# L-THIA LID Tutorials

## 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.

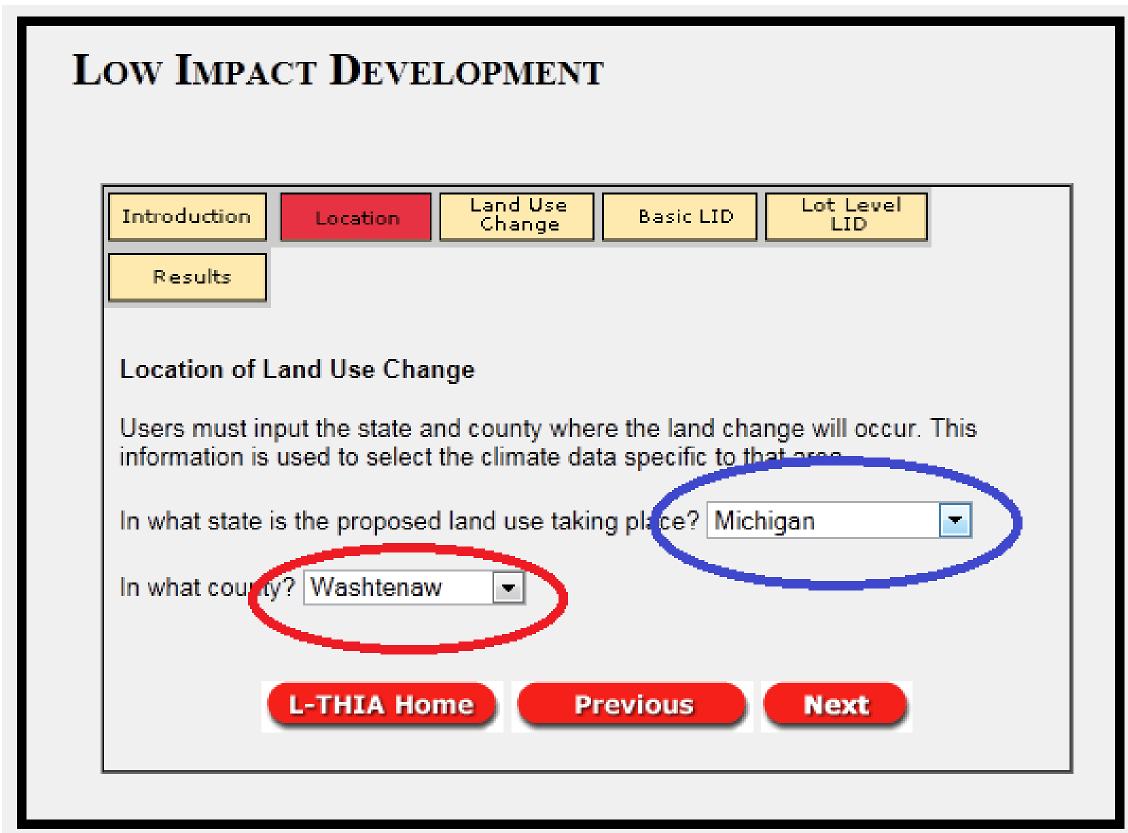



**Figure A.4.1: Selecting state and county.**

**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.

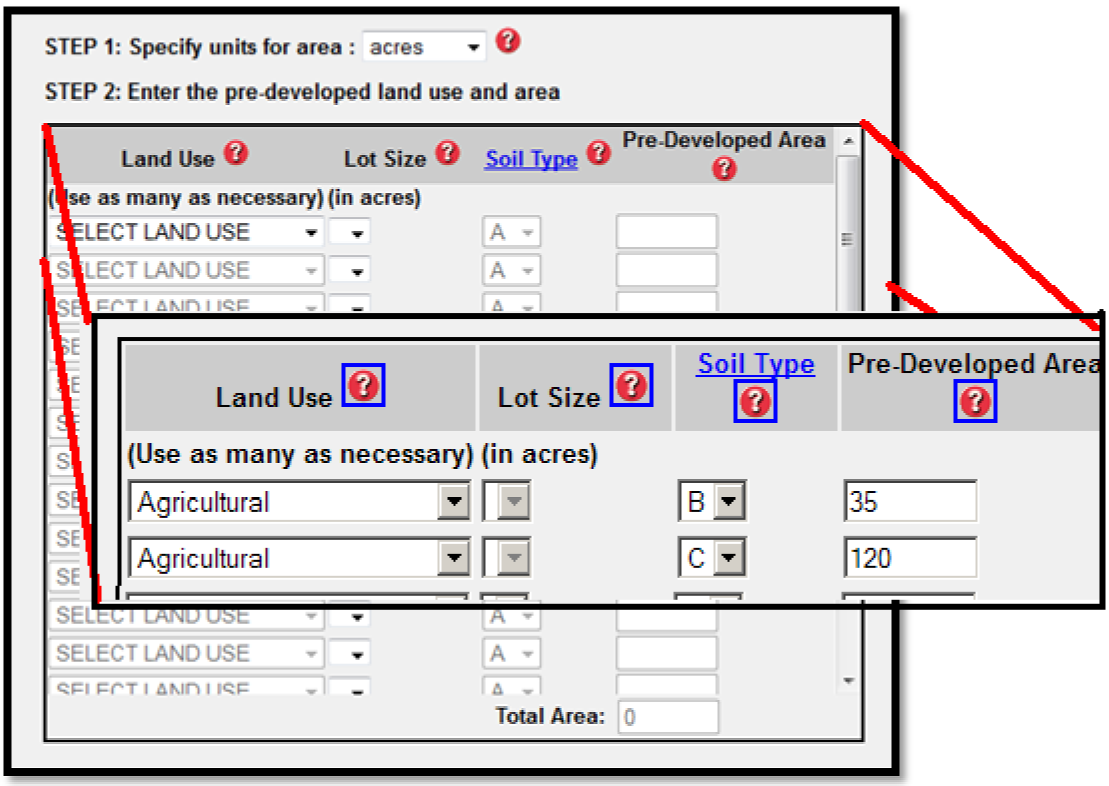



**Figure A.4.2: Selecting pre-developed (existing) land use and soil and corresponding area.**

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.

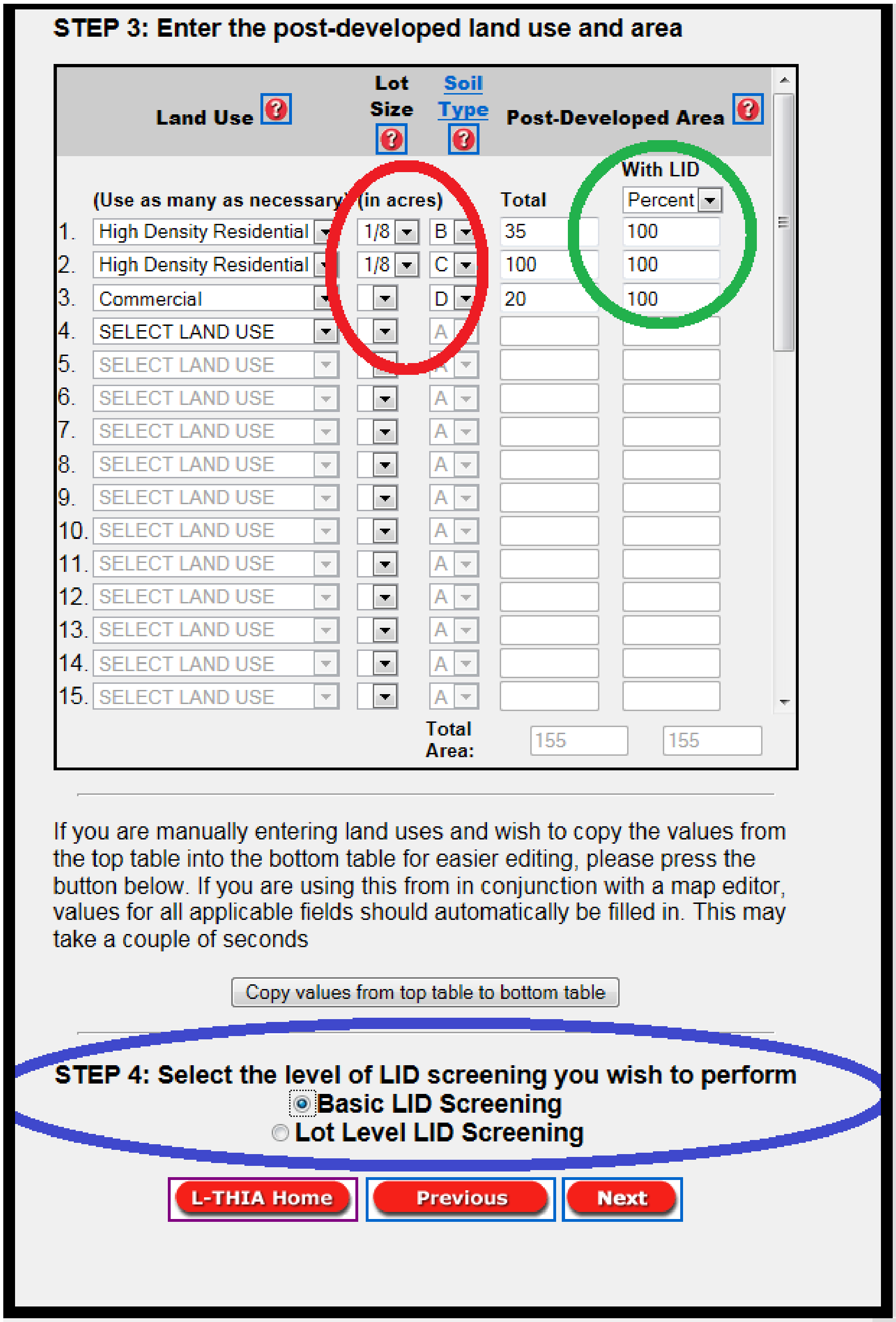



**Figure A.4.3: Selecting post-development land use and soil and corresponding area with LID applied, and screening level.**

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.

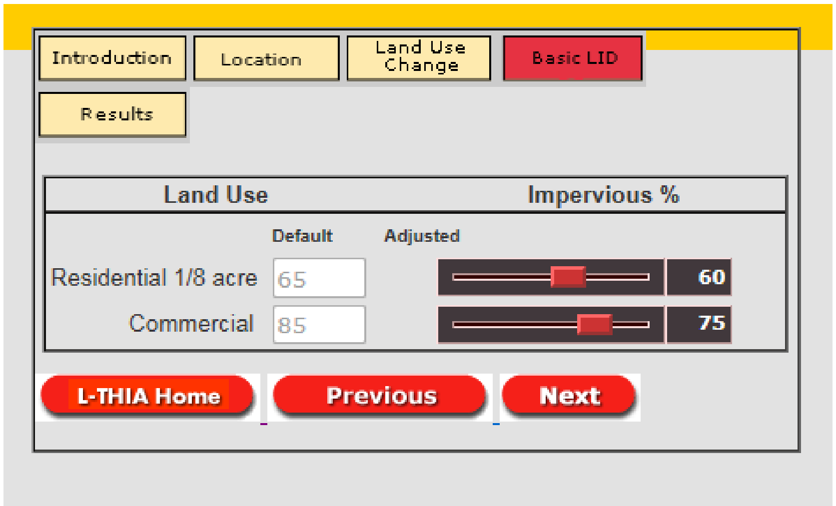



**Figure A.4.4: Selecting the percentage of impervious surfaces.**

**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**

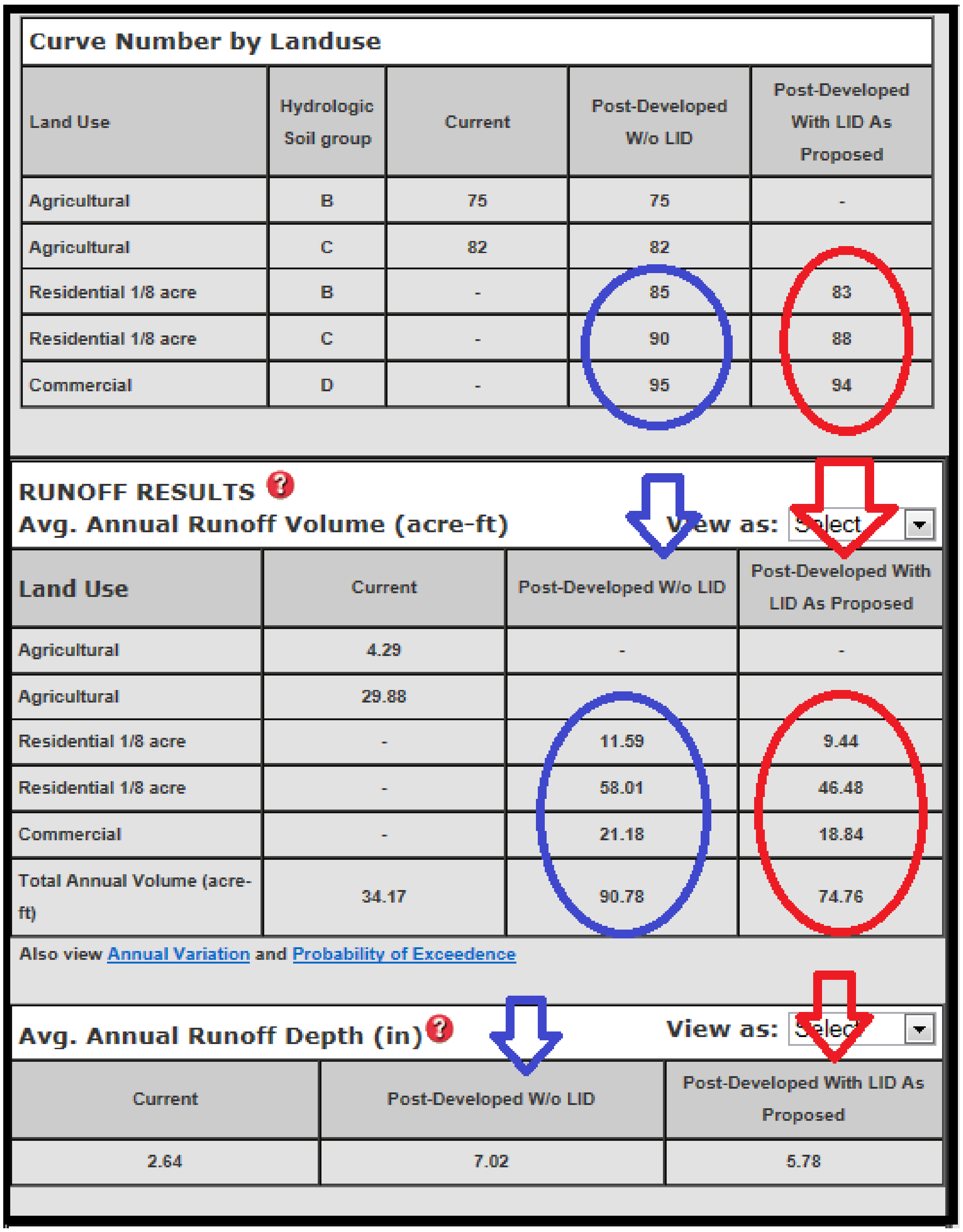
| Land Use | Default | Adjusted |
|---|---|---|
| Residential 1/8 acre | 65 | 60 |
| Commercial | 85 | 75 |

**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).

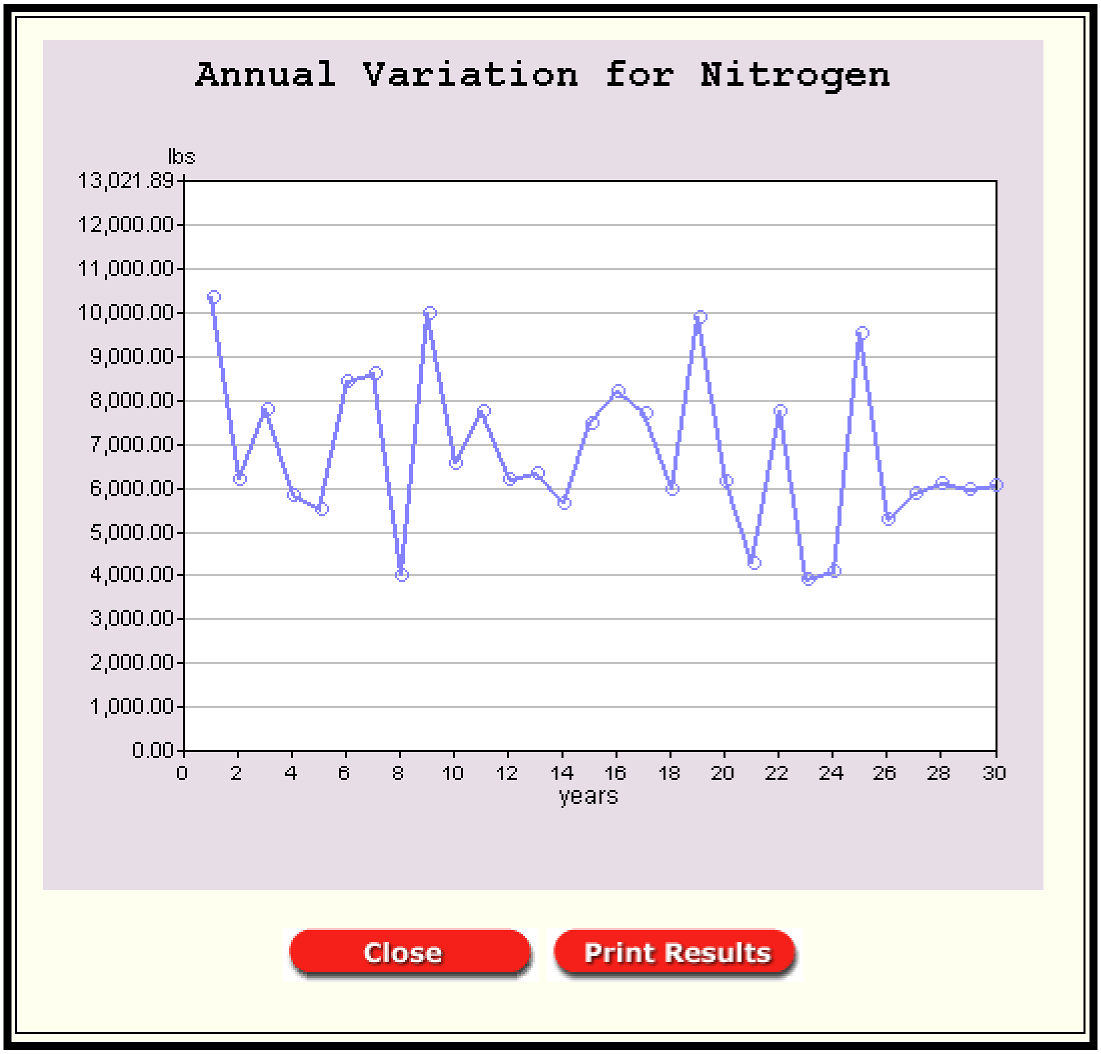



**Figure A.4.9: Graph of Annual Variation for NPS contaminant.**

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.

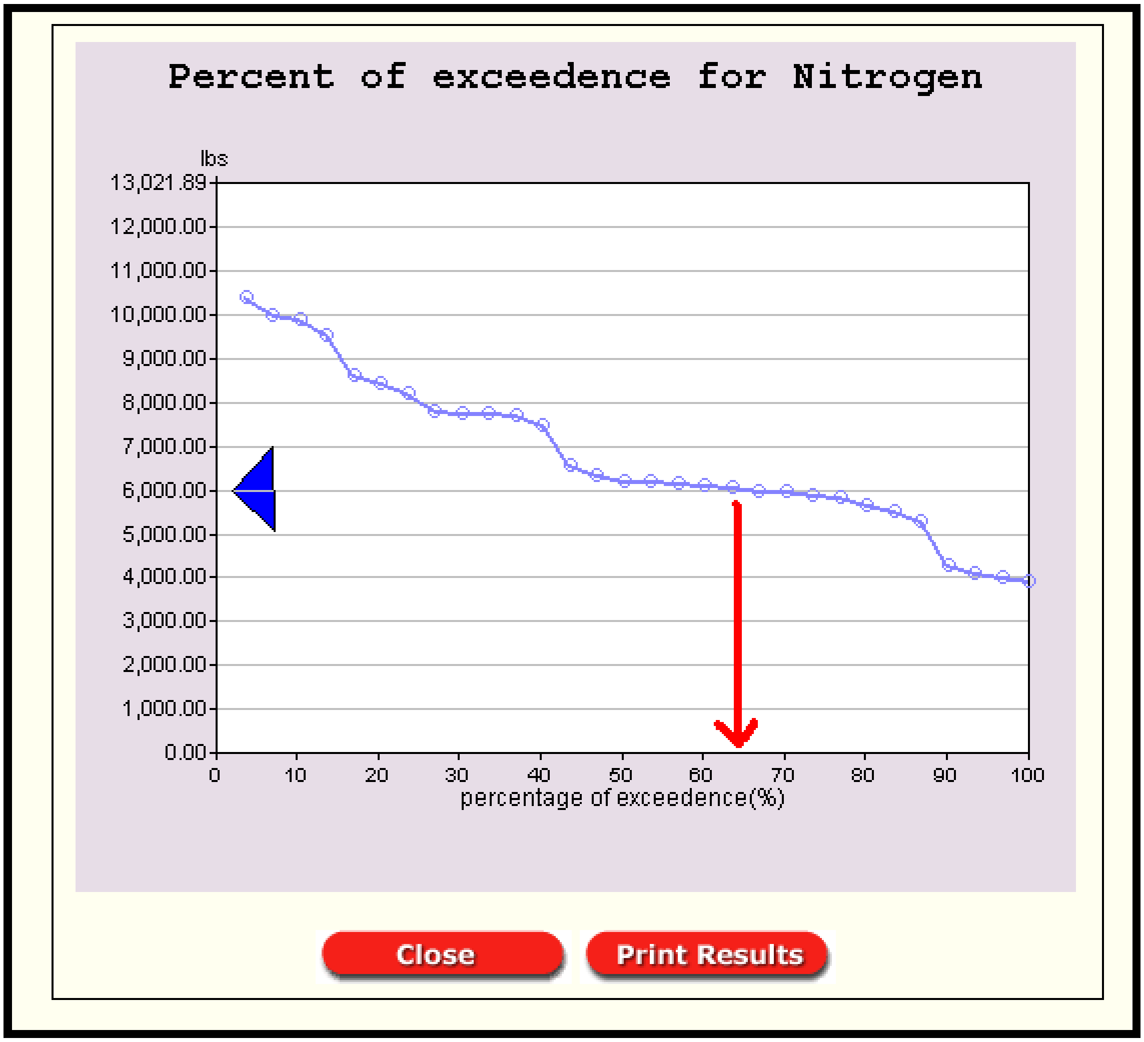



**Figure A.4.10: Percent of Exceedence for NPS contaminant.**

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.

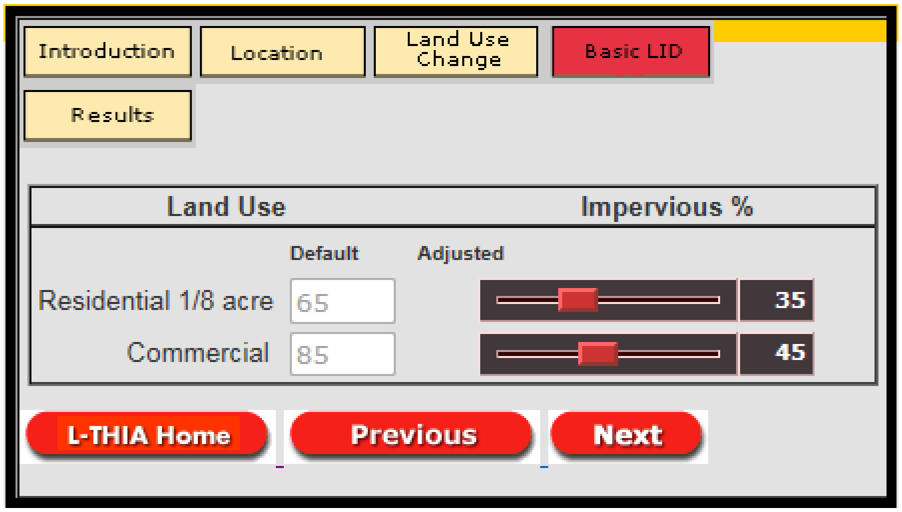


**Figure A.4.11: Impervious % slider.**

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.

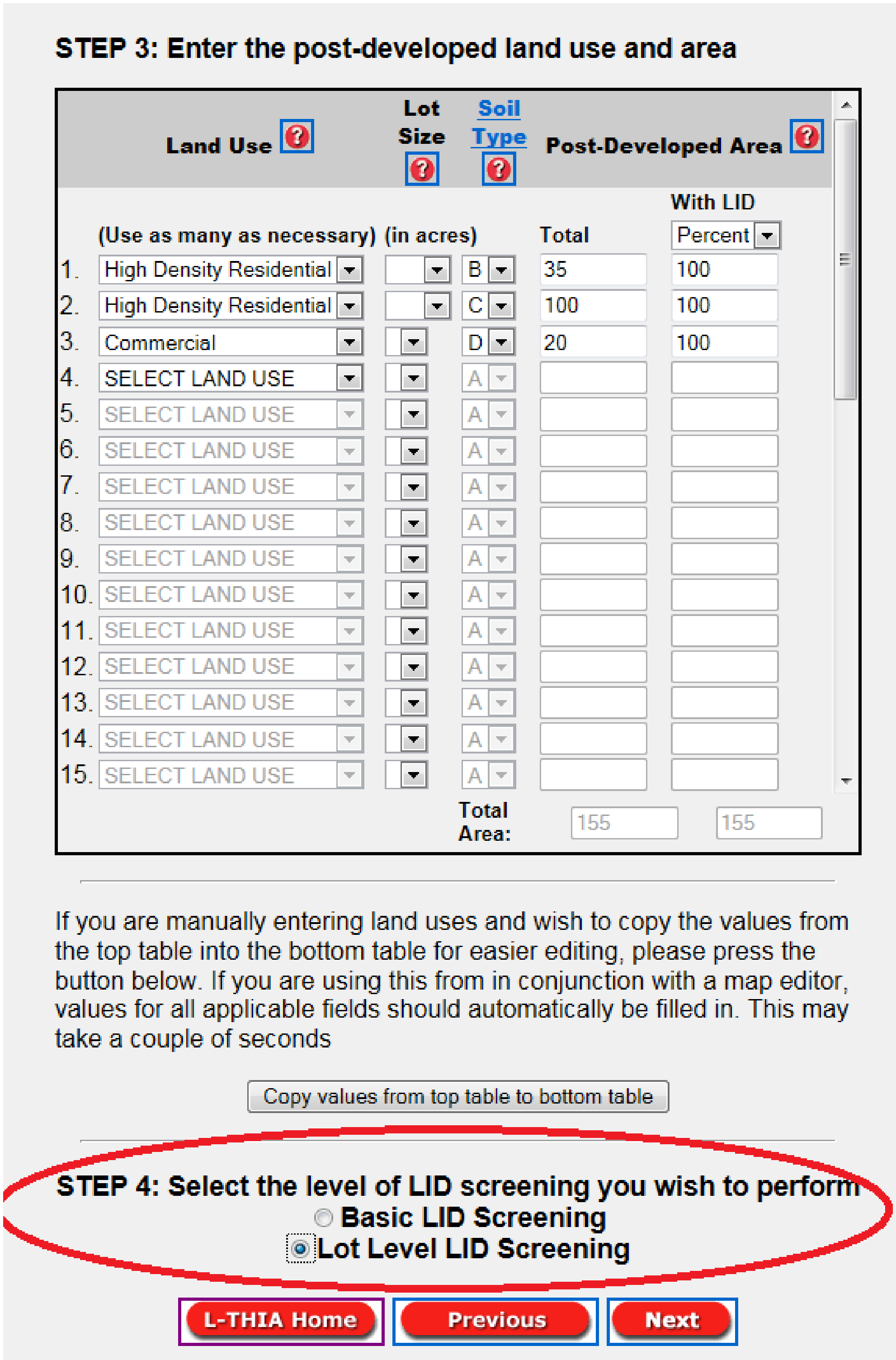



**Figure A.4.12: Selection of Lot Level LID Screening.**

**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.

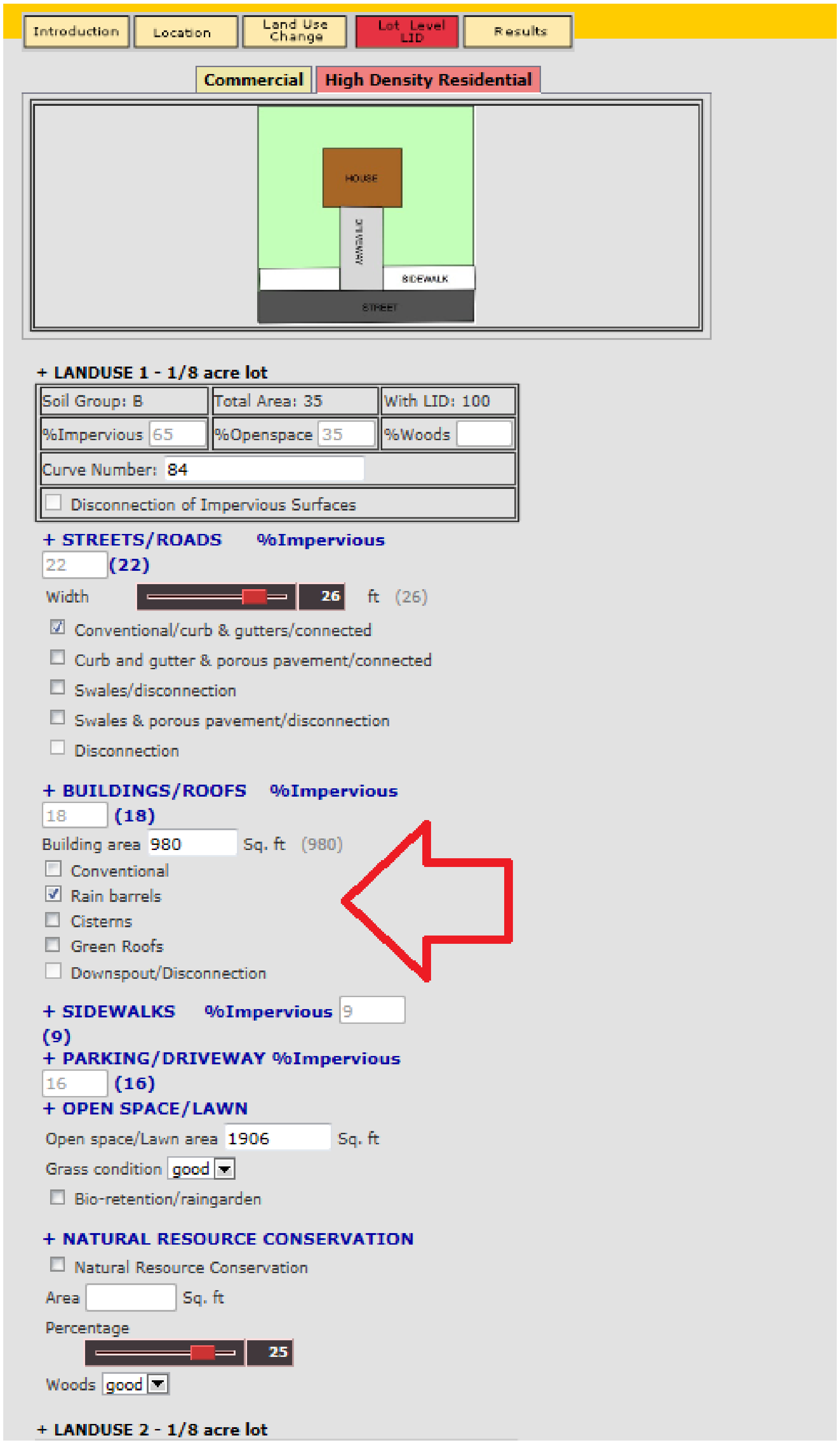



**Figure A.4.13: Lot level LID screening menu.**

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.

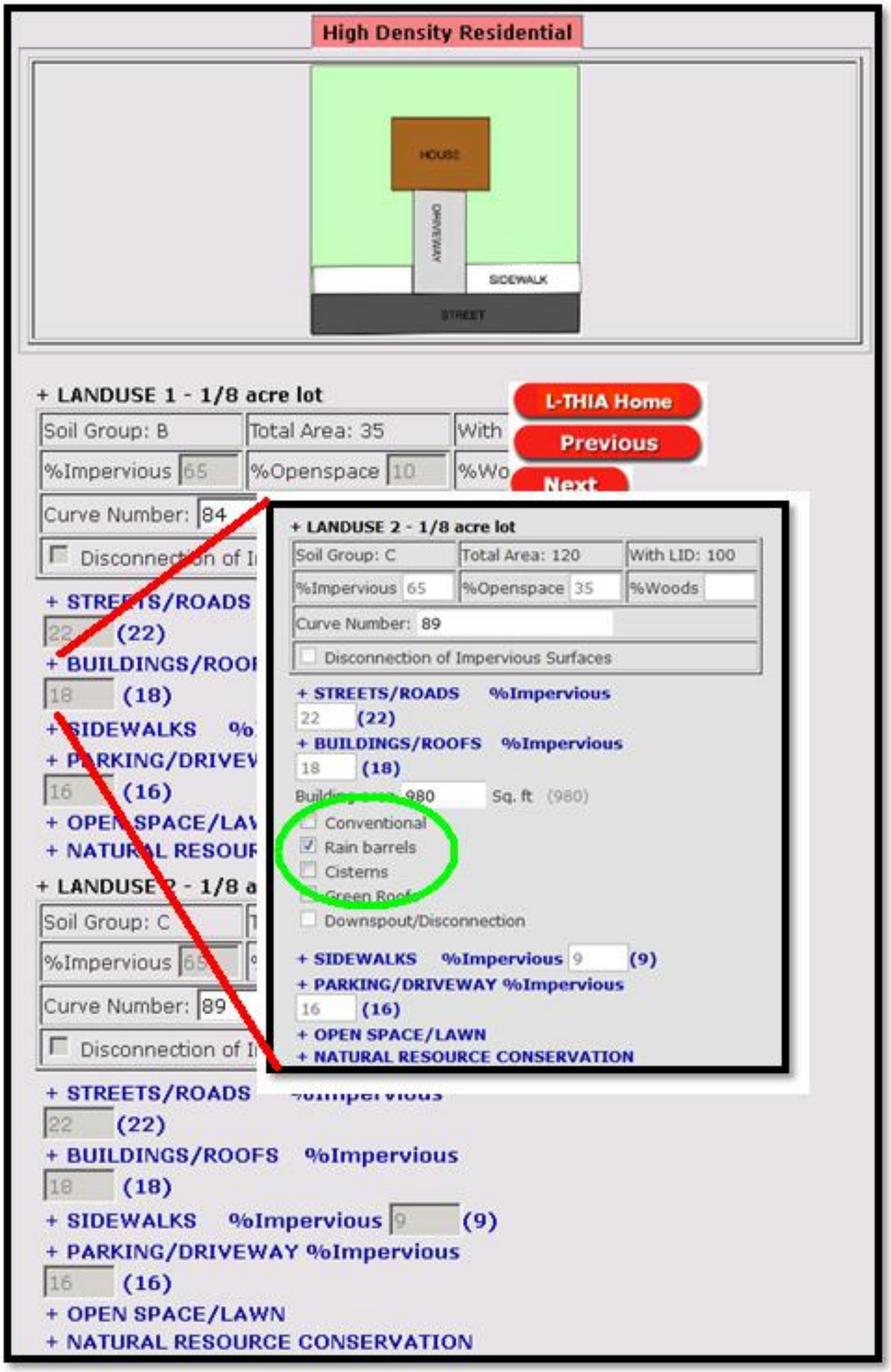



**Figure A.4.14: Expand the + and check the box to select rain barrels.**

**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)

| Practice | Price Range | Default Range Low | Default Range 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 |

## 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.

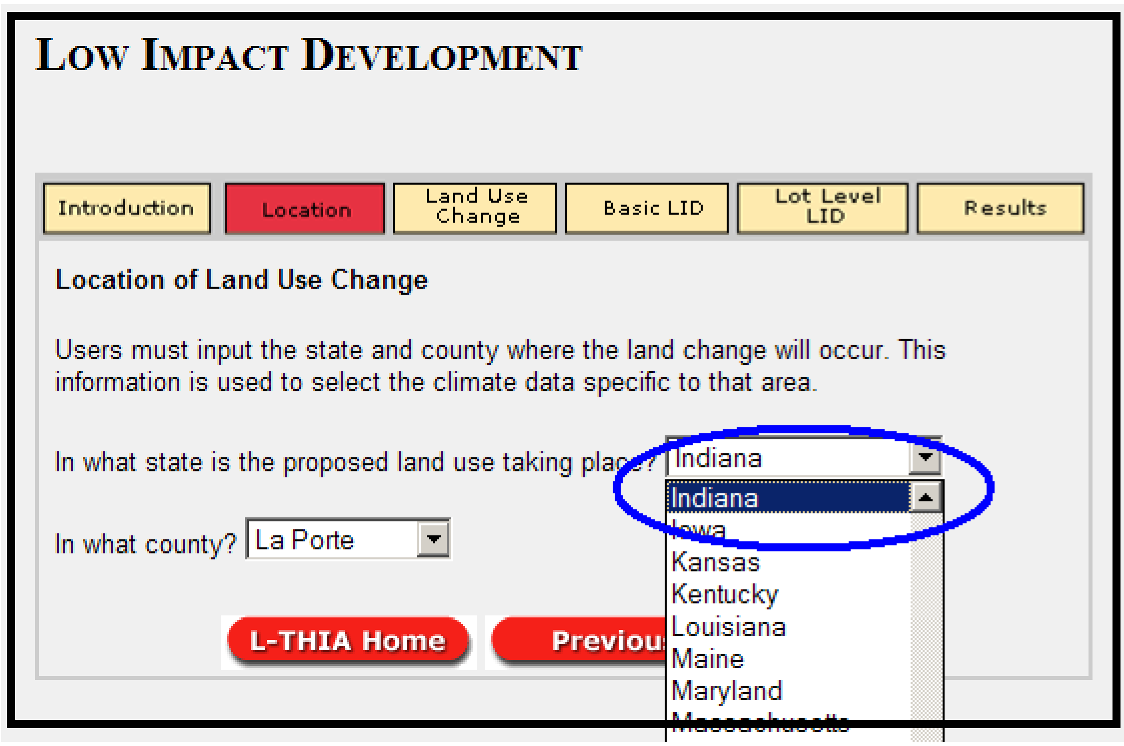



**Figure A.5.1: Selecting state and county.**

**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.

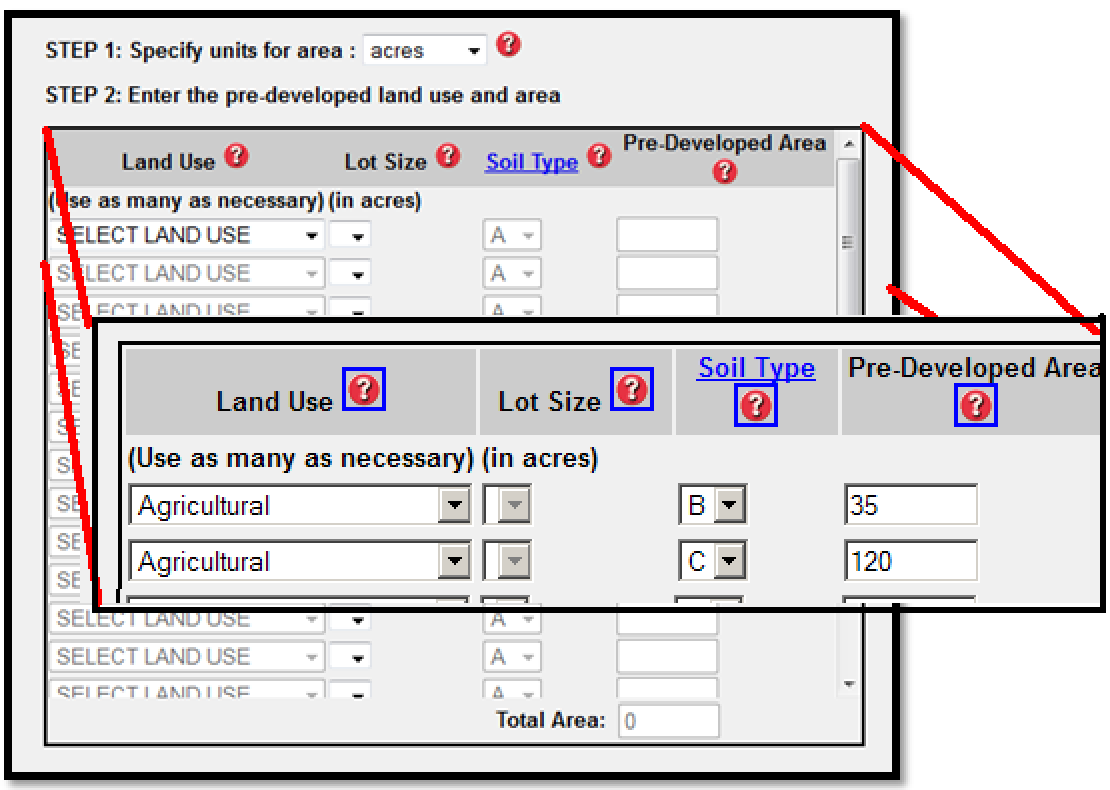



**Figure A.5.2: Selecting pre-developed (existing) land use and soil and corresponding area.**

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.

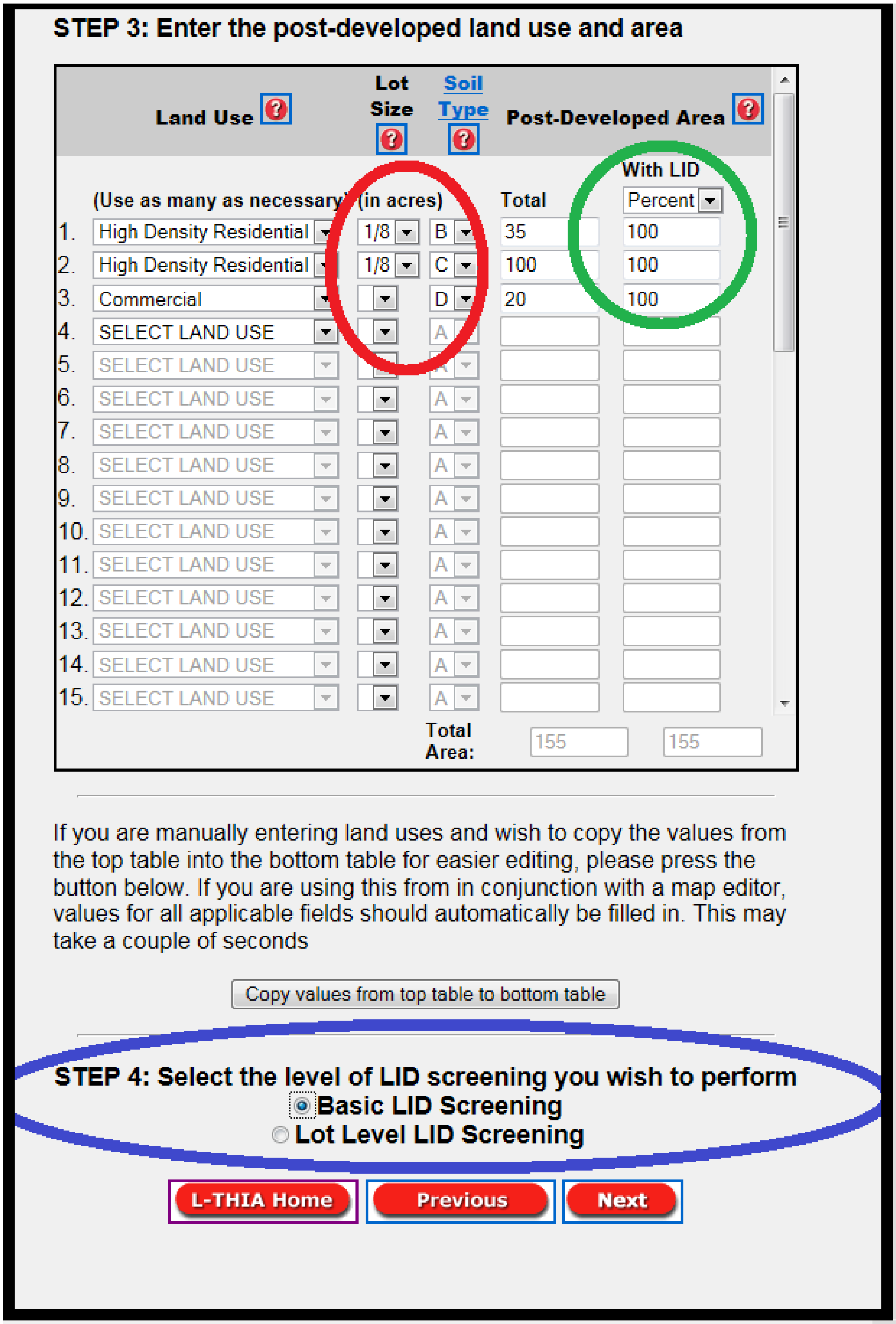



**Figure A.5.3: Selecting post-development land use and soil and corresponding area with LID applied, and screening level.**

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.

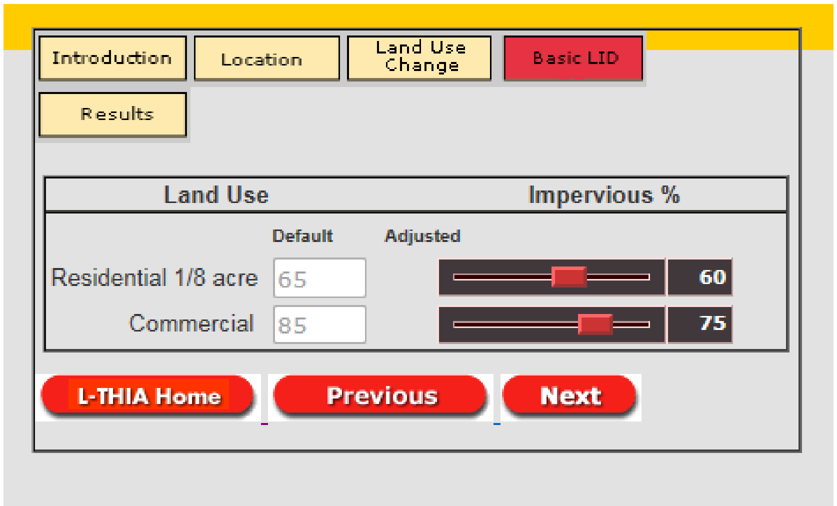



**Figure A.5.4: Selecting the percentage of impervious surfaces.**

**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**

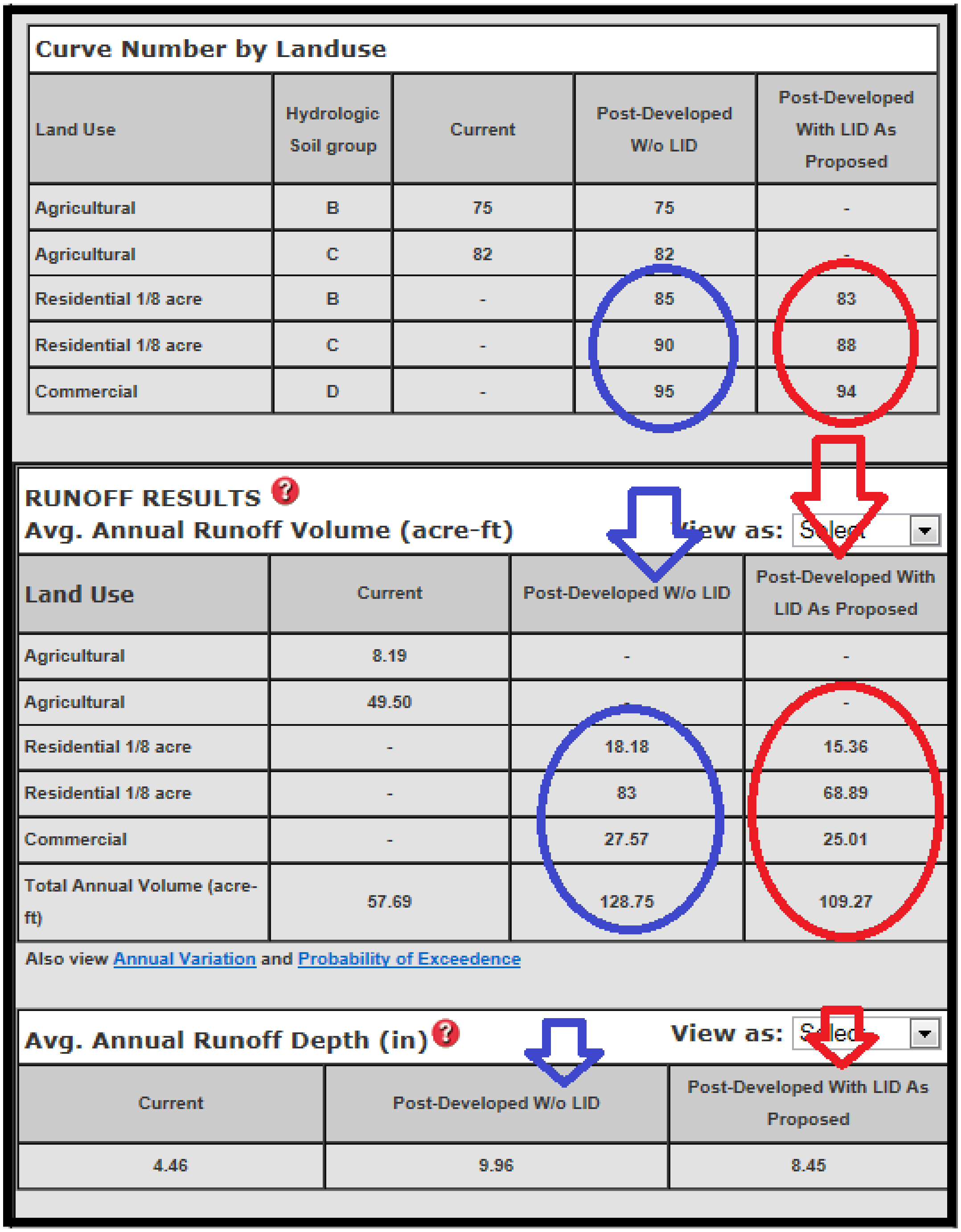
| Land Use | Default | Adjusted |
|---|---|---|
| Residential 1/8 acre | 65 | 60 |
| Commercial | 85 | 75 |

**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).

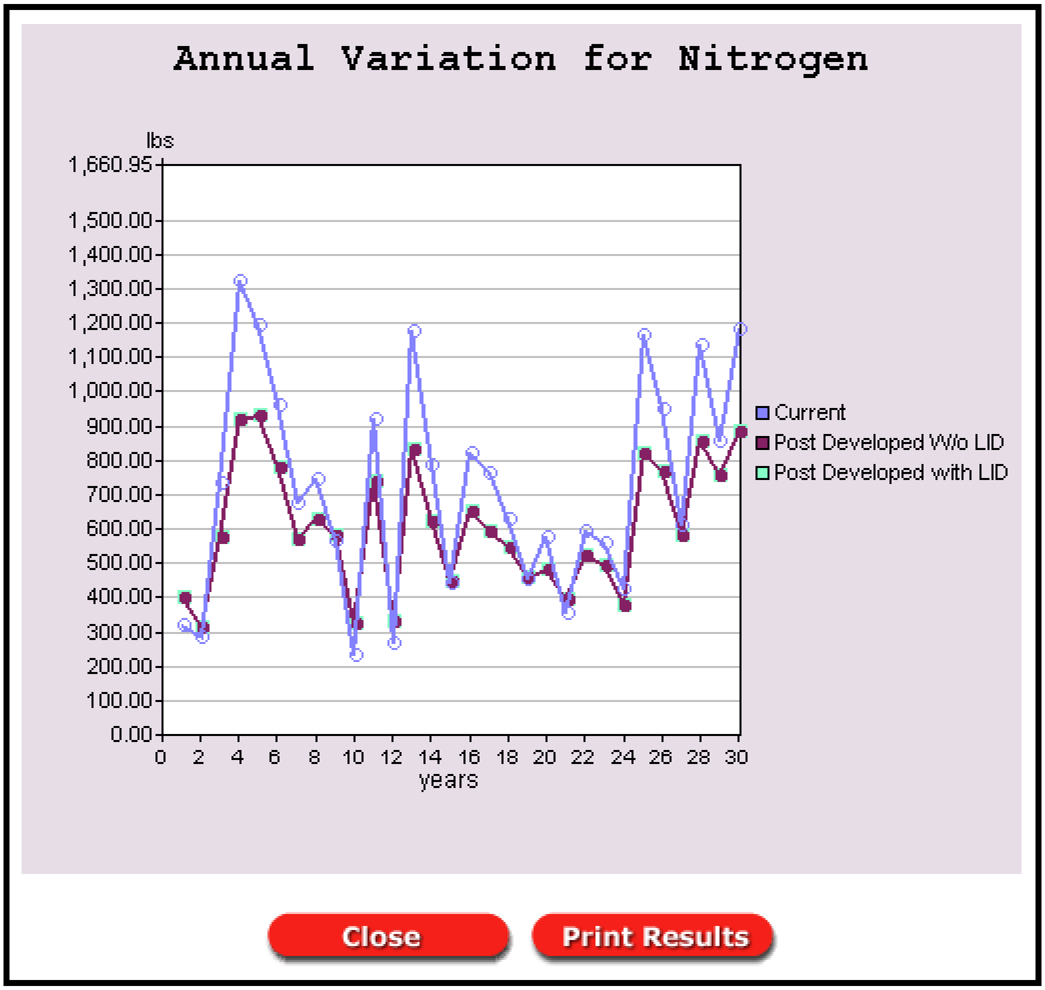


**Figure A.5.9: Graph of Annual Variation for NPS contaminant.**

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.

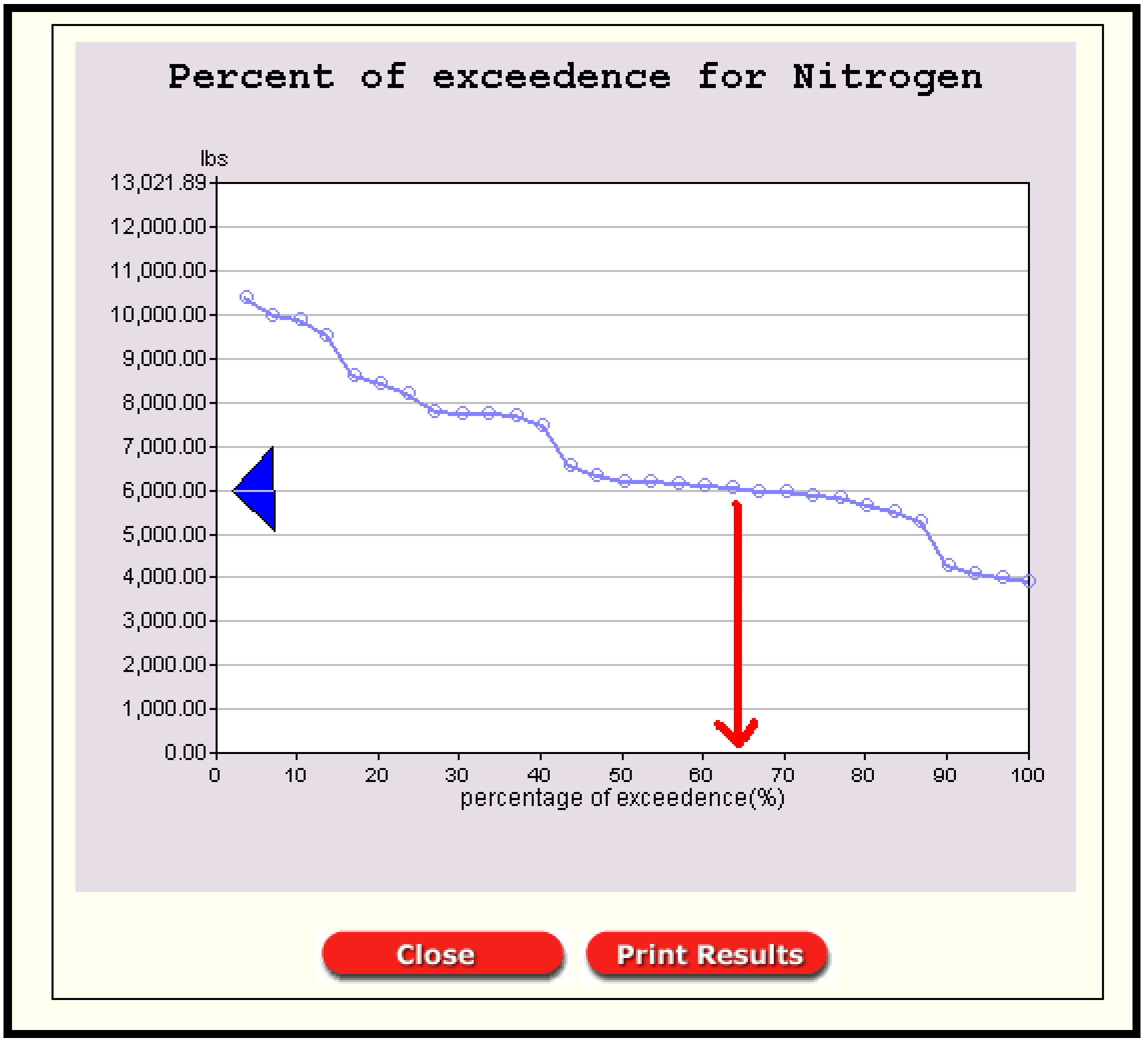



**Figure A.5.10: Percent of Exceedence for NPS contaminant.**

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.

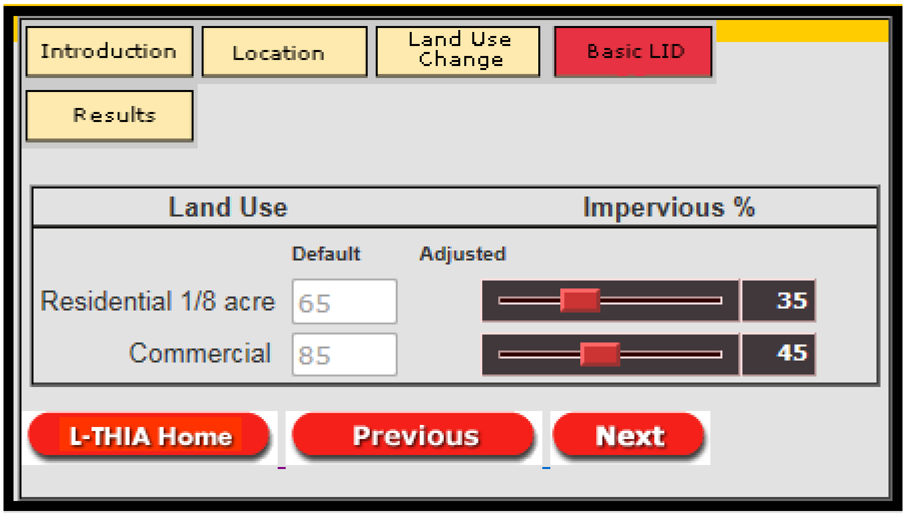



**Figure A.5.11: Impervious % slider.**

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.

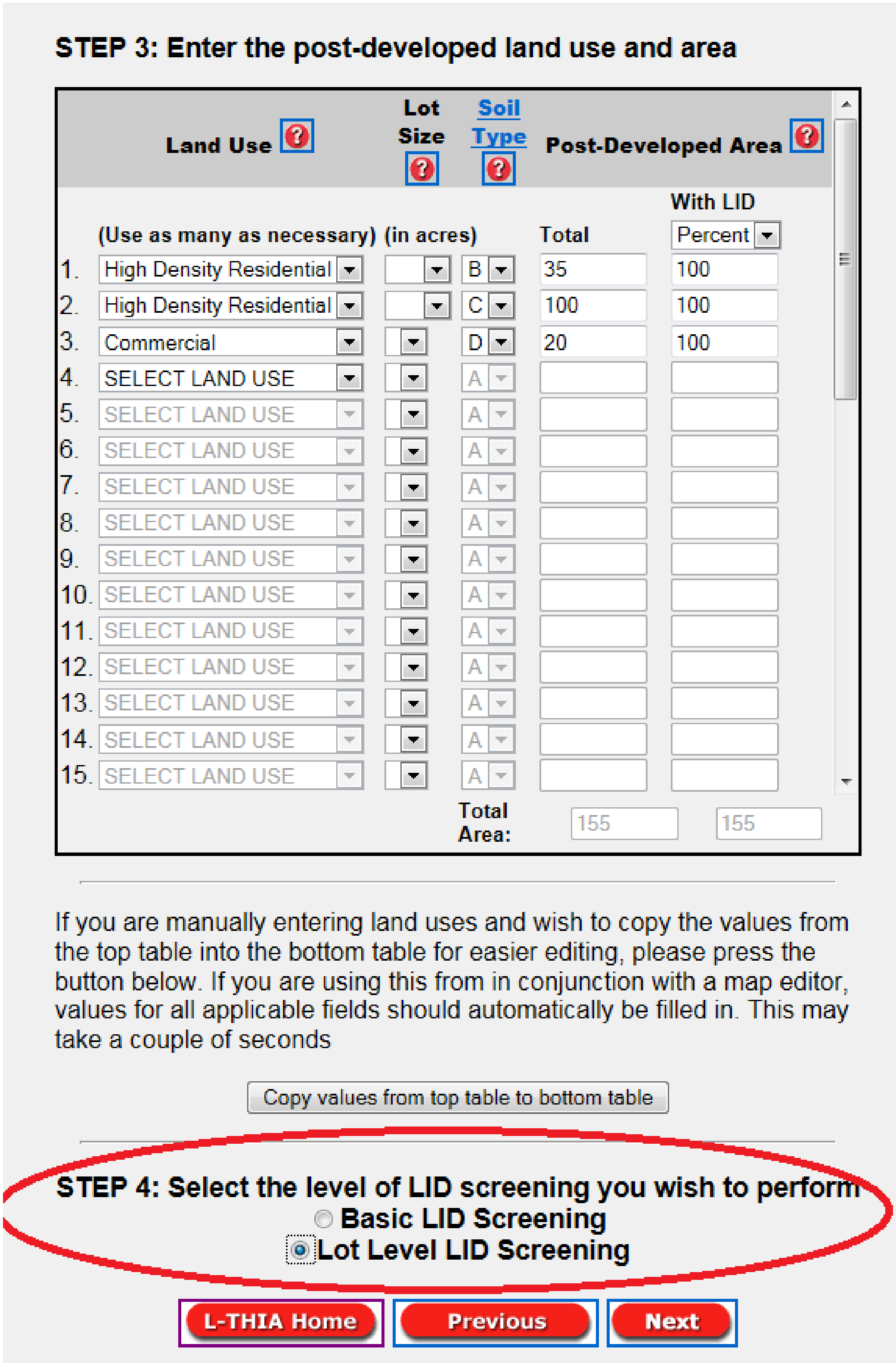



**Figure A.5.12: Selection of Lot Level LID Screening.**

**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.

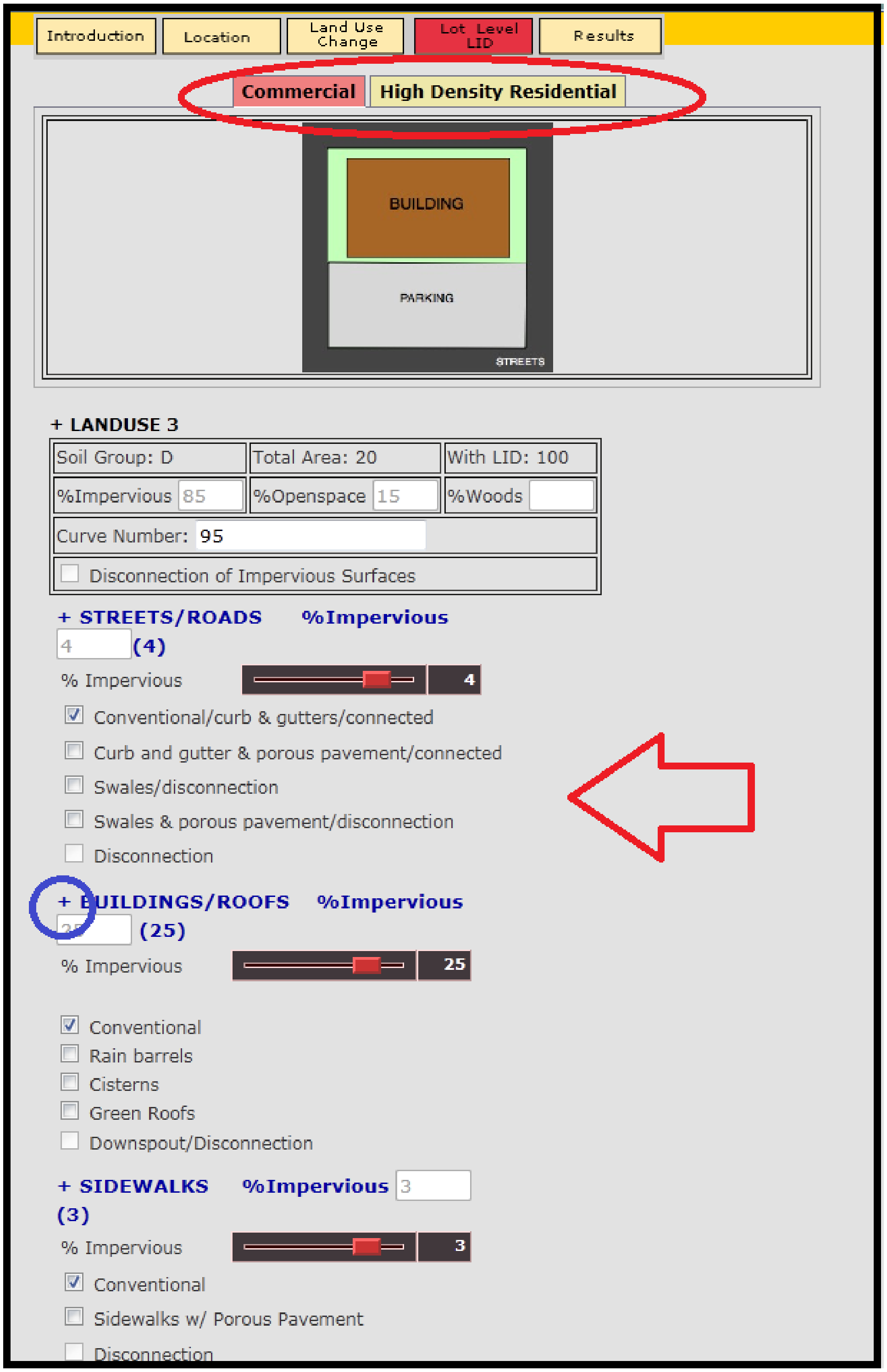



**Figure A.5.13: Lot level LID screening menu.**

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.

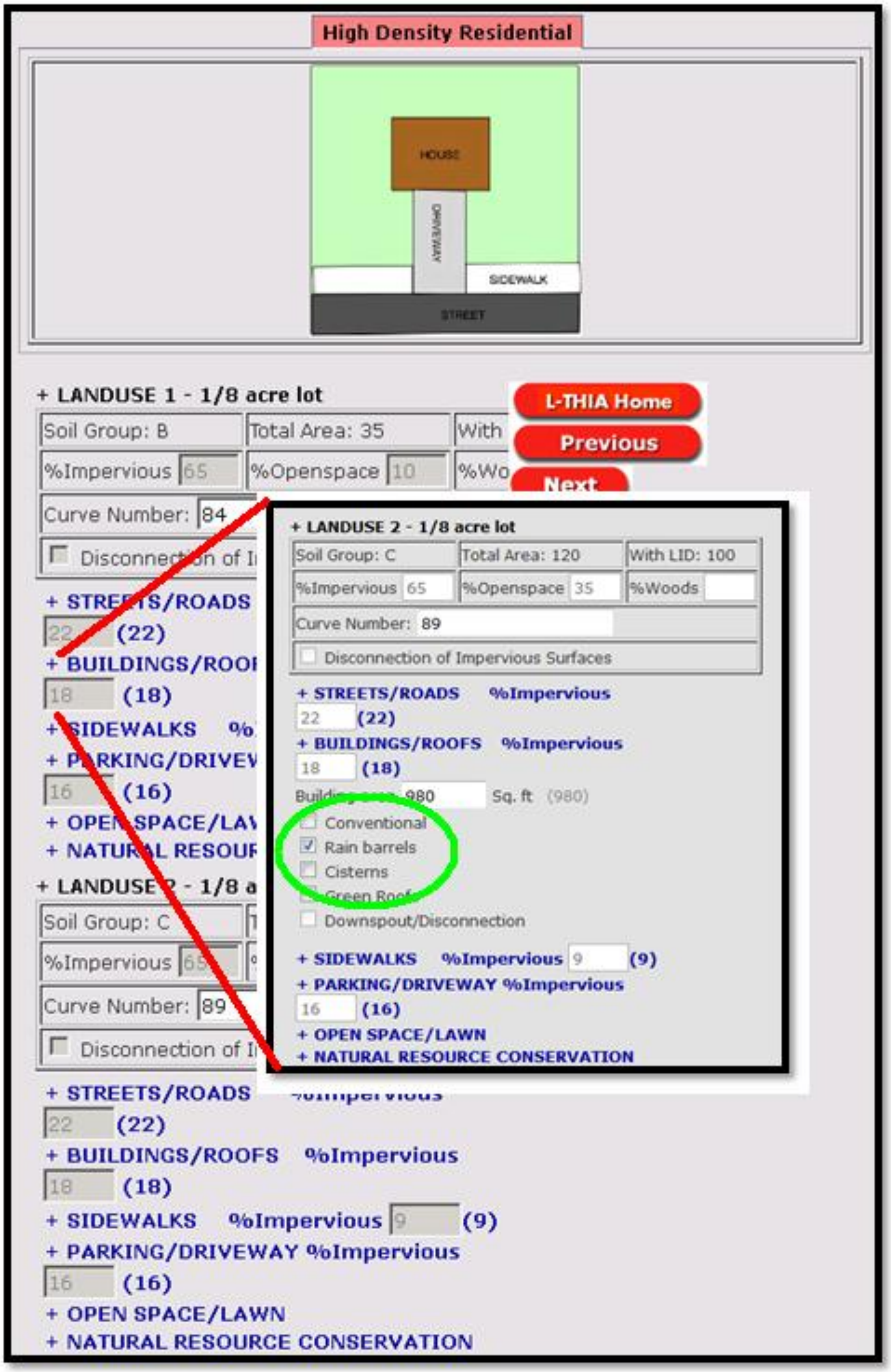



**Figure A.5.14: Expand the + and check the box to select rain barrels.**

**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)

| Practice | Price Range | Default Range Low | Default Range 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 |

# L-THIA Upper Blanchard Watershed Tutorial

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.

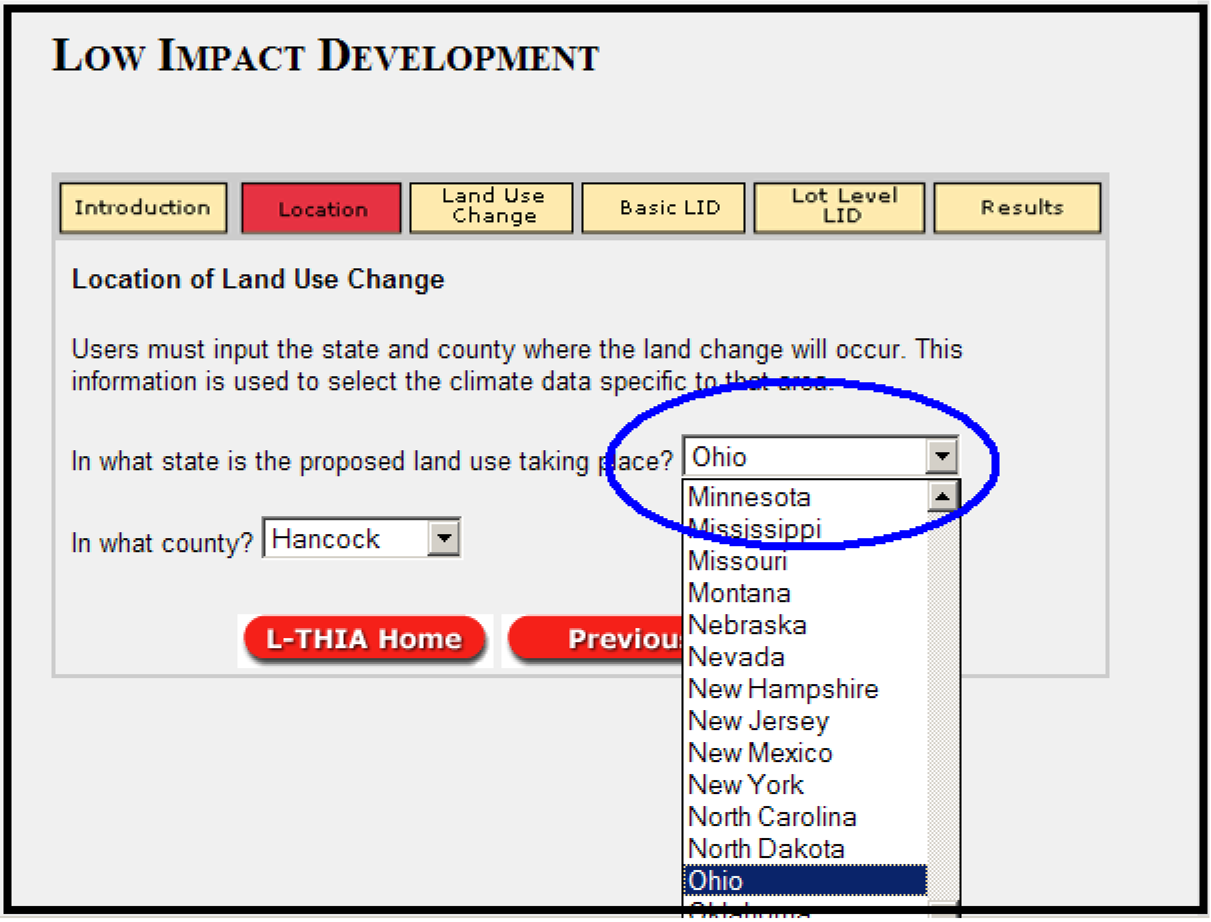



**Figure A.6.1: Selecting state and county.**

**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.

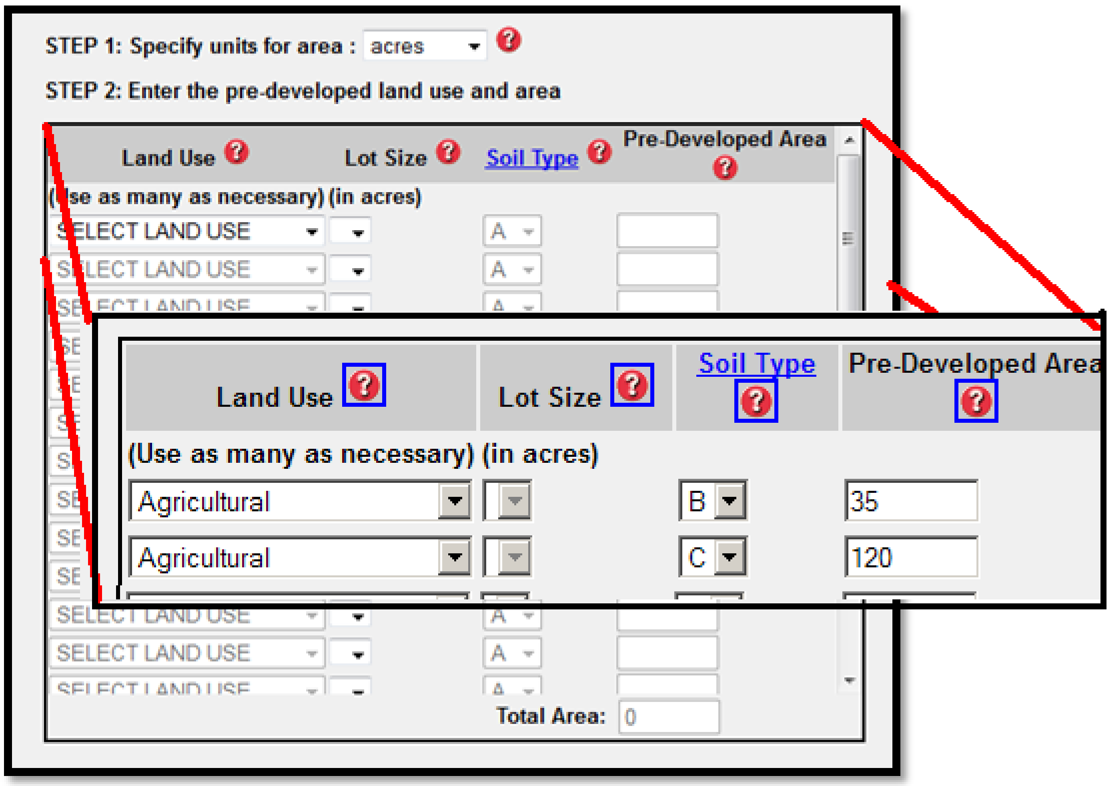



**Figure A.6.2: Selecting pre-developed (existing) land use and soil and corresponding area.**

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.

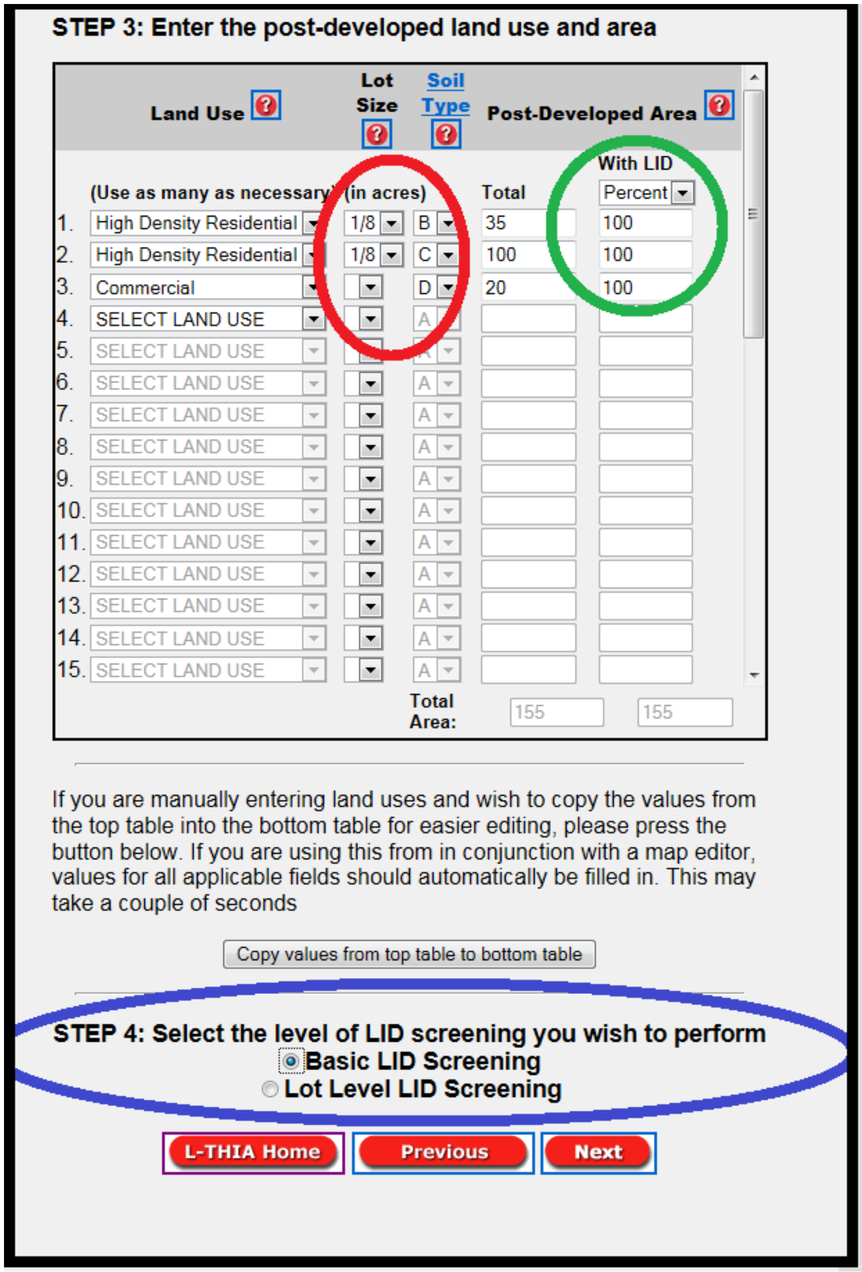



**Figure A.6.3: Selecting post-development land use and soil and corresponding area with LID applied, and screening level.**

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.

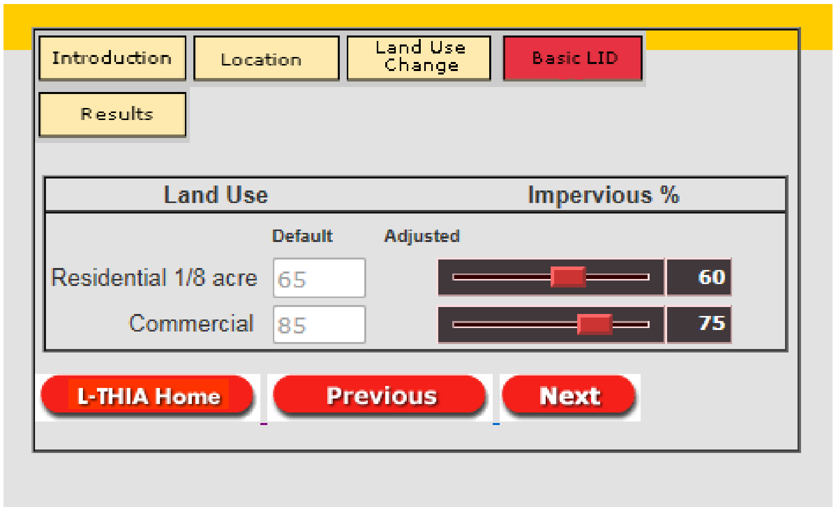



**Figure A.6.4: Selecting the percentage of impervious surfaces.**

**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).

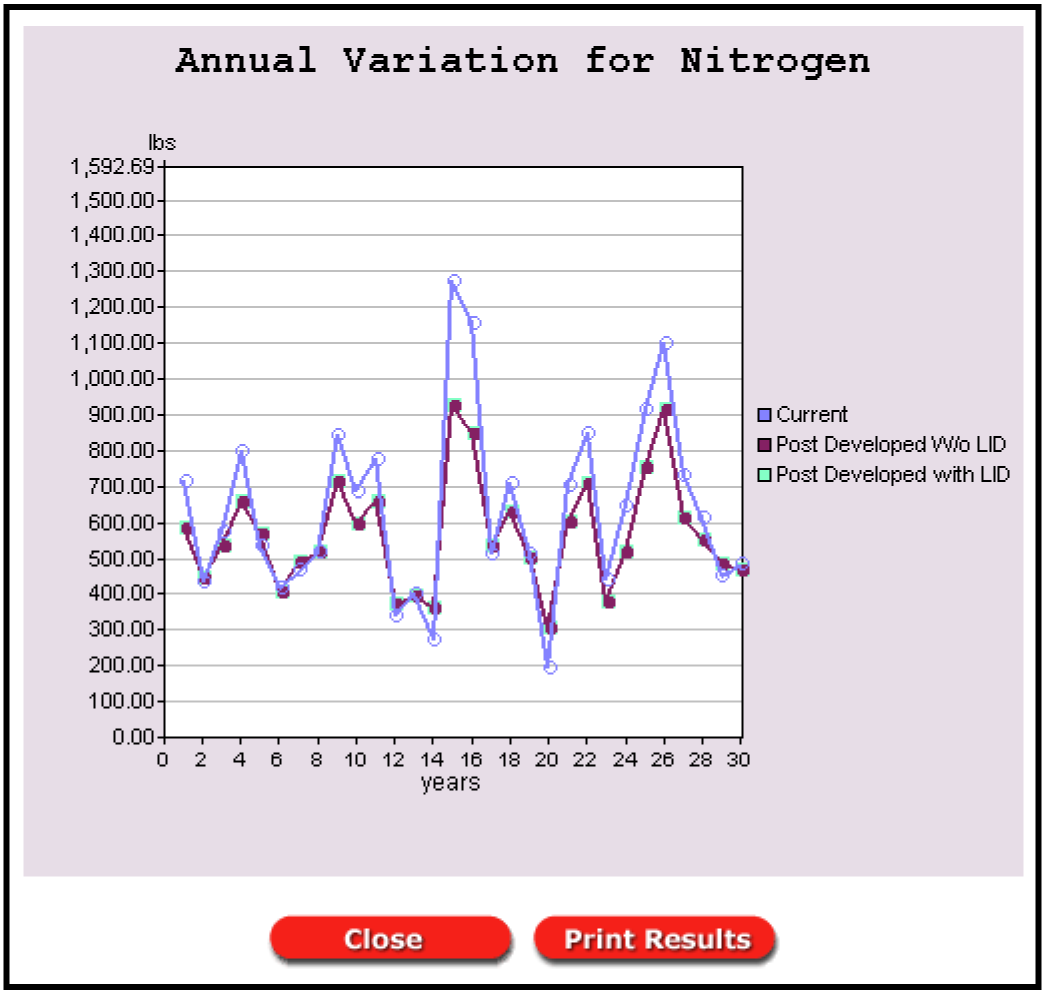



**Figure A.6.9: Graph of Annual Variation for NPS contaminant.**

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.

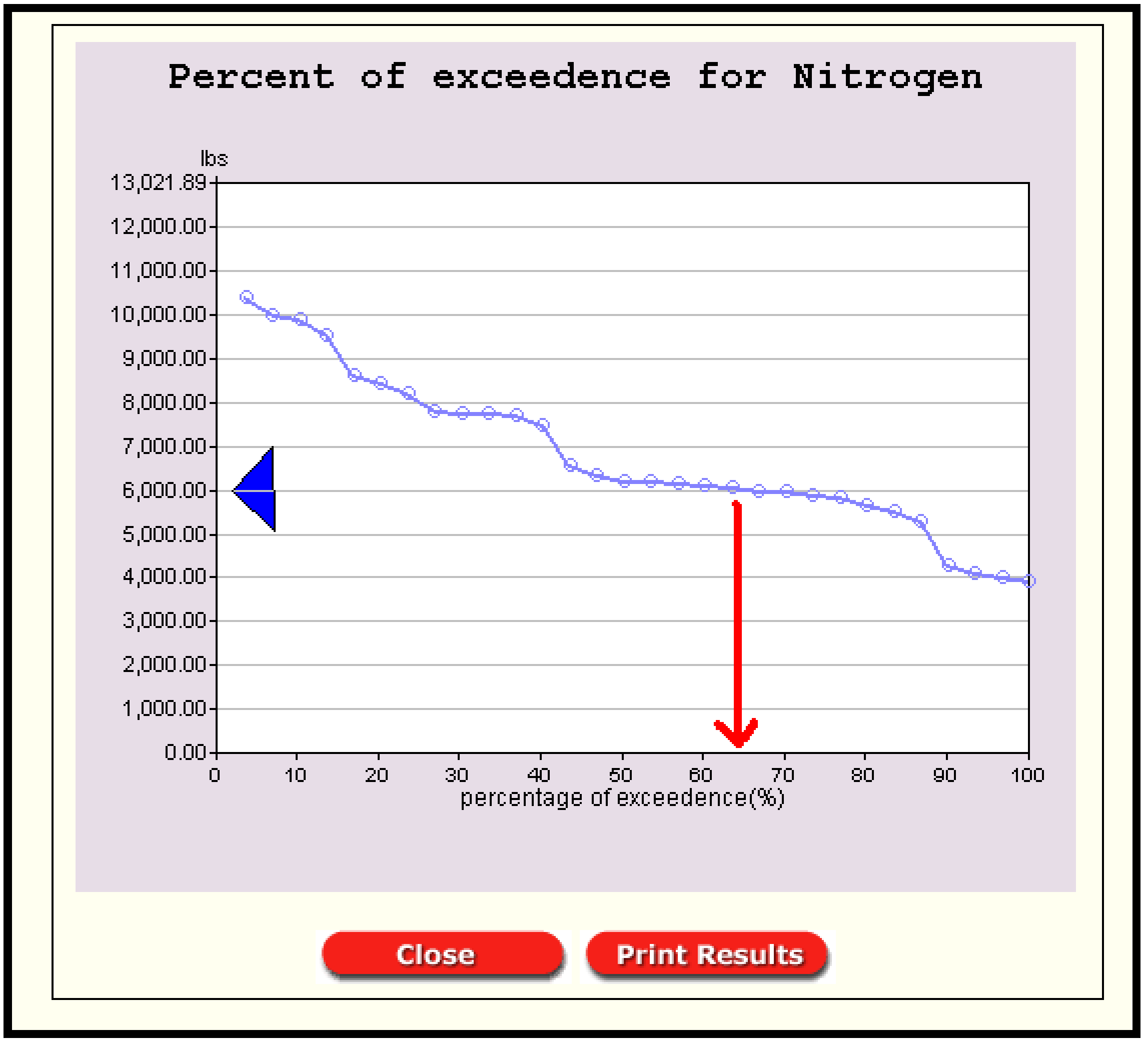



**Figure A.6.10: Percent of Exceedence for NPS contaminant.**

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.

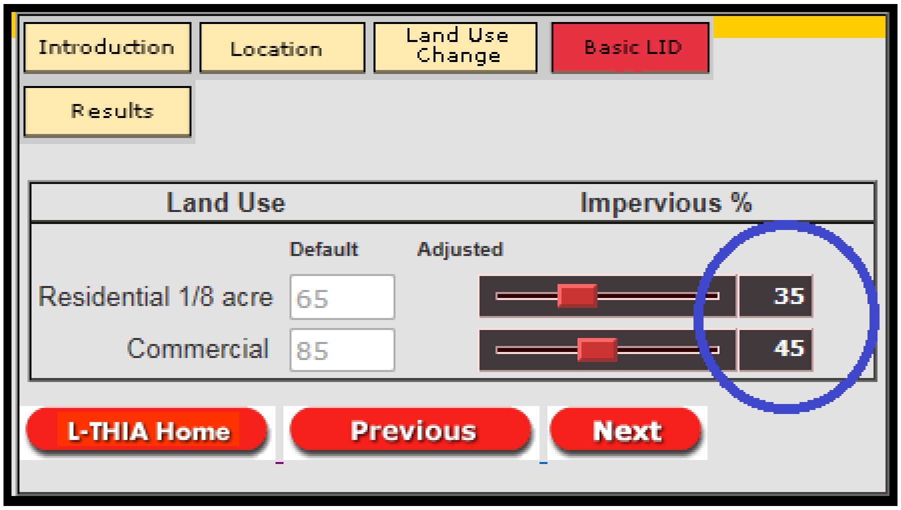


**Figure A.6.11: Impervious % slider.**

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.

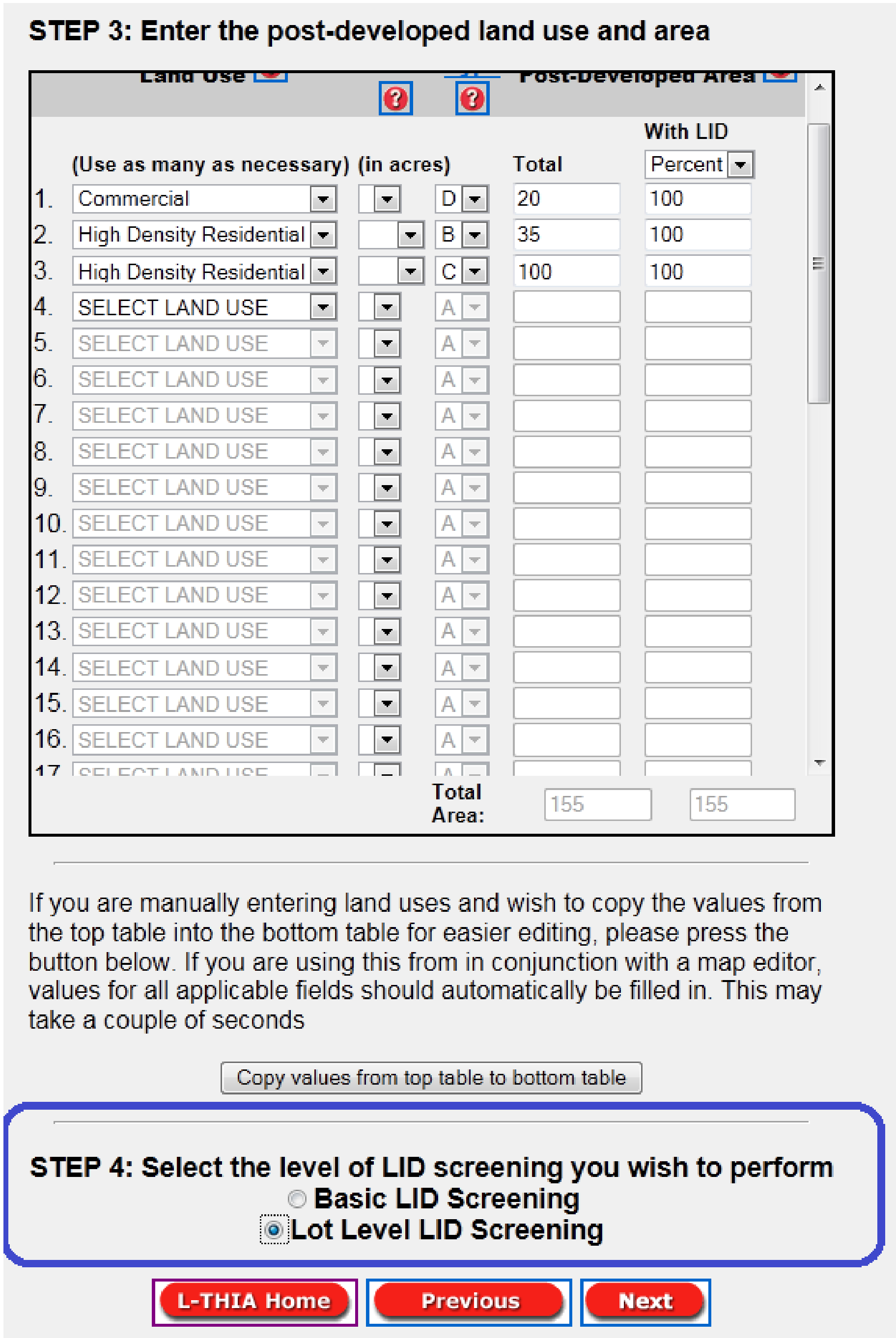



**Figure A.6.12: Selection of Lot Level LID Screening.**

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.

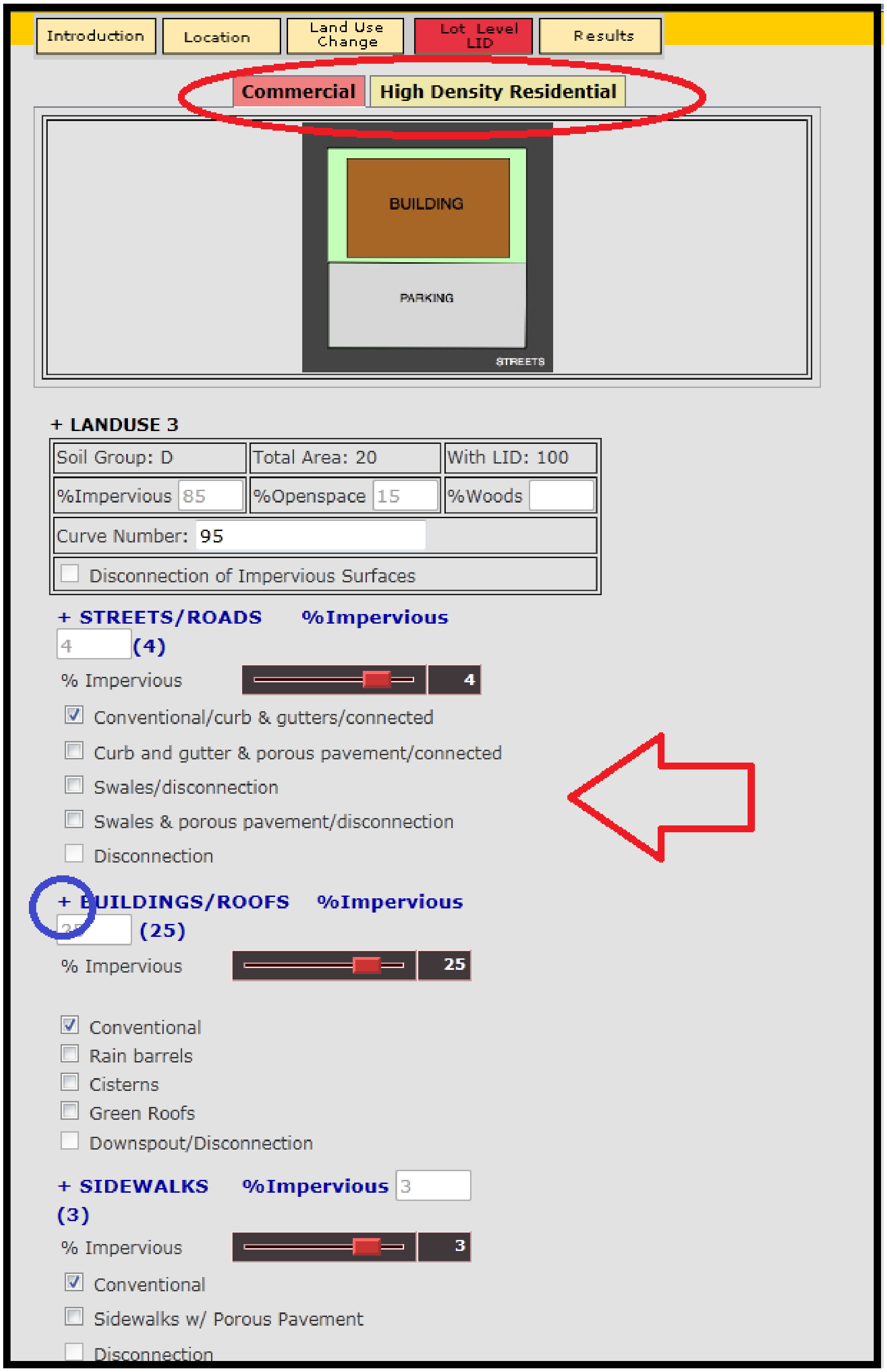



**Figure A.6.13: Lot level LID screening menu.**

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.

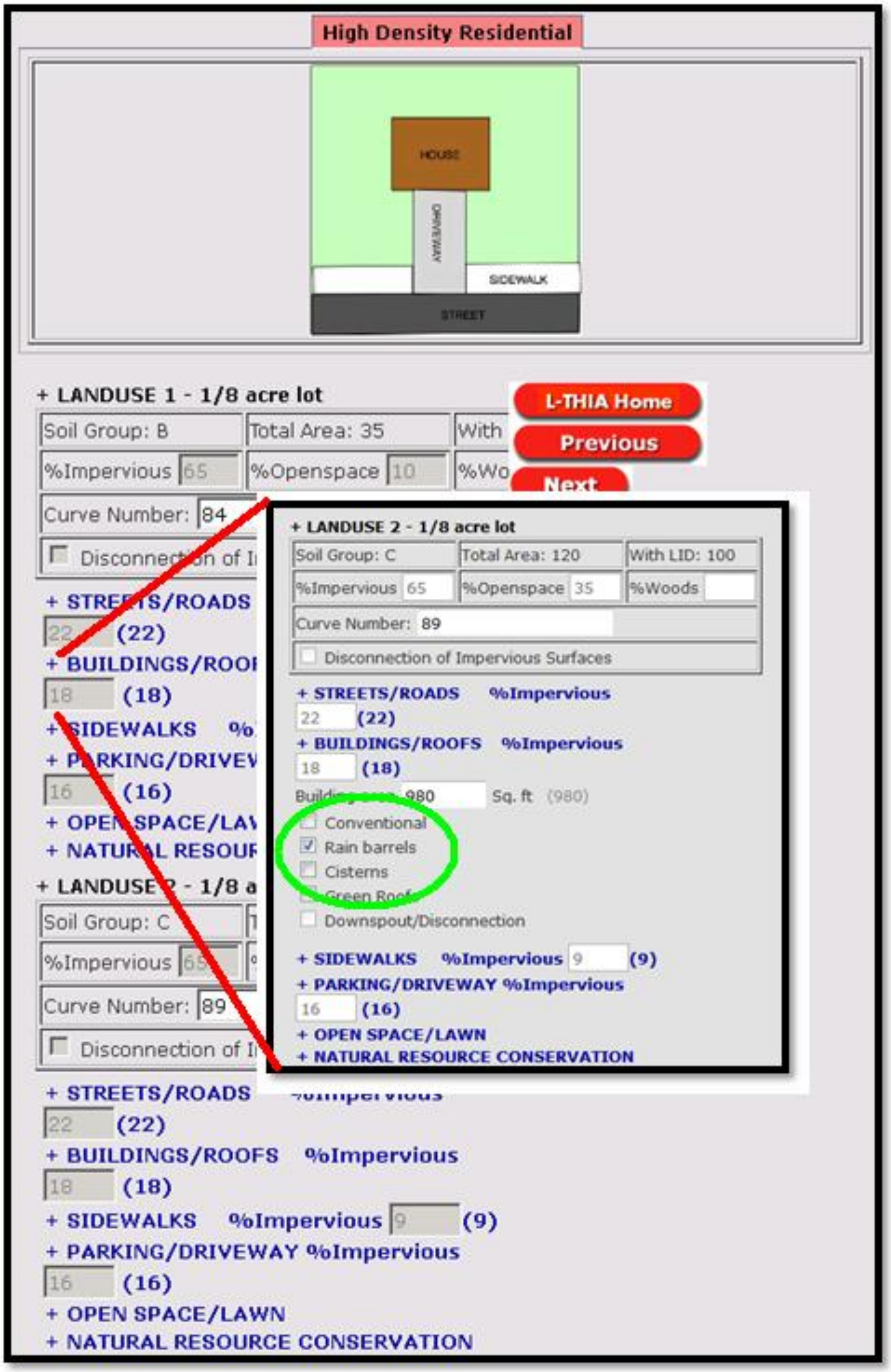



**Figure A.6.14: Expand the + and check the box to select rain barrels.**

**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)

| Practice | Price Range | Default 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:

# 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.

**B3.1.0 Design of Bioretention Facilities**

There are several sources for design guidance as listed below. .

**B3.1.1 Governing Equations** (LIDMM, 2008; Briglio and Novotney, unpublished)

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

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

where:
$A_f$ = surface area of filter bed ($ft^2$)
$Q_v$ = required storage volume ($ft^3$). The 95$^{th}$ 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.

**B3.1.2 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. 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.

**B3.2.1 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.

**B3.2.2 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 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.

**B3.3.1 Governing Equation** (LIDMM, 2008)

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

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

**B3.3.2 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.

**B3.4.0 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.

**B3.4.1 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)

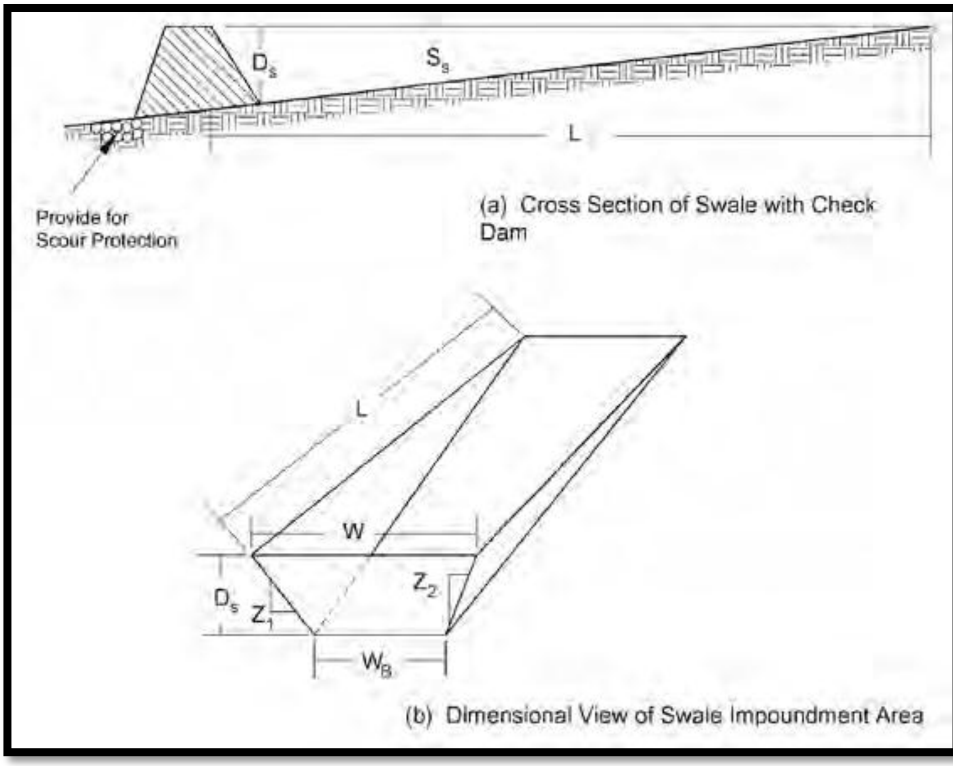


**Figure B.3.1 showing the profile of a swale (from LIDMM, 2008.)**

**B3.4.2 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 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.

**B3.5.1 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)

**B3.5.2-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 A Sizing of Open Wooded Space**

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

**B3.6.1 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.

**B3.6.2_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 B: 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.