershed-scale situations. Both lot and watershed level simulations are based on modified CN values which describe the effects of these practices on hydrology and water quality. **Appendix B3** of this manual describes some design and maintenance considerations for these LID practices.

L-THIA LID and Representation of LID Practices

Evaluating the effectiveness of LID practices with the L-THIA LID model involves the use of user-supplied land use and soil combinations and an optional selection of LID practices that may be applied to some or all of any land use – soil combinations. The CN is a key parameter common to all LID practices used in the model. Seven LID practices including porous pavement, permeable patio, rain barrel/cistern, grass swale, bioretention systems, green roof, and open wooded space, are represented with CN values suggested by Sample et al. (2001) to reflect runoff mitigation capacity of the practices. These recommended CN values are used to adjust CN values in the model to characterize the effects of the LID practices on runoff and pollutant loading, allowing comparison between hydrologic and water quality conditions before and after implementation of the practices.

As in the original L-THIA model, pollutant loadings for non-urban areas as well as urban areas are estimated by multiplying runoff by pollutant loading coefficient (EMC) values, associated with specific categories of land use (Lim et al., 2001).

The LID practices employed in L-THIA LID are described in detail below. The CN and impervious surface assumptions used in the model are tabulated in Appendices B1 and B2.

Bioretention Systems

Bioretention systems consist of shallow depressions designed for holding stormwater runoff from impervious surfaces such as parking lots, rooftops, sidewalks, and drive ways. They promote infiltration by allowing rain water to soak into the ground, thus reducing runoff that can potentially enter stormwater systems. Bioretention systems also support runoff filtration for water quality improvement with planted non-invasive vegetation. In urban communities using combined sewer systems, the use of bioretention reduces the overflow frequency of these combined sewer systems. During winter, bioretention systems may capture the majority of runoff produced by melting snow from impervious surfaces. The values of runoff CN used to represent hydrologic benefits of bioretention systems are 35, 51, 63, and 70 for Hydrologic Soil Group (HSG) A, B, C, and D, respectively.

Rain Barrel and Cistern

Installation of rain barrels and cisterns in residential subdivisions allows harvest of rainfall water for potential reuse. In many countries with water scarcity problems, especially in developing countries, the use of vertical storage systems, tanks, and underground storage structures is a common practice and serves as good water supply reservoirs. The value of runoff CN used to represent rain barrels is 94 and cisterns is 85 for the 4 HSGs (Sample et al., 2001).

Green Roof

Green roofs have been used for many years, especially in Europe, to retain precipitation, provide insulation, and create habitats for wildlife (Miller, 1998; Rowe, 2011). Green roofs have also been credited for lowering urban air temperature and help reduce heat island effects (Miller, 1998; Rowe, 2011). Depending on the thickness of the layers used and the extent of required maintenance, green roofs can be portrayed as extensive or intensive (GRRP, 2010). Green roof was represented using the value of 86 for runoff CN for the 4 HSGs (Sample et al., 2001).

Permeable Pavement and Permeable Patio

Permeable pavements or asphalts are generally used to capture and filter runoff from impervious parking lots, driveways, streets, roads, and patios, thus controlling NPS pollution loading (Dietz, 2007). While traditional pavements turn almost all rainfall into runoff, permeable pavements encourage infiltration of rainfall by creating extra moisture in the soil profile. The original CN value of 98 for conventional asphalt was changed to 70, 80, 85, and 87 for driveways and sidewalks with porous materials as suggested by Sample et al. (2001).

Open Wooded Space

Open wooded spaces are nature preserves with natural landscape features. These natural conditions play a major role in the protection of flora and fauna. Open wooded spaces offer various sites for natural hydrologic and water quality processes to take place by preserving the integrity of the environment. The values of 68, 79, 86, and 89 were used for poor condition open space, 49, 69, 79, and 84 for fair condition open space, and 30, 55, 70, and 77 for good condition open space (Sample et al., 2001), respectively.

Review of L-THIA and L-THIA LID Publications

The L-THIA model has been extensively used for land use impact assessment. In addition, the L-THIA and L-THIA LID model has been used in calibrated and uncalibrated modes, and has been used in case studies to illustrate and inform planners or to mimic real-world conditions.

Some of these studies are presented in **Appendix B4: Literature Review and Case Study References for L-THIA and L-THIA LID**. There is a brief description of the content of each study provided.

Model Operations

The basic operations of the L-THIA LID model [https://engineering.purdue.edu/~lthia/LID/] are simple and direct. As Figure 2.1 illustrates, there are only 5 basic steps from start to finish.

1. The user first selects a state and county, which is used to determine the rainfall data for the 30 period.

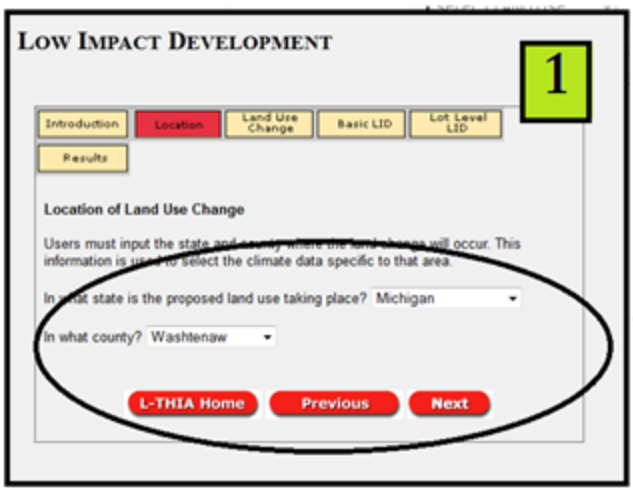

Figure 2.1: Select State and County

The user enters the state and county of the project area as displayed in Figure 2.1. The county is used in a query which produces the precipitation record (recorded over 30 years) from the gages closest to that county. Users should note that running two models with the same land use and soil area, but located in different counties, may produce different output results due to the change in precipitation.

2. User enters land use and soil data and corresponding area for existing conditions.

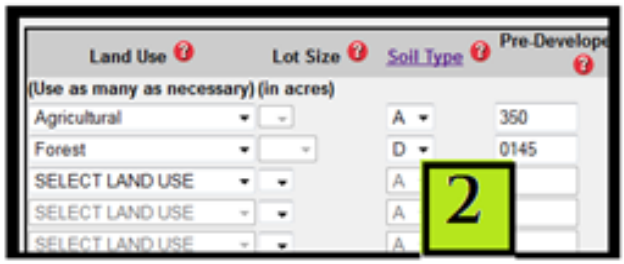

Figure 2.2: Enter the current land use and soil data.

The user enters the various land use types, the associated soil hydrologic group, and the area. This reflects the starting condition which may be current status of the area, a proposal, or a pre-development land use assumption. These choices are the parameters for the starting condition of the model and will be reported under the column "current" in the output table.

3. The user enters "post-developed" land use, soil data and area, reflecting a proposed development, zoning change, or other scenario (Figure 2.3 below). Scenarios might range from a simple one such as a maximum impervious surface rule for a specific area of residential land or a simple 2 acre lot size minimum to a complex model with land use changes and LID practices applied to the individual components may vary but the total area must remain exactly the same.

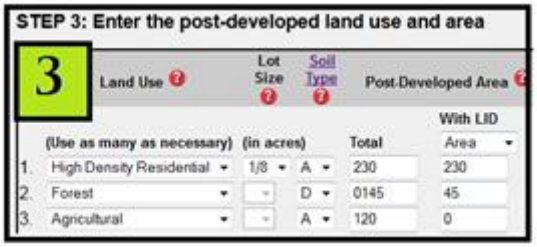

Figure 2.3: Enter the "Post-developed" land use environment.

The user enters the second condition set using the appropriate drop-down boxes and blanks. The simulation can include alterations in land use type, or their area; it may include a change in soil hydrologic group, and it can include the application of LID BMPs (discussed below) on appropriate land use types. The one absolute condition is that the total area figure must exactly agree between current and post-development totals.

4. The user selects the screening level for the model and may chose to select some parameters for LID practices. The LID practices menus are essentially applying a practice as a BMP to the specified portion of that land use type. LID practices are only applied to selected land uses (for example agricultural land use will not have any LID choices available) but may be applied to all or to part of an appropriate land use. The selection of practices may be done through a checkbox or a slider control for impervious surface (see Figure 2.4 below.) The latter method will allow the user to specify the allotted amount of impervious surface in a design feature.

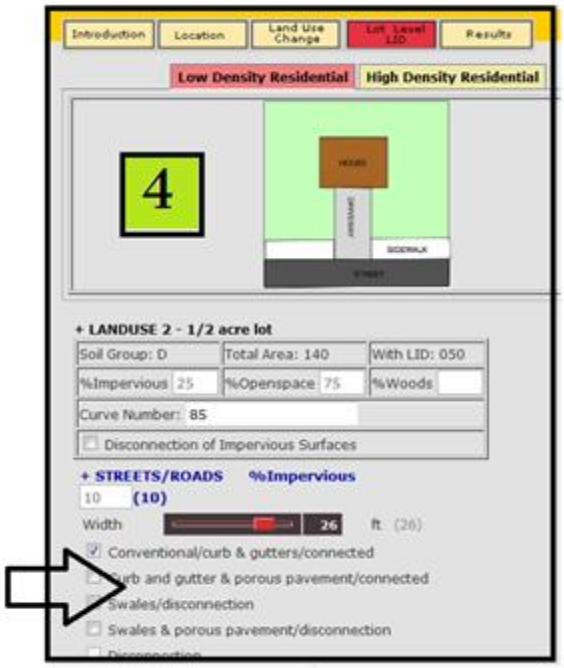

Figure 2.4: Apply BMPs to appropriate land use types.

5. The model runs and produces a table of outputs and graphical outputs (see Figure 2.5 **Results for Current, Post-developed w/o LID, and Post-developed with LID**. The results display the curve numbers and runoff as determined from current and post-development scenarios, and if LID practices were added, the table displays post-development results with and without these practices. Runoff is provided in units selected by the user, either English (acre/feet and inches) or metric (cubic meters and millimeters.) The contribution to annual average runoff of specific land use types is included.

Curve Number by Landuse

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	B	75	75	-
Agricultural	C	82	82	-
Residential 1/8 acre	B	-	85	85
Residential 1/8 acre	C	-	90	89

RUNOFF RESULTS

Avg. Annual Runoff Volume (acre-ft) View as: Select

Land Use	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	7.40	-	-
Agricultural	47.31	-	-
Residential 1/8 acre	-	17.66	17.66
Residential 1/8 acre	-	99.50	88.44
Total Annual Volume (acre-ft)	54.71	117.16	106.10

Also view Annual Variation and Probability of Exceedence

5

Avg. Annual Runoff Depth (in) View as: Select

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
4.23	9.07	8.21

Figure 2.:5 Results for Current, Post-developed w/o LID, and Post-developed with LID

In addition to runoff, the results table also includes the predicted amounts of various Non-Point Source (NPS) contaminants (listed above in the sub-section *The water quality component of the model*.) The results include nitrogen, phosphorous, suspended sediment, metals, and biological indicators (see Figure 2.6 for an example).

Avg. Runoff Depth by Specific Landuse View as: Select

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	B	1.48	1.48	-
Agricultural	C	3	3	-
Residential 1/8 acre	B	-	3.99	3.99
Residential 1/8 acre	C	-	6.99	6.13
Average Annual Rainfall Depth (in)				34.02

NONPOINT SOURCE POLLUTANT RESULTS

Nitrogen (lbs) View as: Select

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	51	-	-
Agricultural	358	-	-
Residential 1/8 acre	-	57	57
Residential 1/8 acre	-	345	302
Total	409	402	359

Also view Annual Variation and Probability of Exceedence

Phosphorous (lbs) View as: Select

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	15	-	-
Agricultural	105	-	-

Figure 2.6: NPS results sample.

The results table has links to produce a graph of annual variation (each point is an annual value calculated from the 30 years of rainfall) which is displayed in Figure 2.7 below.

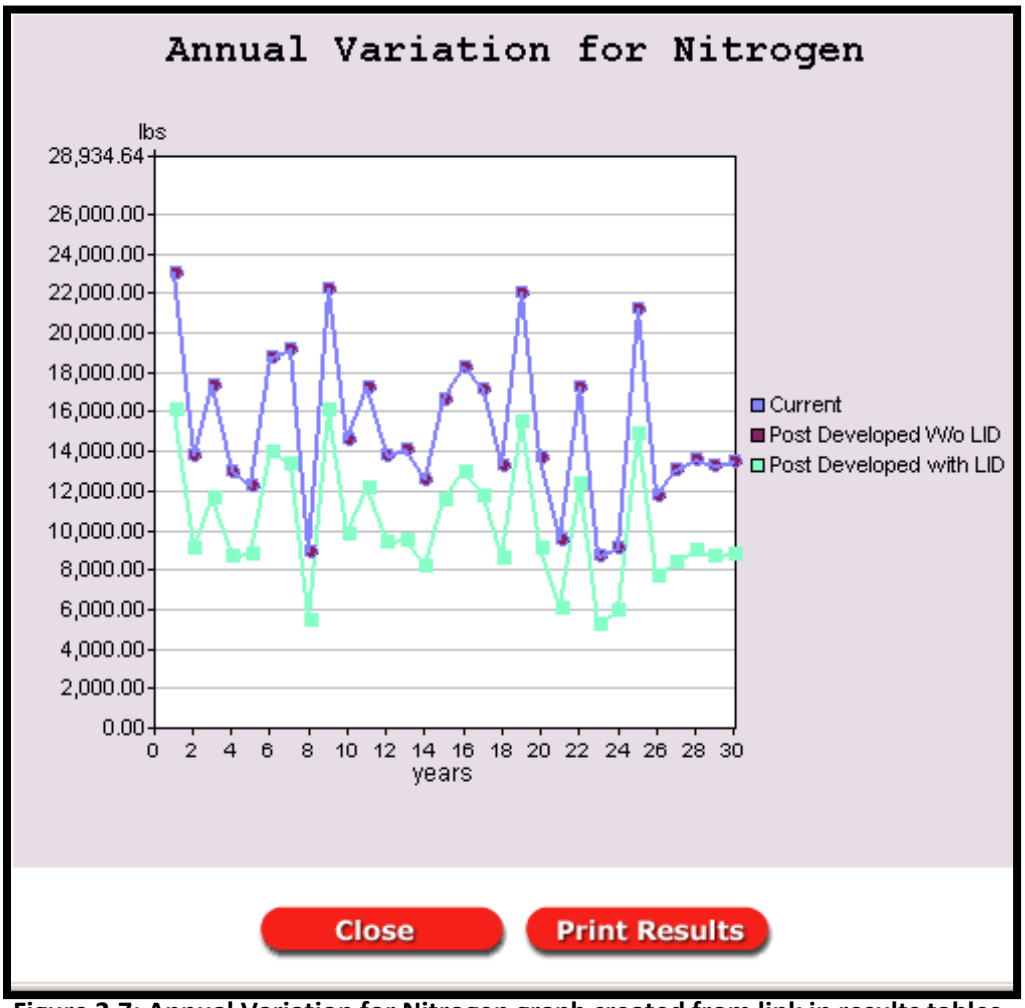

Figure 2.7: Annual Variation for Nitrogen graph created from link in results tables.

The model results reflect the significant effect of land use change upon the quantity and quality of water that moves across a landscape to become runoff, stormwater drainage, or groundwater recharge. The user is encouraged to experiment and perform analyses with various BMPs for their project area, in order to become familiar with the effectiveness of the practices. This model was developed to be an accessible online tool to assess the impacts of methods and practices that attempt to minimize negative effects. Based on community-specific climate data, L-THIA LID estimates changes in runoff and non-point source pollution resulting from past or proposed development. It estimates long-term average annual runoff for land use and soil combinations, based on actual long-term climate data for that area. By using many years of climate data in the analysis, L-THIA LID focuses on the average impact, rather than an extreme year or storm.

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Chapter 3

Digital Watershed

[www.iwr.msu.edu/dw]

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Section 3.1: Overview

The Digital Watershed system is designed to provide both a centralized information repository and a computing center for watersheds in the United States. It links EPA tools and databases with those of Michigan State University and Purdue University in a synergistic manner. The system provides substantive benefits in addressing the specific, emerging landscape analysis needs of local officials, natural resource managers, and the general public to facilitate better local land and water resource management and planning.

As a web-GIS based system, Digital Watershed offers mapping capabilities as well as analytical and modeling tools. It is based on the nation-wide watershed database from EPA BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) system. It also provides dynamic and seamless integration of data from multiple sources through the extensive use of Web services. System users have access to the modeling functions of the U.S. EPA's Unit Stream Power Erosion and Deposition (USPED) and Purdue University's Long Term Hydrologic Impact Assessment (L-THIA) models. USPED calculates the rates and distribution of land erosion and sediment deposited to receiving waters. L-THIA can be used to calculate the extent of increased pollutant loadings from anticipated increases in impervious surfaces associated with new development. In addition, users have access to the results of the Spatially Explicit Sediment Delivery Model and the Revised Universal Soil Loss Equation model to identify high risk sediment yield areas. The Digital Watershed also includes 3D visualization and watershed reporting capabilities. Through its interface, users can also access EPA's modernized STORET water quality database on the fly by utilizing web services hosted by EPA.

Section 3.2: Digital Watershed Functionality

I. Navigating the main page

A. The homepage

Digital Watershed can be accessed at www.iwr.msu.edu/dw. It provides three ways to access Digital Watershed as well as site information.

B. Address entry

This search method allows the user to enter an address of a location and have Digital Watershed locate the watershed containing the address. The address will be starred on the map. This is the default search method (Figure 3.1).

C. Map entry

This search method takes the user to a map of the contiguous U.S. divided by EPA regions. A user must select a region of interest to bring up a drop-down list of states and 8-digit watersheds for that region (Figure 3.2). After hitting "Start Viewer" the user will be taken to a Digital Watershed map of the selected 8-digit HUC (Hydrologic Unit Code).

D. Search entry

This search method allows the user to select a state and watershed of interest from a drop-down menu or specify an 8-digit watershed name or HUC (Figure 3.3).

Figure 3.1: Digital Watershed homepage and address entry

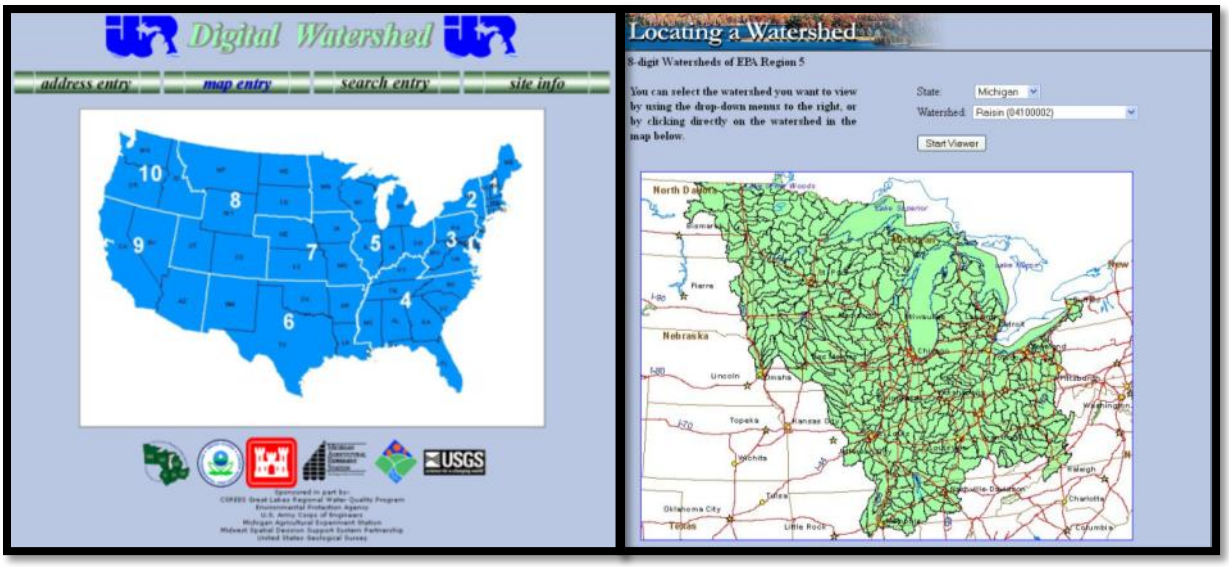

Figure 3.2: Map entry

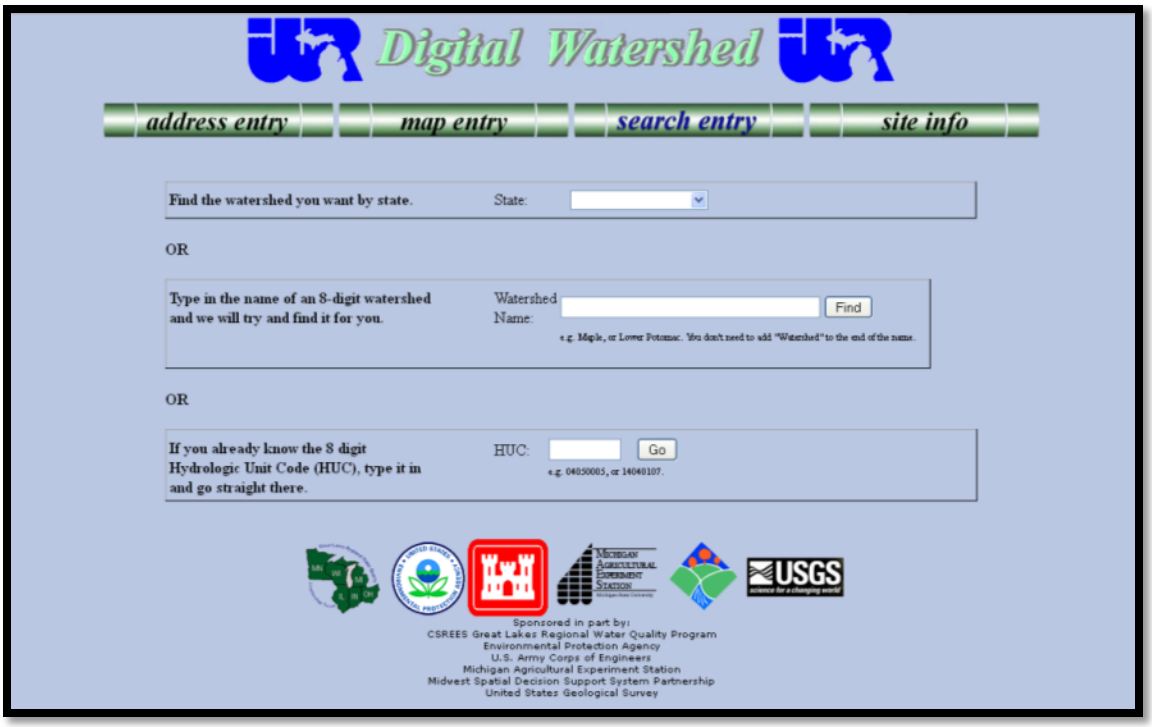

Figure 3.3: Search entry

II. Navigating the map page

A. Map information

The Map Information box to the left of the map contains a Key Map and the Legend. It also allows a user to select a zoom factor for faster zooming.

B. Map layers

The "Get Updated Map" button refreshes the map and adds or removes layers as specified by the user. Note that the map doesn't update automatically so the user must select this button in order to view the layer changes. Multiple layers can be drawn on the map by clicking on the square button next to each layer. Only one layer may be active at a time. To activate a layer, click on the circle button to the left of the layer name. For instance, the "State Soil" and "County Boundaries" layers in Figure 3.4 would both be drawn on the map but only the "State Soil" layer would be active.

C. Metadata

Metadata can be accessed by clicking on the metadata icon next to each layer's heading. Figure 3.4 highlights the metadata icon in red.

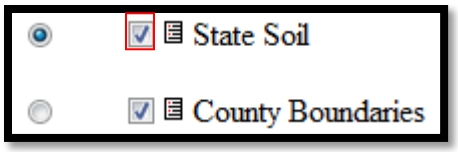

Figure 3.4: Map Layers

III. Digital Watershed Basic Functions

All Digital Watershed Tools can be accessed from the GIS Toolbar, located at the top of the map window.

The Digital Watershed GIS Toolbar contains standard map navigation tools. A user can access these tools by clicking on the corresponding icon and then clicking on a desired location within the map (Table 3.1).

Icon	Tool	Description
	Zoom in	Zoom in to a large scale on the map
	Zoom out	Zoom into a small scale on the map
	Zoom to full extent	Zoom back to the original scale with which the map was first displayed
	Pan	Pan or move to a different area of the map without changing the map scale. The map will re-center on the location clicked.
	Scale down	Transfers the map from 8-digit watershed to the 12-digit sub-watershed. Some Digital Watershed layers may become unavailable (Figure 3.5).
	Identify	Displays the features of the map's active layer. Results will open in a new window (Figure 3.6).
	Refresh	Refreshes the map with any added or removed layers. "Get Updated Map" performs the same function.

Table 3.1: Basic Digital Watershed Functions

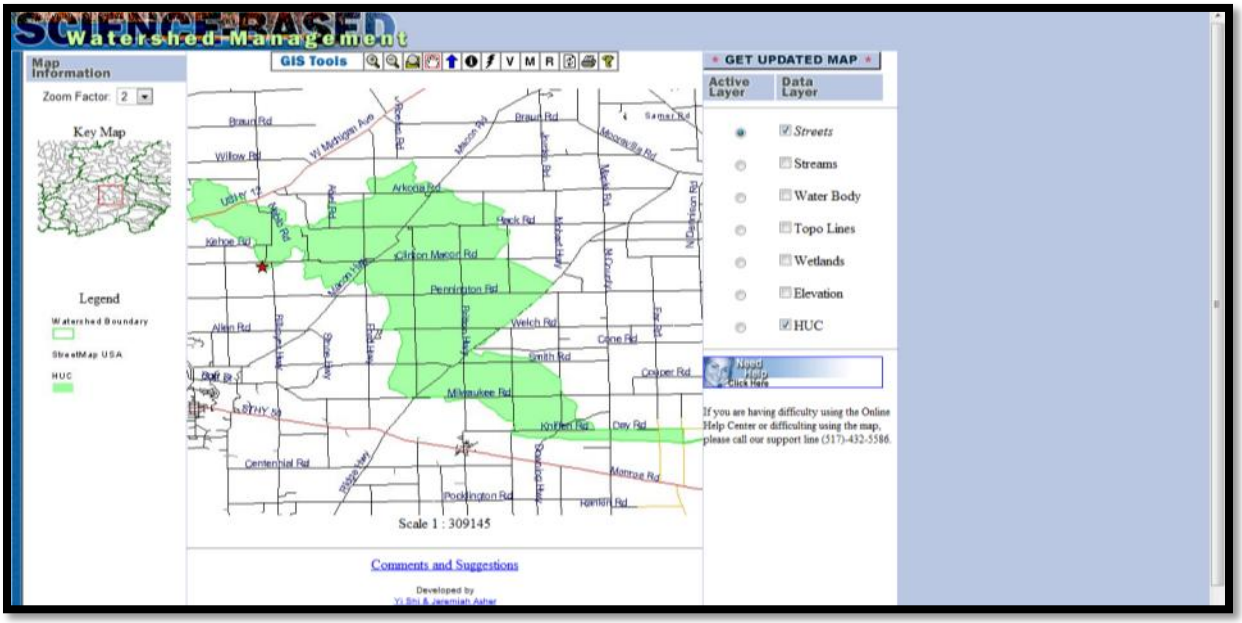

Figure 3.5: Scale down

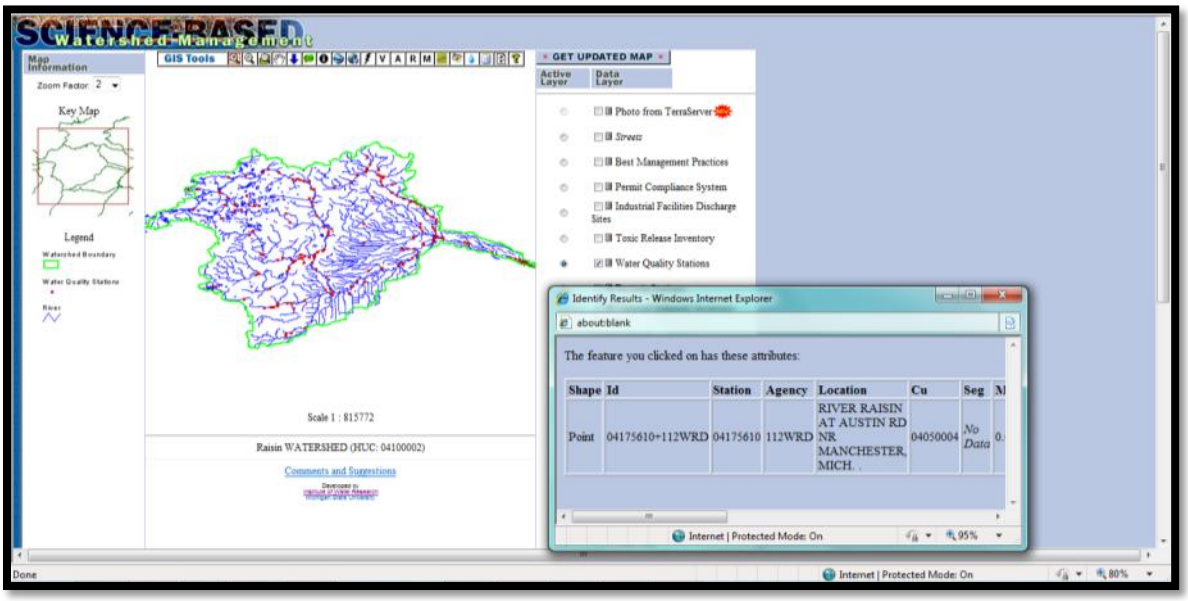

Figure 3.6: Identify

IV. Map Image Functions

Digital Watershed has various map image tools that can be run for the selected watershed. Consult Table 3.2 below for corresponding tool icons.

Icon	Tool
	Google Mapping
	Microsoft Bing Mapping
	Map Image Fetching
	Thematic Mapping
V	Visualize Topography

Table 3.2: Icons for Digital Watershed Mapping Tools

A. High-resolution aerial photo background

A watershed boundary can be displayed over a high-resolution aerial photo background using a Google Maps or Bing Maps platform. A user can access either of these tools by clicking on the preferred mapping platform icon and viewing the map in the pop-up window (Figure 3.7). Note that all other Digital Watershed functions are unavailable in the new map.

Figure 3.7: High-resolution Aerial Background (Google Maps)

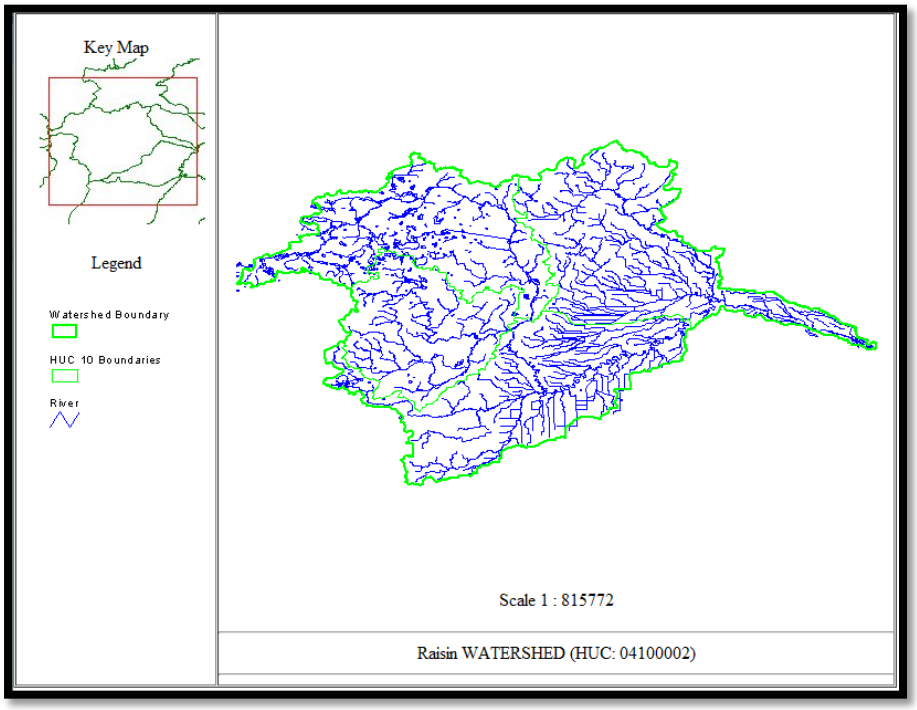

Figure 3.8: Thematic Map Image

B. Accessing map images

Users can access map images and embed them to a watershed report by using the "Map Image Fetching" or "Thematic Mapping" icons. The user should select all desired layers to be displayed, update the map and set a desired map extent before clicking on either of these tools. The map image will be displayed in a new window, and should be saved to a dedicated folder for later use. Refer to Figure 3.8.

C. Visualize Topography

This tool allows the user to display a 3D rendering of the watershed topography. The resultant image will appear in a new window (Figure 3.9).

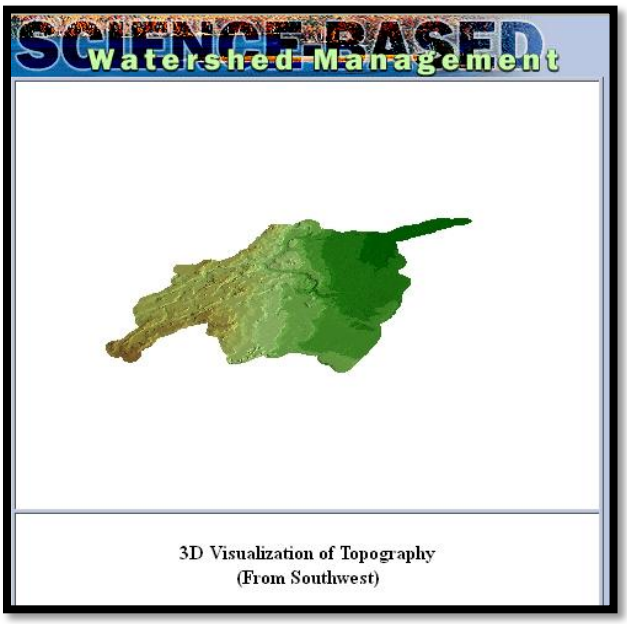

Figure 3.9: Visualize Topography

V. Digital Watershed Analyses and Reports

Digital Watershed's remaining functions provide reports or analyses. These tools can be accessed by clicking on the corresponding icon and clicking on a location on the map. Refer to Table 3.3 below for each tool's icon.

Icon	Tool
	Delineate Watershed
	EPA Surf Your Watershed
A	ATtILA
M	USPED Modeling
	EPA STORET
	Watershed Reporting

Table 3.3: Icons for other Digital Watershed Tools

A. Delineate watershed

This tool runs the L-THIA (https://engineering.purdue.edu/~lthia/) model for the selected watershed and allows the user to delineate the watershed on-the-fly to obtain data on land use, hydrologic soil group, etc. The user should refer to L-THIA tutorial from Purdue University for further information on how to run L-THIA.

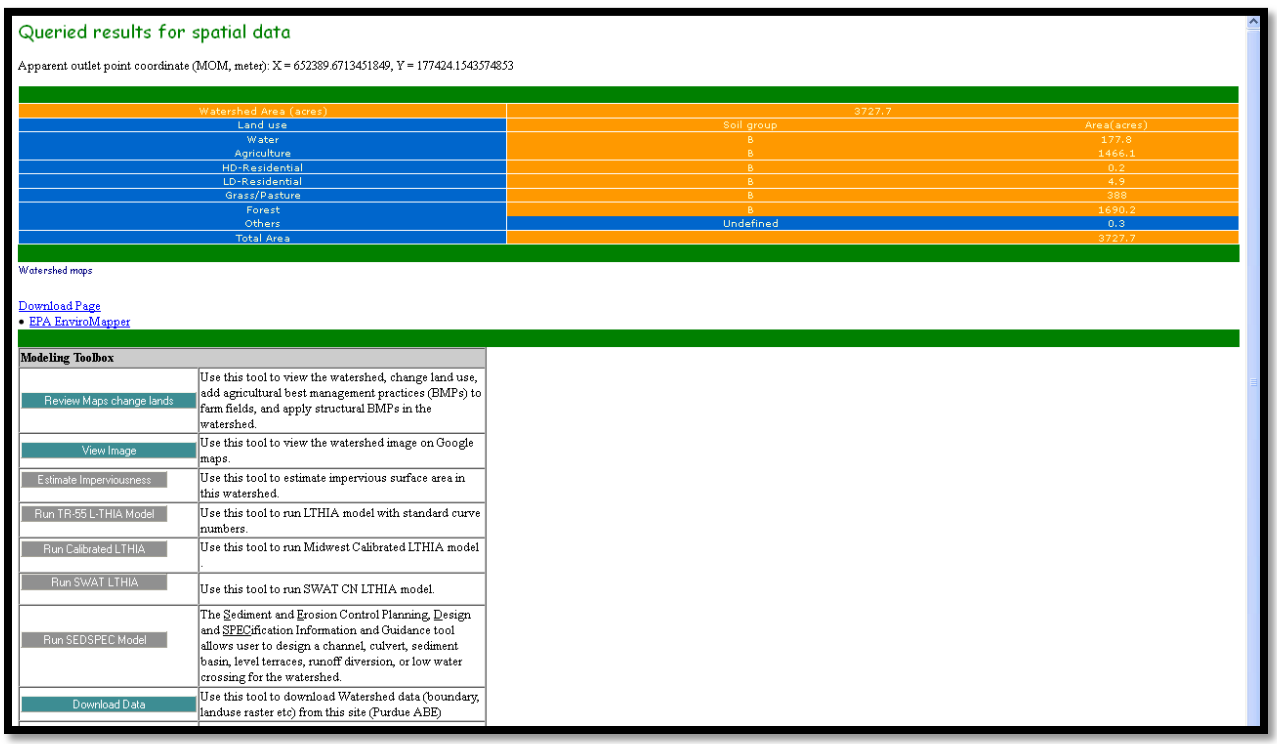

Figure 3.10: Delineation results and L-THIA models available to run

B. EPA Surf Your Watershed

This tool allows the user to view the EPA's Surf Your Watershed site for the selected watershed.

C. ATtILA (Analytical Tools Interface for Landscape Assessment)

The user can access ATtILA (http://www.epa.gov/esd/land-sci/attila/index.htm) to calculate many commonly used landscape metrics for the selected watershed (Figure 3.11). From the EPA's ATtILA website, "The program accepts data from broad range of sources and is equally suitable across all landscapes, from deserts to rain forests to urban areas, and may be used at local, regional, and national scales."

D. USPED Modeling (Unit Stream Power - based Erosion Deposition)

This tool allows the user to run the USPED model and display a map result showing erosion and deposition in the watershed. This result is stored permanently on the system and it can be accessed by turning on the "Erosion and Deposition" layer. See Figure 3.12.

E. EPA STORET

This tool allows the user to display water quality stations contained in the EPA STORET database on Google Maps (Figure 3.13). A user can access more information about water quality at each station by clicking on a station's map pin (Figure 3.14).

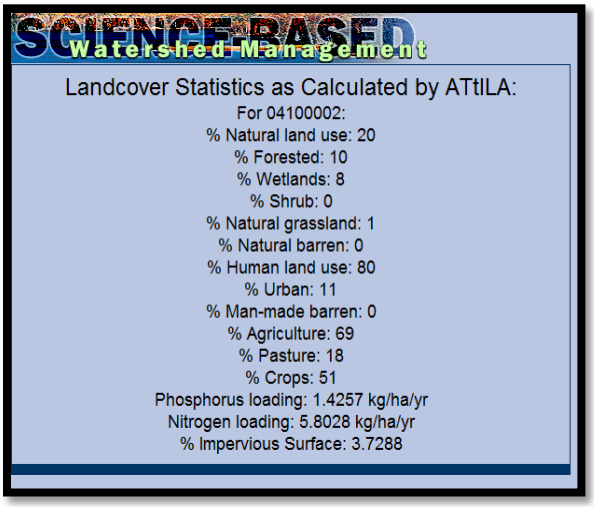

Figure 3.11: ATtILA results for River Raisin Watershed

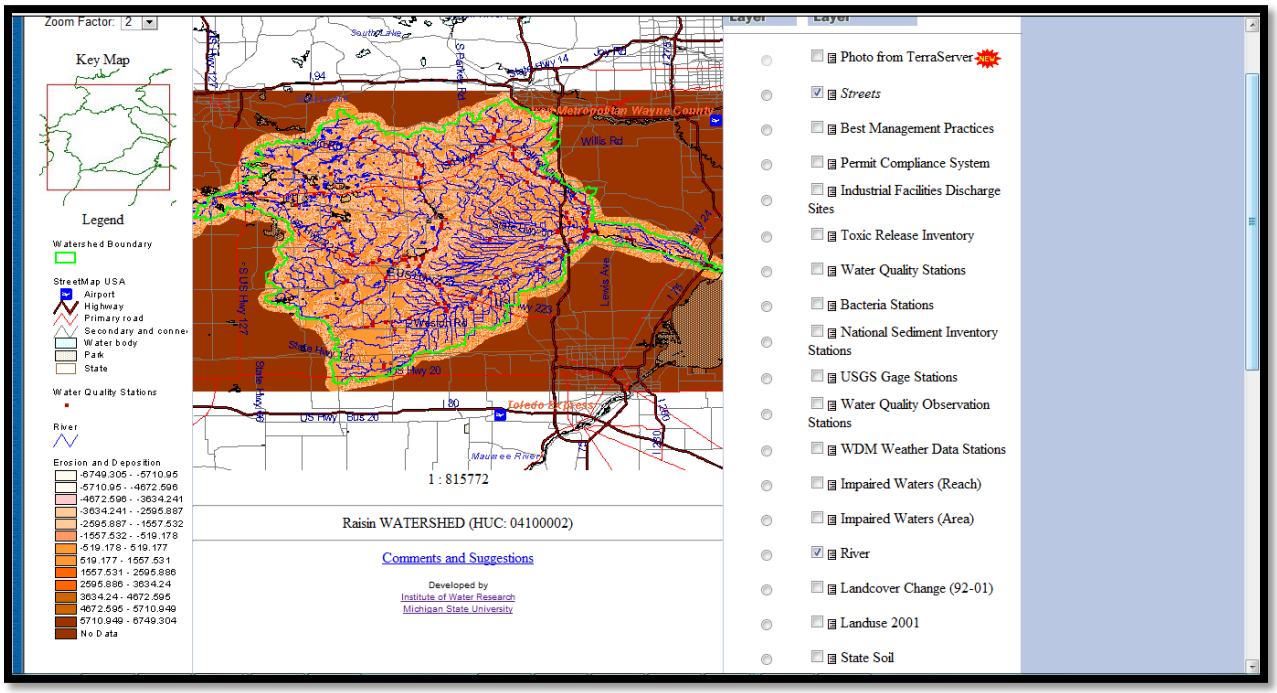

Figure 3.12: UPSED Modeling

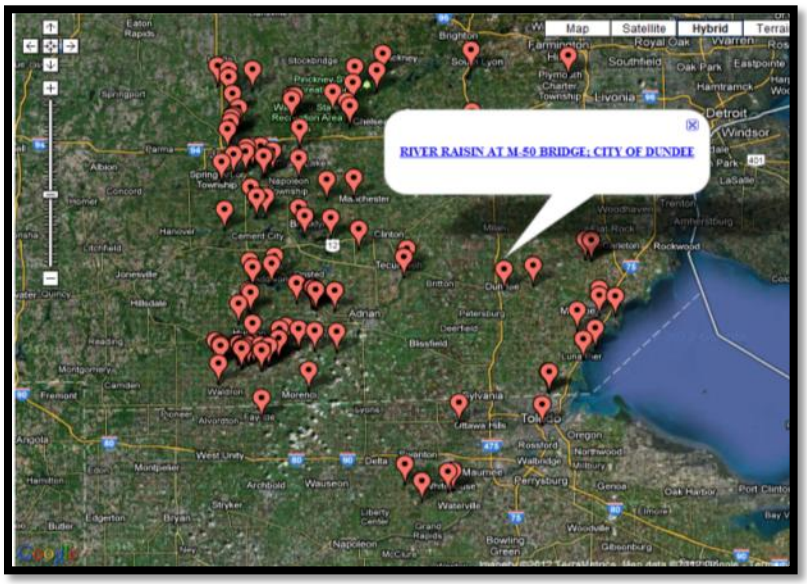

Figure 3.13: EPA STORET map results

EPA STORET Water Quality Data Results :

Organization ID :: 21MICH
Organization Name :: Michigan Department of Environmental Quality
Monitoring Location Name :: RIVER RAISIN AT M-50 BRIDGE; CITY OF DUNDEE

Characteristic	Result Value	Units	Sample Date	Value Type	Depth	Depth Units
Dissolved oxygen (DO)	8700	ug/l	2003-06-27	Actual		
Temperature, water	24.4	deg C	2003-06-27	Actual		
Dissolved oxygen (DO)	8700	ug/l	2003-07-02	Actual		
Dissolved oxygen (DO)	8720	ug/l	2003-07-02	Actual		
Ammonia as NH3	20	ug/l	2003-07-02	Actual		
Kjeldahl nitrogen	1200	ug/l	2003-07-02	Actual		
Nitrogen, Nitrite (NO2) as NO2			2003-07-02	Actual		
Inorganic nitrogen (nitrate and nitrite) as N	870	ug/l	2003-07-02	Actual		
Phosphorus	100	ug/l	2003-07-02	Actual		
Solids, Total Suspended (TSS)	25000	ug/l	2003-07-02	Actual		
Carbonaceous biochemical oxygen demand, standard conditions	5000	ug/l	2003-07-02	Actual		
Orthophosphate as P			2003-07-02	Actual		
Solids, Dissolved	460000	ug/l	2003-07-02	Calculated		

Figure 3.14: EPA STORET output data

F. Watershed Reporting

This tool allows the user to generate a standard watershed report that contains basic watershed information, a watershed map, selected ReVa (Regional Vulnerability Assessment) indicators including land-use statistics, selected L-THIA outputs and EPA STORET water quality data summary tables. See Figure 3.15 below.

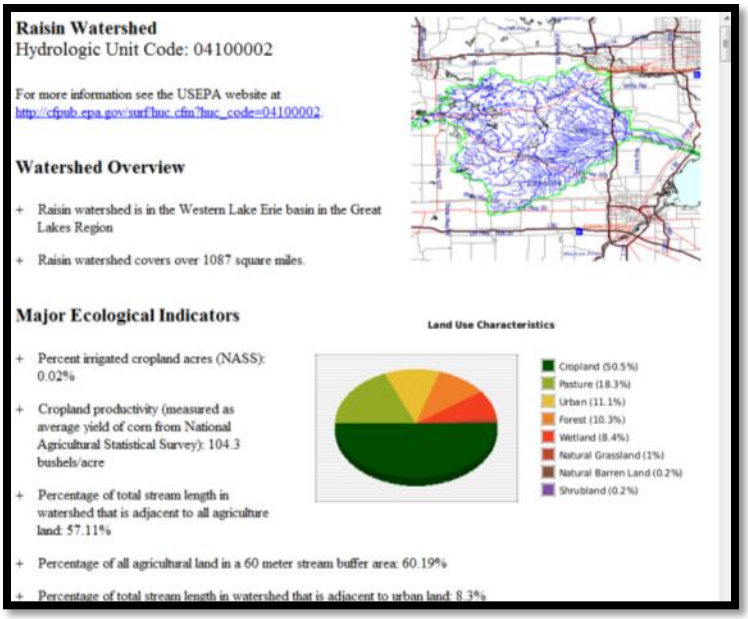

Figure 3.15: Watershed Reporting

APPENDICIES A1-A6

Tool Tutorials

APPENDIX A1:

HIT Tutorial | River Raisin

The Raisin River Watershed Management Plan (http://www.michigan.gov/documents/deq/wb-nps-rr-wmp1_303614_7.pdf) ranks sediment loading as its third highest priority for improving water quality in the watershed behind nitrogen and pathogen loadings. Agricultural runoff is cited in the report as the number one source for sediment loading, making HIT an appropriate tool to help prioritize many of their planned activities involving erosion and sediment loading reductions.

Using the HIT model, complete the following tasks for watershed prioritization:

- **I.** Estimate how much sediment is delivered to the River Raisin annually.
- **II.** Determine which HUC10 is the largest contributor of sediment in the River Raisin.
- **III.** Determine which River Raisin HUC12 has the highest contributing rate of sediment loading.
- **IV.** Assess in which River Raisin HUC12 no-till would yield a maximum economic benefit.
- **V.** Target fields in the Hazen Creek watershed for BMP implementation.

Instructions:

I. Estimate how much sediment is delivered to the River Raisin annually.

A. Open up a web-browser and access the HIT website (www.iwr.msu.edu/hit2). Click on "By watershed" under the Data Access heading.

B. In the search field at the top type in "Raisin" and click on the "Raisin (04100002 – MI, OH)" link from the search results. See Figure A.1.1.

C. Hit the "Table" button at the bottom of the screen and specify "Sediment" and "Totals" from the HIT table menu (Figure A.1.2).

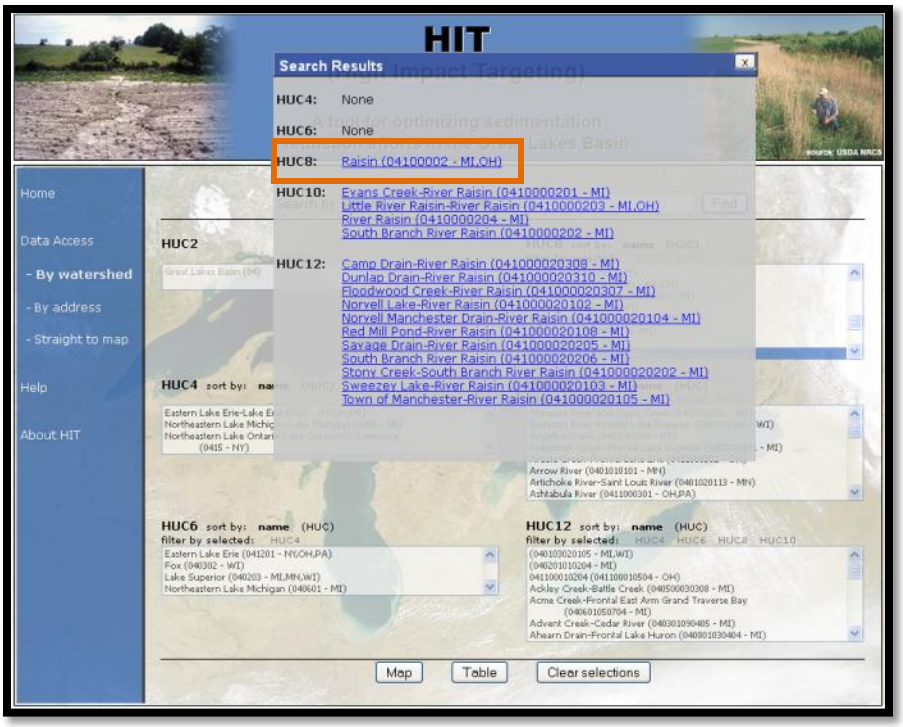

Figure A.1.1: Selecting the River Raisin

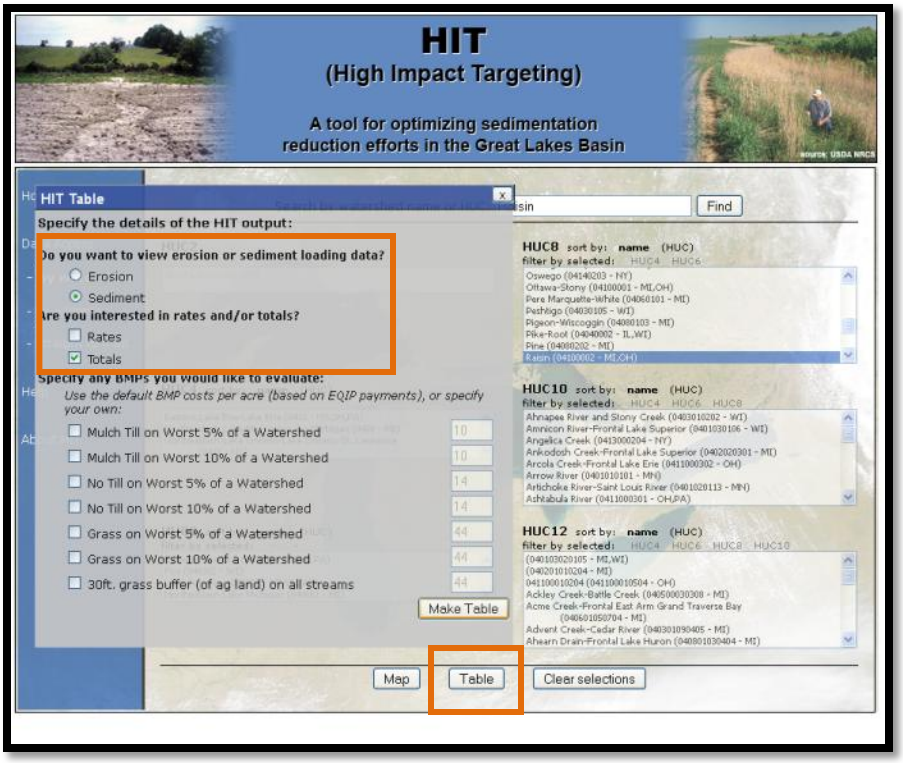

Figure A.1.2: Generating a HIT table

D. The HIT output will open in a new window. Take a moment to review the columns of the HIT table (Figure A.1.3).

- The first three columns (in white) display basic information about the River Raisin.
- The grey column displays the estimated sediment loading in tons/year for the selected watershed.

E. The HIT model estimates that the River Raisin watershed generates 65,287 tons of sediment/year. Recall that HIT outputs should not be considered exact measurements of erosion or sediment loading, but can be helpful in prioritizing watersheds on a relative basis. Next, we'll examine sediment loads at HUC10 and HUC12 scales.

Sediment Click on a column title to sort ascending.

Name	HUC	Acres	Total(tons/yr)
Raisin	04100002	680,332	65,287
TABLE TOTALS		680,332	65,287

Figure A.1.3: HIT table results

II. Determine which HUC10 is the largest contributor of sediment in the River Raisin

A. Close the HIT table and select the "Map" button at the bottom of the screen. This will take you to the map and display a yellow circle for the River Raisin watershed. Notice in the "Map Layers" menu that the *HUC8* layer is already drawn on the map and activated for you.

B. Zoom in further on the River Raisin watershed. Then, activate the *HUC10* layer by clicking on its radio button in the "Map Layers" menu; this will highlight the layer in blue. Next draw the *HUC10* layer by clicking on the checkbox next to the radio button while leaving the *HUC8* boundary drawn. You'll notice that the yellow circle representing the HUC8 River Raisin watershed disappeared when you activated the *HUC10* layer.

C. To select HUC10 watersheds, choose "Select Watersheds" > "On map" from the HIT toolbar. Notice that "Select Watersheds" is bolded, indicating that this tool is turned on. Click individually on the four local watersheds within the River Raisin (Figure A.1.4). If you accidentally click on the wrong watershed, click it again to remove it from your selection. Be sure to deactivate the selection tool by clicking again on the "On map" option under the "Select Watersheds" tab. Deactivated tools will not be bolded.

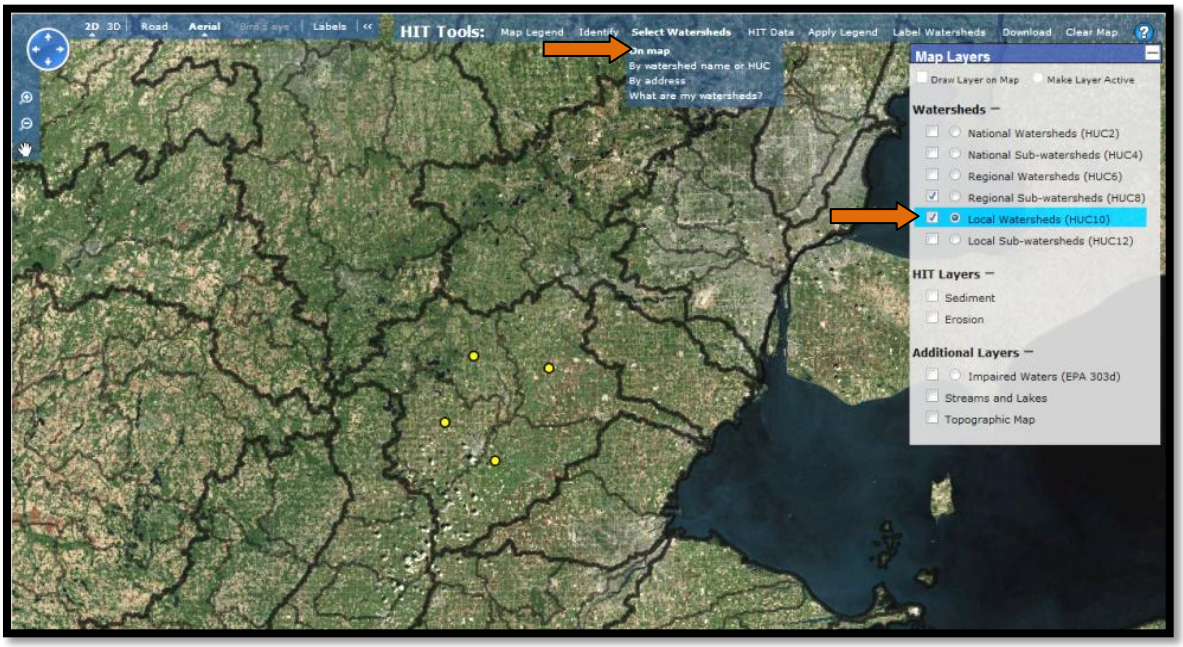

Figure A.1.4: Selecting watersheds "on map"

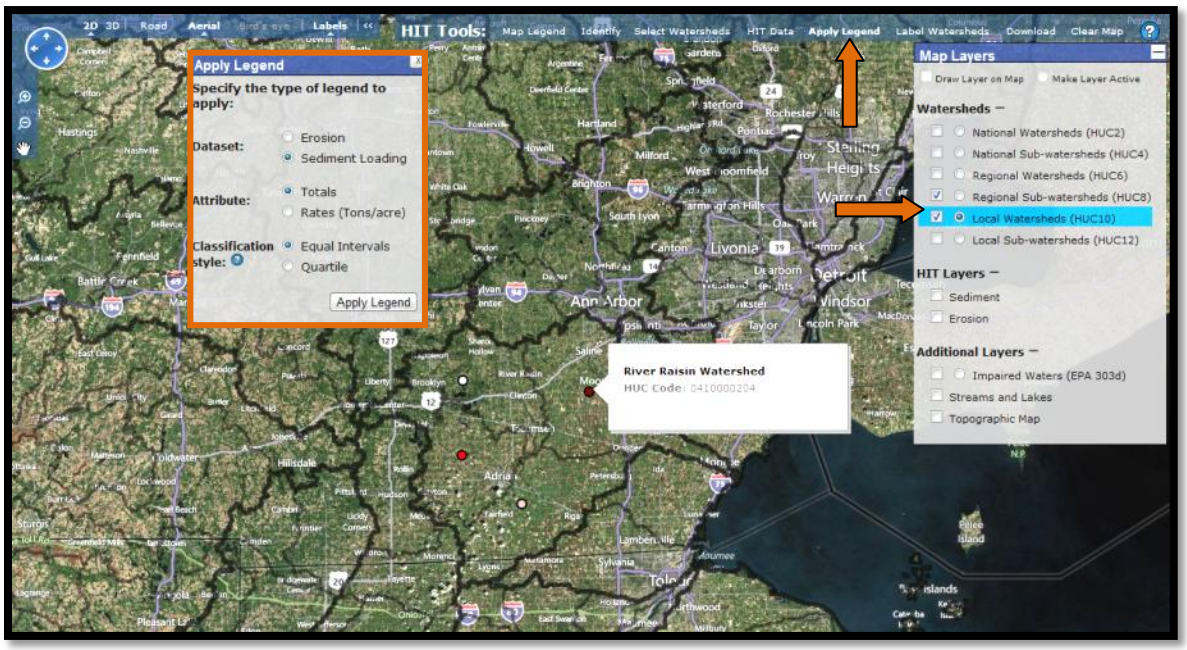

Figure A.1.5: Using the "Apply Legend" Tool

D. To determine the largest HUC10 contributor, we can also use the "Apply Legend" function instead of the table. The "Apply Legend" tool is a quick way to visually see which watersheds are predicted to produce more sediment loading to streams than others.

You will have to choose between equal interval and quartile classification systems to display the data. Equal Intervals defines bins for the watersheds using value ranges of equal size (e.g. 0-2, 2-4, 4-6, 6-8), while Quartiles creates value ranges for the bins so that each bin has roughly the same number of watersheds. Quartiles typically produce the more cartographically appealing map, as Equal Intervals can be skewed by very large values relative to the rest of the sample.

From the HIT toolbar, click on "Apply Legend" and specify "Sediment Loading," "Totals," "Quartile," and hit "Apply Legend."

The selected watersheds are now shaded by their sediment loading. Turn on legend information for the shaded watersheds by clicking on "Map Legend" from the HIT toolbar. Darker shades represent higher sediment loadings. See Figure A.1.5.

E. Hover over the circle with the darkest shading in the northeast corner of the Raisin, indicating that this is the largest HUC10 contributor of sediment. A label for the River Raisin Watershed and its 10-digit code (0410000204) will appear.

III. Determine which River Raisin HUC12 has the highest contributing rate of sediment loading

A. Close the "Apply Legend" menu and draw and activate the *HUC12* layer on the map. Notice that the watersheds are still shaded.

B. From the HIT toolbar, click on "Select Watersheds" > "By watershed name or HUC" and type in the Raisin's 8-digit HUC "04100002." See Figure A.1.6.

C. We will use HIT tables to determine the largest HUC12 contributing rate in the River Raisin. Click on "HIT Data" from the HIT toolbar, select "Sediment" and "Rates" and then click "Make Table." Refer to Figure A.1.7.

D. Sort the table by the "Rate (tons/ac/yr)" column by clicking on its heading. See Figure A.1.8.

E. The Hazen Creek sub-watershed has the largest contributing rate (0.183 tons/acre/year) in the River Raisin.

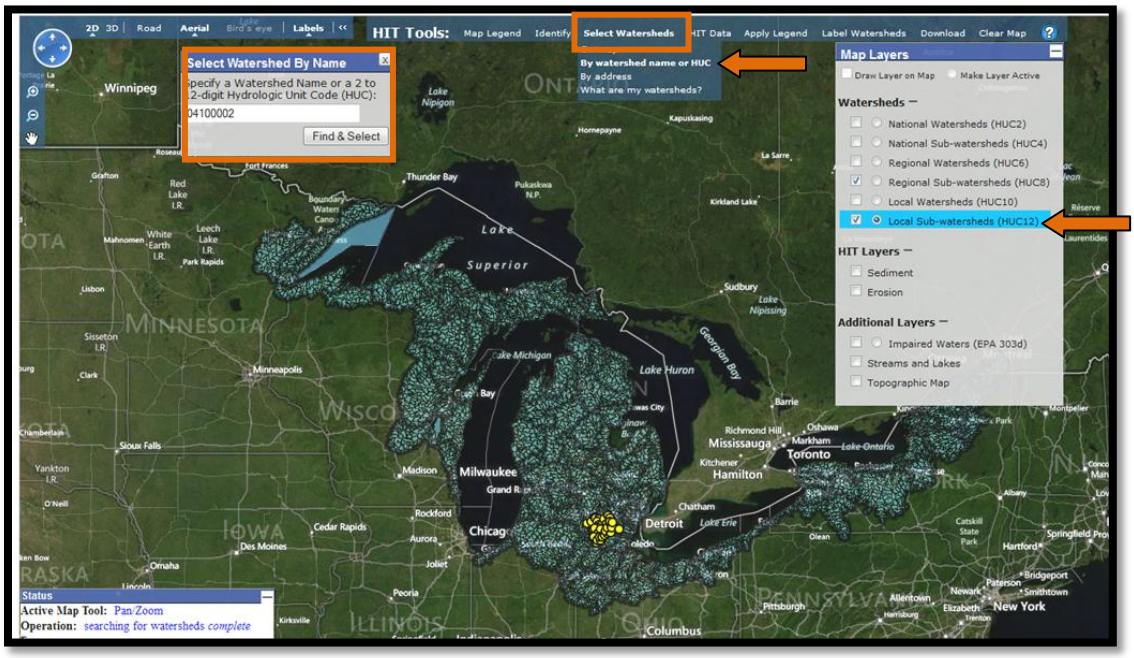

Figure A.1.6: Selecting "by watershed name or HUC"

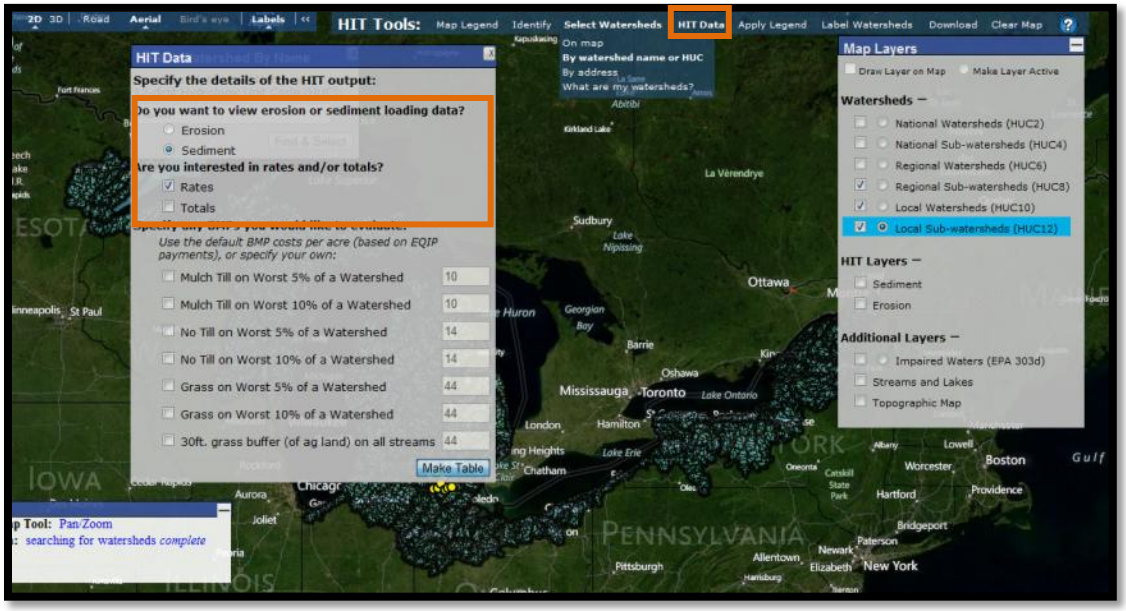

Figure A.1.7: Generating a HIT table on the map

Sediment Click on a column title to sort ascending.

Name	HUC	Acres	Rate(tons/ac/yr)
Sweezey Lake-River Raisin	041000020103	11,126	0.036
Willow Run at mouth	041000020410	25,025	0.044
Norvell Manchester Drain-River Raisin	041000020104	13,923	0.045
Saline River	041000020409	22,431	0.046
Dunlap Drain-River Raisin	041000020310	18,814	0.048
Norvell Lake-River Raisin	041000020102	33,651	0.053
Camp Drain-River Raisin	041000020308	10,719	0.054
Floodwood Creek-River Raisin	041000020307	36,649	0.063
Big Meadow Drain-Black Creek	041000020306	16,343	0.063
Savage Drain-River Raisin	041000020205	13,142	0.064
Macon Creek	041000020408	18,787	0.065
Bear Swamp Creek	041000020406	12,589	0.070
Goose Creek	041000020101	23,017	0.073
Little River Rasin	041000020309	27,406	0.075
Iron Creek	041000020106	20,502	0.077
Bear Creek	041000020304	13,930	0.081
Gleason Brook-Black Creek	041000020305	13,510	0.090
North Branch Macon Creek	041000020407	15,219	0.092
Koch Warner Drain-Saline River	041000020403	11,548	0.094
South Branch Macon Creek	041000020405	27,498	0.095
Wood Outlet Drain-Salina River	041000020402	22,182	0.102
Town of Manchester-River Raisin	041000020105	17,840	0.108
South Branch River Raisin	041000020206	16,575	0.109
Headwaters Bear Creek	041000020301	11,374	0.118
Red Mill Pond-River Raisin	041000020108	28,738	0.119
Headwaters Macon Creek	041000020404	16,627	0.126
Black Creek	041000020203	10,269	0.130
Nile Ditch	041000020303	15,716	0.135
Baker and May Drain-Black Creek	041000020302	25,308	0.136
Wolf Creek	041000020204	36,555	0.144
Stony Creek-South Branch River Raisin	041000020202	29,347	0.145
Headwaters Saline River	041000020401	26,710	0.157
Evans Creek	041000020107	21,232	0.160
Hazen Creek	041000020201	16,030	0.183
TABLE TOTALS		680,332	0.096

Figure A.1.8: HIT table results for River Raisin HUC12 sediment loading rates

IV. Assess in which HUC12 No Till would yield a maximum economic benefit

A. Close the HIT table and return to the map page. The "HIT Data" menu should still be open. In addition to "Sediment" and "Rates," specify "No Till on Worst 5% of a Watershed" and "No Till on Worst 10% of a Watershed" and hit "Make Table."

B. Take a moment to review the BMP columns of the HIT data table.

- The black columns show the estimated reduction in sediment loading for each BMP.
- The green columns show the cost-benefit ($ per ton of sediment loading reduced) of each BMP, essentially the "bang for the buck" number.

C. Sort the table by the "BMP Cost Benefit ($/ton reduced)" column for the "No Till on Worst 5%" scenario (Figure A.1.9).

Sediment

Click on a column title to sort ascending.

Name	HUC	Acres	Rate (tons/ac/yr)	BMP: No Till on Worst 5% of Area				BMP: No Till on Worst 10% of Area			
				Total Reduction (tons/yr)	Reduction %	BMP Cost at $14 per acre	BMP Cost Benefit ($/ton reduced)	Total Reduction (tons/yr)	Reduction %	BMP Cost at $14 per acre	BMP Cost Benefit ($/ton reduced)
Hazen Creek	041000020201	16,030	0.183	488	17%	$11,221	$23	684	23%	$22,442	$33
Evans Creek	041000020107	21,232	0.160	591	17%	$14,863	$25	836	25%	$29,725	$36
Stony Creek-South Branch River Raisin	041000020202	29,347	0.145	733	17%	$20,543	$28	1,023	24%	$41,086	$40
Wolf Creek	041000020204	36,555	0.144	899	17%	$25,588	$28	1,249	24%	$51,177	$41
Nile Ditch	041000020303	15,716	0.135	354	17%	$11,001	$31	503	24%	$22,002	$44
Baker and May Drain-Black Creek	041000020302	25,308	0.136	564	16%	$17,716	$31	800	23%	$35,431	$44
Headwaters Saline River	041000020401	26,710	0.157	573	14%	$18,697	$33	841	20%	$37,394	$44
Black Creek	041000020203	10,269	0.130	217	16%	$7,188	$33	310	23%	$14,377	$46
Headwaters Macon Creek	041000020404	16,627	0.126	349	17%	$11,639	$33	486	23%	$23,277	$48
Red Mill Pond-River Raisin	041000020108	28,738	0.119	583	17%	$20,117	$35	800	23%	$40,233	$50
South Branch River Raisin	041000020206	16,575	0.109	313	17%	$11,603	$37	435	24%	$23,205	$53
Wood Outlet Drain-Salina River	041000020402	22,182	0.102	373	16%	$15,528	$42	502	22%	$31,055	$62
Town of Manchester-River Raisin	041000020105	17,840	0.108	288	15%	$12,488	$43	387	20%	$24,977	$65
South Branch Macon Creek	041000020405	27,498	0.095	435	17%	$19,249	$44	616	23%	$38,497	$63
Headwaters Bear Creek	041000020301	11,374	0.118	176	13%	$7,962	$45	259	19%	$15,923	$61
Goose Creek	041000020101	23,017	0.073	346	20%	$16,112	$47	452	27%	$32,224	$71
Gleason Brook-Black Creek	041000020305	13,510	0.090	202	17%	$9,457	$47	277	23%	$18,915	$68
Koch Warner Drain-Saline River	041000020403	11,548	0.094	171	16%	$8,084	$47	230	21%	$16,168	$70
North Branch Macon Creek	041000020407	15,219	0.092	213	15%	$10,653	$50	301	21%	$21,306	$71
Bear Creek	041000020304	13,930	0.081	181	16%	$9,751	$54	248	22%	$19,502	$79
Iron Creek	041000020106	20,502	0.077	267	17%	$14,352	$54	337	21%	$28,703	$85
Savage Drain-River Raisin	041000020205	13,142	0.064	163	19%	$9,199	$56	212	25%	$18,398	$87
Little River Rasin	041000020309	27,406	0.075	334	16%	$19,184	$57	462	22%	$38,369	$83
Macon Creek	041000020408	18,787	0.065	228	19%	$13,151	$58	294	24%	$26,302	$90
Floodwood Creek-River Raisin	041000020307	36,649	0.063	439	19%	$25,654	$58	553	24%	$51,308	$93
Norvell Lake-River Raisin	041000020102	33,651	0.053	369	21%	$23,556	$64	467	26%	$47,111	$101
Willow Run at mouth	041000020410	25,025	0.044	261	24%	$17,517	$67	333	30%	$35,035	$105
Dunlap Drain-River Raisin	041000020310	18,814	0.048	195	22%	$13,170	$68	250	28%	$26,340	$106
Big Meadow Drain-Black Creek	041000020306	16,343	0.063	168	16%	$11,440	$68	231	22%	$22,880	$99
Camp Drain-River Raisin	041000020308	10,719	0.054	110	19%	$7,503	$68	143	25%	$15,006	$105
Bear Swamp Creek	041000020406	12,589	0.070	129	15%	$8,812	$68	184	21%	$17,625	$96
Saline River	041000020409	22,431	0.046	200	19%	$15,702	$79	256	25%	$31,403	$123
Norvell Manchester Drain-River Raisin	041000020104	13,923	0.045	120	19%	$9,746	$81	155	25%	$19,492	$126
Sweezey Lake-River Raisin	041000020103	11,126	0.036	94	24%	$7,788	$83	128	32%	$15,576	$122
TABLE TOTALS		680,332	0.096	11,123	17	$476,233	$43	15,241	23	$952,465	$62

Figure A.1.9: HIT table results with No Till BMP estimates

D. According to the HIT output, BMP dollars will go the furthest by targeting No Till adoption in the Hazen Creek sub-watershed, with an estimated cost/benefit of $23 per ton of sediment reduction under the scenario.

It is important to reiterate that these estimates are based on a purely hypothetical scenario of targeted No Till installation, and should be used for relative comparison among watersheds. As stated in the manual under the "HIT Functionality" section, HIT's estimates do not account for stream bank, wind, or ephemeral gully erosion; nor does it account for in-stream deposition. It only estimates how much eroded soil is reaching the stream network; therefore the reduction estimates in these scenarios are likely less than what would actually occur if such a practice was installed and monitored at the edge of field.

Furthermore, the precise BMP simulation would be impossible to install in practice. No Till is implemented on entire fields, not within individual 30 by 30 meter grid cells. Nonetheless, this exercise shows how HIT can be a useful prioritization tool for groups and organizations that may not have the resources or expertise to utilize more thorough and robust sediment loading models.

V. Target fields in the Hazen Creek watershed for BMP implementation.

A. Close the HIT table and select "Clear Map" from the HIT toolbar.

B. Next, choose "Select Watersheds" > "By watershed name or HUC" and type in "Hazen Creek." Hit "Find" and zoom in on the watershed.

C. Turn on the *Sediment* layer and zoom in on one of the high-risk areas. If needed, turn off the *HUC12* layer for better visibility. See Figure A1.10.

D. To view the high-risk areas in even greater detail, click on "Bird's eye" from the Bing Maps toolbar (Figure A1.11). Note that "Bird's eye" imagery may not be available in every location.

Figure A1.10: Viewing high-risk areas

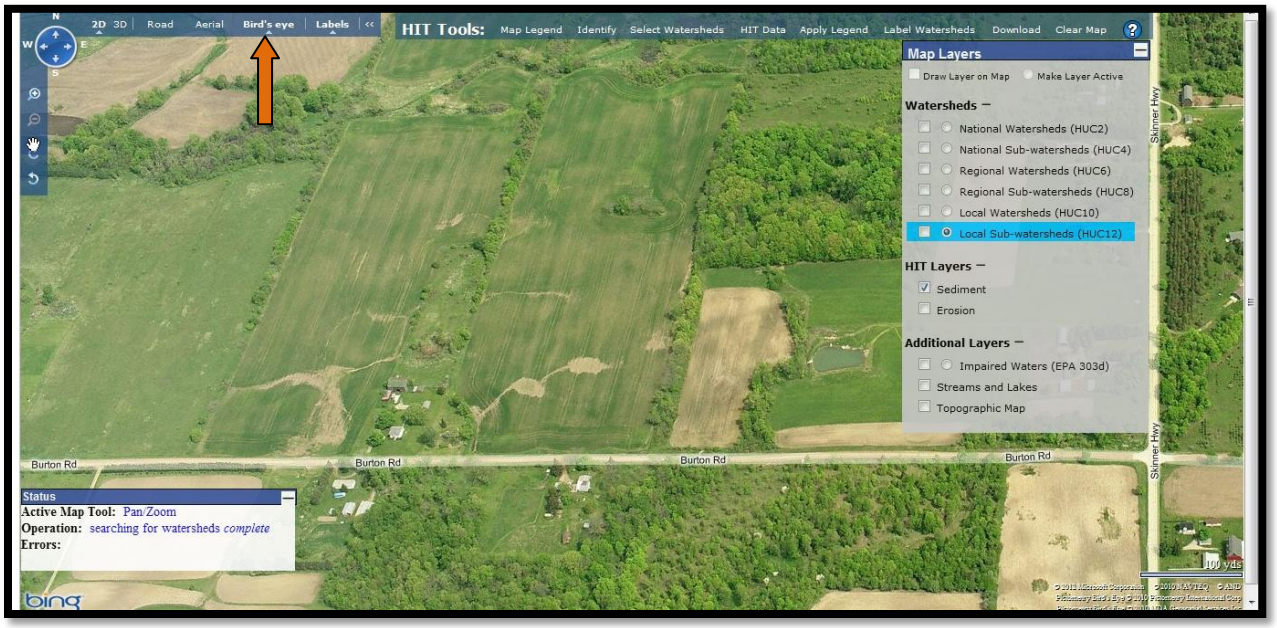

Figure A1.11: Viewing high-risk areas in "Bird's eye" view

Through these steps, you can complete the tasks posed at the beginning of the exercise:

I. **Estimate how much sediment is delivered to the River Raisin annually.**

HIT estimates that the River Raisin watershed generates 65,287 tons of sediment/year.

II. **Determine which HUC10 is the largest contributor of sediment to the Raisin.**

The River Raisin watershed (0410000204) is the largest HUC10 contributor of sediment.

III. **Determine which HUC12 has the highest contributing rate of sediment loading.**

The Hazen Creek sub-watershed (041000020201) has the largest HUC12 contributing rate (0.183 tons of sediment/acre/year) in the River Raisin watershed.

IV. **Assess in which HUC12 no-till would yield a maximum economic benefit.**

According to the HIT output, BMP dollars will go the furthest by targeting No Till adoption in the Hazen Creek sub-watershed, with an estimated cost/benefit of $23 per ton of sediment reduction under the scenario.

V. **Target fields in the Hazen Creek watershed for BMP implementation.**

Review the steps and maps outlined in Task V.

Appendix A2:

HIT Tutorial | Trail Creek

The Trail Creek Watershed Management Plan (ftp://ftp.ecn.purdue.edu/abegis/COE/2012/Trail_Creek_Watershed_Management_Plan%5B1%5D.pdf) cites that conservation management "is estimated to reduce total suspended solid loading by 75%" and that "conservation and restoration of riparian buffers is estimated to reduce total suspended solid (TSS) loadings by 50-75%." Implementation is anticipated to cost around $2,000,000. NRCS is responsible for identifying farms in the watershed for BMP implementation, including conservation tillage and riparian buffers. The HIT model can help determine the areas at highest-risk for erosion and sedimentation to increase the efficiency of this task.

Using the HIT model, complete the following tasks for watershed prioritization:

I. Estimate the total amount of sediment delivered to Trail Creek streams annually.

II. Determine which HUC12 has the highest contributing rate of sediment loading.

III. Assess in which HUC12 No Till would yield a maximum economic benefit.

IV. Compare the estimated cost-benefits of implementing no till and grass in the worst 5% of Trail Creek watersheds.

V. Target fields within the West Branch Trail Creek watershed for BMP implementation.

Instructions:

I. Estimate the total amount of sediment delivered to Trail Creek streams annually

A. Open up a web-browser and access the HIT website (www.iwr.msu.edu/hit2). Click on "By watershed" under the Data Access heading.

B. The Trail Creek Watershed Management Plan accounts only for sub-watersheds that are located within Indiana while the HIT system includes two additional watersheds in Trail Creek located outside of Indiana. For this exercise only the Indiana watersheds (East Branch Trail Creek, West Branch Trail Creek and Trail Creek) will be used, making watershed selection more tedious than usual. While it's possible to select all three sub-watersheds from Data Access under the HUC12 heading, we will instead complete watershed selection in the map.

For now, type "Trail Creek" into the search bar at the top and hit "Find." Click on "Trail Creek (040400010105- IN)" and then click the "Map" button at the bottom of the screen. See Figure A.2.1.

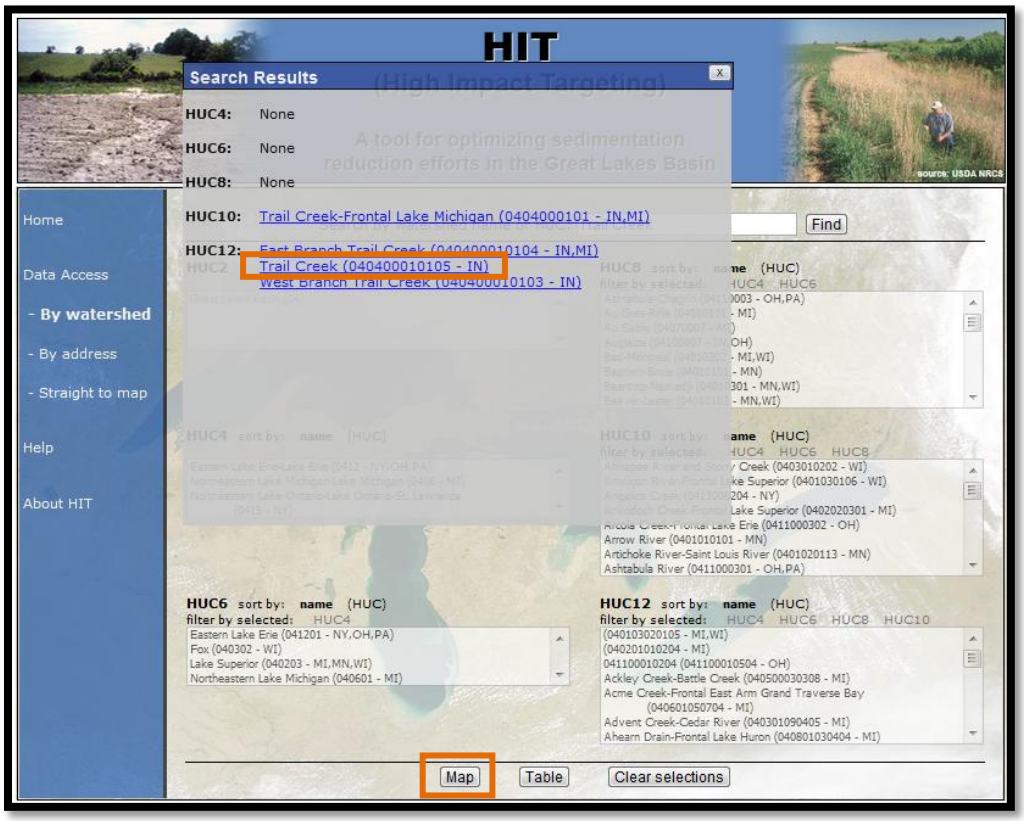

Figure A.2.1: Selecting the Trail Creek HUC12 watershed

C. This will open a map in a new window and display a circle for the Trail Creek HUC12 watershed. Notice that in the "Map Layers" menu the *HUC12* layer is already drawn on the map and activated. A marked, circular radio button next to a layer denotes the active layer. It will also be highlighted in blue. Refer to "HIT Functionality" in the manual for more details.

D. Zoom into the location of Trail Creek. From the "Map Layers" menu, draw the *HUC10* layer on the map by clicking on the checkbox next to the radio button. This will make it easier to see the entire HUC10 Trail Creek watershed. Four watersheds appear to be within the boundary of Trail Creek but we only want to select the three which resides mainly in Indiana.

E. We will use "Label Watersheds" to help identify the desired watersheds. From the HIT toolbar, select "Label Watersheds" and specify "Name." If no labeling options appear, click the radio button for the *HUC12* layer again. Notice that the "Label Watersheds" heading is now in bold, indicating that this tool is active. Hit "Label Features." The names of HUC12 watersheds will appear. Refer to Figure A.2.2.

F. Now, from the HIT toolbar, choose “Select Watersheds” > “On map” and click once on the West and East Branch Trail Creek watersheds to add them to your selection (Figure A.2.2). If needed, select the Trail Creek watershed again if it was de-selected in the previous step. If you accidentally click on the wrong watershed, click it again to remove it from your selection. Be sure to deactivate the selection tool by clicking again on the “On map” option under “Select Watersheds.” Deactivated tools will not be bolded.

Figure A.2.2: Labeling and selecting watersheds on the map

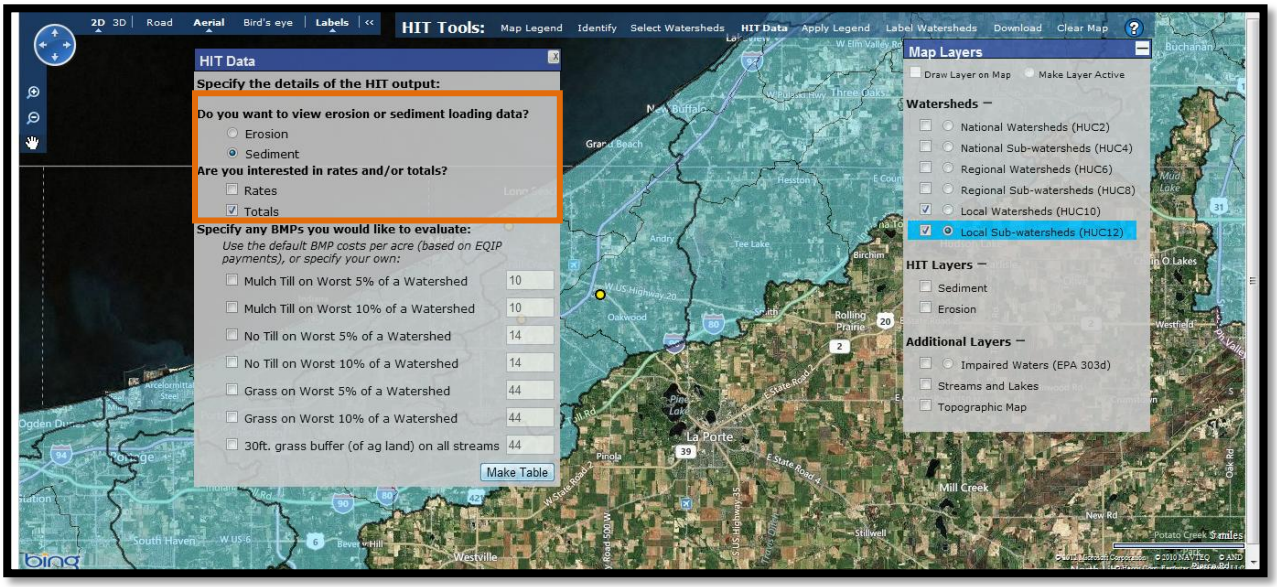

Figure A.2.3: Generating a HIT table from the map

G. From the "Label Watersheds" menu, hit "Remove Labels" and deactivate the tool.

H. Now that the three watersheds are selected, you are ready to make a HIT table to estimate annual sediment loading. Click on "HIT Data" from the HIT toolbar. Specify "Sediment" and "Totals," and hit "Make Table." See Figure A.2.3.

I. A new window will open with the HIT output. Take a moment to review the columns of the HIT table.

- The first three columns (in white) display basic information about the selected sub-watersheds in Trail Creek.
- The grey column displays the estimated sediment loading in tons/acre/year for each sub-watershed.

J. Examine the "TABLE TOTALS" row. Refer to Figure A.2.4. HIT estimates that the total amount of sediment reaching streams in the Trail Creek watershed is 1,198 tons/year. Recall that HIT outputs should not be considered exact measurements of erosion or sediment loading, but can be helpful in prioritizing watersheds on a relative basis. Next, we'll examine individual sediment loading rates for Trail Creek HUC12s.

Sediment Click on a column title to sort ascending.

Name	HUC	Acres	Total(tons/yr)
East Branch Trail Creek	040400010104	13,997	460
Trail Creek	040400010105	8,600	150
West Branch Trail Creek	040400010103	15,352	589
TABLE TOTALS		37,949	1,198

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Figure A.2.4: HIT table results

II. Determine which Trail Creek HUC12 has the highest contributing rate of sediment loading.

A. The "Apply Legend" tool is a quick way to visually see which watersheds are predicted to produce more sediment loading to streams than others, and will be used to complete this task.

You will have to choose between equal interval and quartile classification systems to display the data. Equal Intervals defines bins for the watersheds using value ranges of equal size (e.g. 0-2, 2-4, 4-6, 6-8), while Quartiles creates value ranges for the bins so that each bin has roughly the same number of watersheds. Quartiles typically produce the more cartographically appealing map, as Equal Intervals can be skewed by very large values relative to the rest of the sample.

B. Close the HIT table and the "HIT Data" menu. From the HIT toolbar, select "Apply Legend" and specify "Sediment Loading," "Rates (Tons/acre)," and "Quartile."

C. The selected watersheds are now shaded by their sediment loading. Turn on legend information for the shaded watersheds by clicking on "Map Legend" from the HIT toolbar. Darker shades represent higher sediment loadings.

D. Hover over the circle with the darkest shading. A label for the West Branch Trail Creek watershed and its HUC (040400010103) will appear, indicating that this watershed is predicted to contribute more tons of sediment/acre than the other two watersheds. See Figure A.2.5.

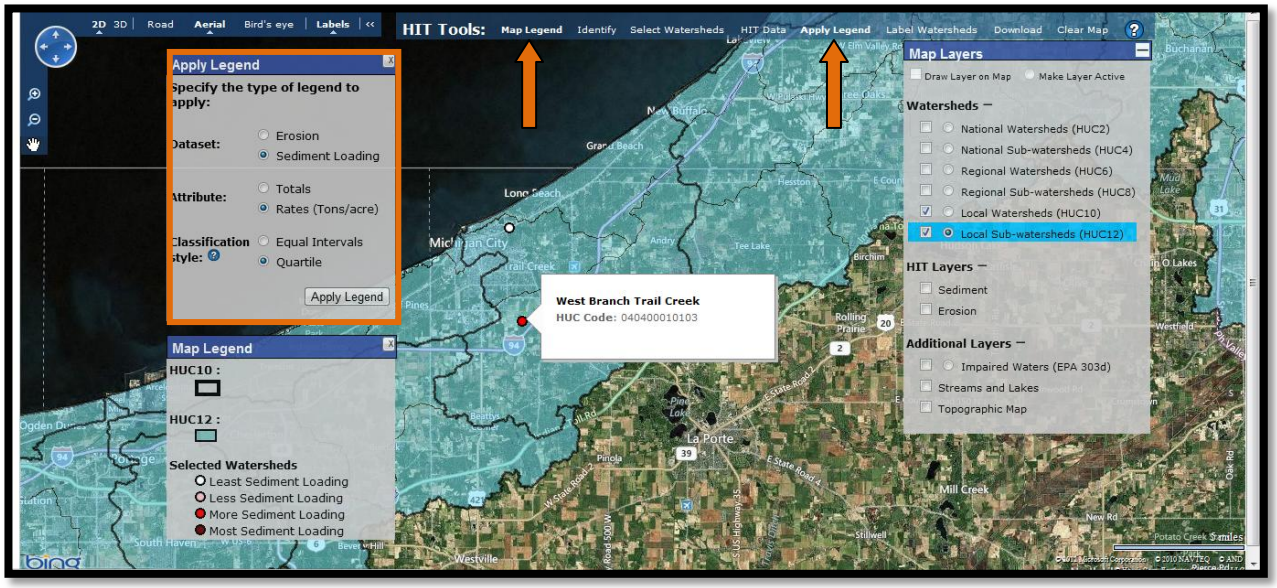

Figure A.2.5: Shading watersheds by sediment loading rates

III. Assess in which HUC12 No Till would yield a maximum economic benefit.

A. Deactivate "Apply Legend." Notice that the watersheds remain shaded.

B. Reopen "HIT Data." The previous specifications from the last HIT table are still selected. In addition to "Sediment" and "Totals," specify "No Till on Worst 5% of a Watershed" and hit "Make Table."

C. Again, the HIT table will open in a new window. Take a moment to review the BMP columns of the HIT data table.

- The black columns show the estimated reduction in sediment loading for each BMP.
- The green columns show the cost-benefit ($ per ton of sediment loading reduced) of each BMP, essentially the "bang for the buck" number.

D. Sort the table by the "BMP Cost Benefit ($/ ton reduced)" column by clicking on the column heading (Figure A.2.6).

E. According to the HIT output, BMP dollars will go the furthest by targeting No Till adoption in the West Branch Trail Creek sub-watershed, with an estimated cost/benefit of $61 per ton of sediment reduction under the scenario.

It is important to reiterate that these estimates are based on a purely hypothetical scenario of targeted No Till installation, and should be used for relative comparison among watersheds. As stated in the manual under the "HIT Functionality" section, HIT's estimates do not account for stream bank, wind, or ephemeral gully erosion; nor does it account for in-stream deposition. It only estimates how much eroded soil is reaching the stream network; therefore the reduction estimates in these scenarios are likely less than what would actually occur if such a practice was installed and monitored at the edge of field.

Furthermore, the precise BMP simulation would be impossible to install in practice. No Till is implemented on entire fields, not within individual 30 by 30 meter grid cells. Nonetheless, this exercise shows how HIT can be a useful prioritization tool for groups and organizations that may not have the resources or expertise to utilize more thorough and robust sediment loading models.

Sediment

Click on a column title to sort ascending.

Name	HUC	Acres	Total(tons/yr)	BMP: No Till on Worst 5% of Area			
				Total Reduction (tons/yr)	Reduction %	BMP Cost at $14 per acre	BMP Cost Benefit ($/ton reduced)
West Branch Trail Creek	040400010103	15,352	589	177	30%	$10,746	$61
East Branch Trail Creek	040400010104	13,997	460	144	31%	$9,798	$68
Trail Creek	040400010105	8,600	150	49	33%	$6,020	$123
TABLE TOTALS		37,949	1,198	369	31	$26,564	$72
Specify new values to recalculate BMP cost:						$ 14	
Recalculate BMP Cost							

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Figure A.2.6: HIT table results

IV. Compare the estimated cost-benefits of implementing No Till and Grass on the worst 5% of the Trail Creek watershed

A. Close the HIT table and adjust the "HIT Data" BMP parameters to also include "Grass on Worst 5% of a Watershed." Hit "Make Table."

B. In the new window, examine the "TABLE TOTALS" row and compare the "Reduction %" columns for No Till and Grass (Figure A.2.7).

HIT predicts that nearly twice as much sediment could be reduced by grass BMP implementation on the worst 5% of Trail Creek versus No Till adoption, though for a higher cost. This suggests that with proper financial resources, grass BMP implementation could potentially help meet a larger proportion of the desired TSS reductions outlined in the management plan for Trail Creek. Bear in mind that these reduction percentages are not exact, nor are the BMP costs. However, they can be useful in informing management and prioritization decisions.

Sediment

Click on a column title to sort ascending.

				BMP: No Till on Worst 5% of Area				BMP: Grass on Worst 5% of Area			
Name	HUC	Acres	Total(tons/yr)	Total Reduction (tons/yr)	Reduction %	BMP Cost at $14 per acre	BMP Cost Benefit ($/ton reduced)	Total Reduction (tons/yr)	Reduction %	BMP Cost at $44 per acre	BMP Cost Benefit ($/ton reduced)
East Branch Trail Creek	040400010104	13,997	460	144	31%	$9,798	$68	263	57%	$30,793	$117
Trail Creek	040400010105	8,600	150	49	33%	$6,020	$123	90	60%	$18,920	$210
West Branch Trail Creek	040400010103	15,352	589	177	30%	$10,746	$61	324	55%	$33,773	$104
TABLE TOTALS		37,949	1,198	369	31	$26,564	$72	677	57	$83,487	$123
Specify new values to recalculate BMP cost:						$ 14				$ 44	

Recalculate BMP Cost

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Figure A.2.7: No Till on Worst 5% vs. Grass on Worst 5% of the Trail Creek watershed

V. Target fields within the West Branch Trail Creek watershed for BMP implementation.

A. Close the HIT table and the "HIT Data" menu. Turn on the *Sediment* layer and zoom into the West Branch Trail Creek watershed.

B. Zoom in on one of the high-risk areas. If needed, turn off the *HUC12* layer for better visibility. See Figure A.2.10.

C. To view high-risk areas in even greater detail, click on "Bird's eye" from the Bing Maps toolbar. Note that Bird's eye imagery is not available in every location. Refer to Figure A.2.11.

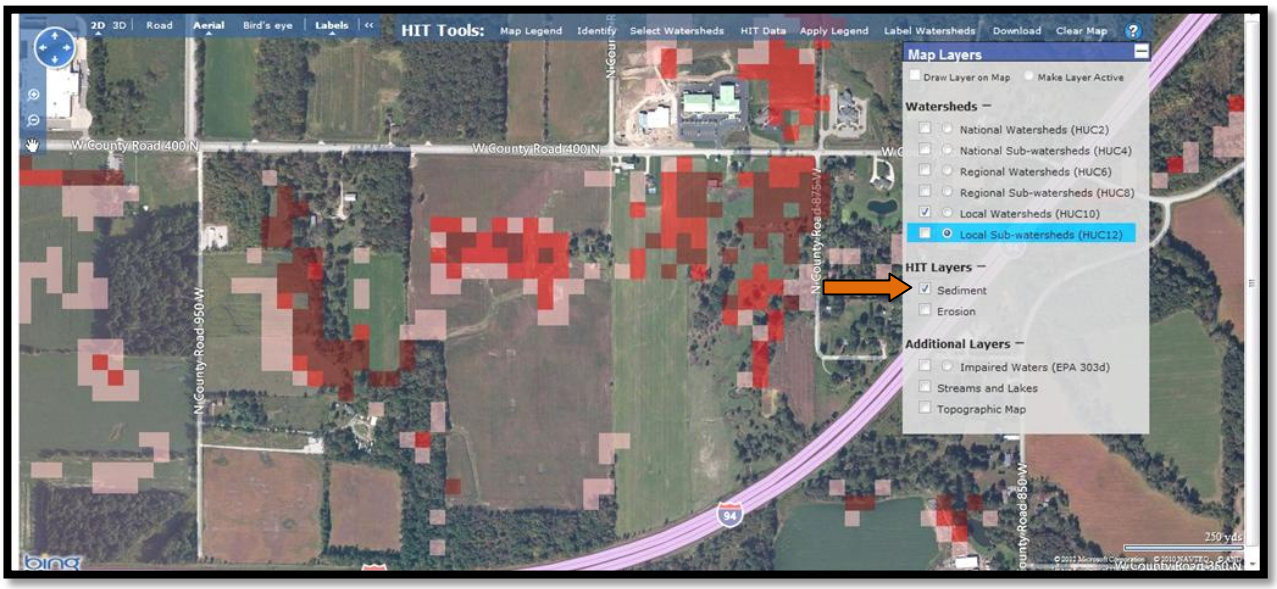

Figure A.2.10: Viewing high risk areas

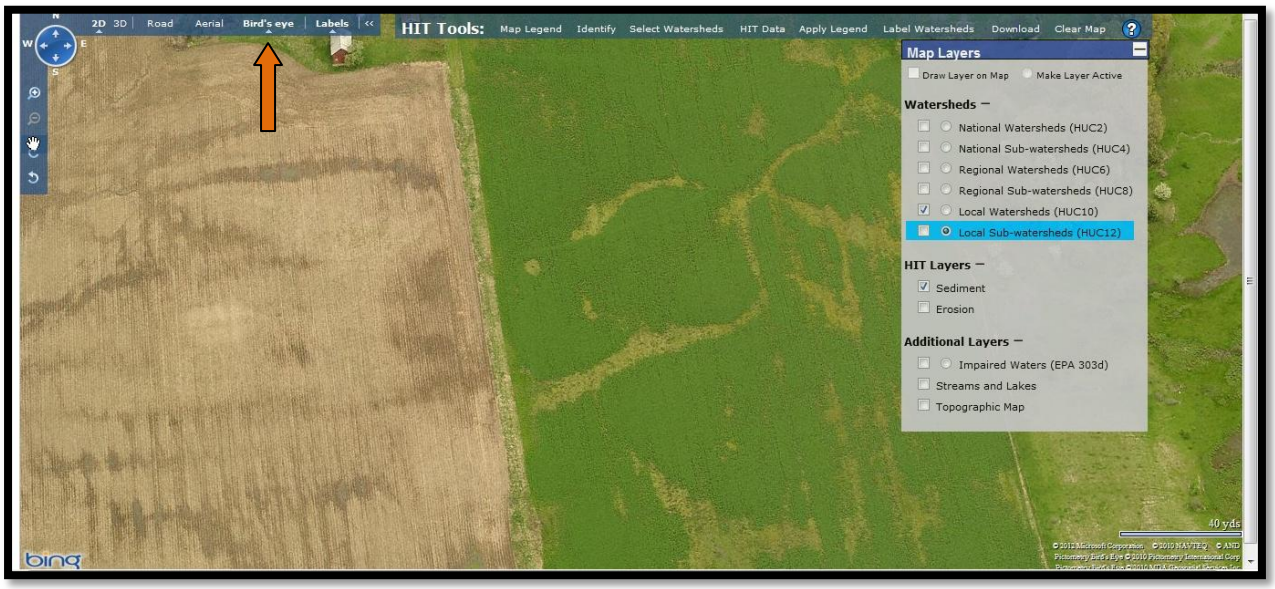

Figure A.2.11: Viewing high risk areas in "Bird's eye" view

Through these steps, you can complete the tasks posed at the beginning of the exercise:

I. **Estimate the total amount of sediment delivered to Trail Creek streams annually.**

   HIT predicts that the total amount of sediment delivered to streams from Trail Creek is 1,198 tons/year.

II. **Determine which HUC12 has the highest contributing rate of sediment loading.**

   The West Branch Trail Creek (040400010103) is predicted to be the HUC12 with the highest contributing rate of sediment loading to Trail Creek streams.

III. **Assess in which HUC12 No Till would yield a maximum economic benefit**

   According to the HIT output, BMP dollars will go the furthest by targeting No Till adoption in the West Branch Trail Creek sub-watershed, with an estimated cost/benefit of $61 per ton of sediment reduction under the scenario.

IV. **Compare the estimated cost-benefits of implementing no-till and grass in the worst 5% of watersheds.**

   Grass installations are estimated to reduce nearly twice as much sediment as no till and could potentially help meet a larger proportion of the desired sediment reductions outlined in the management plan for Trail Creek. However, grass BMP implementation is also predicted to cost roughly three times as much as no till and may be financially unreasonable.

V. **Target fields within the West Branch Trail Creek watershed for BMP implementation.**

   Review the steps and maps outlined in Task V.

Appendix A3:

HIT Tutorial | Blanchard

The TMDL for the Blanchard River Watershed states that (www.epa.ohio.gov/dsw/**tmdl/BlanchardRiverTMDL**.aspx*)*, "Agriculture is…the predominant land use in the Blanchard River watershed," making the HIT model an appropriate prioritization tool for reducing erosion and sediment loading in the watershed.

The TMDL report specifically lists the Ottawa Creek, Riley Creek, and Cranberry Creek HUC10 watersheds as areas with erosion and sedimentation impairments, and recommends vegetating at least one side of streams in these watersheds to address the problem. It also suggests placing "filter strips on all tributaries, permanent protection of stream side buffers, and conservation tillage" to tackle erosion and sedimentation in the Blanchard River watershed.

Using the HIT model, complete the following tasks for watershed prioritization:

I. Estimate how much sediment is delivered to the Blanchard River annually.

II. Determine which HUC10 is the largest contributor of sediment in the Blanchard.

III. Determine which HUC12s from Ottawa Creek, Cranberry Creek and Riley Creek have the highest rates of sediment loading.

IV. Assess in which HUC12 no till would yield a maximum economic benefit (from Ottawa Creek, Cranberry Creek and Riley Creek only).

V. Target fields within the Riley Creek watershed for BMP implementation.

Instructions:

I. Estimate how much sediment is delivered to the Blanchard River annually.

A. Open up a web-browser and access the HIT website (www.iwr.msu.edu/hit2). Click on "By watershed" under the Data Access heading.

B. In the search field at the top, type in "Blanchard," hit "Find," and click on the "Blanchard (04100008 – OH) link from the search results. See Figure A.3.1.

C. Select the "Table" button at the bottom of the screen and specify "Sediment" and "Totals" from the HIT table menu. Refer to Figure A.3.2.

Figure A.3.1.: Selecting the Blanchard watershed

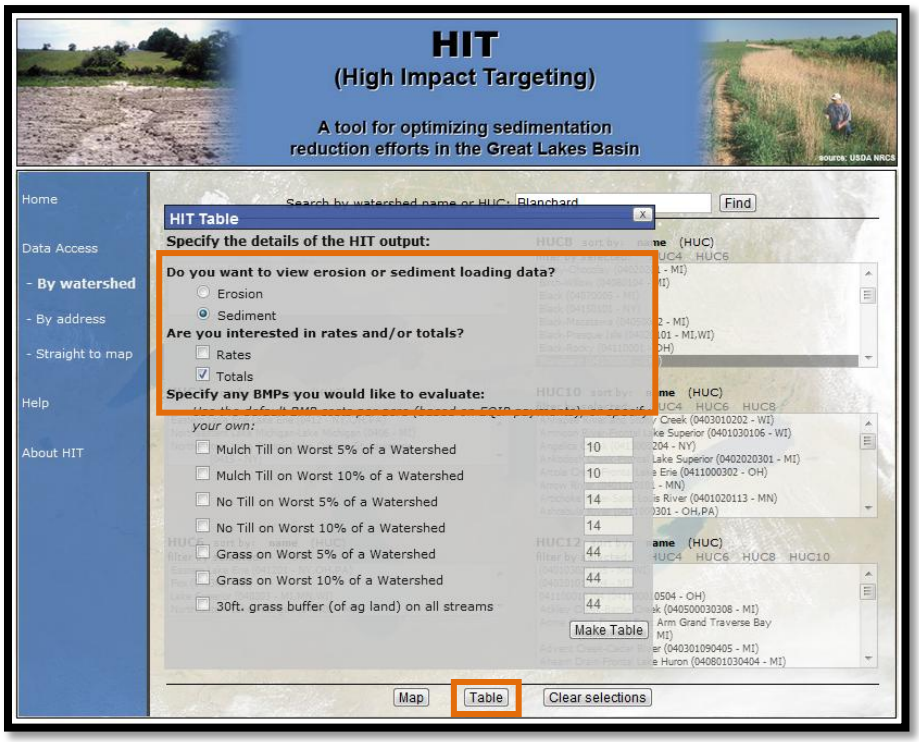

Figure A.3.2: Generating a HIT table

D. The HIT output table will open in a new window. Take a moment to review the columns of the HIT table (Figure A.3.3).

- The first three columns (in white) display basic information about the Blanchard watershed.
- The grey column displays the estimated sediment loading in tons/year for the selected watershed.

E. The HIT output estimates that the Blanchard watershed generates 58,528 tons of sediment/year. Recall that HIT outputs should not be considered exact measurements of erosion or sediment loading, but can be helpful in prioritizing watersheds on a relative basis. Next, we'll examine sediment contributions at HUC10 and HUC12 scales.

Sediment Click on a column title to sort ascending.

Name	HUC	Acres	Total(tons/yr)
Blanchard	04100008	494,045	58,528
TABLE TOTALS		494,045	58,528

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Figure A.3.3: HIT table results

II. Determine which HUC10 is the largest contributor of sediment in the Blanchard.

A. Close the HIT table and select the "Map" button at the bottom of the screen. This will take you to the map and display a yellow circle for the Blanchard watershed. Notice that in the "Map Layers" menu, the *HUC8* layer is already drawn on the map and activated for you.

B. Zoom in further on the Blanchard watershed. Then, activate and draw the *HUC10* layer on the map by clicking on its circular radio button from the "Map Layers" menu; this will highlight the layer in blue. Next, draw the *HUC10* layer by clicking on the checkbox next to the radio button while leaving the *HUC8* boundary drawn. You'll notice that the yellow dot representing the HUC8 Blanchard disappeared when you activated the *HUC10* layer.

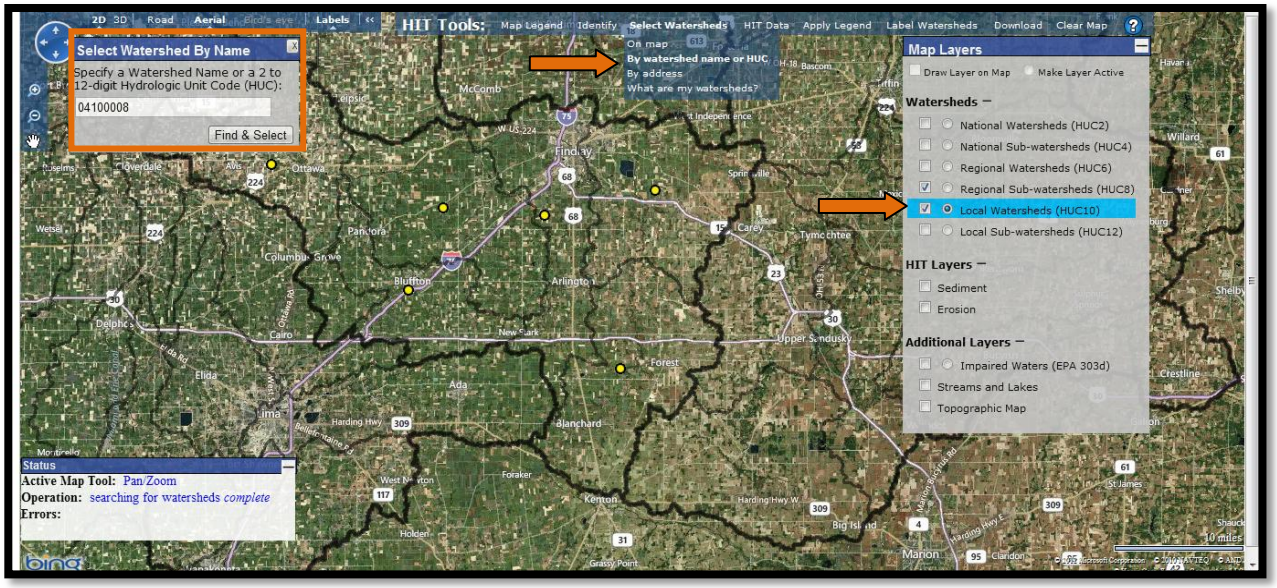

Figure A.3.4: Selecting watersheds "By watershed name or HUC"

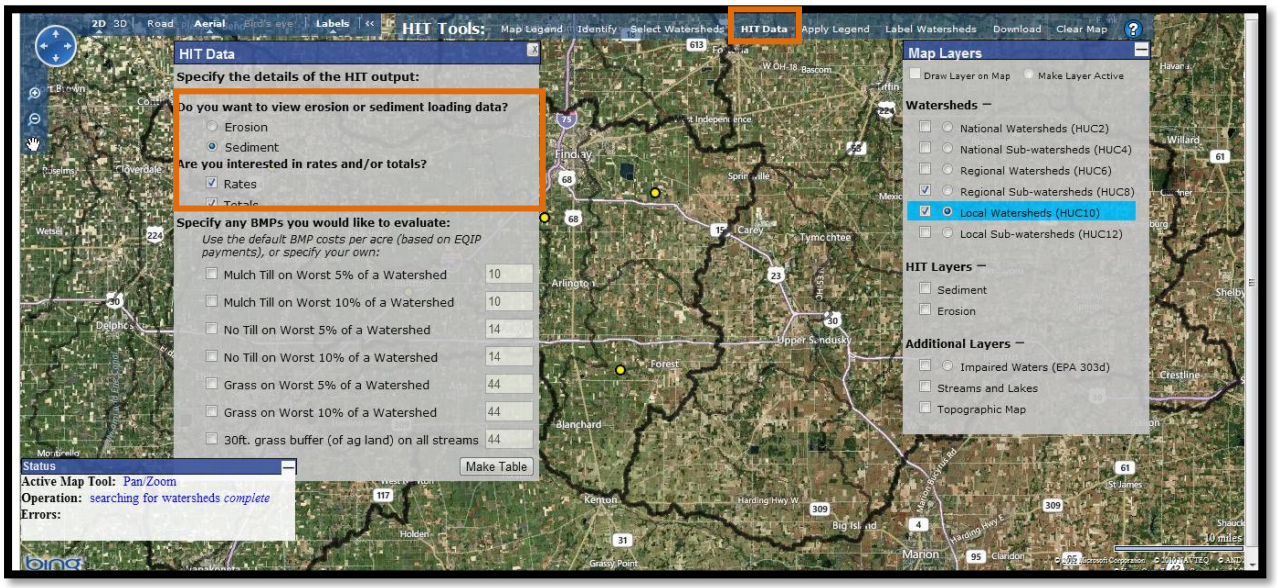

Figure A.3.5: Generating a HIT table on the map

C. To select new watersheds, choose “Select Watersheds” > “By watershed name or HUC” from the HIT toolbar. Notice that “Select Watersheds” is bolded, indicating that this tool is tuned on.

D. Type in “04100008” into the “Select Watershed By Name” menu and hit “Find and Select.” Six yellow circles for each HUC10 watershed will appear (Figure A.3.4). We can use another HIT table to determine which HUC10 is the largest contributor of sediment loading in the Blanchard.

E. Click on “HIT Data” from the HIT toolbar, specify “Sediment,” “Rates,” and “Totals.” Click “Make Table.” Refer to Figure A.3.5.

F. The table will again open in a new window. Sort the table by the “Rate (tons/ac/yr)” column by clicking on the column’s heading. See Figure A.3.6.

G. HIT predicts that the Headwaters Blanchard River watershed has the highest rate of sediment loading (0.156 tons/acre/year) and the highest total sediment load (14,191 tons/year) within the Blanchard. Notice that the second highest estimated rate (0.142 tons/acre/year) comes from the Riley Creek watershed, which has the smallest acreage of all Blanchard HUC10 watersheds.

Since the TMDL for the Blanchard specifically lists Ottawa Creek, Cranberry Creek and Riley Creek as watersheds at risk for erosion and sediment impairments, we will focus on these watersheds to complete the next task.

Sediment Click on a column title to sort ascending.

Name	HUC	Acres	Total(tons/yr)	Rate(tons/ac/yr)
Lye Creek-Blanchard River	0410000802	85,116	7,371	0.087
Eagle Creek-Blanchard River	0410000803	73,348	6,992	0.095
Cranberry Creek-Blanchard River	0410000806	95,014	10,921	0.115
Ottawa Creek-Blanchard River	0410000805	95,045	11,249	0.118
Riley Creek	0410000804	54,836	7,805	0.142
Headwaters Blanchard River	0410000801	90,686	14,191	0.156
TABLE TOTALS		494,045	58,528	0.118

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Figure A.3.6: HIT table results

III. Determine which HUC12s from Ottawa Creek, Cranberry Creek and Riley Creek have the highest rates of sediment loading.

A. We only want to select HUC12 watersheds within Ottawa Creek, Cranberry Creek, and Riley Creek. Identify the locations of these three watersheds for the next step. (If you hover over the circles of selected watersheds, a label with the watershed's name and HUC will appear).

B. Next, activate and draw the *HUC12* layer on the map. The previously selected watersheds will disappear.

C. From the HIT toolbar, choose "Select Watersheds" > "On map." Draw a box around the desired HUC12 watersheds. You probably won't be able to select all sixteen HUC12s at once, so click individually on the remaining watersheds to add them to your selection. See Figure A.3.7. If you make a mistake, click again on an already selected watershed to remove it from your selection. When finished, deactivate the tool by clicking on the "On map" option again. Deactivated tools will not be bolded.

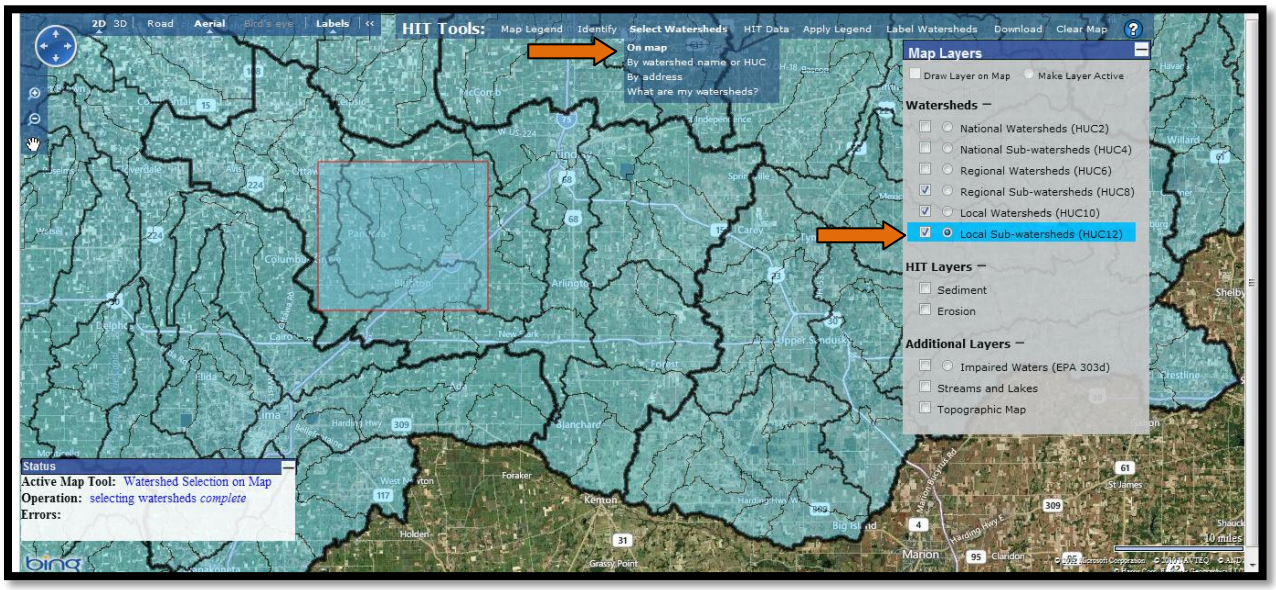

Figure A.3.7: Selecting watersheds on the map

D. Instead of using a HIT table to determine sediment loading rates, we can use the "Apply Legend" tool. This is a quick way to visually see which watersheds are predicted to produce more sediment loading to streams than others. From the HIT toolbar, select "Apply Legend" and specify "Sediment Loading," "Rates (Tons/acre)," and "Quartile." Click "Apply Legend." See the HIT Factsheet for more information on quartiles and equal intervals.

You will have to choose between equal interval and quartile classification systems to display the data. Equal Intervals defines bins for the watersheds using value ranges of equal size (e.g. 0-2, 2-4, 4-6, 6-8), while Quartiles creates value ranges for the bins so that each bin has roughly the same number of watersheds. Quartiles typically produce the more cartographically appealing map, as Equal Intervals can be skewed by very large values relative to the rest of the sample.

E. The selected watersheds are now shaded by their sediment loading rate. Turn on legend information for the shaded watersheds by clicking on "Map Legend" from the HIT toolbar. Darker shades represent higher sediment loadings. Refer to Figure A.3.8.

F. Hover over the circles with the darkest shading. By shading these watersheds, we can quickly determine that the Upper Riley Creek, Binkley Ditch-Little Riley Creek, Marsh Run-Little Riley Creek, and Pike Run-Blanchard River watersheds are predicted by HIT to have higher sediment loading rates than the other HUC12s within Ottawa Creek, Cranberry Creek and Riley Creek.

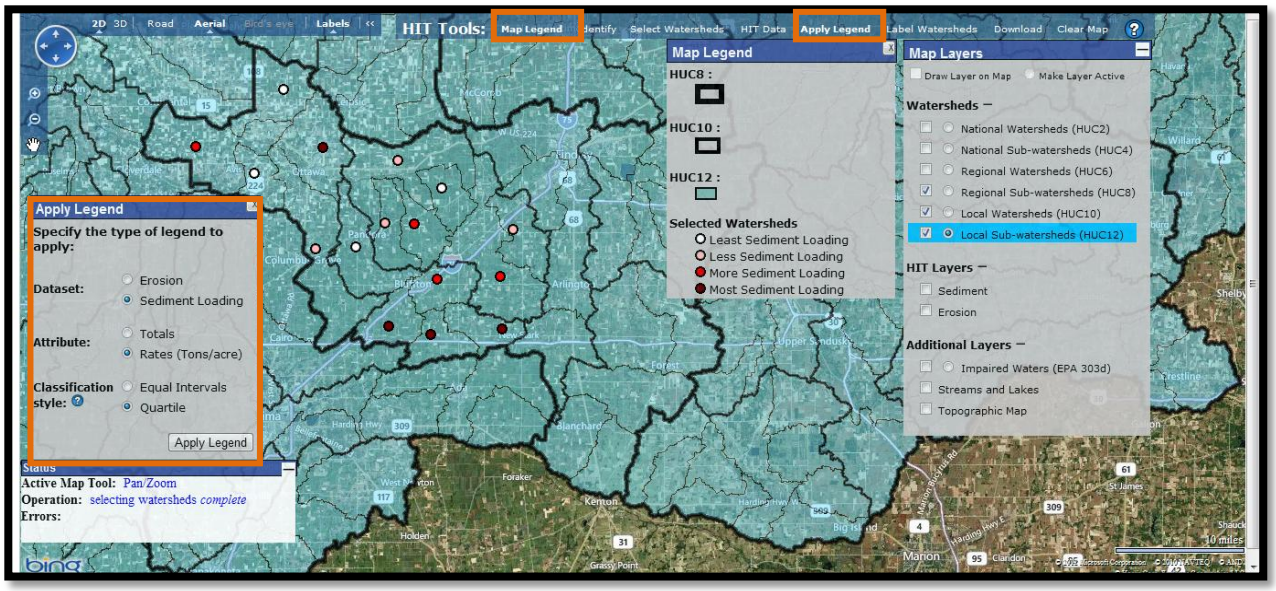

Figure A.3.8: Shading watersheds by sediment loading rate

IV. Assess in which HUC12 no till would yield a maximum economic benefit (from Ottawa Creek, Cranberry Creek and Riley Creek only).

A. We will use the currently selected watersheds for this task. Deactivate the "Apply Legend" tool. Notice that the watersheds are still shaded.

B. From the HIT toolbar, select "HIT Data" and specify "Sediment," "Totals," "No Till on Worst 5% of a Watershed," and "No Till on Worst 10% of a Watershed," and hit "Make Table."

C. The HIT table will open in a new window. Take a moment to review the BMP columns of the HIT data table.

- The black columns show the estimated reduction in sediment loading for each BMP.
- The green columns show the cost-benefit ($ per ton of sediment loading reduced) of each BMP, essentially the "bang for the buck" number.

D. Sort the table by the "BMP Cost Benefit ($/ ton reduced)" column by clicking on the column heading. See Figure A.3.9.

E. According to the HIT output, BMP dollars will go the furthest by targeting No Till adoption in the Binkley Ditch- Little Riley Creek sub-watershed, with an estimated cost/benefit of $14 per ton of sediment reduction under the scenario.

It is important to reiterate that these estimates are based on a purely hypothetical scenario of targeted No Till installation, and should be used for relative comparison among watersheds. As stated in the manual under the "HIT Functionality" section, HIT's estimates do not account for stream bank, wind, or ephemeral gully erosion; nor does it account for in-stream deposition. It only estimates how much eroded soil is reaching the stream network; therefore the reduction estimates in these scenarios are likely less than what would actually occur if such a practice was installed and monitored at the edge of field.

Furthermore, the precise BMP simulation would be impossible to install in practice. No Till is implemented on entire fields, not within individual 30 by 30 meter grid cells. Nonetheless, this exercise shows how HIT can be a useful prioritization tool for groups and organizations that may not have the resources or expertise to utilize more thorough and robust sediment loading models.

Sediment

Click on a column title to sort ascending.

					BMP: No Till on Worst 5% of Area				BMP: No Till on Worst 10% of Area			
Name	HUC	Acres	Total(tons/yr)	Rate(tons/ac/yr)	Total Reduction (tons/yr)	Reduction %	BMP Cost at $14 per acre	BMP Cost Benefit ($/ton reduced)	Total Reduction (tons/yr)	Reduction %	BMP Cost at $14 per acre	BMP Cost Benefit ($/ton reduced)
Binkley Ditch-Little Riley Creek	041000080401	9,188	2,073	0.226	464	22%	$6,431	$14	609	29%	$12,863	$21
Deer Creek-Blanchard River	041000080605	25,171	3,197	0.127	1,018	32%	$17,620	$17	1,192	37%	$35,239	$30
Pike Run-Blanchard River	041000080602	18,314	2,448	0.134	691	28%	$12,820	$19	842	34%	$25,639	$30
Upper Riley Creek	041000080402	9,180	1,451	0.158	330	23%	$6,426	$20	428	30%	$12,851	$30
Dukes Run	041000080504	9,607	1,255	0.131	326	26%	$6,725	$21	419	33%	$13,450	$32
Village of Gilboa-Blanchard River	041000080506	26,346	3,028	0.115	860	28%	$18,442	$21	1,059	35%	$36,884	$35
Cranberry Creek	041000080601	28,945	3,430	0.119	931	27%	$20,262	$22	1,176	34%	$40,523	$34
Ottawa Creek	041000080502	28,731	3,817	0.133	899	24%	$20,112	$22	1,171	31%	$40,223	$34
Dutch Run	041000080505	9,443	988	0.105	289	29%	$6,610	$23	351	35%	$13,220	$38
Marsh Run-Little Riley Creek	041000080403	10,397	1,406	0.135	300	21%	$7,278	$24	403	29%	$14,556	$36
Tiderishi Creek	041000080501	12,261	1,358	0.111	352	26%	$8,582	$24	439	32%	$17,165	$39
Middle Riley Creek	041000080404	9,989	1,294	0.130	286	22%	$6,992	$24	381	29%	$13,985	$37
Lower Riley Creek	041000080405	16,082	1,582	0.098	441	28%	$11,258	$26	540	34%	$22,515	$42
Bear Creek	041000080604	8,105	637	0.079	207	32%	$5,673	$27	239	37%	$11,347	$48
Moffitt Ditch	041000080503	8,658	804	0.093	219	27%	$6,060	$28	269	33%	$12,121	$45
Miller City Cutoff	041000080603	14,479	1,208	0.083	329	27%	$10,135	$31	407	34%	$20,271	$50

Figure A.3.9: HIT table results with No Till BMP estimates

V. Target fields within the Riley Creek watershed for BMP implementation.

A. Close the HIT table and locate and zoom to the Binkley Ditch-Little Riley Creek watershed. Draw the *Sediment* layer on the map.

B. Zoom in on one of the high-risk areas. If needed, turn off the *HUC12* layer for better visibility. See Figure A.3.10.

C. To view the high-risk areas in even greater detail, click on "Bird's eye" from the Bing Maps toolbar (Figure A.3.11).

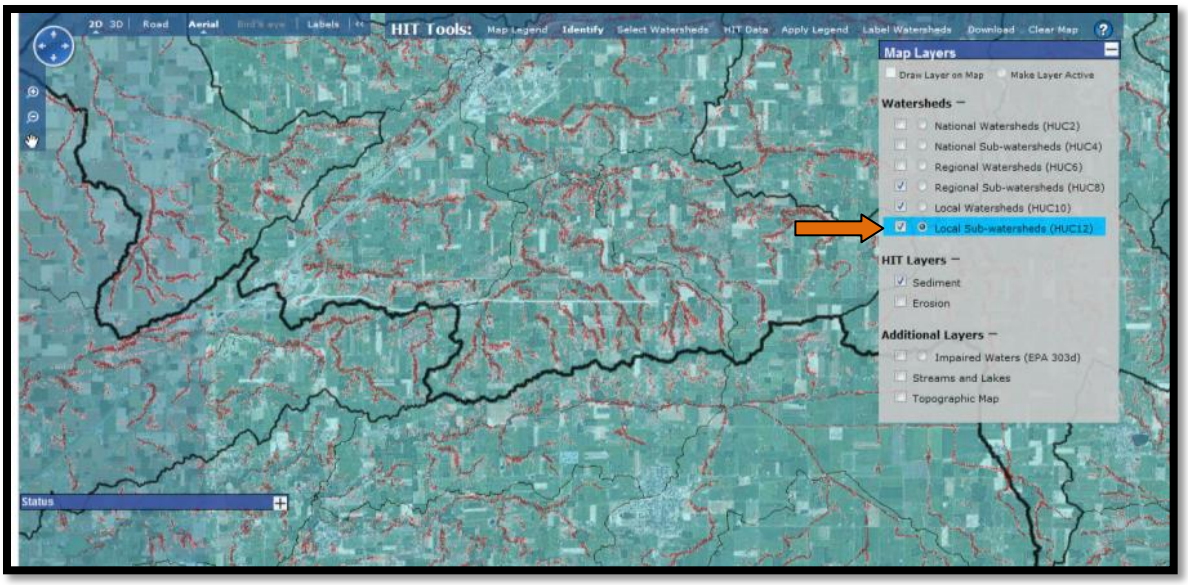

Figure A.3.10: Viewing high-risk areas

Figure A.3.11: "Bird's eye" view of high-risk areas

Through these steps, you can complete the tasks posed at the beginning of the exercise:

I. **Estimate how much sediment is delivered to the Blanchard annually.**

HIT predicts that the Blanchard watershed generates 58,528 tons of sediment/year.

II. **Determine which HUC10 is the largest contributor of sediment in the Blanchard.**

The Headwaters Blanchard River (0410000801) watershed, with an estimated 0.156 tons of sediment/acre/year has the highest contributing rate, and also has the highest total sediment load at 14,191 tons/year.

III. **Determine which HUC12s from Ottawa Creek, Cranberry Creek and Riley Creek have the highest rates of sediment loading.**

Upper Riley Creek, Binkley Ditch-Little Riley Creek, Marsh Run-Little Riley Creek, and Pike Run-Blanchard River are the HUC12 watersheds with the highest rates of sediment loading from the specified HUC10 watersheds.

IV. **Assess in which HUC12 no till would yield a maximum economic benefit (from Ottawa Creek, Cranberry Creek and Riley Creek only).**

According to the HIT output, BMP dollars will go the furthest by targeting No Till adoption in the Binkley Ditch- Little Riley Creek sub-watershed, with an estimated cost/benefit of $14 per ton of sediment reduction under the scenario.

V. **Target fields within the Riley Creek watershed for BMP implementation.**

Review the steps and maps outlined in Task V.

Appendix A4:

L-THIA LID Tutorial | River Raisin

The L-THIA LID model tutorial will answer these questions: (1) What is the impact upon runoff volume from the addition of a 1000+ unit housing development?; (2) What is the predicted impact on non-point source pollutants within that runoff?; (3) What kind of reduction in runoff volume may come from specific Low Impact Development practices?; and (4) What maximum % impervious surface would be allowed if the regional planners want to add this amount of high density housing but want to maintain the pre-development hydrology (in terms of volume of runoff)?

The required steps in running the model are documented in the images below. The 5 part process is this: (1) The user first selects a state and county, which is used to determine the rainfall data for the 30 period (Figure A.4.1). (2) User enters land use and soil data for existing conditions (Figure A.4.2) (3) The user enters changed land use, reflecting a proposed development, (Figure A.4.3). (4) The user selects the proportion of the area that will receive LID practices, and may chose to select some parameters for LID practices (Figure A.4.). (5) The model runs and produces a table of outputs for examination (Figure A.4.5).

At the completion of this tutorial, the user should be able to design a similar scenario, enter the needed input data in L-THIA LID, run the model, and create output tables and graphs to address development questions such as above.

To set the stage for this tutorial, it is useful to become familiar with the River Raisin management plan [www.michigan.gov/documents/deq/wb-nps-rr-wmp1_303614_7.pdf]

To quote from that document:

"In 2000, agriculture accounted for 65% of the watershed's land use; urbanized areas represented 11%, wetlands 8% and forested and grassland areas 7% each. There are 41 NPDES point-source dischargers and 13 public water supply systems. During low flow periods most, if not all, of the river and its tributary flow can be removed for consumptive uses. Some urbanizing areas are experiencing explosive growth pressures.

Recently, massive 1,000+ unit single-family housing developments have been proposed for the Milan and Saline areas. These watershed pressures have created sediment, nutrient, pesticide, pathogen and heavy metals loads, flow instability and habitat impairments. Currently there are 12 separate 303d water-quality impaired reaches and lakes along the Raisin River and its tributaries.

Four reaches have TMDLs for untreated sewage discharge, pathogens, and PCBs. Other water quality impairments include pesticides, metals and turbidity. Fish consumption advisories due to PCBs have also been issued for three locations on the river. "

Task: Use L-THIA LID to explore a 1000+ unit housing proposal for the Milan or Saline area. We will start with the assumption of 1/8 acre lot sizes on 155 acres of land. The development will include 20 acres of commercial land use. The model will produce predictions for runoff volume and NPS sediment changes in various configurations of housing unit density including LID vs. non-LID results. While local political focus is on several NPS chemistries, this tutorial's main focus is on sediment and runoff volume.

A. Open L-THIA LID through the following url: [**https://engineering.purdue.edu/~lthia/LID**]

After reading through the introduction, click Next near the bottom of the page.

B. Select the state of Michigan and Washtenaw County using the two dropdown boxes. See Figure A.4.1 below. Click Next.

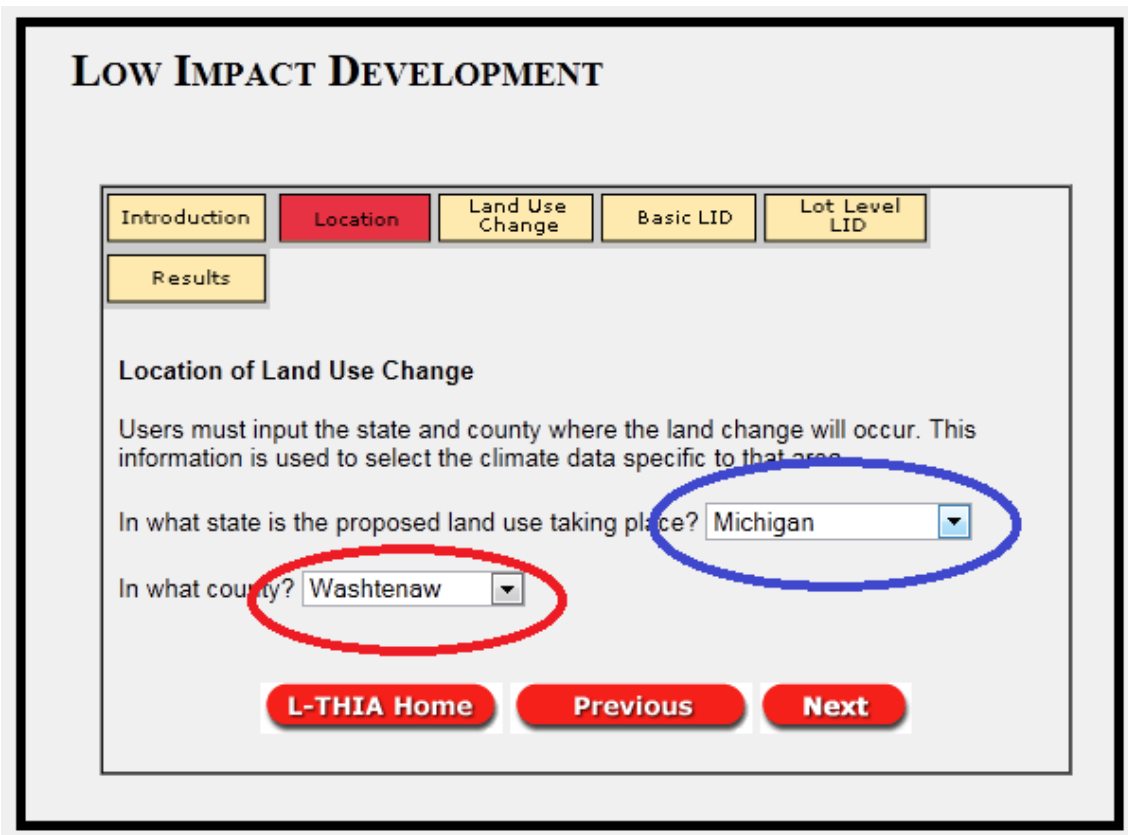

Figure A.4.1: Selecting state and county.

C. Pre-Developed Land use and Soil: To create a scenario, the user will enter existing land use and soil combinations with area into the top half of the spreadsheet like interface. This is the pre-development land use, soil type, and area. For this tutorial, we will be developing an **agricultural** area into a 1000 unit single-family housing development with 20 acres of commercial development. The agricultural parcel is split into two different soil hydrologic types. This is not a reference to named soil types, rather it is related to the soil hydrologic condition that is determined by its drainage and infiltration ability (as discussed above in Section 2.2). This hydrologic condition can

change; for example compaction of soil by large earthmoving equipment such as found at large housing developments has been shown to lower the hydrologic condition of the entire development area. In the tutorial example, the agricultural land is comprised of some B and some C soil. A user could make an assumption that when the development operations for something this size has been constructed, the entire area has had some compaction effects and is then a C soil, rather than remaining a B soil (Lim et al., 2006b). Thus, the model user may choose to preserve the soil group proportions or change them as desired. The compaction increases the amount of runoff, and that will also increase the predicted NPS pollutants in the runoff. Soil hydrologic group for a specific location can be found in a typical soil survey. Many Michigan counties including Washtenaw have soil surveys available online at http://soils.usda.gov/survey/printed_surveys/state.asp?state=Michigan&abbr=MI .

In the scenario, we will plan for high-density residential units at 1/8 acre lot size. This is to represent a dense urban residential development, which would present a footprint size in stark size contrast to a typical 2 acre rural-suburban lots for 1000 + houses. Use the drop-down and numerical entry spots to do this (see expanded box on Figure A.4.2). Enter 35 acres of agricultural land use on B-type soil and 120 acres of agricultural land use on C-type soil. See Figure A.4.2.

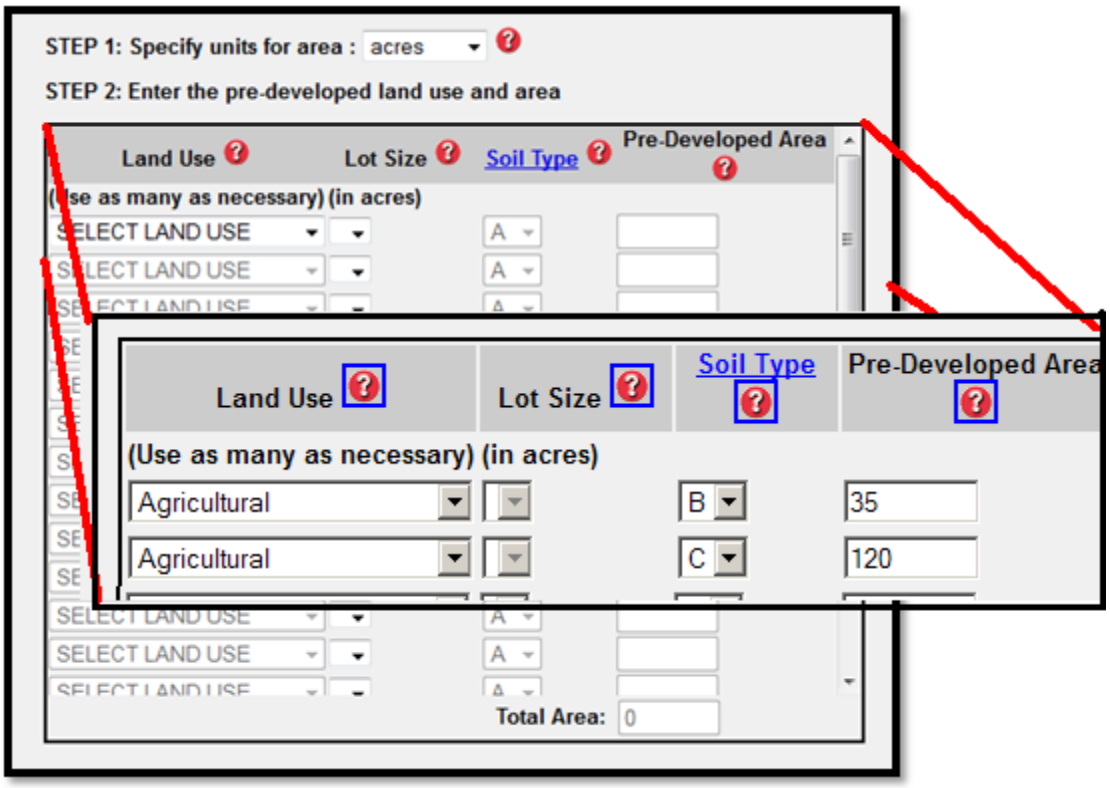

Figure A.4.2: Selecting pre-developed (existing) land use and soil and corresponding area.

We are using typical soils for this scenario. A more sophisticated scenario looking at a specific location could use data from a local soil map, where the soil hydrologic group (A – D) may be presented as a value known as “hydgrpdcd” or hydrologic group code.

Typically while the land use will almost always change between pre- and post- development, the soil group may or may not change, so a scenario with 1000 acres of C soils in pre-development may have a mixture of C and D soils in post-development. Some recent research suggests that it is reasonable to assume soils in large dense residential or industrial developments undergo compaction during the construction phase, and so the end result is a C soil transformed into a D soil (Lim et al., 2006). The scenario could be run with both original soil and compacted soil assumptions to estimate the degree to which compaction increases the runoff. For the tutorial we will assume the residential development preserved the soil infiltration abilities, but the commercial development has unavoidable compaction. This means the 20 acres of commercial land use will be entered as a “D” soil group.

Note: You may also select at this time to work in area units of square kilometers, square miles, acres, or hectares.

D. Post-Developed Land use: See Figure A.4.3. Scroll down and enter the post-development land use, soil type, and area. In this scenario of a single large development, we will build– High Density Residential 1/8 acre lot – on all the residential land that is being developed. That is not required; a model can mix the land use types in post-development including leaving some of the land undeveloped. In fact the model will accommodate changes in soil type as well. In other words, the user can change the hydrologic condition from B to C for example, to mimic the compaction that may occur during construction of large developments. However, the final total **area** must be exactly the same as the pre-development area.

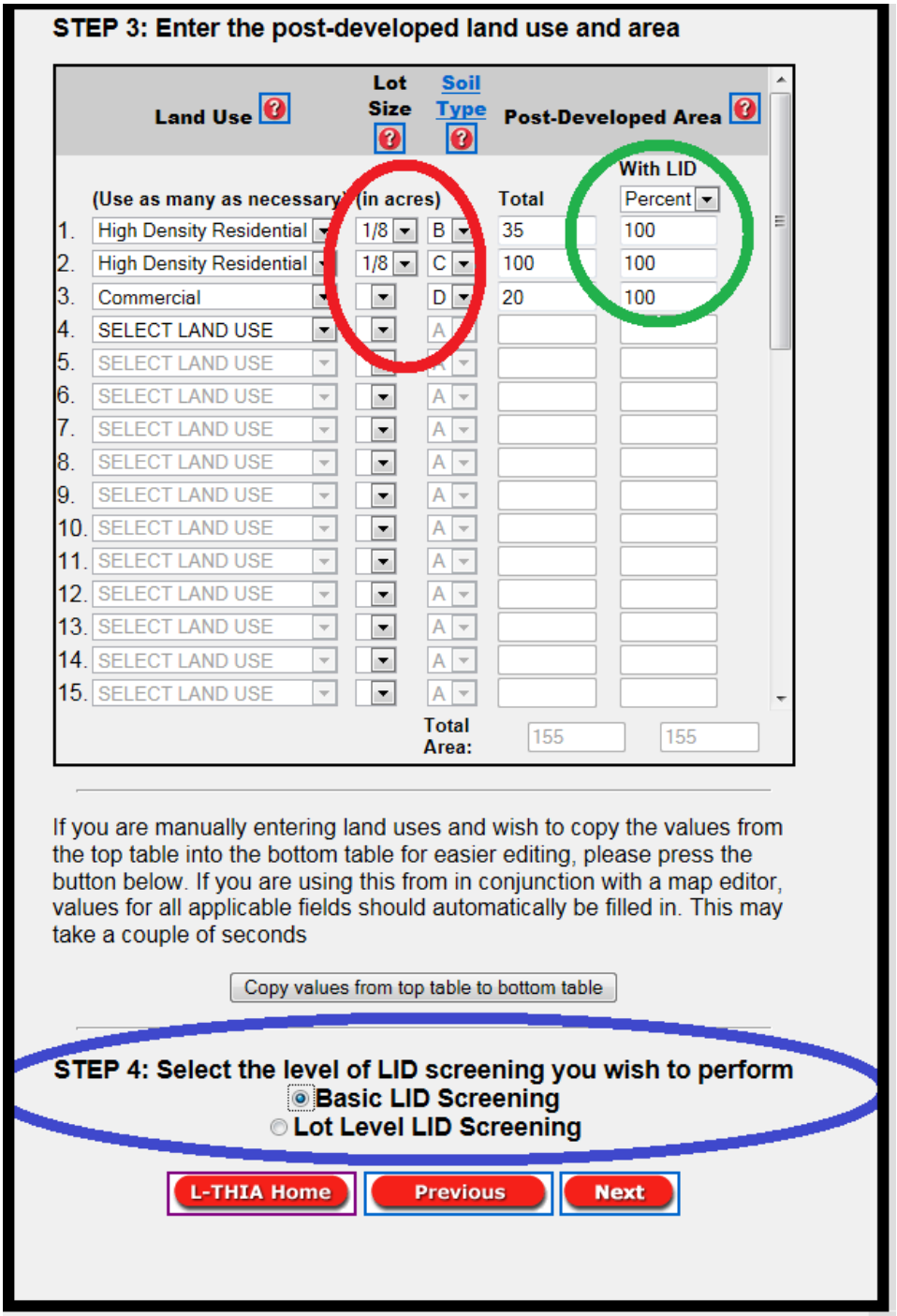

Figure A.4.3: Selecting post-development land use and soil and corresponding area with LID applied, and screening level.

In this example, we convert land from both land use-soil pairs entirely to High Density Residential and add a third row of commercial land use, with a compacted soil changed top "D". This is a subset removed from the formerly "C" soil area. It is permissible to split a land use-soil pair. For example, if only ½ of the agricultural parcel on the C soil were to be built upon, then the second

row in the table would be 60 acres of High Density Residential 1/8 acre soil C, and the third row would be 60 acres of agricultural soil C. The overall total acres after development must match the total acres of pre-developed land. The LID practices will be applied to a specified proportion of the area, or to a specified acreage, for each of the land use–soils combination. In this scenario, the user should select Percent under "With LID" (**green circle** on Figure A.4.3) and enter 100, to describe what portion of the area will have LID practices applied.

For this scenario, enter 35 acres of high density residential, 1/8 acre lot size on B-type soil and then enter 100 acres of high density residential 1/8 acre lot size on C-type soil. Select the 1/8 acre lot size using the smaller drop-down menu (in **red circle** on Figure A.4.3). Enter 20 acres of commercial on D-type soil.

E. Scroll down, check to see "Basic LID Screening" from the level of LID screening list (in the **blue circle** on Figure A.4.3) and click Next.

F. Note the impervious surface slider that appears for some land uses. See Figure A.4.4. When the screen opens, the slider is preset to 65% (the TR 55 default) for impervious % for high density residential land use. Try adjusting this to demonstrate how the sliders work. During this "Basic Screening" run you will model LID practices by sliding to a lower number to represent the impact of adopting zoning or a national LID standard for percent impervious for example. Return the slider to 60 for residential and 75 for commercial (about a 10% reduction) for this scenario. Click Next. The L-THIA LID model will run for approximately 10 - 15 seconds before producing results.

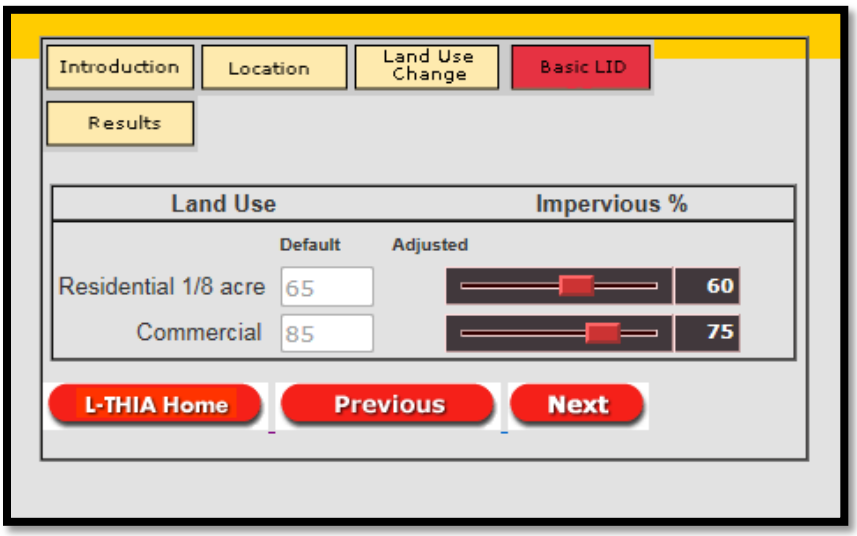

Figure A.4.4: Selecting the percentage of impervious surfaces.

G. Results: Take a moment to review the results table.

The "Summary of Scenarios" portion (see Figure A.4.5 below) of the table reports the area in acres per each land use in pre- and post- development scenarios. It reports the default and adjusted (after development) percentage impervious surface. It also reports a composite curve number for existing,

post-developed, and post-developed with LID. The LID practices are applied as modifications of the curve number.

SUMMARY OF SCENARIOS View as: Select

State: Michigan

County: Washtenaw

Land Use	Hydrologic Soil Group	acres Pre-Developed	acres Post-Developed W/o LID	acres Post-Developed With LID As Proposed
Agricultural	B	35	-	-
Agricultural	C	120	-	-
Residential 1/8 acre	B	-	35	35
Residential 1/8 acre	C	-	100	100
Commercial	D	-	20	20

PERCENTAGE IMPERVIOUS

Land Use	Default	Adjusted
Residential 1/8 acre	65	60
Commercial	85	75

COMPOSITE CURVE NUMBER

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
80	90	88

Figure A.4.5: Summary of Scenarios from Results Table.

An additional group of sections in the results table include those displayed in Figure A.4.6 below. The top section in this figure is “Curve Number by Land use” which reports curve numbers for each land use. This includes the adjustments added by the LID practices. In this table the user will note that 1/8 acre density residential land use on C soil has a CN of 90 but with some LID practices applied, it is adjusted to an effective CN of 88 which will reduce runoff and pollutant loads.

Curve Number by Landuse

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	B	75	75	-
Agricultural	C	82	82	
Residential 1/8 acre	B	-	85	83
Residential 1/8 acre	C	-	90	88
Commercial	D	-	95	94

RUNOFF RESULTS

Avg. Annual Runoff Volume (acre-ft) View as: Select

Land Use	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	4.29	-	-
Agricultural	29.88		
Residential 1/8 acre	-	11.59	9.44
Residential 1/8 acre	-	58.01	46.48
Commercial	-	21.18	18.84
Total Annual Volume (acre-ft)	34.17	90.78	74.76

Also view Annual Variation and Probability of Exceedence

Avg. Annual Runoff Depth (in) View as: Select

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
2.64	7.02	5.78

Figure A.4.6: Curve Number by Land use and Specific Runoff results.

The Runoff Results portion of the results table (See Figure A.4.6) displays the runoff volume (in acre-feet) and runoff depth in inches (e.g. 5.78 inches runoff per year over the whole area of 155 acres is expressed in acre-feet as 74.76 acre feet per year of runoff) for each land use-soil pair and shows the before and after impact of the LID processes. In this scenario, the model indicates that basic LID practices could reduce the 90.78 acre feet of runoff to 74.76 acre feet of runoff.

The final sections of the results table (see Figure A.4.7) are runoff values by specific land use listing and the Nonpoint Source Pollutants results. This listing includes the predicted results from 11

chemicals or metals, sediment, and 2 bacteria. The chemistry is reported by each land use and totaled for the analysis. This is the predicted annual load from a 30 year average runoff volume. This value is only from nonpoint sources, so if a user is trying to estimate a total load, then all known point sources must be added in as well.

NONPOINT SOURCE POLLUTANT RESULTS

Nitrogen (lbs) View as: Select

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	51	-	-
Agricultural	358	-	
Residential 1/8 acre	-	57	46
Residential 1/8 acre	-	287	230
Commercial	-	77	68
Total	409	421	344

Also view Annual Variation and Probability of Exceedence

Phosphorous (lbs) View as: Select

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	15	-	-
Agricultural	105	-	-
Residential 1/8 acre	-	18	14
Residential 1/8 acre	-	90	72
Commercial	-	18	16
Total	120	126	102

Also view Annual Variation and Probability of Exceedence

Figure A.4.7: Nonpoint Source Pollutant Results portion of the table

The entire table or values from specific rows can be copied and pasted into a spreadsheet for further analysis or tabulation. Notice the various entries for average annual runoff volume and depth.

Please notice the "Select" box, which allows you to focus on specific targets from the nonpoint source pollutant levels. Figure A.4.8 below, highlights one of the NPS results, the predicted

Suspended Solids (lbs) (e.g. sediment) result. This calculation is based upon the volume of runoff and the type of land use it flows across, where the runoff is assumed to cover the entire watershed. In other words, remember that L-THIA LID is not a routing model and does not include slope or slope length in any fashion. This calculation is based upon specific constants for each land use (given in Appendix B1) and the volume of runoff predicted for the analysis area.

Suspended Solids (lbs)		View as: Select	
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	1253	-	-
Agricultural	8711	-	-
Residential 1/8 acre	-	1294	1054
Residential 1/8 acre	-	6481	5192
Commercial	-	3203	2849
Total	9964	10978	9095

Also view Annual Variation and Probability of Exceedence

Figure A.4.8: Suspended Solids portion of the table.
Table values may be copy-pasted into Excel™.

The links at the bottom of the figure open a line graph (Figure A.4.9) of the Annual Variation for a specific NPS compound and a line graph (Figure A.4.10) of Percent of exceedence. In the Annual Variation figure, the predicted load (vertical scale is pounds of N) of Nitrogen is displayed against 30 years of average annual rainfall (the horizontal scale).

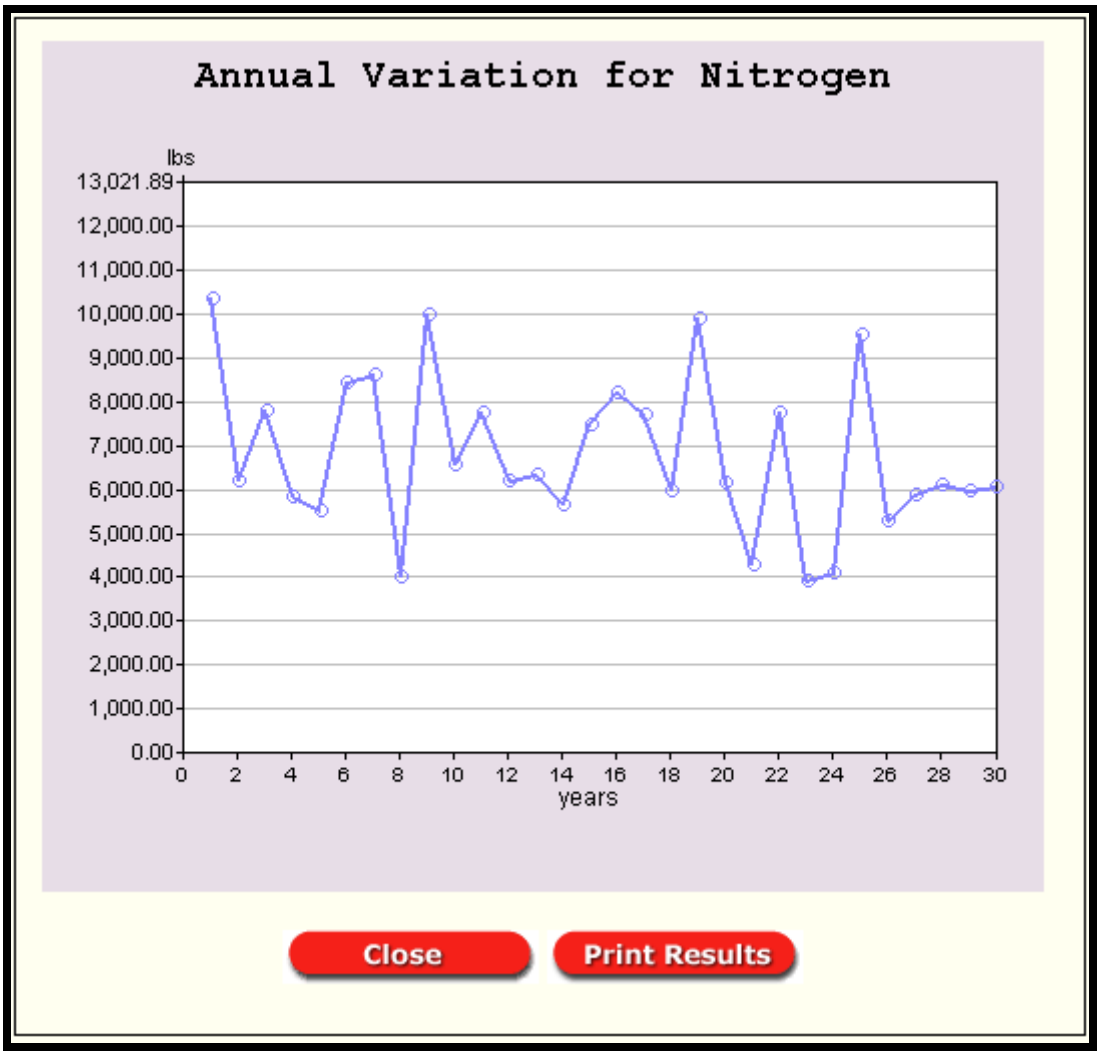

Figure A.4.9: Graph of Annual Variation for NPS contaminant.

The percent of exceedence graph plots 30 points (each representing annual totals) against the estimated percentage of years in which the load will exceed the total at the point. This display is intended to allow watershed managers, for example, to be able to estimate what percent of the time the annual load will exceed a particular value, which is an estimated annual load. In figure 3.10, the graph indicates that a 6,000 pound target (blue arrow) will be exceeded in about 65% (red arrow) of years.

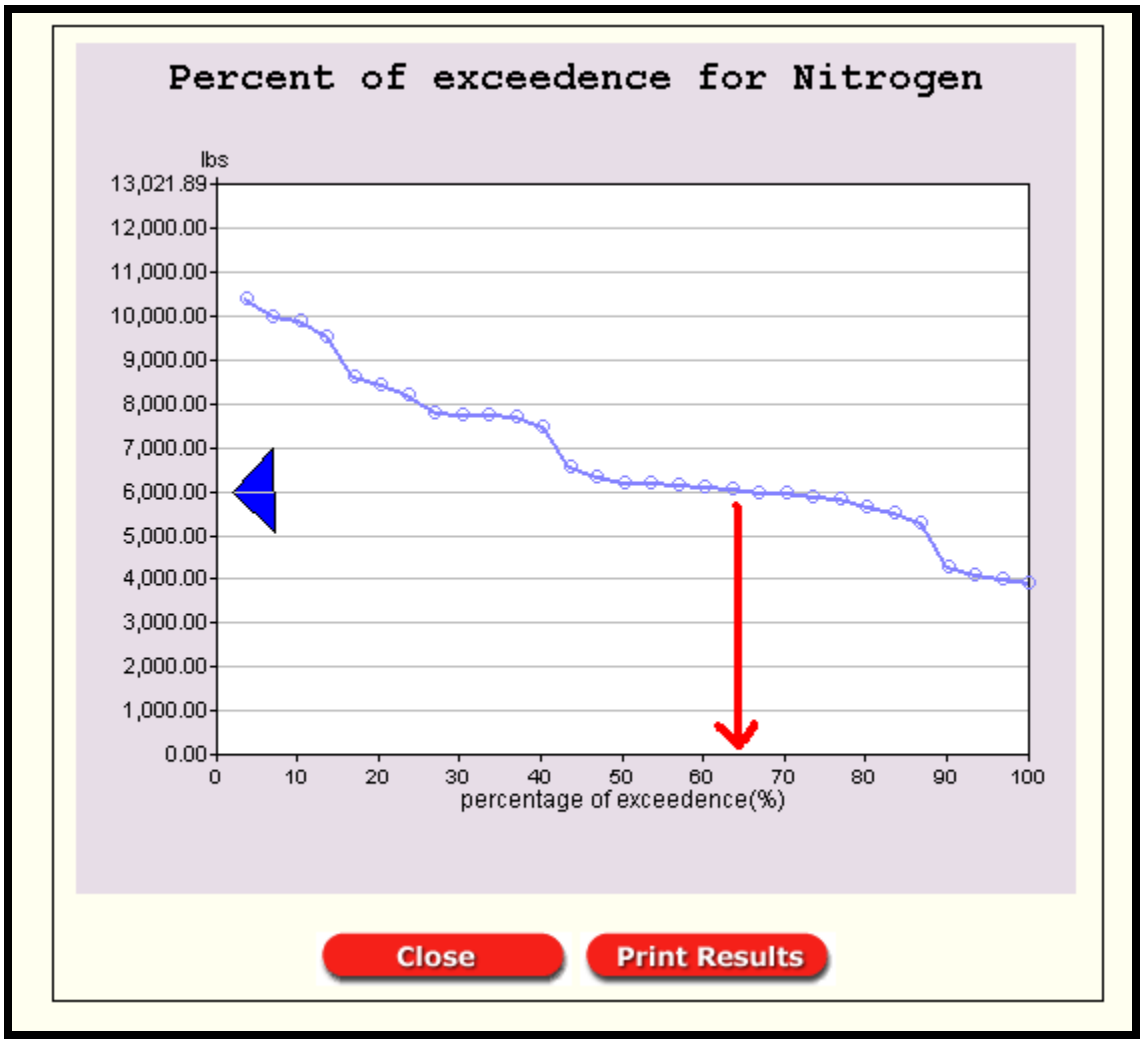

Figure A.4.10: Percent of Exceedence for NPS contaminant.

The next set of steps in the tutorial will use "lot-level screening" to examine the reductions in more detail. The goal of that approach is to determine LID practices that will either offer more reduction or offer the best "bang-for-the-buck."

H. Examine the effect of impervious surface: One useful approach with L-THIA LID is to determine a target % impervious to maintain pre-development hydrology. For example, what maximum % impervious surface would be allowed if we want to add this amount of high density housing but want to maintain something close to the pre-development hydrology? The user could experiment with different values while doing several model runs.

Click the link at the bottom of the results page that says "return to spreadsheet" and reenter your model inputs (repeat steps C, D, and E) and follow the instructions below.

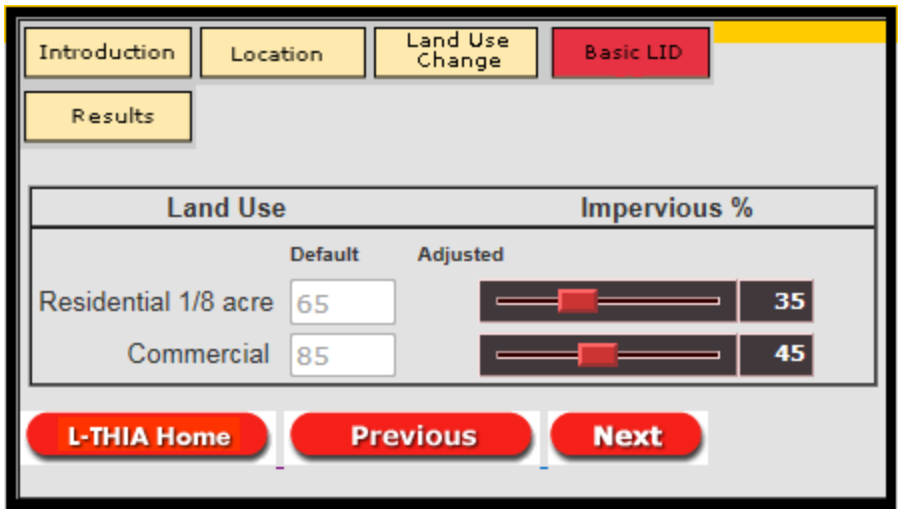

Figure A.4.11: Impervious % slider.

Adjust the impervious surface slider (Figure A.4.11) to about half the starting impervious surface, around 35% for Residential and 45% for Commercial; click next and continue to results page. This time the runoff from the 1/8 acre lots and commercial area will be around 38 acre feet, very close to the original pre-development hydrology which had a predicted average annual runoff of 34.2 acre feet. This indicates that *if* the planned development could incorporate an effective 50% design reduction in its impervious surfaces, the whole development could occur while maintaining the original hydrology, in terms of volume. The reduction in runoff volume is directly related to reduction in sediment transported, because the model assumes that the more runoff that is generated in an area, the higher the entrained sediment load and the higher the other NPS chemistry load. Simply put, lowering the runoff through LID practices will lower the predicted sediment and NPS chemistry in the resulting runoff, as compared to a similar development without LID, which would have much more runoff traveling across the various land uses.

I. **Lot–Level Screening:** This portion of the model will allow the user to test the implementation of specific practices – like rain barrels or including porous pavement for roads or parking. Where local cost estimates exist for these practices, the predicted runoff and pollutant reductions can be compared to the installation costs of the practices.

The lot-level practices that are available will vary depending on the land use selected for the model. For example, high density residential land use in the model will trigger the list to include specific practices and options for:

Streets / Roads
Buildings / Roofs
Sidewalks
Parking / Driveway
Open Space / Lawn
Natural Resource Conservation (Rain Garden)

Each of these options has a specific set of variables that impact the curve number assigned to the land use, and hence the runoff. For more information on exactly what constitutes a practice like "porous pavement," the user can consult web resources such as the Low Impact Development Center at [http://www.lid-stormwater.net/index.html].

The next scenario will step through the LID practice options one at a time to compare their relative benefits. Now, again follow the link at the bottom of the results page that says "return to spreadsheet" and reenter your model inputs (steps C, D, and E) or begin again at Step A if you have closed your web browser.

This time, after step E, select "**Lot Level LID Screening**" from the dropdown list (in the red circle on Figure A.4.12). Remember to select 1/8 acre for Lot Size again for the post-development scenario. Click Next.

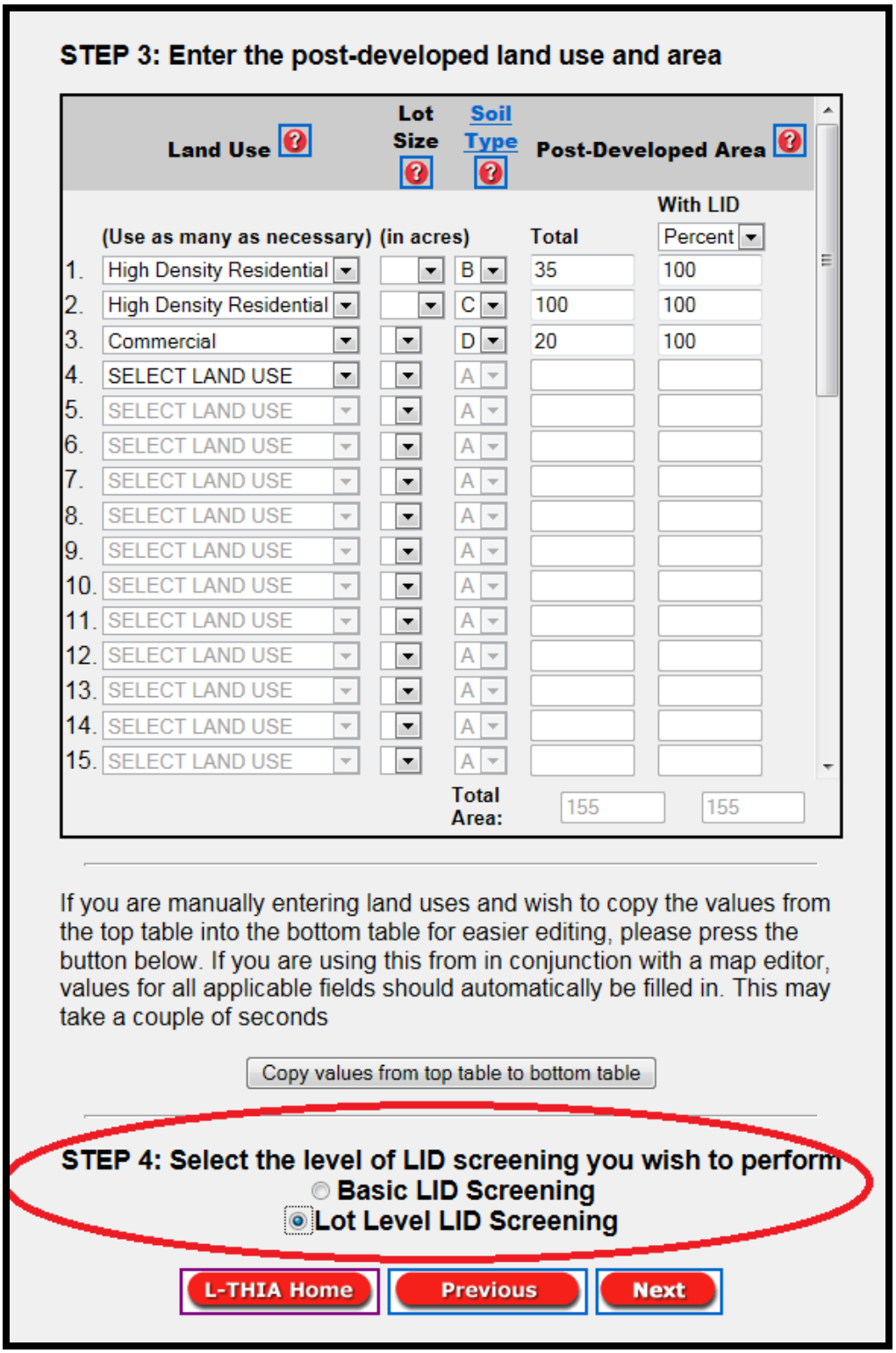

Figure A.4.12: Selection of Lot Level LID Screening.

J. **Specific Practices:** In the modeling process, the user will look through the lot level LID page to see which LID practices are available. For example, "agricultural" has no LID practices and will not appear here, but low density residential will, and so will industrial and commercial; but they will have different LID practice options.

You may expand the menus by clicking on items with a plus sign. LID practices are grouped by whether that practice is associated with the streets/roads, buildings/roofs, sidewalks, parking/driveways, open space/lawn, or natural resource conservation. To edit the LID practices on different land use types, click on the red tabs above the picture of the lot (this scenario only has two). See Figure A.4.13 below.

Figure A.4.13: Lot level LID screening menu.

K. **Click the "+" for Buildings / Roofs** to open the menu that includes rain barrels. The model assumes they will be placed on all buildings for this land use.

Repeat the process for the second land use (the other soil group.) Click Next.

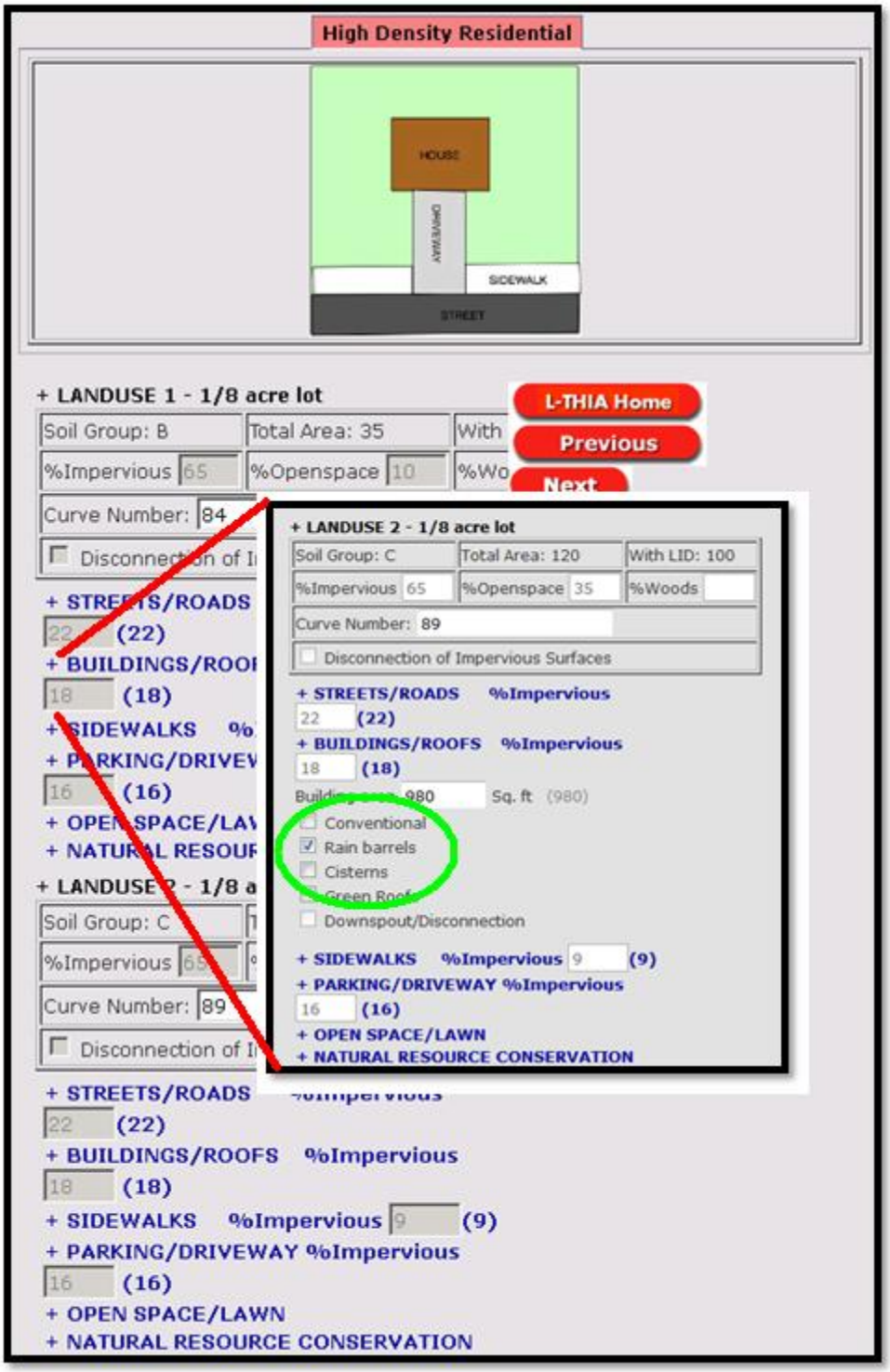

Figure A.4.14: Expand the + and check the box to select rain barrels.

L. Basic Screening Results: Look over the results table and notice the difference in runoff volume between the current scenario, post-developed scenario without LID, and post-developed scenario with LID as proposed. See Figure A.4.15.

RUNOFF RESULTS

Avg. Annual Runoff Volume (acre-ft) View as: Select

Land Use	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	4.29	-	-
Agricultural	29.88	-	-
Residential 1/8 acre	-	11.59	10.66
Residential 1/8 acre	-	58.01	50.87
Commercial	-	21.18	18.84
Total Annual Volume (acre -ft)	34.17	90.78	80.38

Also view Annual Variation and Probability of Exceedence

Avg. Annual Runoff Depth (in) View as: Select

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
2.64	7.02	6.22

Avg. Runoff Depth by Specific Landuse View as: Select

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	B	1.48	1.48	-
Agricultural	C	3	3	-
Residential 1/8 acre	B	-	3.99	3.67
Residential 1/8 acre	C	-	6.99	6.13
Commercial	D	-	12.76	11.35

Average Annual Rainfall Depth (in) 34.02

Figure A.4.15: Portion of the Results table.

M. Detailed Analysis: Most analyses combine several LID practices, but by returning to Step A and repeating the instructions in this guide, the user could run the model several times and each time evaluate a single LID practice. By compiling the results of several runs, the user can create a table that compares the alternatives by their effectiveness in reducing runoff and NPS pollutants including sediment (TSS in the model). This has been done for the tutorial data in Table A.4.1 below.

Table A.4.1: Average annual runoff volume from the tutorial model for various standard LID practices. These practices, defined in Section 2.2, are modeled using this tutorial data for the L-THIA LID model. See Appendix B2 for the Curve Number assumptions used in the model for these practices. See Appendix B3 for design details. See below in this section for a compilation of range of costs for these practices.

LID Scenario	**Avg. Annual Runoff Volume (acre-ft)**
Pre-Development (existing hydrology)	34.2
Post-Development without LID	90.78
LID Options	
Post-Development with Green Roof	82.72
Post-Development with Rain Barrels	80.38
Post-Development with Bioretention	65.03
Post-Development with Porous Parking	**50.05**
Post-Development with Roads with Swales	65.07
Post-Development with Nature Conservation Area	80.38

In this comparison, the single practice that has the largest impact on average annual runoff volume reduction is Porous Parking, although we project that Bioretention and Natural Resource Conservation areas will be similar in effect. This table used the standard impervious surface assumptions, but the % impervious sliders could be employed to create more options. Typically, a user would then compare typical LID installation costs against effectiveness.

N. Projected Costs of LID Practices: It is difficult to project the cost of LID practices unless detailed specifications are provided in terms of how the practice is implemented in a particular situation. For example, the cost of a "green roof" practice is obviously dependent upon the size of the roof covered, but many other design specifications are highly involved.

Some averages have been compiled for the sake of this tutorial and are listed in Table A.4.3 LID Practices Cost Range, but the user is advised to read associated material that treat the subject more fully.

The data in Table A.4.3 displays the price range of each practice compiled from sources published in 2007–2009. The resulting minimum and maximum values of cost (columns C and D) are based on typical sizing of each practice from design specifications, such as those given in Appendix B. LID design specifications are subject to local ordinances and will vary considerably, so be advised.

These cost estimates are from three cost calculators listed below in Table A.4.2.

Table A.4.2: LID Cost Calculators

LID Practice Cost Calculator	Organization
NATIONAL GREEN VALUES™ CALCULATOR METHODOLOGY	The Center for Neighborhood Technology (CNT). 2009.
LIDMM Low Impact Development Manual for Michigan (2008)	Available at: http://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf
Stormwater BMP Costs (2007)	North Carolina Department of Environment and Natural Resources. Division of Soil & Water Conservation Community Conservation Assistance Program

The table of LID Practices Cost ranges can be used for broad estimates of the cost of different practices. For example the cost of "Green Roof" is listed in Table 3.3 as a range of $ 8.50 to $ 48.5 per square foot. A mid-range number then might be $ 29.00 per square foot. The user may notice when applying this practice during a model run, as instructed in Step I (see Figure A.4.8) that the L-THIA LID model assumes 980 square feet of roof per lot in the 1/8 acre high-density residential land use category. The per unit treatment then could be estimated by multiplying the 980 square foot area times the cost.

"Typical" Green Roof = 980 ft^2 * $29.00 /$ft^2$= $28,420 per unit

The user can multiply this times the "8 lots per acre" in that category to obtain a "ball-park" cost for an acre of the "Green Roof" LID practice as

980 ft^2 /lot * 8 lots/acre * $29.00 / ft^2 = $227,360 per acre treated this way.

Table A.4.3: LID Practices Cost Range (2008-2009)		Default Range	
Practice	Price Range	Low	High
Green roof	$4.25 - 24.25/ SF	$ 8.50	$ 48.50
Rain Barrel/Cistern	$100 - 380 per barrel, $0.72-6.76 per gallon cistern	$ 40.18	$ 377.21
Swales	$0.60 - 20.00/ SF	$ 499.47	$ 16,649.11
Porous Pavement	$1.48 - 12.00 / SF	-	-
Swale and Porous Pavement	$2.08 - 32.00/ SF	$ 499.47	$ 16,649.11
Permeable Patio	$0.60 - 20.00/ SF	-	-
Open Wooded Space	$2.40 - 6.50/ SF or $1800 - 2600/ acre	-	-
Bioretention	$3.48 - 47.62/SF	$ 0.87	$ 11.91

Appendix A5:

L-THIA LID Tutorial | Trail Creek

The L-THIA LID model tutorial will answer these questions: (1) What is the impact upon runoff volume from the addition of a 1000+ unit housing development in a rural area?; (2) What is the predicted impact on non-point source pollutants within that runoff?; (3) What kind of reduction in runoff volume may come from specific Low Impact Development practices?; and (4) What maximum % impervious surface would be allowed if the regional planners want to add this amount of high density housing but want to maintain the pre-development hydrology (in terms of volume of runoff)?

The required steps in running the model are documented in the images below. The 5 part process is this: (1) The user first selects a state and county, which is used to determine the rainfall data for the 30 period (Figure A.1). (2) User enters land use and soil data for existing conditions (Figure A.5.2) (3) The user enters changed land use, reflecting a proposed development, (Figure A.5.3). (4) The user selects the proportion of the area that will receive LID practices, and may chose to select some parameters for LID practices (Figure A.5.). (5) The model runs and produces a table of outputs for examination (Figure A.5.5).

At the completion of this tutorial, the user should be able to design a similar scenario, enter the needed input data in L-THIA LID, run the model, and create output tables and graphs to address development questions such as above.

To set the stage for this tutorial, it is useful to become familiar with the Trail Creek Management Plan and the Countywide Development Plan for La Porte County. To quote from that document:

The Trail Creek Watershed Management Plan states that “at this point in time, Trail Creek is a tale of two creeks, heavily influenced by stormwater and watershed land use. The first creek is a rich, vibrant, high quality, cold water habitat full of salmon, steelhead and trout. This creek’s water is clear and flows gently over cobble riffles. The streambanks are stable and vegetation covers the entire width of the creek. This creek is a source of pride and enjoyment for the community with multiple parks and recreational areas along the creek.

The second creek, the one influenced by stormwater pollutants during rain events, is murky and muddy carrying untold pollutants and trash. Sediment carried by the creek fills the riffles and high water flows cause streambank erosion. Pollutant loads associated with stormwater runoff, including bacterial contamination, are excessive and warnings are issued to avoid touching the creek’s water and to avoid entering Lake Michigan as a result.”

The management plan lists erosion and sedimentation as its second largest concern, right after E. coli bacteria. It is the goal of both the Trial Creek Watershed Management Plan and The Countywide Development Plan for La Porte County to improve the water quality and protect Trial Creek by reducing the volume of runoff that enters it. Based on the projected distribution changes of the population in

2030 from the Countywide Development Plan, the tutorial will examine a scenario where residential area spreads out into rural areas (contrary to the goals in the Countywide Plan) to determine how much runoff will be generated.

Task: Use L-THIA LID to explore a 1000+ unit housing proposal in a rural area. We will start with the assumption of 1/8 acre lot sizes on 155 acres of land. The development will include 20 acres of commercial land use. The model will produce predictions for runoff volume and NPS sediment changes in various configurations of housing unit density including LID vs. non-LID results. While local political focus is on several NPS chemistries, this tutorial's main focus is on sediment and runoff volume.

A. Open L-THIA LID through the following url: [**https://engineering.purdue.edu/~lthia/LID**]

After reading through the introduction, click Next near the bottom of the page.

B. Select the state of Indiana and La Porte County using the two dropdown boxes. See Figure A.5.1 below. Click Next.

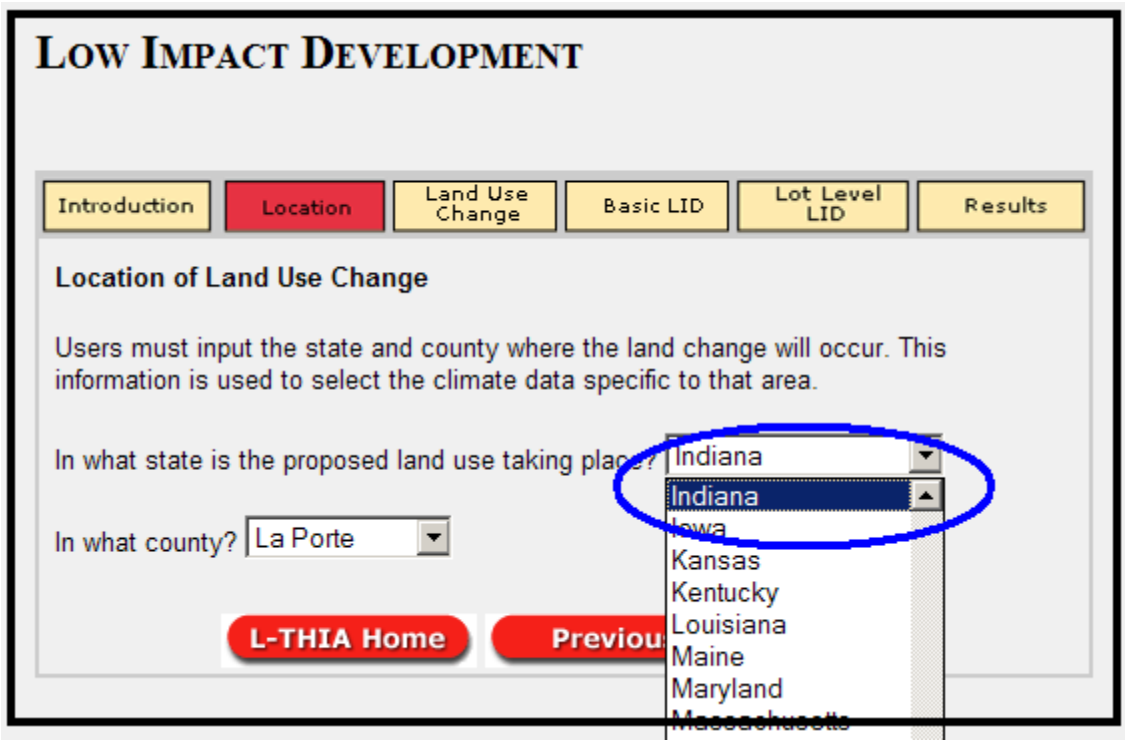

Figure A.5.1: Selecting state and county.

C. Pre-Developed Land use and Soil: To create a scenario, the user will enter existing land use and soil combinations with area into the top half of the spreadsheet like interface. This is the pre-development land use, soil type, and area. For this tutorial, we will be developing an **agricultural** area into a 1000 unit single-family housing development with 20 acres of commercial land use. The agricultural parcel is split into two different soil hydrologic types. This is not a reference to named soil types, rather it is related to the soil hydrologic condition that is determined by its drainage and

infiltration ability (as discussed above in Section 2.2). This hydrologic condition can change; for example compaction of soil by large earthmoving equipment such as found at large housing developments has been shown to lower the hydrologic condition of the entire development area. In the tutorial example, the agricultural land is comprised of some B and some C soil. A user could make an assumption that when the development operations for something this size has been constructed, the entire area has had some compaction effects and is then a C soil, rather than remaining a B soil (Lim et al., 2006b). Thus, the model user may choose to preserve the soil group proportions or change them as desired. The compaction increases the amount of runoff, and that will also increase the predicted NPS pollutants in the runoff. Soil hydrologic group for a specific location can be found in a typical soil survey. Soil data can be downloaded from NRCS at http://soildatamart.nrcs.usda.gov/, and in Indiana can be viewed and downloaded from the IndianaMap, http://maps.indiana.edu/.

In the scenario, we will plan for high-density residential units at 1/8 acre lot size. This is to represent a dense urban residential development, which would present a footprint size in stark size contrast to a typical 2 acre rural-suburban lots for 1000 + houses. Use the drop-down and numerical entry spots to do this (see expanded box on Figure A.5.2). Enter 35 acres of agricultural land use on B-type soil and 120 acres of agricultural land use on C-type soil. See Figure A.5.2.

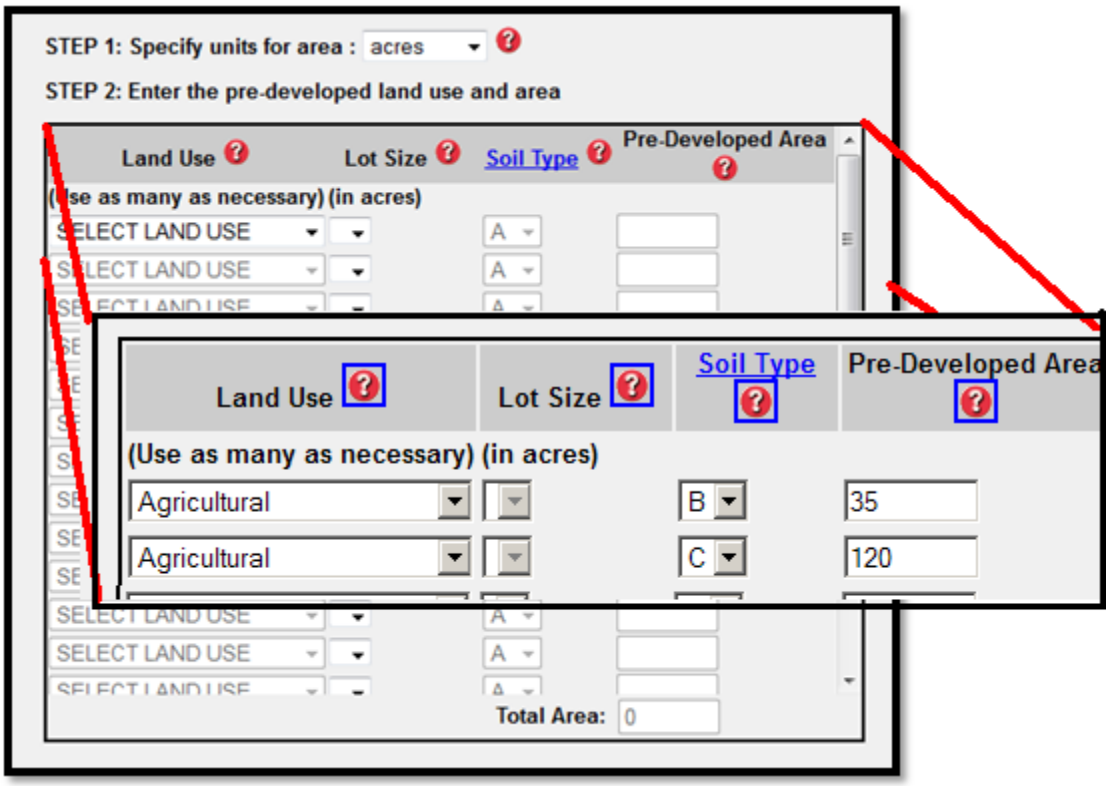

Figure A.5.2: Selecting pre-developed (existing) land use and soil and corresponding area.

We are using typical soils for this scenario. A more sophisticated scenario looking at a specific location could use data from a local soil map, where the soil hydrologic group (A – D) may be presented as a value known as “hydgrpdcd” or hydrologic group code.

Typically while the land use will almost always change between pre- and post- development, the soil group may or may not change, so a scenario with 1000 acres of C soils in pre-development may have a mixture of C and D soils in post-development. Some recent research suggests that it is reasonable to assume soils in large dense residential or industrial developments undergo compaction during the construction phase, and so the end result is a C soil transformed into a D soil (Lim et al., 2006). The scenario could be run with both original soil and compacted soil assumptions to estimate the degree to which compaction increases the runoff. For the tutorial we will assume the residential development preserved the soil infiltration abilities, but the commercial development has unavoidable compaction. This means the 20 acres of commercial land use will be entered as a “D” soil group.

Note: You may also select at this time to work in area units of square kilometers, square miles, acres, or hectares.

D. **Post-Developed Land use:** See Figure A.5.3. Scroll down and enter the post-development land use, soil type, and area. In this scenario of a single large development, we will build– High Density Residential 1/8 acre lot – on all the residential land that is being developed. That is not required; a model can mix the land use types in post-development including leaving some of the land undeveloped. In fact the model will accommodate changes in soil type as well. In other words, the user can change the hydrologic condition from B to C for example, to mimic the compaction that may occur during construction of large developments. However, the final total **area** must be exactly the same as the pre-development area.

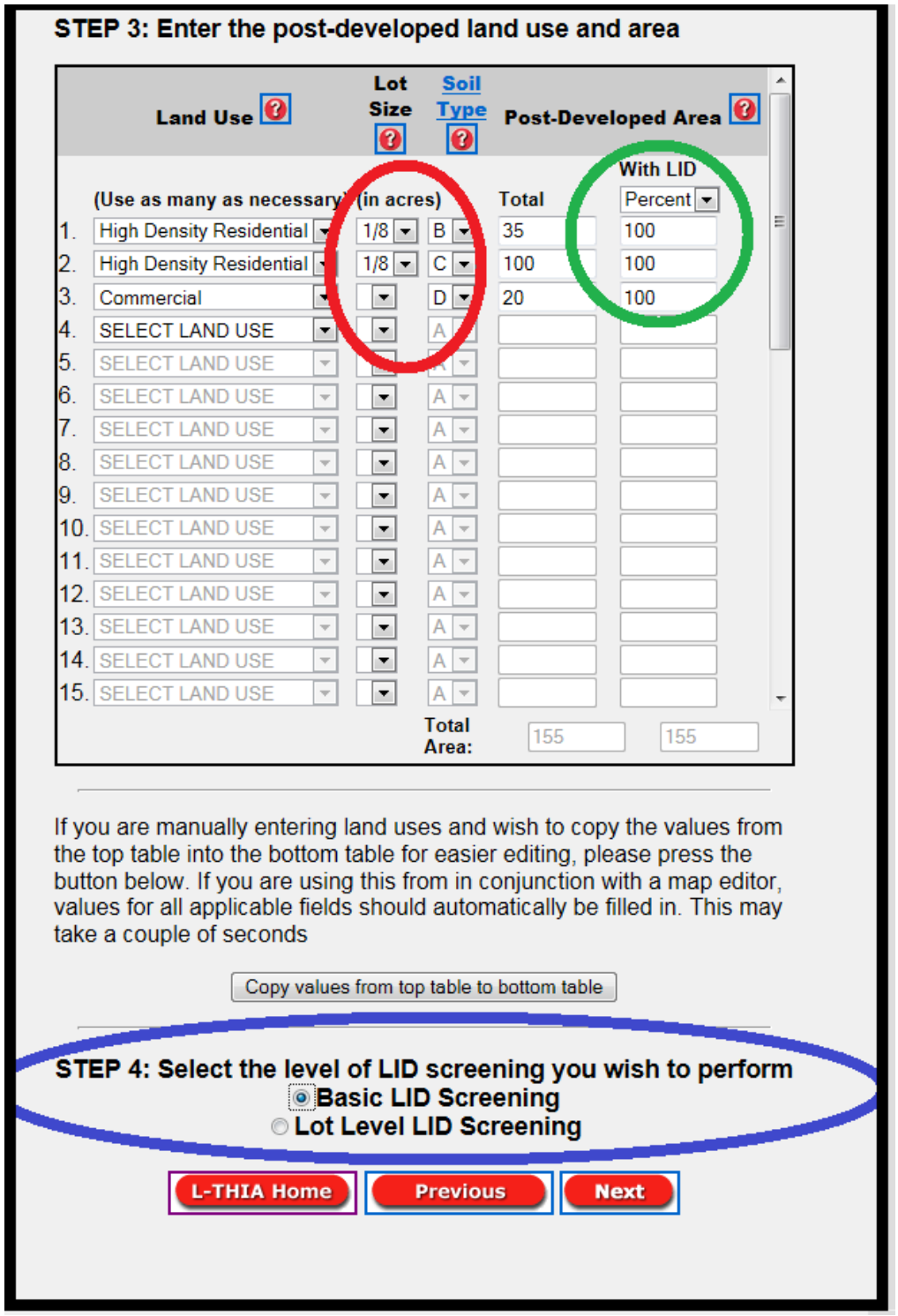

Figure A.5.3: Selecting post-development land use and soil and corresponding area with LID applied, and screening level.

In this example, we convert land from both land use-soil pairs to High Density Residential and add a third row of commercial land use, with a compacted soil changed to "D". This is a subset removed from the formerly "C" soil area. It is permissible to split a land use-soil pair. For example, if only ½ of

the agricultural parcel on the C soil were to be built upon, then the second row in the table would be 60 acres of High Density Residential 1/8 acre soil C, and the third row would be 60 acres of agricultural soil C. The overall total acres after development **must match** the total acres of pre-developed land. The LID practices will be applied to a specified proportion of the area, or to a specified acreage, for each of the land use–soils combination. In this scenario, the user should select Percent under "With LID" (**green circle** on Figure A.5.3) and enter 100, to describe what portion of the area will have LID practices applied.

For this scenario, enter 35 acres of high density residential, 1/8 acre lot size on B-type soil and then enter 100 acres of high density residential 1/8 acre lot size on C-type soil. Select the 1/8 acre lot size using the smaller drop-down menu (in **red circle** on Figure A.5.3). Enter 20 acres of commercial on D-type soil.

E. Scroll down, check to see "Basic LID Screening" from the level of LID screening list (in the **blue circle** on Figure A.5.3) and click Next.

F. Note the impervious surface slider that appears for some land uses. See Figure A.5.4. When the screen opens, the slider is preset to 65% (the TR 55 default) for impervious % for high density residential land use. Try adjusting this to demonstrate how the sliders work. During this "Basic Screening" run, you will model LID practices by sliding to a lower number, to represent the impact of adopting zoning or a national LID standard for percent impervious for example. Return the slider to 60 for residential and 75 for commercial (about a 10% reduction) for this scenario. Click Next. The L-THIA LID model will run for approximately 10 - 15 seconds before producing results.

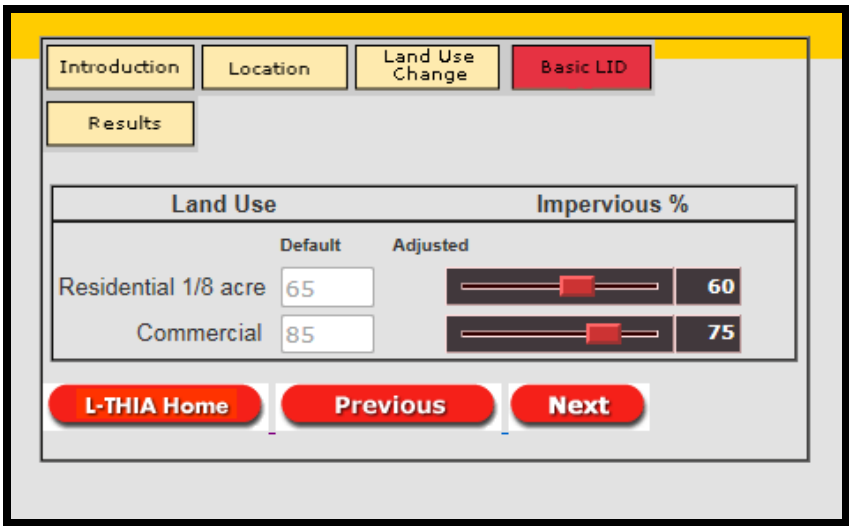

Figure A.5.4: Selecting the percentage of impervious surfaces.

G. **Results:** Take a moment to review the results table.

The "Summary of Scenarios" portion (see Figure A.5.5 below) of the table reports the area in acres per each land use in pre- and post- development scenarios. It reports the default and adjusted (after development) percentage impervious surface. It also reports a composite curve number for existing,

post-developed, and post-developed with LID. The LID practices are applied as modifications of the curve number.

SUMMARY OF SCENARIOS View as: Select

State: Indiana

County: La Porte

Land Use	Hydrologic Soil Group	acres Pre-Developed	acres Post-Developed W/o LID	acres Post-Developed With LID As Proposed
Agricultural	B	35	-	-
Agricultural	C	120	-	-
Residential 1/8 acre	B	-	35	35
Residential 1/8 acre	C	-	100	100
Commercial	D	-	20	20

PERCENTAGE IMPERVIOUS

Land Use	Default	Adjusted
Residential 1/8 acre	65	60
Commercial	85	75

COMPOSITE CURVE NUMBER

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
80	90	88

Figure A.5.5: Summary of Scenarios from Results Table.

An additional group of sections in the results table include those displayed in Figure A.5.6 below. The top section in this figure is “Curve Number by Land use” which reports curve numbers for each land use. This includes the adjustments added by the LID practices. In this table the user will note (at the dark arrow) that 1/8 acre density residential land use on C soil has a CN of 90 but with some LID practices applied, it is adjusted to an effective CN of 88 which will reduce runoff and pollutant loads.

Curve Number by Landuse

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	B	75	75	-
Agricultural	C	82	82	-
Residential 1/8 acre	B	-	85	83
Residential 1/8 acre	C	-	90	88
Commercial	D	-	95	94

RUNOFF RESULTS

Avg. Annual Runoff Volume (acre-ft) View as: Select

Land Use	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	8.19	-	-
Agricultural	49.50		-
Residential 1/8 acre	-	18.18	15.36
Residential 1/8 acre	-	83	68.89
Commercial	-	27.57	25.01
Total Annual Volume (acre-ft)	57.69	128.75	109.27

Also view Annual Variation and Probability of Exceedence

Avg. Annual Runoff Depth (in) View as: Select

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
4.46	9.96	8.45

Figure A.5.6: Curve Number by Land use and Specific Runoff results.

The Runoff Results portion of the results table (See Figure A.5.6) displays the runoff volume (in acre-feet) and runoff depth in inches (e.g. 8.45 inches runoff per year over the whole area of 155 acres is expressed in acre-feet as 109.27 acre feet per year of runoff) for each land use-soil pair and shows the before and after impact of the LID processes. In this scenario, the model indicates that basic LID practices could reduce the predicted unmodified 128.75 acre feet of runoff to 109.27 acre feet of runoff.

The final sections of the results table (see Figure A.5.7) are runoff values by specific land use listing and the Nonpoint Source Pollutants results. This listing includes the predicted results from 11 chemicals or metals, sediment, and 2 bacteria. The chemistry is reported by each land use and totaled for the analysis. This is the predicted annual load from a 30 year average runoff volume. This value is only from nonpoint sources, so if a user is trying to estimate a total load, then all known point sources must be added in as well.

Avg. Runoff Depth by Specific Landuse View as: Select

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	B	2.82	2.82	-
Agricultural	C	4.97	4.97	-
Residential 1/8 acre	B	-	6.26	5.29
Residential 1/8 acre	C	-	10	8.3
Commercial	D	-	16.61	15.07
Average Annual Rainfall Depth (in)				37.56

NONPOINT SOURCE POLLUTANT RESULTS

Nitrogen (lbs) View as: Select

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	98	-	-
Agricultural	593	-	-
Residential 1/8 acre	-	90	76
Residential 1/8 acre	-	411	341
Commercial	-	100	91
Total	691	601	508

Also view Annual Variation and Probability of Exceedence

Figure A.5.7: Nonpoint Source Pollutant Results portion of the table.

The entire table or values from specific rows can be copied and pasted into a spreadsheet for further analysis or tabulation. Notice the various entries for average annual runoff volume and depth.

Please notice the "Select" box, which allows you to focus on specific targets from the nonpoint source pollutant levels. Figure A.5.8 below, highlights one of the NPS results, the predicted

Suspended Solids (lbs) (e.g. sediment) result. This calculation is based upon the volume of runoff and the type of land use it flows across, where the runoff is assumed to cover the entire watershed. In other words, remember that L-THIA LID is not a routing model and does not include slope or slope length in any fashion. This calculation is based upon specific constants for each land use (given in Appendix B1) and the volume of runoff predicted for the analysis area.

Suspended Solids (lbs)		View as: Select	
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	2388	-	-
Agricultural	14431	-	-
Residential 1/8 acre	-	2031	1716
Residential 1/8 acre	-	9272	7695
Commercial	-	4169	3782
Total	16819	15472	13193
Also view Annual Variation and Probability of Exceedence			

Figure A.5.8: Suspended Solids portion of the table.
Table values may be copy-pasted into Excel™.

The links at the bottom of the figure open a line graph (Figure A.5.9) of the Annual Variation for a specific NPS compound and a line graph (Figure A.5.10) of Percent of exceedence. In the Annual Variation figure, the predicted load (vertical scale is pounds of N) of Nitrogen is displayed against 30 years of average annual rainfall (the horizontal scale).

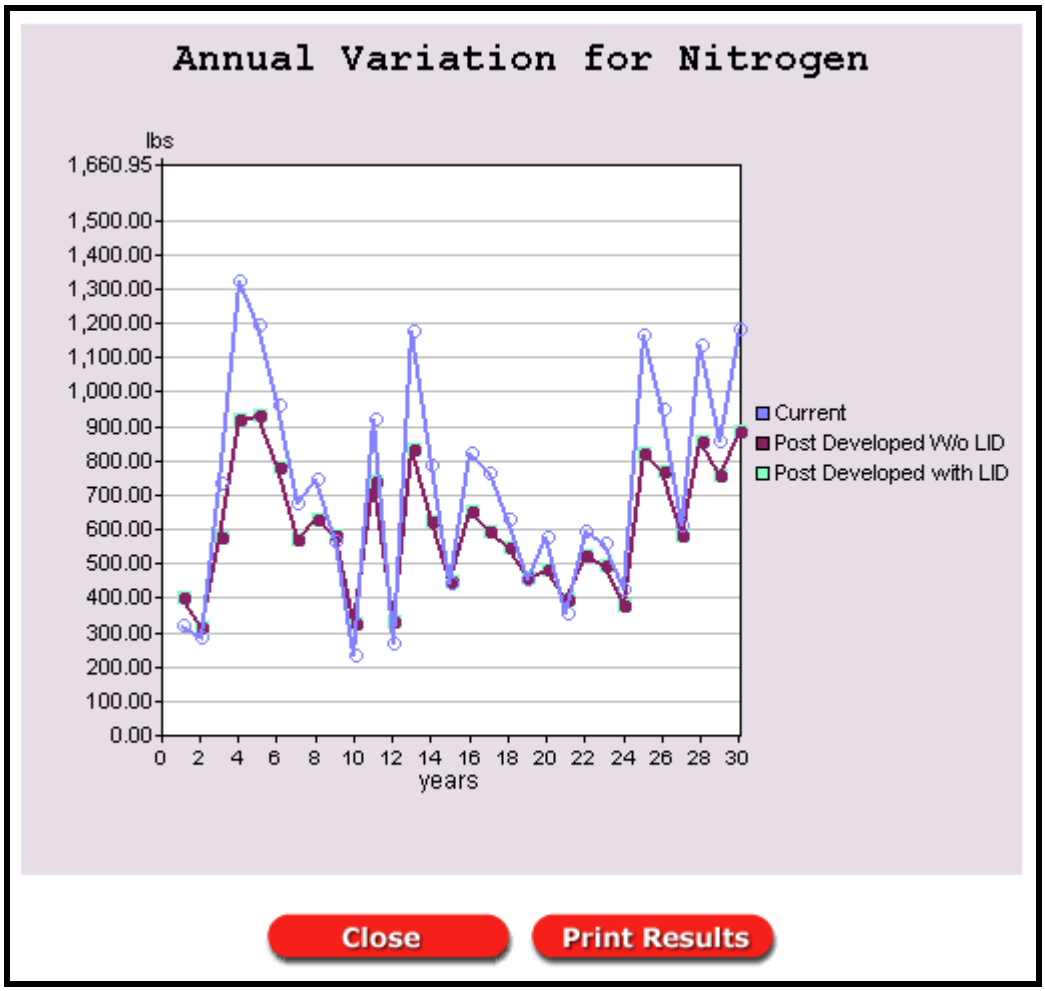

Figure A.5.9: Graph of Annual Variation for NPS contaminant.

The percent of exceedence graph plots 30 points (each representing annual totals) against the estimated percentage of years in which the load will exceed the total at the point. This display is intended to allow watershed managers, for example, to be able to estimate what percent of the time the annual load will exceed a particular value, which is an estimated annual load. In figure A.5.10, the graph indicates that a 6,000 pound target (blue arrow) will be exceeded in about 65% (red arrow) of years.

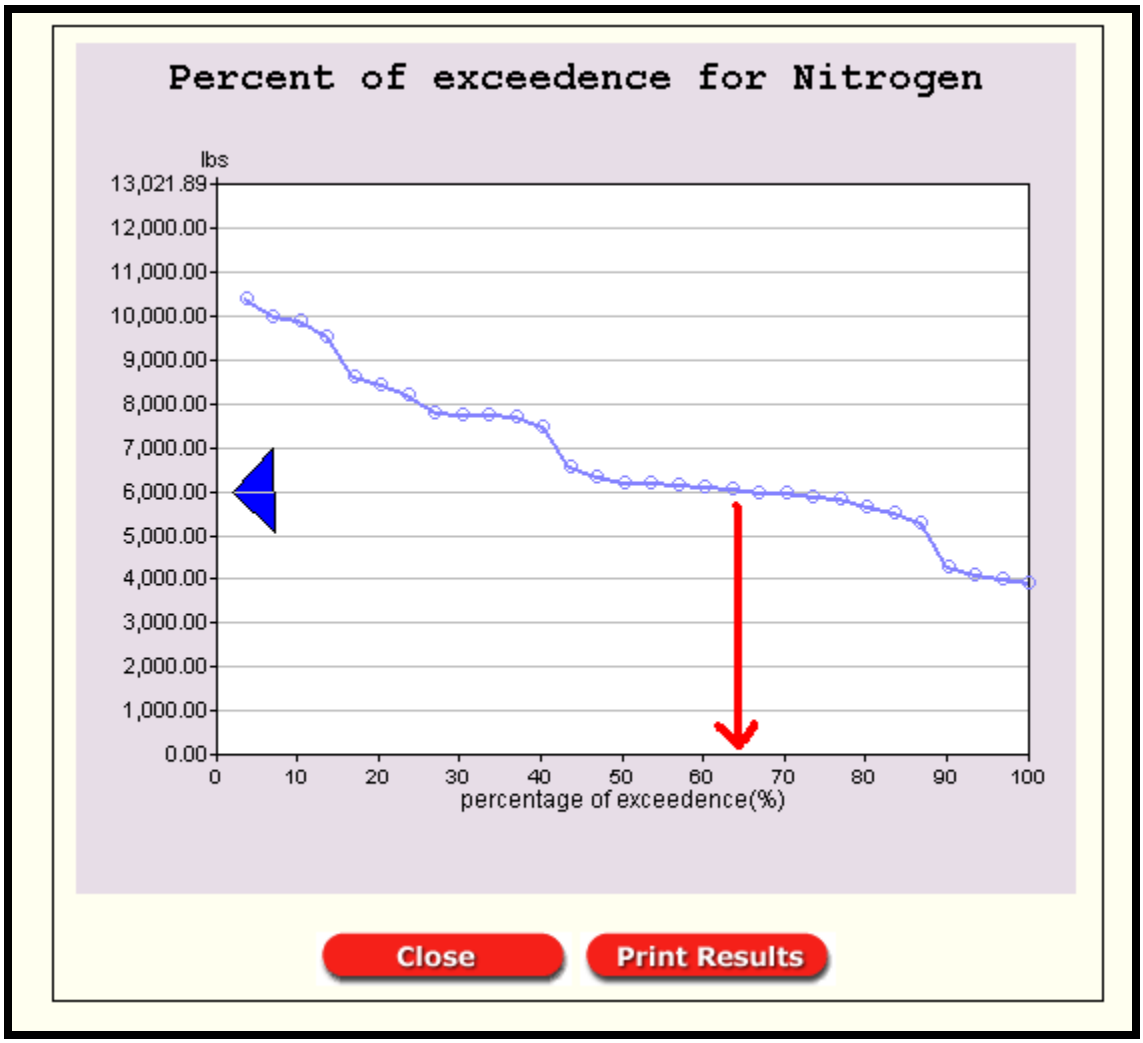

Figure A.5.10: Percent of Exceedence for NPS contaminant.

The next set of steps in the tutorial will use "lot-level screening" to examine the reductions in more detail. The goal of that approach is to determine LID practices that will either offer more reduction or offer the best "bang-for-the-buck."

H. Examine the effect of impervious surface: One useful approach with L-THIA LID is to determine a target % impervious to maintain pre-development hydrology. For example, what maximum % impervious surface would be allowed if we want to add this amount of high density housing but want to maintain something close to the pre-development hydrology? The user could experiment with different values while doing several model runs.

Click the link at the bottom of the results page that says "return to spreadsheet" and reenter your model inputs (repeat steps C, D, and E) and follow the instructions below.

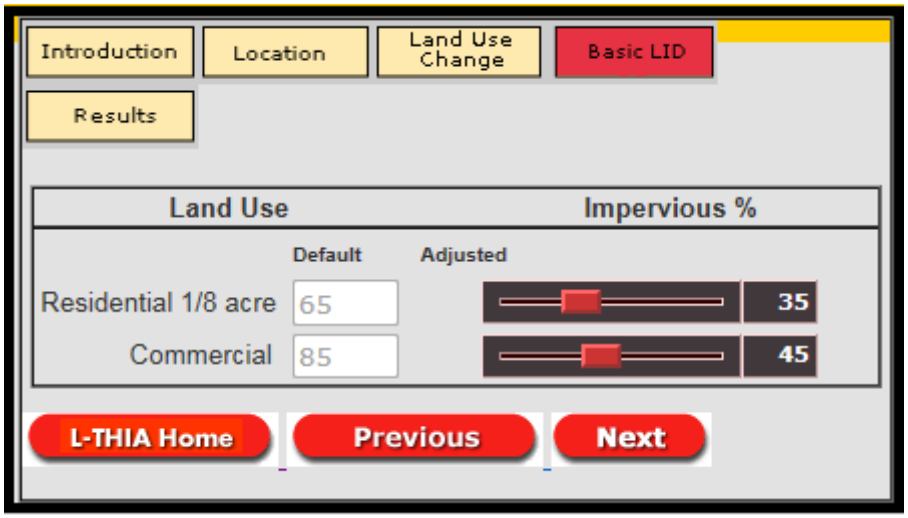

Figure A.5.11: Impervious % slider.

Adjust the Residential impervious surface slider (Figure A.5.11) to about half the starting impervious surface, around 33- 35%, and adjust the commercial slider to 45%. Click next and continue to results page. This time the runoff from the 1/8 acre lots and the commercial area will be around 62.46 acre feet, close to the original pre-development hydrology which had a predicted average annual runoff of 57.69 acre feet. This indicates that *if* the planned development could incorporate an effective 50% design reduction in its impervious surfaces, the whole development could occur while maintaining the original hydrology, in terms of volume. The reduction in runoff volume is directly related to reduction in sediment transported, because the model assumes that the more runoff that is generated in an area, the higher the entrained sediment load and the higher the other NPS chemistry load. Simply put, lowering the runoff through LID practices will lower the predicted sediment and NPS chemistry in the resulting runoff, as compared to a similar development without LID, which would have much more runoff traveling across the various land uses.

I. **Lot–Level Screening:** This portion of the model will allow the user to test the implementation of specific practices – like rain barrels or including porous pavement for roads or parking. Where local cost estimates exist for these practices, the predicted runoff and pollutant reductions can be compared to the installation costs of the practices.

The lot-level practices that are available will vary depending on the land use selected for the model. For example, high density residential land use in the model will trigger the list to include specific practices and options for:

Streets / Roads
Buildings / Roofs
Sidewalks
Parking / Driveway
Open Space / Lawn
Natural Resource Conservation (Rain Garden)

Each of these options has a specific set of variables that impact the curve number assigned to the land use, and hence the runoff. For more information on exactly what constitutes a practice like "porous pavement," the user can consult web resources such as the Low Impact Development Center at [http://www.lid-stormwater.net/index.html].

The next scenario will step through the LID practice options one at a time to compare their relative benefits. Now, again follow the link at the bottom of the results page that says "return to spreadsheet" and reenter your model inputs (steps C, D, and E) or begin again at Step A if you have closed your web browser.

This time, after step E, select "**Lot Level LID Screening**" from the dropdown list (in the red circle on Figure A.5.12). Remember to select 1/8 acre for Lot Size again for the post-development scenario. Click Next.

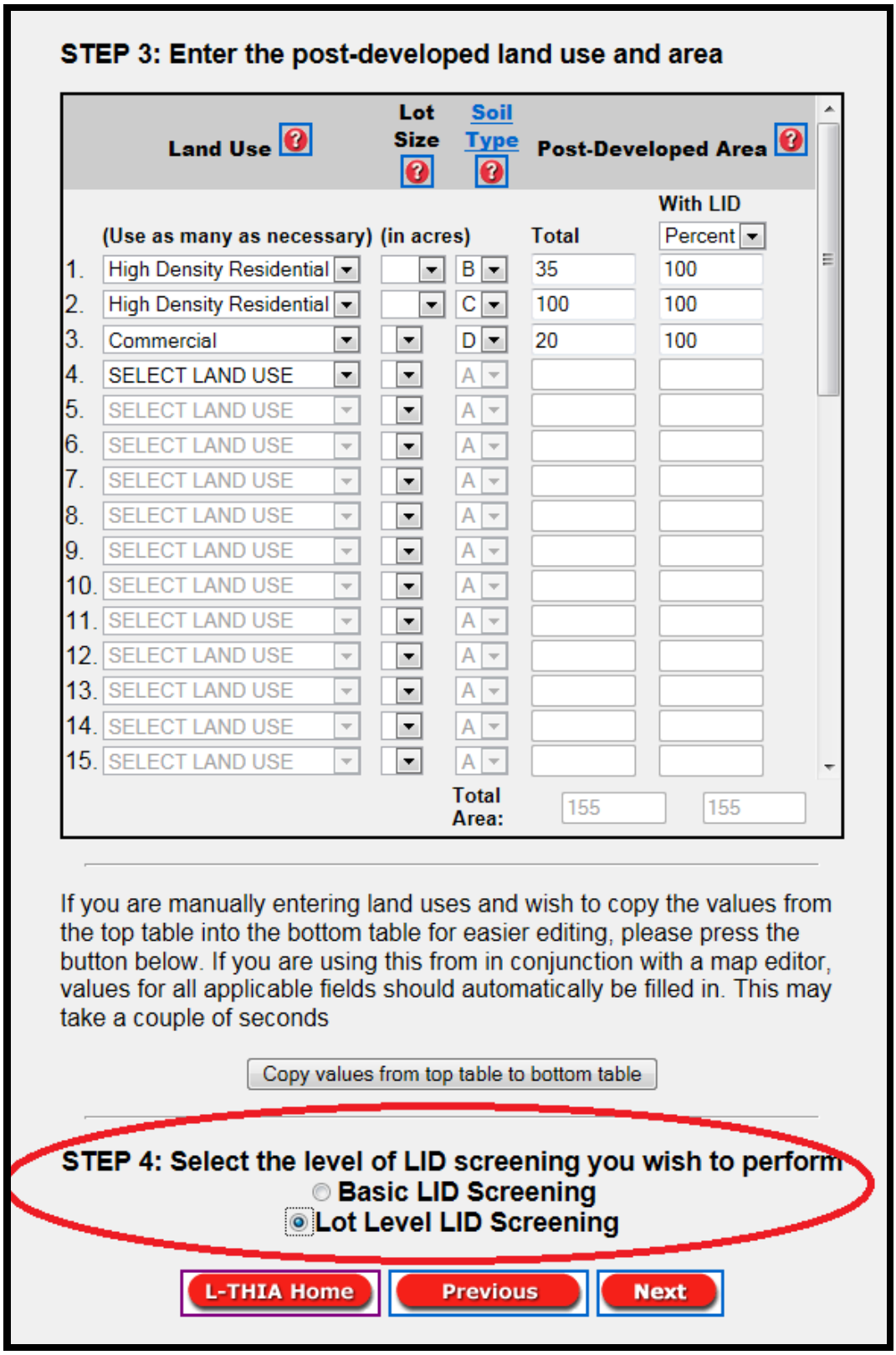

Figure A.5.12: Selection of Lot Level LID Screening.

J. **Specific Practices:** In the modeling process, the user will look through the lot level LID page to see which LID practices are available. For example, "agricultural" has no LID practices and will not appear here, but low density residential will, and so will industrial and commercial; but they will have different LID practice options.

You may expand the menus by clicking on items with a plus sign. LID practices are grouped by whether that practice is associated with the streets/roads, buildings/roofs, sidewalks, parking/driveways, open space/lawn, or natural resource conservation. To edit the LID practices on different land use types, click on the red tabs above the picture of the lot (this scenario has two). See Figure A.5.13 below.

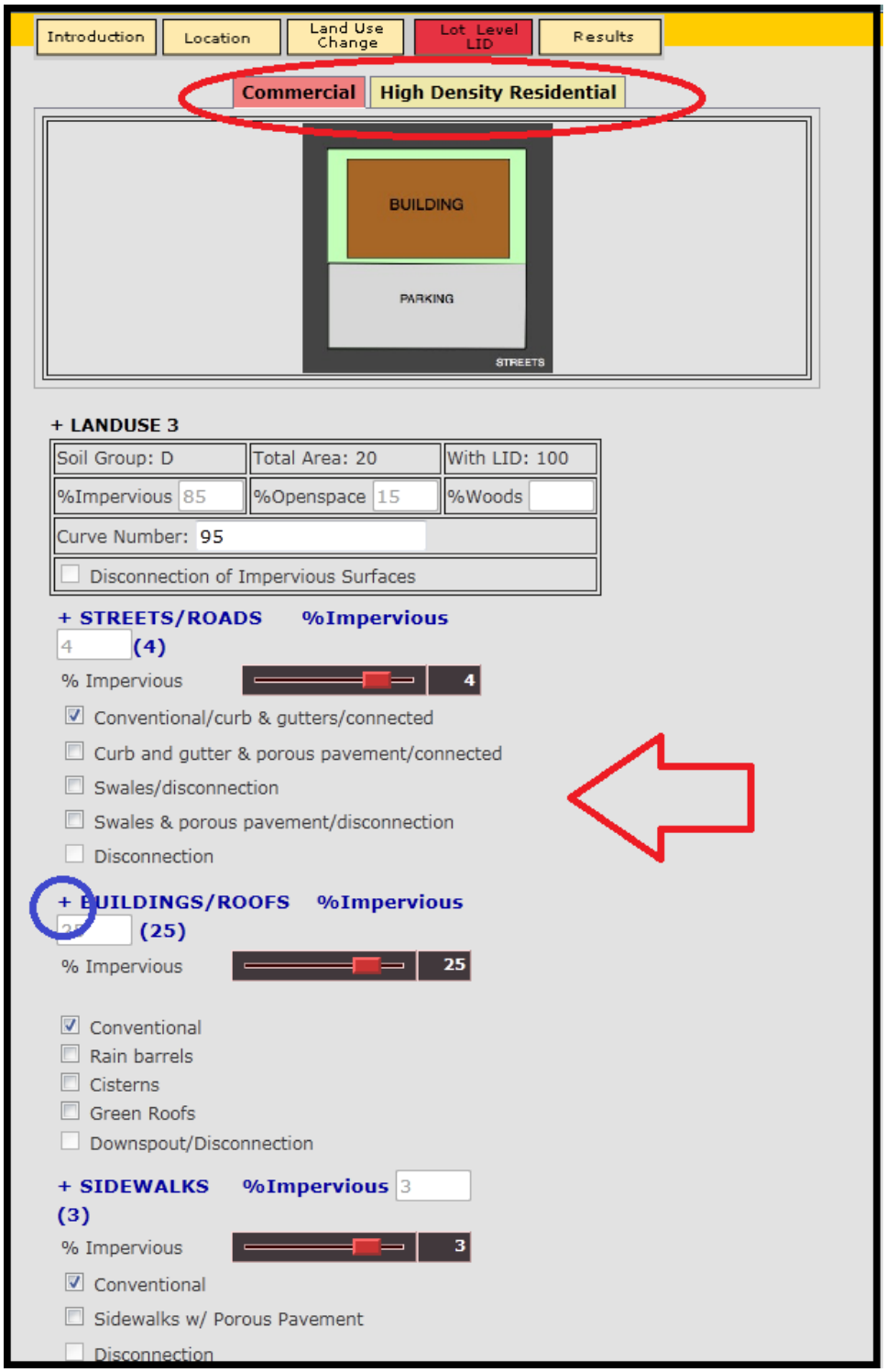

Figure A.5.13: Lot level LID screening menu.

K. **Click the "+" for Buildings / Roofs** to open the menu that includes rain barrels. The model assumes they will be placed on all buildings for this land use.

Repeat the process for the second land use (the other soil group.) Then tab to the Commercial category and repeat the selection. Click Next.

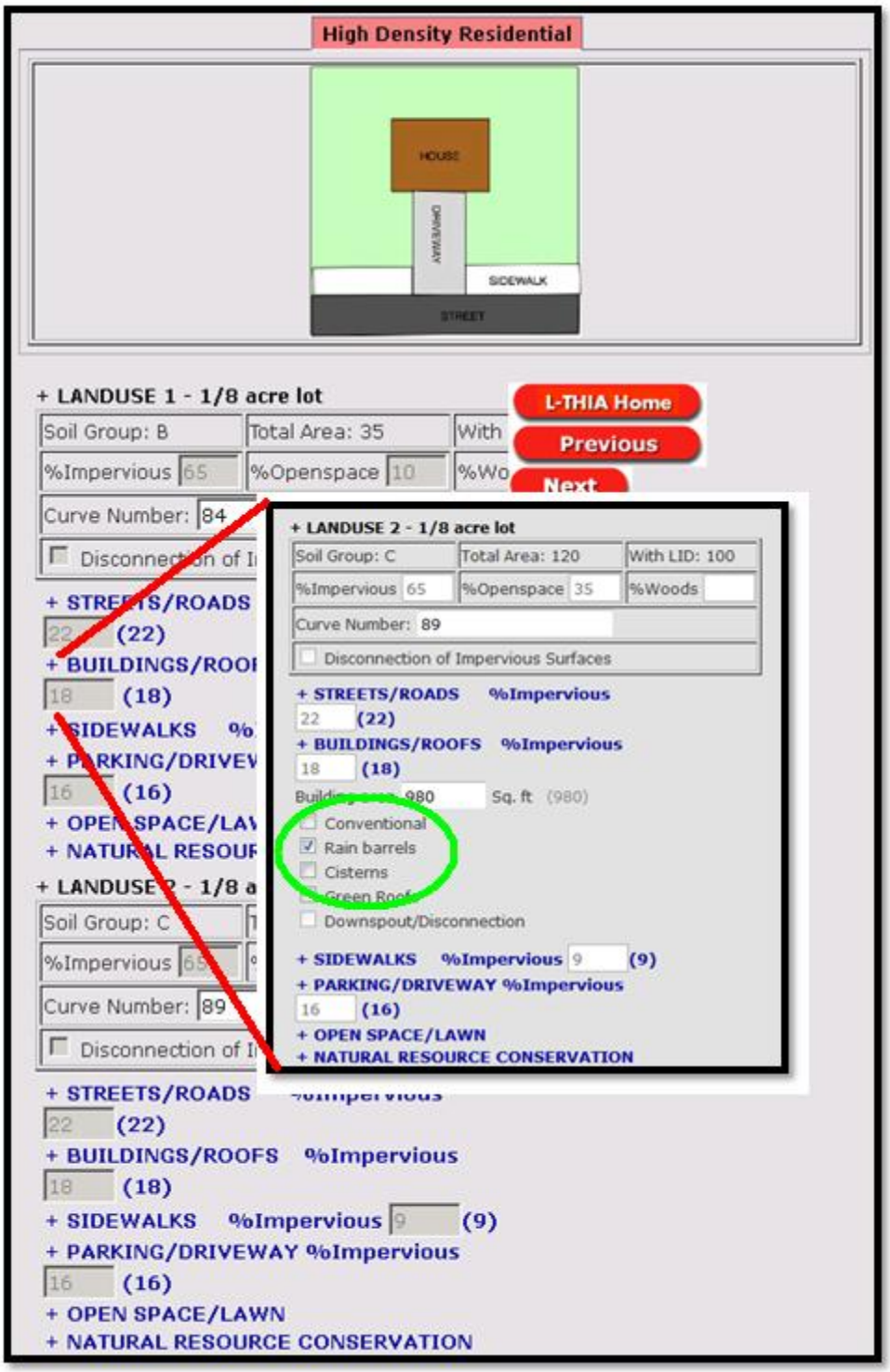

Figure A.5.14: Expand the + and check the box to select rain barrels.

L. Basic Screening Results: Look over the results table and notice the difference in runoff volume between the current scenario, post-developed scenario without LID, and post-developed scenario with LID as proposed. See Figure A.5.15.

RUNOFF RESULTS

Avg. Annual Runoff Volume (acre-ft) View as: Select

Land Use	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	8.19	-	-
Agricultural	49.50	-	-
Residential 1/8 acre	-	18.18	17.02
Residential 1/8 acre	-	83	74.20
Commercial	-	27.57	25.01
Total Annual Volume (acre -ft)	57.69	128.75	116.24

Also view Annual Variation and Probability of Exceedence

Avg. Annual Runoff Depth (in) View as: Select

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
4.46	9.96	8.99

Avg. Runoff Depth by Specific Landuse View as: Select

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	B	2.82	2.82	-
Agricultural	C	4.97	4.97	-
Residential 1/8 acre	B	-	6.26	5.86
Residential 1/8 acre	C	-	10	8.94
Commercial	D	-	16.61	15.07

Average Annual Rainfall Depth (in) 37.56

Figure A.5.15: Portion of the Results table.

M. Detailed Analysis: Most analyses combine several LID practices, but by returning to Step A and repeating the instructions in this guide, the user could run the model several times and each time evaluate a single LID practice. By compiling the results of several runs, the user can create a table that compares the alternatives by their effectiveness in reducing runoff and NPS pollutants including sediment (TSS in the model). This has been done for the tutorial data in Table A.5.1 below.

Table A.5.1: Average annual runoff volume from the tutorial model for various standard LID practices. These practices, defined in Appendix B3, are modeled using this tutorial data for the L-THIA LID model. To produce this table, the scenario was entered six times, and one practice was chosen for both landuses each time. See Appendix B2 for the Curve Number assumptions used in the model for these practices. See Appendix B3 for design details. See below in this section for a compilation of range of costs for these practices.

LID Scenario	**Avg. Annual Runoff Volume (acre-ft)**
Pre-Development (existing hydrology)	57.69
Post-Development without LID	128.75
LID Options	
Post-Development with Green Roof	97.42
Post-Development with Rain Barrels	116.24
Post-Development with Bioretention	97.13
Post-Development with Porous Parking (Medium)	**82.34**
Post-Development with Roads with Swales (Disc.)	110.90
Post-Development with Nature Conservation Area	118.79

In this comparison, the single practice that has the largest impact on average annual runoff volume reduction is Porous Parking, although we project that Bioretention and Natural Resource Conservation areas will be similar in effect. This table used the standard impervious surface assumptions, but the % impervious sliders could be employed to create more options. Typically, a user would then compare typical LID installation costs against effectiveness.

N. Projected Costs of LID Practices: It is difficult to project the cost of LID practices unless detailed specifications are provided in terms of how the practice is implemented in a particular situation. For example, the cost of a "green roof" practice is obviously dependent upon the size of the roof covered, but many other design specifications are highly involved.

Some averages have been compiled for the sake of this tutorial and are listed in Table A.5.3 LID Practices Cost Range, but the user is advised to read associated material that treat the subject more fully.

The data in Table A.5.3 displays the price range of each practice compiled from sources published in 2007–2009. The resulting minimum and maximum values of cost (columns C and D) are based on typical sizing of each practice from design specifications, such as those given in Appendix B. LID design specifications are subject to local ordinances and will vary considerably, so be advised.

These cost estimates are from three cost calculators listed below in Table A.5.2.

Table A.5.2: LID Cost Calculators

LID Practice Cost Calculator	Organization
NATIONAL GREEN VALUES™ CALCULATOR METHODOLOGY	The Center for Neighborhood Technology (CNT). 2009.
LIDMM Low Impact Development Manual for Michigan (2008)	Available at: http://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf
Stormwater BMP Costs (2007)	North Carolina Department of Environment and Natural Resources. Division of Soil & Water Conservation Community Conservation Assistance Program

The table of LID Practices Cost ranges can be used for broad estimates of the cost of different practices. For example the cost of "Green Roof" is listed in Table 3.3 as a range of $ 8.50 to $ 48.5 per square foot. A mid-range number then might be $ 29.00 per square foot. The user may notice when applying this practice during a model run, as instructed in Step I (see Figure A.5.8) that the L-THIA LID model assumes 980 square feet of roof per lot in the 1/8 acre high-density residential land use category. The per unit treatment then could be estimated by multiplying the 980 square foot area times the cost.

"Typical" Green Roof = 980 ft^2 * $29.00 /$ft^2$= $28,420 per unit

The user can multiply this times the "8 lots per acre" in that category to obtain a "ball-park" cost for an acre of the "Green Roof" LID practice as

980 ft^2 /lot * 8 lots/acre * $29.00 / ft^2 = $227,360 per acre treated this way.

Table A.5.3: LID Practices Cost Range (2008-2009)		Default Range	
Practice	Price Range	Low	High
Green roof	$4.25 - 24.25/ SF $100 - 380 per barrel, $0.72-6.76	$ 8.50	$ 48.50
Rain Barrel/Cistern	per gallon cistern	$ 40.18	$ 377.21
Swales	$0.60 - 20.00/ SF	$ 499.47	$ 16,649.11
Porous Pavement	$1.48 - 12.00 / SF	-	-
Swale and Porous Pavement	$2.08 - 32.00/ SF	$ 499.47	$ 16,649.11
Permeable Patio	$0.60 - 20.00/ SF	-	-
Open Wooded Space	$2.40 - 6.50/ SF or $1800 - 2600/ acre	-	-
Bioretention	$3.48 - 47.62/SF	$ 0.87	$ 11.91

Appendix A6:

L-THIA LID Tutorial | Upper Blanchard Watershed

The L-THIA LID model tutorial will answer these questions: (1) What is the impact upon runoff volume from the addition of a 1000+ unit housing development in a rural area?; (2) What is the predicted impact on non-point source pollutants within that runoff?; (3) What kind of reduction in runoff volume may come from specific Low Impact Development practices?; and (4) What maximum % impervious surface would be allowed if the regional planners want to add this amount of high density housing but want to maintain the pre-development hydrology (in terms of volume of runoff)?

The required steps in running the model are documented in the images below. The 5 part process is this: (1) The user first selects a state and county, which is used to determine the rainfall data for the 30 period (Figure A.1). (2) User enters land use and soil data for existing conditions (Figure A.6.2) (3) The user enters changed land use, reflecting a proposed development, (Figure A.6.3). (4) The user selects the proportion of the area that will receive LID practices, and may chose to select some parameters for LID practices (Figure A.6.4). (5) The model runs and produces a table of outputs for examination (Figure A.6.5).

At the completion of this tutorial, the user should be able to design a similar scenario, enter the needed input data in L-THIA LID, run the model, and create output tables and graphs to address development questions such as above.

To set the stage for this tutorial, it is useful to become familiar with the TMDL document for the Blanchard River (http://www.epa.ohio.gov/dsw/tmdl/BlanchardRiverTMDL.aspx) The Hancock county seat, Findlay Ohio, has suffered substantial flooding events in the past 10 years. This tutorial will be looking at how changes in upstream development might be driving changes in runoff (leading to flooding) and how LID practices might lower the runoff volume to ease flooding issues. In this generally rural watershed, it may seem difficult for urban BMP practices to impact runoff; however the tutorial will illustrate the benefits of planning development to use LID practices as development moves out of the urban areas into suburbs and rural areas.

Task: Use L-THIA LID to explore a 1000+ unit housing proposal in a rural area. We will start with the assumption of 1/8 acre lot sizes and a 20 acre commercial development on 155 acres of land. The model will produce predictions for runoff volume and NPS sediment changes in various configurations of housing unit density including LID vs. non-LID results. While local political focus is on several NPS chemistries, this tutorial's main focus is on sediment and runoff volume.

A. Open L-THIA LID through the following url: [**https://engineering.purdue.edu/~lthia/LID**]

After reading through the introduction, click Next near the bottom of the page.

B. Select the state of Ohio and Hancock County using the two dropdown boxes. See Figure A.6.1 below. Click Next.

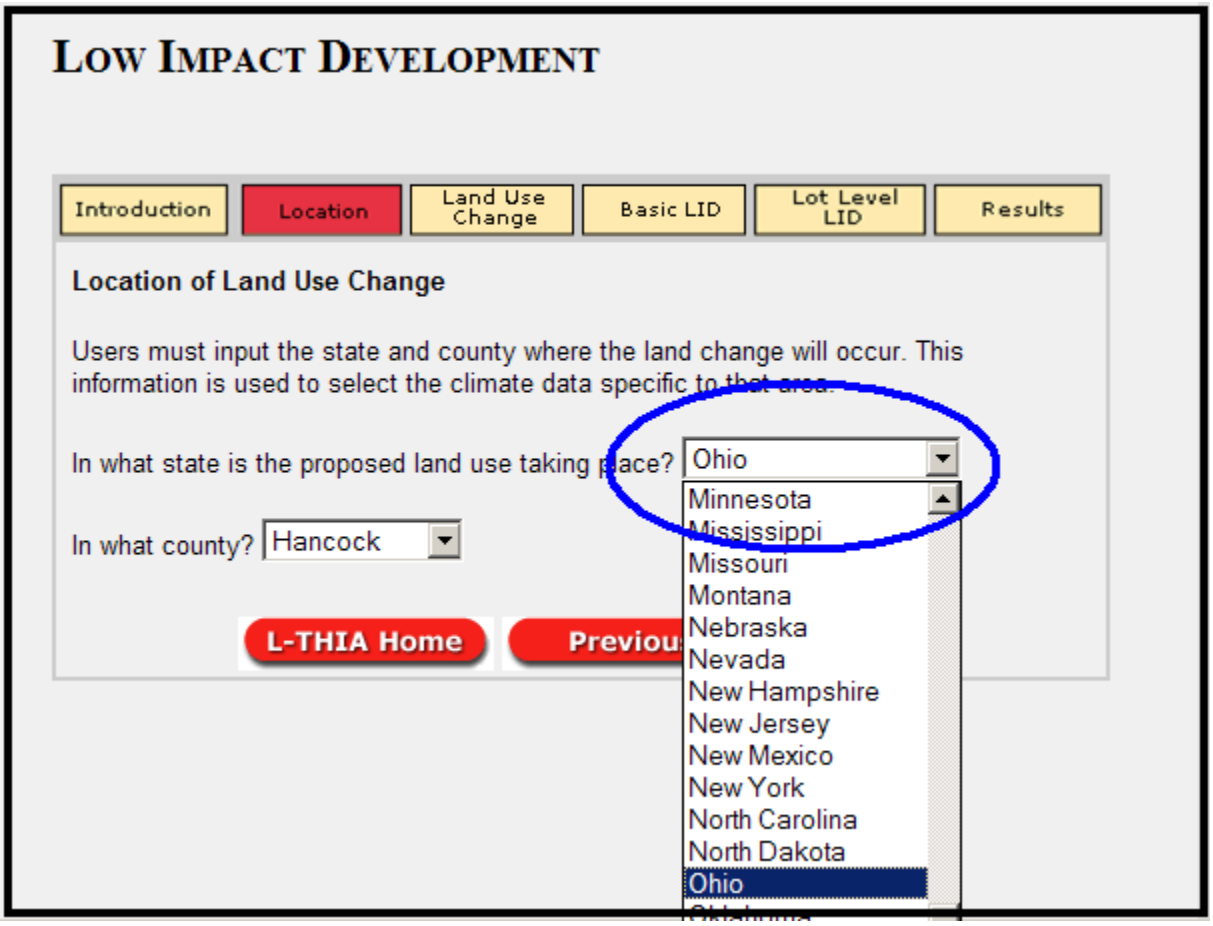

Figure A.6.1: Selecting state and county.

C. **Pre-Developed Land use and Soil:** To create a scenario, the user will enter existing land use and soil combinations with area into the top half of the spreadsheet like interface. This is the pre-development land use, soil type, and area. For this tutorial, we will be developing an **agricultural** area into a 1000 unit single-family housing development with a 20 acre commercial development. The agricultural parcel is split into two different soil hydrologic types. This is not a reference to named soil types, rather it is related to the soil hydrologic condition that is determined by its drainage and infiltration ability (as discussed above). This hydrologic condition can change; for example compaction of soil by large earthmoving equipment such as found at large housing developments has been shown to lower the hydrologic condition of the entire development area. In the tutorial example, the agricultural land is comprised of some B and some C soil. A user could make an assumption that when the development operations for something this size has been constructed, the entire area has had some compaction effects and is then a C soil, rather than remaining a B soil (Lim et al., 2006b). Thus, the model user may choose to preserve the soil group proportions or change them as desired. The compaction increases the amount of runoff, and that

will also increase the predicted NPS pollutants in the runoff. Soil hydrologic group for a specific location can be found in a typical soil survey. Soil data can be downloaded from NRCS at http://soildatamart.nrcs.usda.gov/.

In the scenario, we will plan for high-density residential units at 1/8 acre lot size. This is to represent a dense urban residential development, which would present a footprint size in stark size contrast to a typical 2 acre rural-suburban lots for 1000 + houses. Use the drop-down and numerical entry spots to do this (see expanded box on Figure A.6.2). Enter 35 acres of agricultural land use on B-type soil and 120 acres of agricultural land use on C-type soil. See Figure A.6.2.

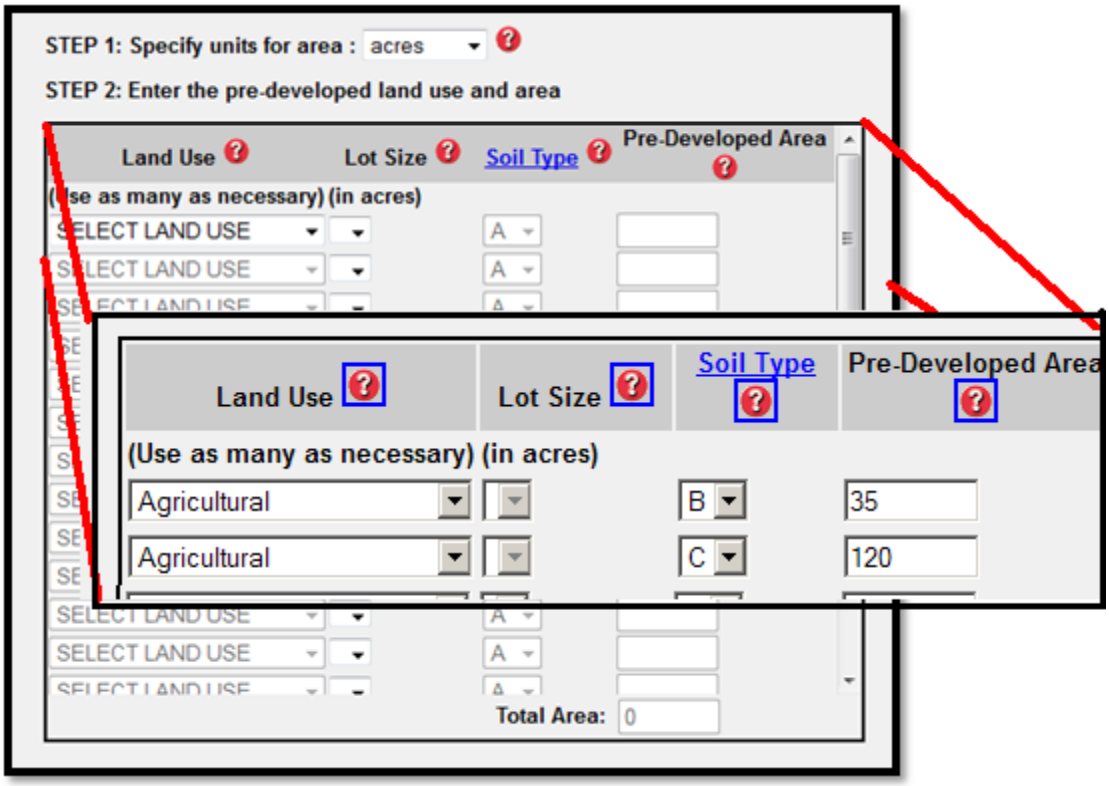

Figure A.6.2: Selecting pre-developed (existing) land use and soil and corresponding area.

We are using typical soils for this scenario. A more sophisticated scenario looking at a specific location could use data from a local soil map, where the soil hydrologic group (A – D) may be presented as a value known as "hydgrpdcd" or hydrologic group code.

Typically while the land use will almost always change between pre- and post- development, the soil group may or may not change, so a scenario with 1000 acres of C soils in pre-development may have a mixture of C and D soils in post-development. Some recent research suggests that it is reasonable to assume soils in large dense residential or industrial developments undergo compaction during the construction phase, and so the end result is a C soil transformed into a D soil (Lim et al., 2006). The scenario could be run with both original soil and compacted soil assumptions to estimate the degree

to which compaction increases the runoff. For the tutorial we will assume the residential development preserved the soil infiltration abilities, but the commercial development has unavoidable compaction. This means the 20 acres of commercial land use will be entered as a “D” soil group.

Note: You may also select at this time to work in area units of square kilometers, square miles, acres, or hectares.

D. Post-Developed Land use: See Figure A.6.3. Scroll down and enter the post-development land use, soil type, and area. In this scenario of a single large development, we will build– High Density Residential 1/8 acre lot – on all the residential land that is being developed. That is not required; a model can mix the land use types in post-development including leaving some of the land undeveloped. In fact the model will accommodate changes in soil type as well. In other words, the user can change the hydrologic condition from B to C for example, to mimic the compaction that may occur during construction of large developments. However, the final total **area** must be exactly the same as the pre-development area.

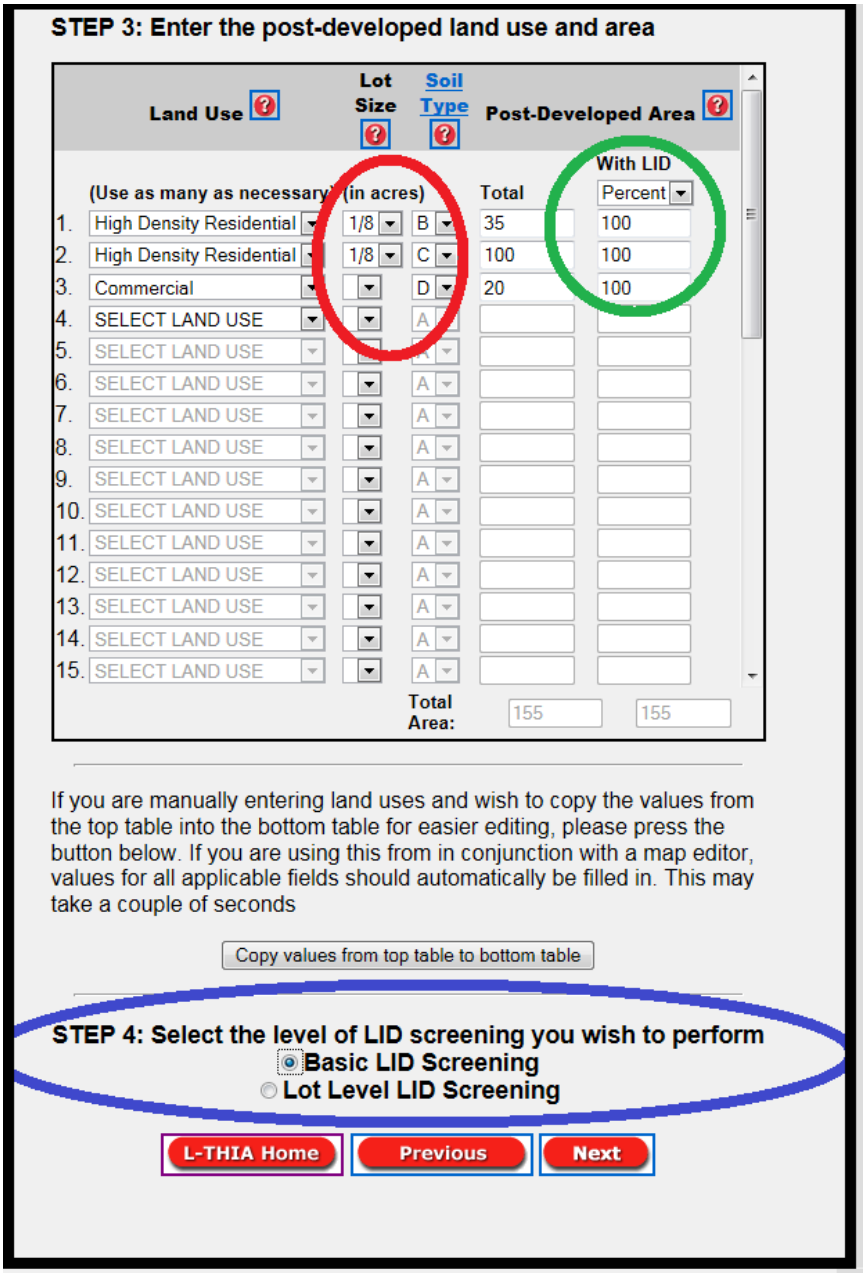

Figure A.6.3: Selecting post-development land use and soil and corresponding area with LID applied, and screening level.

In this example, we convert land from both landuse-soil pairs entirely to High Density Residential and add a third row of commercial land use, with a compacted soil changed to "D". This is a subset removed from the formerly "C" soil area. It is permissible to split a land use-soil pair. For example, if only ½ of the agricultural parcel on the C soil were to be built upon, then the second row in the table would be 60 acres of High Density Residential 1/8 acre soil C, and the third row would be 60 acres of agricultural soil C. The overall total acres after development **must match** the total acres of pre-developed land. The LID practices will be applied to a specified proportion of the area, or to a specified acreage, for each of the land use–soils combination. In this scenario, the user should select

Percent under “With LID” (**green circle** on Figure A.6.3) and enter 100, to describe what portion of the area will have LID practices applied.

For this scenario, enter 35 acres of high density residential, 1/8 acre lot size on B-type soil and then enter 100 acres of high density residential 1/8 acre lot size on C-type soil. Select the 1/8 acre lot size using the smaller drop-down menu (in **red circle** on Figure A.6.3). Enter 20 acres of commercial on type D soil.

E. Scroll down, check to see “Basic LID Screening” from the level of LID screening list (in the **blue circle** on Figure A.6.3) and click Next.

F. Note the impervious surface slider that appears for some land uses. See Figure A.6.4. When the screen opens, the slider is preset to 65% (the TR 55 default) for impervious % for high density residential land use. Try adjusting this to demonstrate how the sliders work. During this “Basic Screening” run you will model LID practices by sliding to a lower number, to represent the impact of adopting zoning or a national LID standard for percent impervious for example. Return the slider to 60 for residential and 75 for commercial (about a 10% reduction) for this scenario. Click Next. The L-THIA LID model will run for approximately 10 - 15 seconds before producing results.

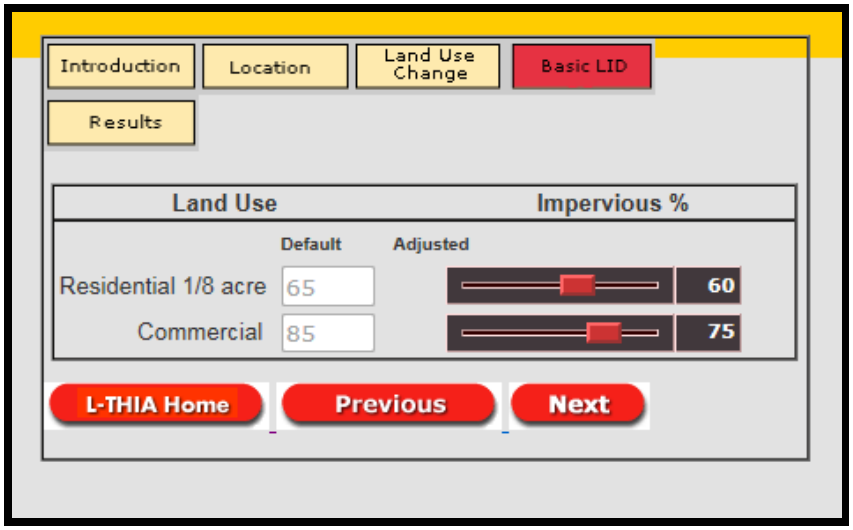

Figure A.6.4: Selecting the percentage of impervious surfaces.

G. Results: Take a moment to review the results table.

The “Summary of Scenarios” portion (see Figure A.6.5 below) of the table reports the area in acres per each land use in pre- and post- development scenarios. It reports the default and adjusted (after development) percentage impervious surface. It also reports a composite curve number for existing, post-developed, and post-developed with LID. The LID practices are applied as modifications of the curve number.

SUMMARY OF SCENARIOS View as: Select

State: Indiana

County: La Porte

Land Use	Hydrologic Soil Group	acres Pre-Developed	acres Post-Developed W/o LID	acres Post-Developed With LID As Proposed
Agricultural	B	35	-	-
Agricultural	C	120	-	-
Residential 1/8 acre	B	-	35	35
Residential 1/8 acre	C	-	100	100
Commercial	D	-	20	20

PERCENTAGE IMPERVIOUS

Land Use	Default	Adjusted
Residential 1/8 acre	65	60
Commercial	85	75

COMPOSITE CURVE NUMBER

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
80	90	88

Figure A.6.5: Summary of Scenarios from Results Table.

An additional group of sections in the results table include those displayed in Figure A.6.6 below. The top section in this figure is "Curve Number by Land use" which reports curve numbers for each land use. This includes the adjustments added by the LID practices. In this table the user will note (at the dark arrow) that 1/8 acre density residential land use on C soil has a CN of 90 but with some LID practices applied, it is adjusted to an effective CN of 88 which will reduce runoff and pollutant loads.

Curve Number by Landuse

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	B	75	75	-
Agricultural	C	82	82	-
Commercial	D	-	95	94
Residential 1/8 acre	B	-	85	83
Residential 1/8 acre	C	-	90	88

RUNOFF RESULTS

Avg. Annual Runoff Volume (acre-ft) View as: Select

Land Use	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	7.40	-	-
Agricultural	47.31		-
Commercial	-	28.08	25.41
Residential 1/8 acre	-	17.66	14.75
Residential 1/8 acre	-	82.91	68.22
Total Annual Volume (acre-ft)	54.71	128.66	108.39

Also view Annual Variation and Probability of Exceedence

Avg. Annual Runoff Depth (in) View as: Select

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
4.23	9.96	8.39

Figure A.6.6: Curve Number by Land use and Specific Runoff results.

The Runoff Results portion of the results table (See Figure A.6.6) displays the runoff volume (in acre-feet) and runoff depth in inches (e.g. 9.96 inches runoff per year over the whole area of 155 acres is expressed in acre-feet as 128.66 acre feet per year of runoff) for each land use-soil pair and shows the before and after impact of the LID processes. In this scenario, the model indicates that basic LID practices could reduce the 126.66 acre feet of runoff to 108.39 acre feet of runoff.

The final sections of the results table (see Figure A.6.7) are runoff values by specific land use listing and the Nonpoint Source Pollutants results. This listing includes the predicted results from 11 chemicals or metals, sediment, and 2 bacteria. The chemistry is reported by each land use and totaled for the analysis. This is the predicted annual load from a 30 year average runoff volume. This value is only from nonpoint sources, so if a user is trying to estimate a total load, then all known point sources must be added in as well.

Avg. Runoff Depth by Specific Landuse View as: Select

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	B	2.55	2.55	-
Agricultural	C	4.75	4.75	-
Commercial	D	-	16.92	15.31
Residential 1/8 acre	B	-	6.08	5.08
Residential 1/8 acre	C	-	9.99	8.22
Average Annual Rainfall Depth (in)				39.00

NONPOINT SOURCE POLLUTANT RESULTS

Nitrogen (lbs) View as: Select

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	88	-	-
Agricultural	567	-	
Commercial	-	102	92
Residential 1/8 acre	-	87	73
Residential 1/8 acre	-	411	338
Total	655	600	503

Also view Annual Variation and Probability of Exceedence

Phosphorous (lbs) View as: Select

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	26	-	-
Agricultural	167	-	-
Commercial	-	24	22
Residential 1/8 acre	-	27	22
Residential 1/8 acre	-	128	105
Total	193	179	149

Also view Annual Variation and Probability of Exceedence

Figure A.6.7: Nonpoint Source Pollutant Results portion of the table.

The entire table or values from specific rows can be copied and pasted into a spreadsheet for further analysis or tabulation. Notice the various entries for average annual runoff volume and depth.

Please notice the "Select" box, which allows you to focus on specific targets from the nonpoint source pollutant levels. Figure A.6.8 below, highlights one of the NPS results, the predicted Suspended Solids (lbs) (e.g. sediment) result. This calculation is based upon the volume of runoff and the type of land use it flows across, where the runoff is assumed to cover the entire watershed. In other words, remember that L-THIA LID is not a routing model and does not include slope or slope length in any fashion. This calculation is based upon specific constants for each land use (given in Appendix B1) and the volume of runoff predicted for the analysis area.

Suspended Solids (lbs)		View as: Select	
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	2159	-	-
Agricultural	13792	-	-
Commercial	-	4247	3843
Residential 1/8 acre	-	1973	1648
Residential 1/8 acre	-	9262	7621
Total	15951	15482	13112

Also view Annual Variation and Probability of Exceedence

Figure A.6.8: Suspended Solids portion of the table.
Table values on web page may be copy-pasted into Excel™.

The links at the bottom of the figure open a line graph (Figure A.6.9) of the Annual Variation for a specific NPS compound and a line graph (Figure A.6.10) of Percent of exceedence. In the Annual Variation figure, the predicted load (vertical scale is pounds of N) of Nitrogen is displayed against 30 years of average annual rainfall (the horizontal scale).

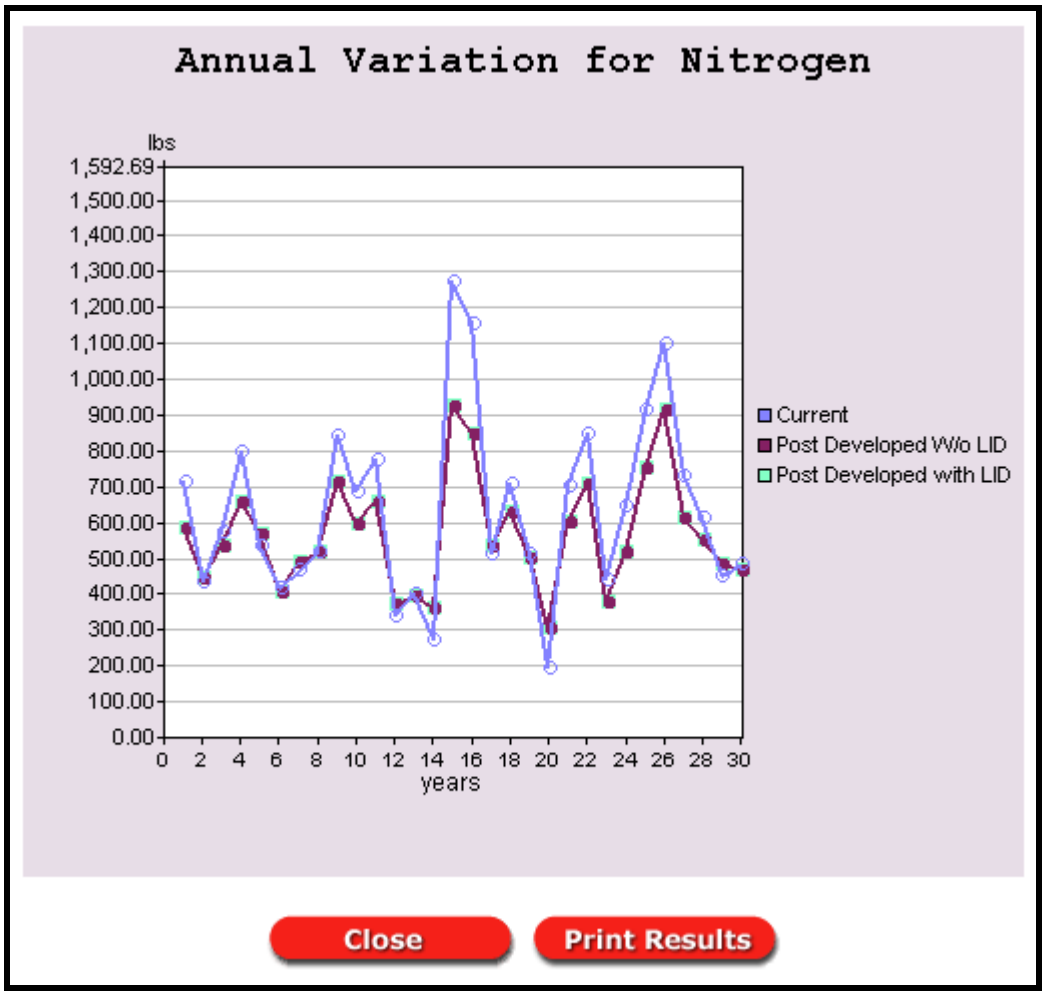

Figure A.6.9: Graph of Annual Variation for NPS contaminant.

The percent of exceedence graph plots 30 points (each representing annual totals) against the estimated percentage of years in which the load will exceed the total at the point. This display is intended to allow watershed managers, for example, to be able to estimate what percent of the time the annual load will exceed a particular value, which is an estimated annual load. In figure A.6.10, the graph indicates that a 6,000 pound target (blue arrow) will be exceeded in about 65% (red arrow) of years.

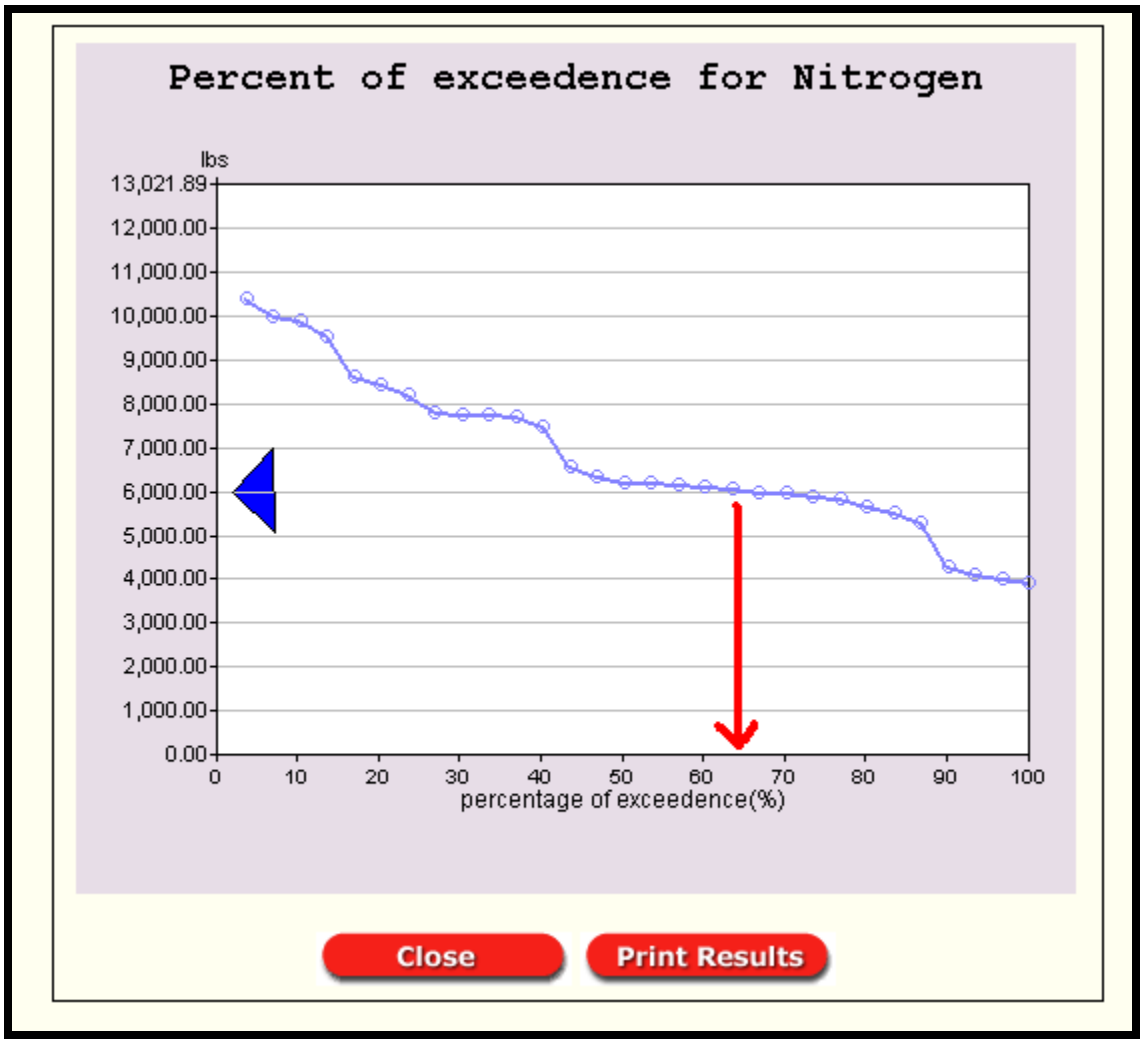

Figure A.6.10: Percent of Exceedence for NPS contaminant.

The next set of steps in the tutorial will use "lot-level screening" to examine the reductions in more detail. The goal of that approach is to determine LID practices that will either offer more reduction or offer the best "bang-for-the-buck."

H. Examine the effect of impervious surface: One useful approach with L-THIA LID is to determine a target % impervious to maintain pre-development hydrology. For example, what maximum % impervious surface would be allowed if we want to add this amount of high density housing but want to maintain something close to the pre-development hydrology? The user could experiment with different values while doing several model runs.

Click the link at the bottom of the results page that says "return to spreadsheet" and reenter your model inputs (repeat steps C, D, and E) and follow the instructions below.

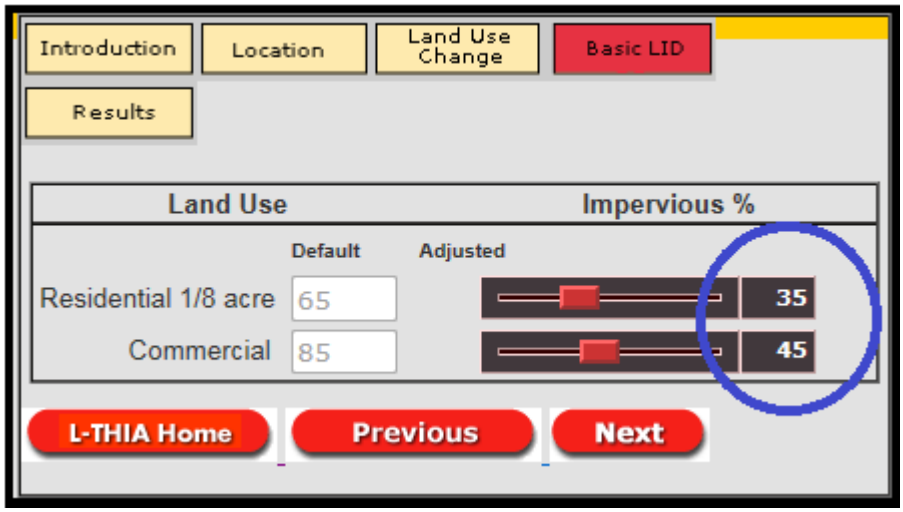

Figure A.6.11: Impervious % slider.

Adjust the Residential impervious surface slider (Figure A.6.11) to about half the starting impervious surface, around 33- 35%, and adjust the commercial slider to 45%. Click next and continue to results page. This time the runoff from the 1/8 acre lots and the commercial area will be around 59.72 acre feet, very close to the original pre-development hydrology which had a predicted average annual runoff of 54.71 acre feet. This indicates that *if* the planned development could incorporate an effective 50% design reduction in its impervious surfaces, the whole development could occur while maintaining the original hydrology, in terms of volume. The reduction in runoff volume is directly related to reduction in sediment transported, because the model assumes that the more runoff that is generated in an area, the higher the entrained sediment load and the higher the other NPS chemistry load. Simply put, lowering the runoff through LID practices will lower the predicted sediment and NPS chemistry in the resulting runoff, as compared to a similar development without LID, which would have much more runoff traveling across the various land uses.

I. **Lot–Level Screening:** This portion of the model will allow the user to test the implementation of specific practices – like rain barrels or including porous pavement for roads or parking. Where local cost estimates exist for these practices, the predicted runoff and pollutant reductions can be compared to the installation costs of the practices.

The lot-level practices that are available will vary depending on the land use selected for the model. For example, high density residential land use in the model will trigger the list to include specific practices and options for:

Streets / Roads
Buildings / Roofs
Sidewalks
Parking / Driveway
Open Space / Lawn
Natural Resource Conservation (Rain Garden)

Each of these options has a specific set of variables that impact the curve number assigned to the land use, and hence the runoff. For more information on exactly what constitutes a practice like "porous pavement," the user can consult web resources such as the Low Impact Development Center at [http://www.lid-stormwater.net/index.html].

The next scenario will step through the LID practice options one at a time to compare their relative benefits. Now, again follow the link at the bottom of the results page that says "return to spreadsheet" and reenter your model inputs (steps C, D, and E) or begin again at Step A if you have closed your web browser.

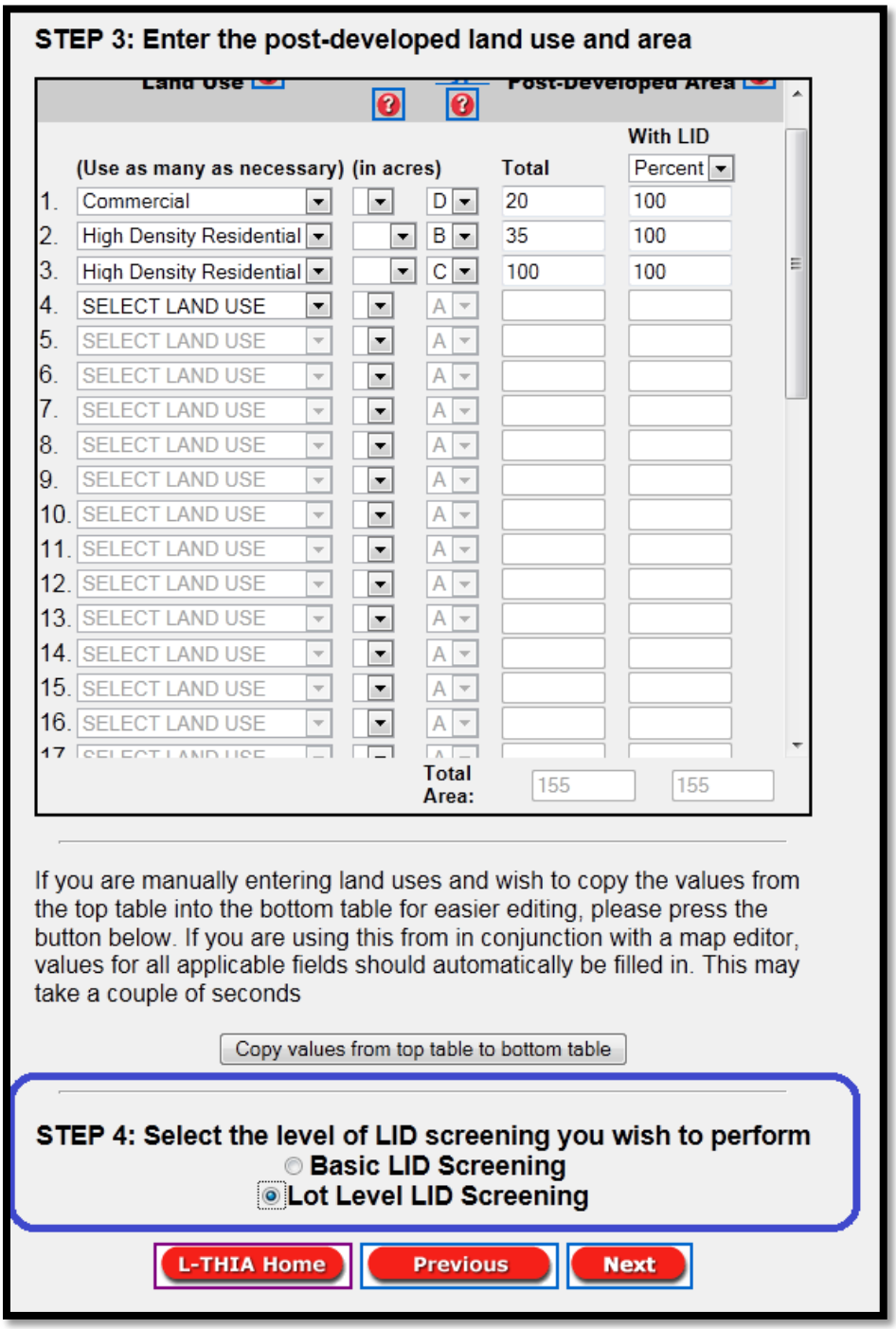

Figure A.6.12: Selection of Lot Level LID Screening.

This time, after step E, select "**Lot Level LID Screening**" from the dropdown list (in the red circle on Figure A.6.12). Remember to select 1/8 acre for Lot Size again for the post-development scenario, and add the commercial land use. Click Next.

J. **Specific Practices:** In the modeling process, the user will look through the lot level LID page to see which LID practices are available. For example, “agricultural” has no LID practices and will not appear here, but low density residential will, and so will industrial and commercial; but they will have different LID practice options.

You may expand the menus by clicking on items with a plus sign. LID practices are grouped by whether that practice is associated with the streets/roads, buildings/roofs, sidewalks, parking/driveways, open space/lawn, or natural resource conservation. To edit the LID practices on different land use types, click on the red tabs above the picture of the lot (this scenario only has two). See Figure A.6.13 below.

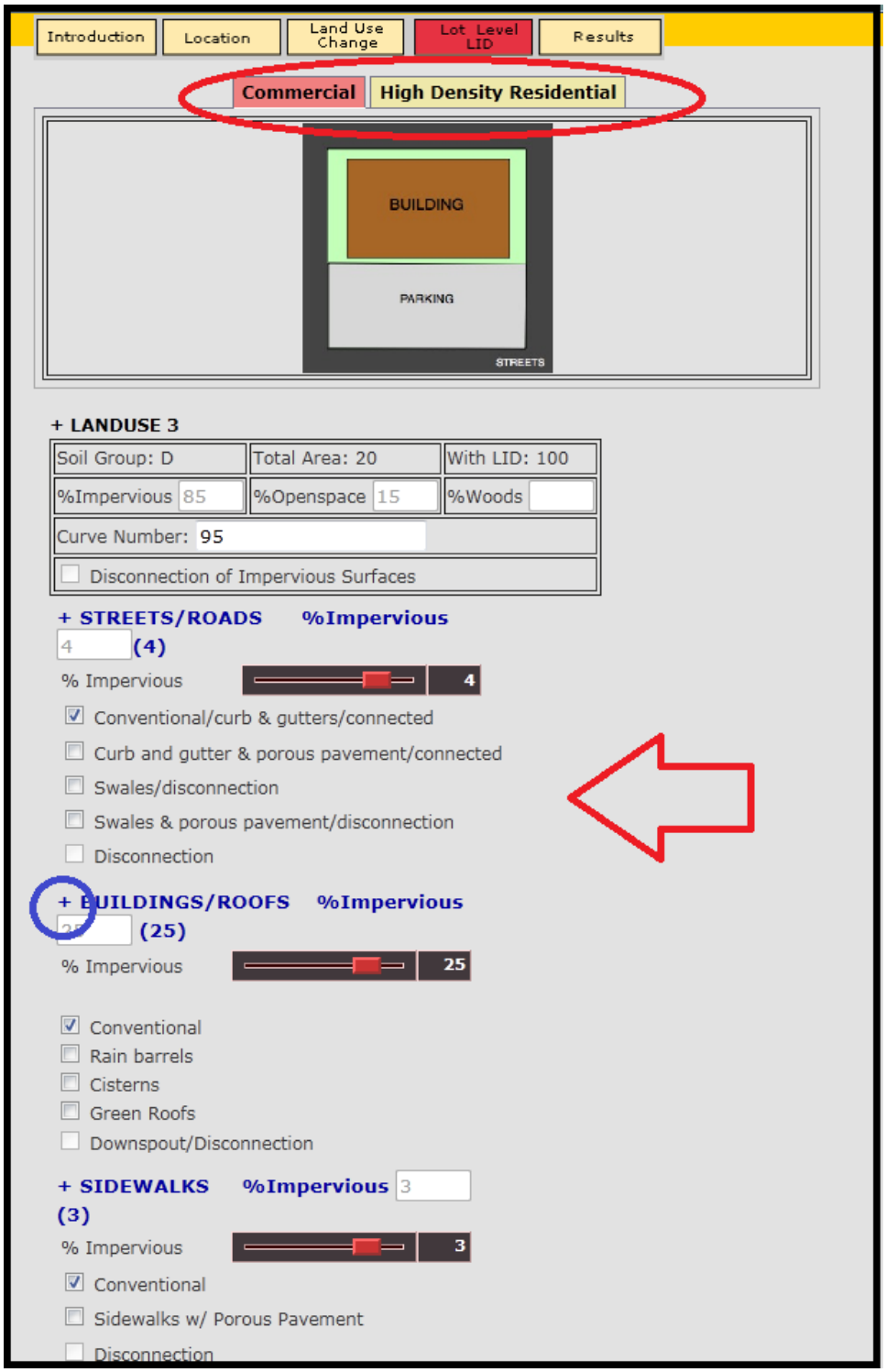

Figure A.6.13: Lot level LID screening menu.

K. **Click the "+" for Buildings / Roofs** to open the menu that includes rain barrels. The model assumes they will be placed on all buildings for this land use.

Repeat the process for the second land use (the other soil group.) Click Next.

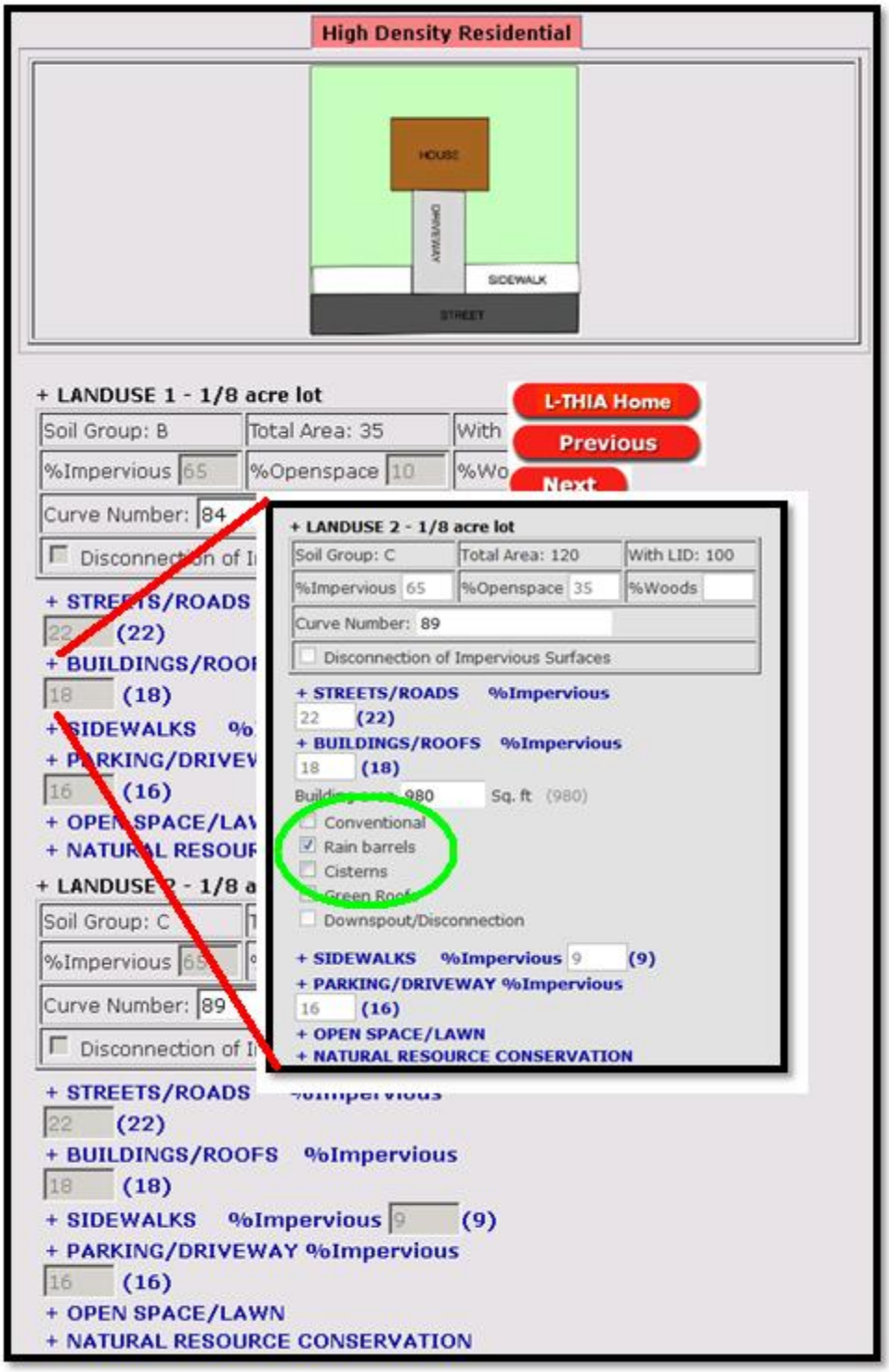

Figure A.6.14: Expand the + and check the box to select rain barrels.

L. **Basic Screening Results:** Look over the results table and notice the difference in runoff volume between the current scenario, post-developed scenario without LID, and post-developed scenario with LID as proposed. See Figure A.6.15.

RUNOFF RESULTS

Avg. Annual Runoff Volume (acre-ft) View as: Select

Land Use	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	7.40	-	-
Agricultural	47.31	-	-
Commercial	-	28.08	25.41
Residential 1/8 acre	-	17.66	16.47
Residential 1/8 acre	-	82.91	73.70
Total Annual Volume (acre -ft)	54.71	128.66	115.58

Also view Annual Variation and Probability of Exceedence

Avg. Annual Runoff Depth (in) View as: Select

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
4.23	9.96	8.94

Avg. Runoff Depth by Specific Landuse View as: Select

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Agricultural	B	2.55	2.55	-
Agricultural	C	4.75	4.75	-
Commercial	D	-	16.92	15.31
Residential 1/8 acre	B	-	6.08	5.67
Residential 1/8 acre	C	-	9.99	8.88

Average Annual Rainfall Depth (in) 39.00

Figure A.6.15: Portion of the Results table.

M. Detailed Analysis: Most analyses combine several LID practices, but by returning to Step A and repeating the instructions in this guide, the user could run the model several times and each time evaluate a single LID practice. By compiling the results of several runs, the user can create a table that compares the alternatives by their effectiveness in reducing runoff and NPS pollutants including sediment (TSS in the model). This has been done for the tutorial data in Table A.6.1 below.

Table A.6.1: Average annual runoff volume from the tutorial model for various standard LID practices. These practices, defined in Appendix B3, are modeled using this tutorial data for the L-THIA LID model. To produce this table, the scenario was entered six times, and one practice was chosen for both landuses each time. See Appendix B2 for the Curve Number assumptions used in the model for these practices. See Appendix B3 for design details. See below in this section for a compilation of range of costs for these practices.

LID Scenario	**Avg. Annual Runoff Volume (acre-ft)**
Pre-Development (existing hydrology)	57.69
Post-Development without LID	128.75
LID Options	
Post-Development with Green Roof	95.98
Post-Development with Rain Barrels	116.24
Post-Development with Bioretention	95.73
Post-Development with Porous Parking(Med.)	**80.28**
Post-Development with Roads with Swales / disc.	110.11
Post-Development with Nature Conservation Area	118.26

In this comparison, the single practice that has the largest impact on average annual runoff volume reduction is Porous Parking, although we project that Bioretention and Natural Resource Conservation areas will be similar in effect. This table used the standard impervious surface assumptions, but the % impervious sliders could be employed to create more options. Typically, a user would then compare typical LID installation costs against effectiveness.

N. Projected Costs of LID Practices: It is difficult to project the cost of LID practices unless detailed specifications are provided in terms of how the practice is implemented in a particular situation. For example, the cost of a "green roof" practice is obviously dependent upon the size of the roof covered, but many other design specifications are highly involved.

Some averages have been compiled for the sake of this tutorial and are listed in Table A.6.3 LID Practices Cost Range, but the user is advised to read associated material that treat the subject more fully.

The data in Table A.6.3 displays the price range of each practice compiled from sources published in 2007–2009. The resulting minimum and maximum values of cost (columns C and D) are based on typical sizing of each practice from design specifications, such as those given in Appendix B. LID design specifications are subject to local ordinances and will vary considerably, so be advised.

These cost estimates are from three cost calculators listed below in Table A.6.2.

Table A.6.2: LID Cost Calculators

LID Practice Cost Calculator	Organization
NATIONAL GREEN VALUES™ CALCULATOR METHODOLOGY	The Center for Neighborhood Technology (CNT). 2009.
LIDMM Low Impact Development Manual for Michigan (2008)	Available at: http://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf
Stormwater BMP Costs (2007)	North Carolina Department of Environment and Natural Resources. Division of Soil & Water Conservation Community Conservation Assistance Program

The table of LID Practices Cost ranges can be used for broad estimates of the cost of different practices. For example the cost of "Green Roof" is listed in Table 3.3 as a range of $ 8.50 to $ 48.5 per square foot. A mid-range number then might be $ 29.00 per square foot. The user may notice when applying this practice during a model run, as instructed in Step I (see Figure A.6.8) that the L-THIA LID model assumes 980 square feet of roof per lot in the 1/8 acre high-density residential land use category. The per unit treatment then could be estimated by multiplying the 980 square foot area times the cost.

"Typical" Green Roof = 980 ft^2 * $29.00 /$ft^2$= $28,420 per unit

The user can multiply this times the "8 lots per acre" in that category to obtain a "ball-park" cost for an acre of the "Green Roof" LID practice as

980 ft^2 /lot * 8 lots/acre * $29.00 / ft^2 = $227,360 per acre treated this way.

Table A.6.3: LID Practices Cost Range (2008-2009)		Default Range	
Practice	Price Range	Low	High
Green roof	$4.25 - 24.25/ SF $100 - 380 per barrel, $0.72-6.76	$ 8.50	$ 48.50
Rain Barrel/Cistern	per gallon cistern	$ 40.18	$ 377.21
Swales	$0.60 - 20.00/ SF	$ 499.47	$ 16,649.11
Porous Pavement	$1.48 - 12.00 / SF	-	-
Swale and Porous Pavement	$2.08 - 32.00/ SF	$ 499.47	$ 16,649.11
Permeable Patio	$0.60 - 20.00/ SF	-	-
Open Wooded Space	$2.40 - 6.50/ SF or $1800 - 2600/ acre	-	-
Bioretention	$3.48 - 47.62/SF	$ 0.87	$ 11.91

APPENDCIES B1-B4

Supplementary Documentation

Appendix B1: L-THIA LID Assumptions

Assumptions used in L-THIA LID about percent impervious for various conditions.

Land use or feature	Area or Length (if used) Sq Feet	Percent Impervious surface
Building/ Roof 2 acre lot	3920	4.5
Building/ Roof 1 acre lot	3049	7
Building/ Roof 1/2 acre lot	1960	9
Building/ Roof 1/4 acre lot	1307	12
Building/ Roof 1/8 acre lot	980	18
Commercial Building portion		25
Industrial Building portion		22
Roads 2 acre lot	Area = 5663 Length = 217.8	6.5
Roads 1 acre lot	Area = 4356 Length = 167.5	10
Roads 1/2 acre lot	Area = 2178 Length = 83.8	10
Roads 1/4 acre lot	Area = 1525 Length = 58.6	14
Roads 1/8 acre lot	Area = 1198 Length = 46.1	22
Commercial (roads portion)		4
Industrial roads (roads portion)		4
Sidewalks 2 acre lot area	Area = 0 Length = 0	0
Sidewalks 1 acre lot area	Area = 436 Length 109=	1
Sidewalks 1/2 acre lot area	Area = 436 Length =109	2
Sidewalks 1/4 acre lot area	Area = 436 Length =109	4
Sidewalks 1/8 acre lot area	Area = 490 Length =123	9
Commercial (sidewalk portion)		4

Industrial roads (sidewalk portion)		4
Driveway 2 acre area	871	1
Driveway 1 acre lot area	871	2
Driveway 1/2 acre lot area	871	4
Driveway 1/4 acre lot area	871	8
Driveway 1/8 acre lot area	871	16
Commercial (Driveway portion)		53
Industrial roads (Driveway portion)		43
TR 55 General for 2 acre area	Whole area	12
TR 55 General for 1 acre lot area	Whole area	20
TR 55 General for 1/2 acre lot area	Whole area	25
TR 55 General for 1/4 acre lot area	Whole area	38
TR 55 General for 1/8 acre lot area	Whole area	65
TR 55 General for Commercial	Whole area	85
TR 55 General for Industrial	Whole area	72

L-THIA LID Event Mean Concentration Values						
	EMC as Pounds per ac-ft of runoff for given land use					
L-THIA LID NPS Outputs:	Commercial	Industrial	Residential	Grass - Pasture	Agricultural	Forest
Nitrogen	3.6508	3.4323	4.9577	1.8825	11.9866	1.8933
Phosphorous	0.8714	0.7628	1.5528	0.0251	3.5416	0.0272
Suspended solids	151.2172	164.8411	111.7097	2.7108	291.5354	2.6678
Lead	0.0353	0.0407	0.0237	0.0136	0.0028	0.0136
Copper	0.0391	0.0407	0.0237	0.0251	0.0028	0.0272
Zinc	0.4900	0.6667	0.2178	0.0163	0.0420	0.0163
Cadmium	0.0022	0.0046	0.0012	0.0027	0.0027	0.0027
Chromium	0.0270	0.0185	0.0047	0.0204	0.0252	0.0204
Nickel	0.0320	0.0222	0.0272	0.0000	0.0000	0.0000
BOD (Biological Oxygen Demand)	62.67	38.14	69.48	1.36	10.90	1.29
COD (Chemical Oxygen Demand)	316.06	123.97	134.87	0.00	0.00	0.00
Oil and Grease	24.52	8.17	4.63	0.00	0.00	0.00
	EMC as Million CFU per ac-ft of runoff for given land use					
Fecal Coliform	85	120	248	2	322	2
Fecal Strep	223	76	694	0	0	0

L-THIA LID Event Mean Concentration Values - Metric Units						
	EMC as mg/L of runoff for given land use					
L-THIA LID NPS Outputs:	Commercial	Industrial	Residential	Grass - Pasture	Agricultural	Forest
Nitrogen	1.34	1.26	1.82	0.7	4.4	0.7
Phosphorous	0.32	.28	.57	.01	1.3	.01
Suspended solids	55.5	60.5	41	1	107	1
Lead	.013	.015	.009	.005	.0015	.005
Copper	.0145	.015	.009	.01	.0015	.01
Zinc	.18	.245	.08	.006	.016	.006
Cadmium	.00096	.002	.00075	.001	.0001	.001
Chromium	.01	.007	.0021	.0075	.01	.0075
Nickel	.0118	.0083	.01	0	0	0
BOD (Biological Oxygen Demand)	23	14	25.5	0.5	4	.5
COD (Chemical Oxygen Demand)	116	45.5	49.5	0	0	0
Oil and Grease	9	3	1.7	0	0	0
	EMC as Million CFU per L of runoff for given land use					
Fecal Coliform	6900	9700	20000	200	26000	200
Fecal Strep	18000	6100	56000	0	0	0

Appendix B2: TR 55 and L-THIA LID Curve Numbers

Land Use Description on Input Screen	Description and Curve Numbers from TR-55					
	Cover Description		Curve Number for Hydrologic Soil Group			
	Cover Type and Hydrologic Condition	% Impervious Areas	A	B	C	D
TR – 55 Curve Numbers						
Agricultural	Row Crops - Straight Rows + Crop Residue Cover- Good Condition(1)	0	64	75	82	85
Commercial	Urban Districts: Commercial and Business	85	89	92	94	95
Forest	Woods(2) - Good Condition	0	30	55	70	77
Grass/Pasture	Pasture, Grassland, or Range(3) - Good Condition	0	39	61	74	80
High Density Residential	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Industrial	Urban district: Industrial	72	81	88	91	93
Low Density Residential	Residential districts by average lot size: 1/2 acre lot	25	54	70	80	85
Open Spaces	Open Space (lawns, parks, golf courses, cemeteries, etc.)(4) Fair Condition (grass cover 50% to	0	49	69	79	84

Parking and Paved Spaces	Impervious areas: Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	100	98	98	98	98
Residential 1/8 acre	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Residential 1/4 acre	Residential districts by average lot size: 1/4 acre	38	61	75	83	87
Residential 1/3 acre	Residential districts by average lot size: 1/3 acre	30	57	72	81	86
Residential 1/2 acre	Residential districts by average lot size: 1/2 acre	25	54	70	80	85
Residential 1 acre	Residential districts by average lot size: 1 acre	20	51	68	79	84
Residential 2 acres	Residential districts by average lot size: 2 acre	12	46	65	77	82
Water/ Wetlands		0	0	0	0	0

L-THIA LID Modified Curve Numbers				
Cover Description	**Curve Number for Hydrologic Soil Group**			
Cover Type and Hydrologic Condition	A	B	C	D
parking with porous pavement - good	61	75	83	87
parking with porous pavement - fair	46	65	77	82
parking with porous pavement – poor	46	65	67	72

Street curbs with porous pavement	70	80	85	87
Street swales	76	85	89	97
Street Swales and porous pavement	61	75	83	87
driveway with porous pavement	70	80	85	87
Sidewalks with porous pavement	70	80	85	87
Rain Barrels	94	94	94	94
Cistern	85	85	85	85
Green Roof	86	86	86	86
Bioretention	35	51	63	70
Agricultural land	64	75	82	85
Open space - good	30	55	70	77
Open space - fair	49	69	79	84
Open space -poor	68	79	86	89
Woods space - good	30	55	70	77
Woods space - fair	36	60	73	79
Woods space -poor	45	66	77	83

Appendix B3: Design specifications of common LID practices.

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The following is a compilation of design guidance for LID practices and a summary of maintenance processes for those practices.

B3.1.1 Design of Bioretention Facilities

There are several sources for design guidance as listed below.

B3.1.2 Governing Equations (LIDMM, 2008; Briglio and Novotney, unpublished)

With an underdrain: $A_f = \dfrac{Q_v \times d_f}{\left[k \times (h_f + d_f) \times t_f\right]}$

Without an underdrain: $A_f = \dfrac{Q_v \times d_f}{\left[i \times (h_f + d_f) \times t_f\right]}$

where:
A_f = surface area of filter bed (ft^2)
Q_v = required storage volume (ft^3). The 95th percentile event.
d_f = filter bed depth (ft)
k = coefficient of permeability of filter media (ft. day^{-1})
i = infiltration rate of underlying soils (ft. day^{-1})
h_f = average height of water above filter bed (ft)
t_f = design filter bed drain time (days). 48 hours is recommended.

B3.1.3 System Maintenance (visit the references mentioned below for more information on maintenance.)

Bioretention maintenance can be easily incorporated, with some small modifications into the routine landscaping maintenance.

- Weed removal from established vegetation, preferably by hand.
- Frequent inspection for accumulation of sediment or organic matter and removal of organic materials twice by year, preferably by hand.
- Irrigation during the first season to help vegetation establishment.
- Removal of debris, mulch, and other materials that may block inlets and outlets as needed and after large rainfall events.
- Trimming, removal or replacement of vegetation to maintain healthy plant growth.
- Removal of sediment buildup and erosion from bioretention area, preferably when sediment buildup reaches 25% of the ponding depth.

B3.2.1 Design of Porous Pavement

The storage volume in the underlying bed could be determined given a specific depth of media and a percent void space. In addition, if designed as such, the area underlying porous pavement may then allow infiltration.

B3.2.2 Governing Equations (LIDMM, 2008):

$$Vs = D \times A \times Sv$$

$$V_I = A_{bb} \times i \times t \times \frac{1}{12}$$

$$V_T = Vs + V_I$$

where:
V_s = storage volume (cft)
D = depth of the water stored during a storm event (ft)
A = practice area (sft)
Sv = void space (%)
V_I = infiltration volume (cft)
A_{bb} = bed bottom area (sft)
i = infiltration rate (in/hr)
t = infiltration period (hr) when bed is receiving runoff and capable of infiltration at the design rate (Not to exceed 72 hrs).
V_T = total volume.

B3.2.3 System Maintenance (visit the references mentioned below for more information on maintenance)

- Monthly inspections for cracks and clogging.
- Street sweep pavement one to four times annually.
- Although sealing should never be used, potholes or large cracks may be serviced with patching mixes. Holes may then be drilled with a 0.5” holes to restore porosity.
- Inspection and removal of debris and other materials from inlet structures twice a year.
- Maintenance of soil structure and adjacent areas to prevent erosion and clogging.
- Plowing over porous pavement is fine, but it may be necessary to slightly raise the blade height.

B3.3.1 Design of Green Roof

The storage volume in the soil bed could be determined given a specific depth of media and a percent void space. There is no other retention due to infiltration.

B3.3.2 Governing Equation (LIDMM, 2008)

$$Vs = D \times A \times Sv$$

All variables are defined as same as in porous pavement sizing.

B3.3.3 System maintenance (visit the references mentioned below for more information on maintenance)

- Irrigation and removal of weeds as necessary during first year and time of drought to promote healthy plant growth.
- Frequent drain inspection to remove accumulated debris.
- Frequent inspection of building for structural concerns and leakage.
- Annual inspection of the layers underlying the growth media.

B3.4.1 Design of Swales

Swales are not storage practices unless check dams are used (figure below). Swales are generally utilized to convey runoff at reduced velocity (for erosion control), promoting thus infiltration, and treat runoff for quarter quality improvement.

B3.4.2 Governing Equation (LIDMM, 2008)

The following equation is used to determine the total flow capacity of the channel as:

$$Q = VA = \frac{1.49}{n}\left(\frac{A}{WP}\right)^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

where:

Q = flow (cfs)
V = velocity (ft/s)
A = area (ft^2)
n = Manning's Roughness Coefficient
WP = wetted perimeter (ft)
S = slope (ft/ft)

If check dams (see Figure 7.1) are employed, the storage behind each dam is calculated as:

$$Vs = \frac{1}{2} L \times D \times \left(\frac{W + W_B}{2}\right)$$

where:

Vs = storage volume (cft)
L = length of swale impoundment area per check dam (ft)
D = depth of check dam (ft)
Ss = swale bottom slope (ft/ft)
W = top width of check dam (ft)
W_B = bottom width of check dam (ft)
$Z_{1\&2}$ = ratio of horizontal to vertical change in swale side slope (ft/ft)

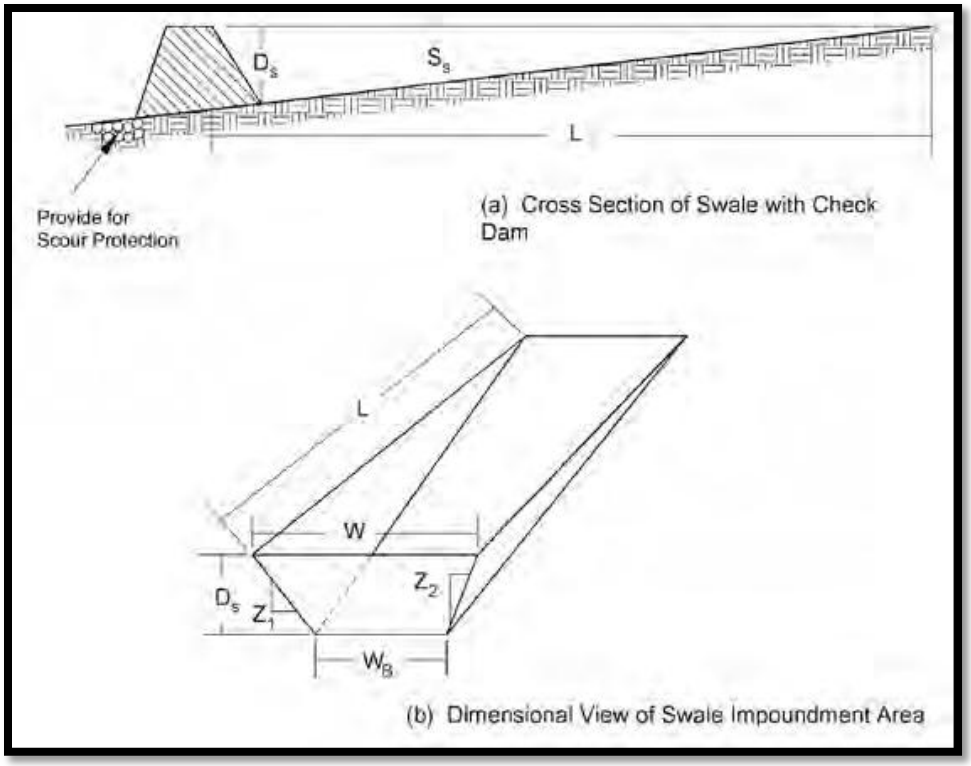

Figure B.3.1 showing the profile of a swale (from LIDMM, 2008.)

B3.4.3 System Maintenance (visit the references mentioned below for more information on maintenance)

Swales can be easily incorporated into the routine landscaping maintenance. Swale maintenance practices are similar to bioretention maintenance.

- Irrigation and weeding during the first year to allow plants to establish.
- Monthly inspection for erosion and removal of debris.
- Repair rills and other eroded areas with compacted soil anchored with mesh, seed and mulch.
- Mowing of grass no shorter than six inches.
- Avoid compaction by reducing use of heavy equipment while mowing or performing other maintenance.
- Frequent (monthly) removal of obstruction from inlets and outlets
- Annually check of the overall grade of the structure.

B3.5.1 Sizing of Cistern

Sizing the tank is a mathematical exercise that balances the available collection (roof) area, annual rainfall, intended use of rainwater and cost.

B3.5.2 Governing Equation (LIDMM, 2008)

$$V = 0.62 \times C \times P \times A$$

where:

V = available volume for capture (gallons)

0.62 = unit conversion (gal/in./sft)

C = volumetric runoff coefficient (unitless), typically 0.9 to 0.95 for impervious areas

P = precipitation amount (in)

A = drainage area to cistern (sft)

B3.5.3 System Maintenance (visit the references mentioned below for more information on maintenance)

- Monitor drainage area (rooftop) for high loading of contaminants and debris and address as necessary.
- Inspect four times per year. Remove any debris clogging downspouts, inlets, and replace warn spigots, screens, and other fixtures as necessary.
- Drain prior to winter to prevent freezing and to flush out any accumulated sediment.
- Clean and disinfect tanks.

B3.6.1 A Sizing of Open Wooded Space

Open wooded space is a conservation approach to preserve existing forest/meadow or replanting tress.

B3.6.2 Governing Equation:

$$Size_{LID\ practice} = Cs \times AIS$$

where:
Cs = sizing factor (use 0.15)
AIS = area of impervious surfaces at the site to be treated.
Example: for the open wooded space to be effective, its area should be 15% of the area of the contributing impervious surface.

B3.6.3 System Maintenance (visit the references mentioned below for more information on maintenance)

- Typical landscaping and forest management practices are used to maintain open wooded space.
- In some areas revegetation, irrigation and weed control may be necessary for the first two years.
- Modest rate of plant failure (10-20%) is expected and plants should be replaced when necessary.
- Frequent inspection to remove invasive plant species.
- Avoid using heavy equipment that would cause soil compaction.

Appendix B3 References

Atchison D, Potter K, Severson L (2006) Design guidelines for stormwater bioretention facilities. University of Wisconsin-Madison Water Resources Institute. Publication No. WIS-WRI-06-01.

Briglio, D and Novotney, M. unpublished personal communication. Clean Water Services. 2009. Low Impact Development Approaches Handbook. Washington County, Oregon.

LIDMM (Low Impact Development Manual for Michigan). 2008. Available at: http://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf. Accessed April 12, 2011.

New York State Stormwater Management Design Manual. 2010. Green Infrastructure Practices (Chapter 5). New York.

U.S. Army Corps of Engineers. 2008. Low impact development for sustainable installations: stormwater design and planning guidance for development within army training areas. Public Works Technical Bulletin 200-1-62.

Appendix B4: Literature Review and Case Study References for L-THIA and L-THIA LID.

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.