Section 2.2: The L-THIA LID Model Description

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

Theoretical background:

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

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

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

The hydrologic component of the model.

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

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

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

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

Table 2.2 Estimated HSG from Surface Soil Texture.

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

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

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

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

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

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

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

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

The volume of runoff from an area is determined by:

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

where Q_v is the volume of water; and *A* is the area of interest.

Once runoff **water quantity** is predicted in L-THIA LID, then runoff **water quality** is determined by multiplying simulated runoff against specific coefficients for land use types.

The water quality component of the model.

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

L-THIA LID Land Uses:

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

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

L-THIA LID NPS Outputs:
Nitrogen
Phosphorous
Suspended solids
Lead
Copper
Zinc
Cadmium
Chromium
Nickel
BOD (Biological Oxygen Demand)
COD (Chemical Oxygen Demand)
Oil and Grease
Fecal Coliform
Fecal Strep

LID Practices employed in the Model

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

1) bioretention/rain garden,

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

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

L-THIA LID and Representation of LID Practices:

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

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

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

Bioretention Systems

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

Rain Barrel and Cistern

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

Green Roof

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

Permeable Pavement and Permeable Patio

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

Open Wooded Space

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

Review of L-THIA and L-THIA LID Publications.

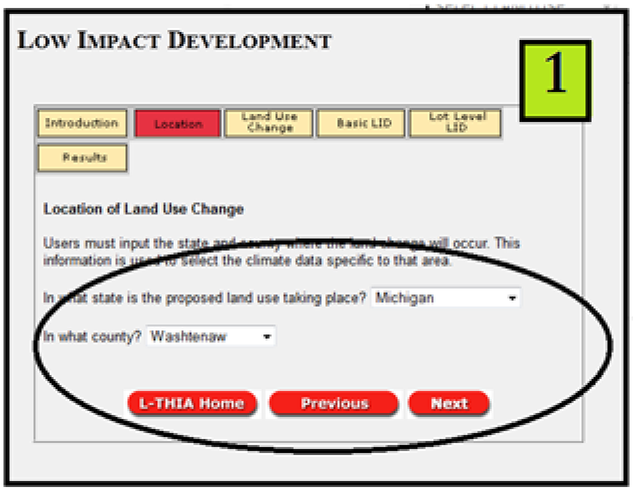
The L-THIA model has been extensively used for land use impact assessment. In addition, the L-THIA and L-THIA LID model has been used in calibrated and uncalibrated modes, and has been used in case studies to illustrate and inform planners or to mimic real-world conditions.

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

Model Operations:

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

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



Location of Land Use Change

Users must input the state and county where the land change will occur. This information is used to select the climate data specific to that area.

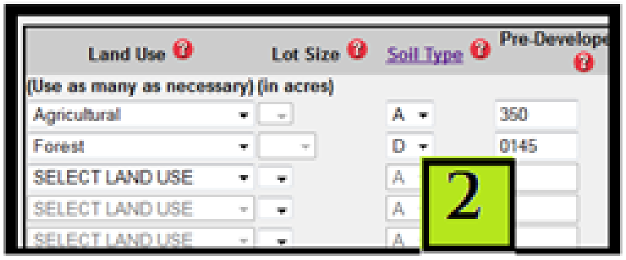
In what state is the proposed land use taking place? Michigan

In what county? Washtenaw

Figure 2.1 Select State and County

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

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

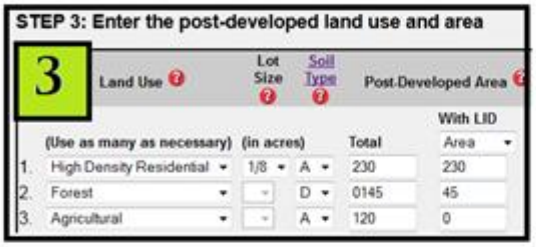


Land Use (Use as many as necessary)	Lot Size (in acres)	Soil Type	Pre-Develope
Agricultural		A	350
Forest		D	0145
SELECT LAND USE		A	
SELECT LAND USE		A	
SELECT LAND USE		A	

Figure 2.2 Enter the current land use and soil data.

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

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



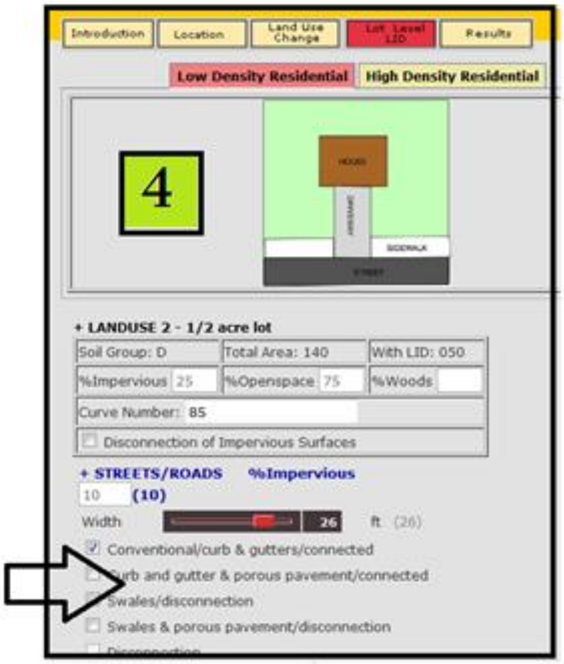
STEP 3: Enter the post-developed land use and area

	Land Use	Lot Size	Soil Type	Post-Developed Area	
					With LID
	(Use as many as necessary)	(in acres)		Total	Area
1.	High Density Residential	1/8	A	230	230
2.	Forest		D	0145	45
3.	Agricultural		A	120	0

Figure 2.3 Enter the “Post-developed” land use environment.

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

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



+ LANDUSE 2 - 1/2 acre lot

Soil Group: D	Total Area: 140	With LID: 050
%Impervious 25	%Openspace 75	%Woods
Curve Number: 85		

☐ Disconnection of Impervious Surfaces

+ STREETS/ROADS %Impervious

10 (10)

Width 26 ft. (26)

☑ Conventional/curb & gutters/connected

☐ Curb and gutter & porous pavement/connected

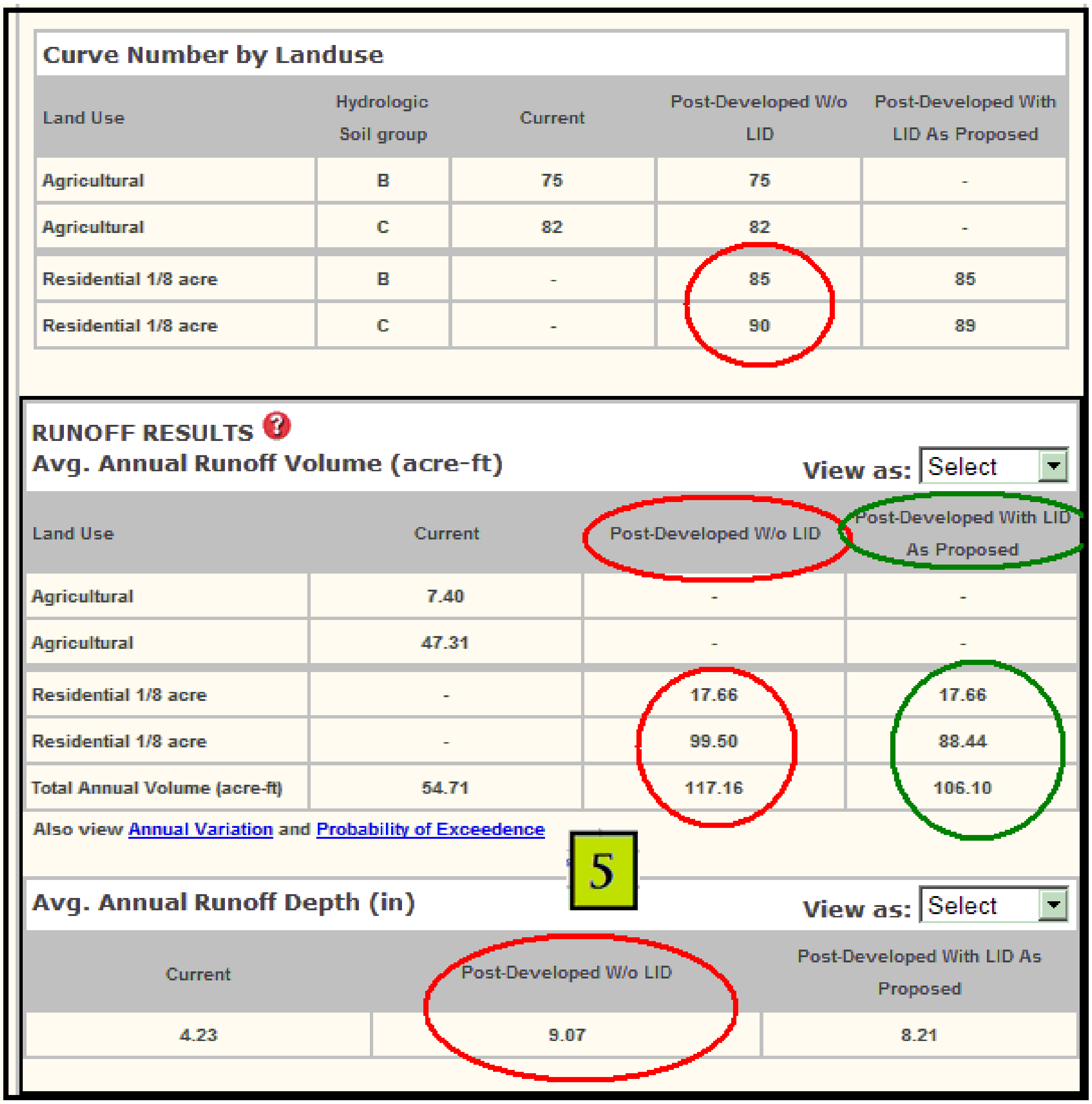
☐ Swales/disconnection

☐ Swales & porous pavement/disconnection

☐ Disconnection

Figure 2.4 Apply BMPs to appropriate land use types.

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



Curve Number by Landuse

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

RUNOFF RESULTS

Avg. Annual Runoff Volume (acre-ft)

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

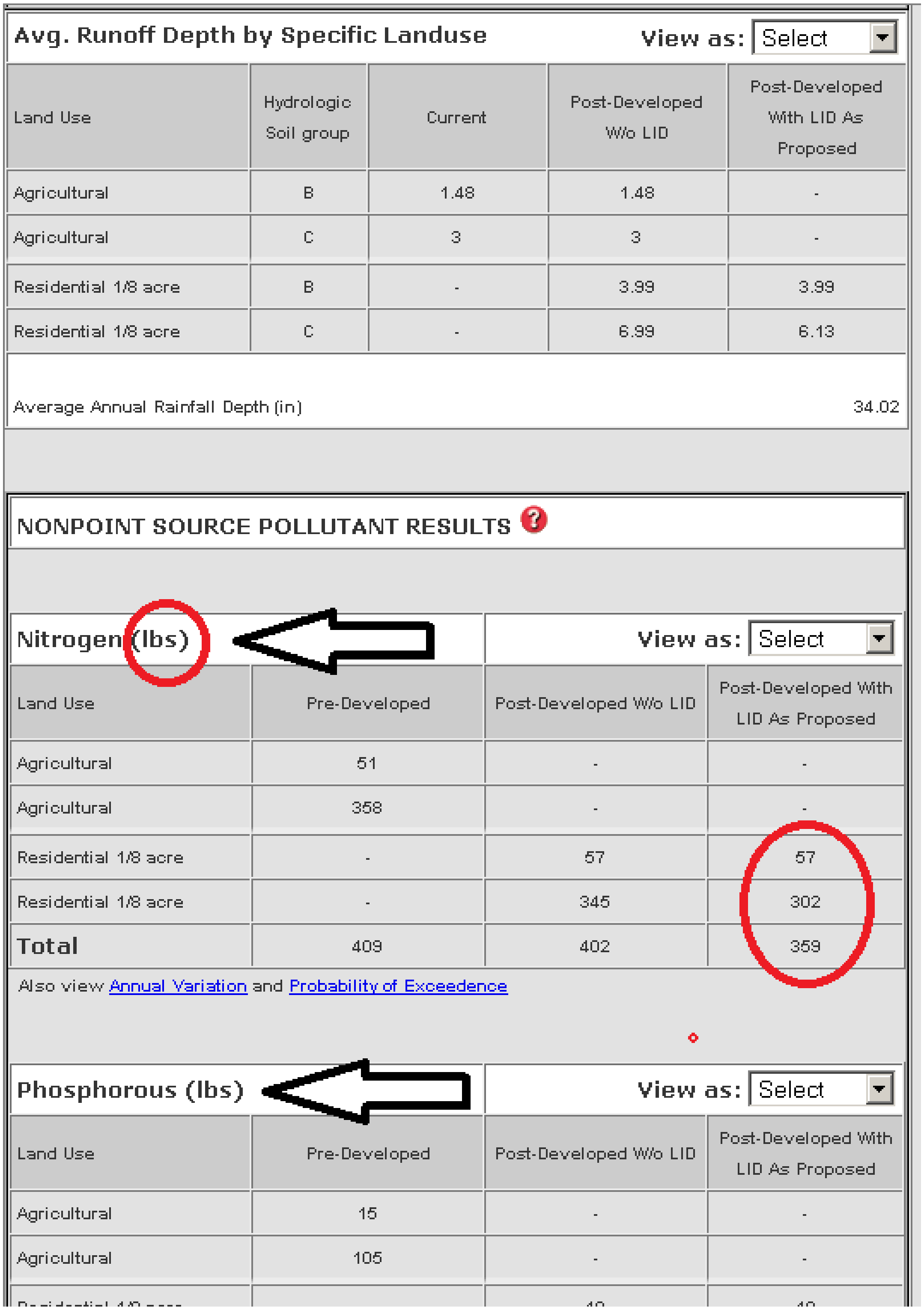
Also view Annual Variation and Probability of Exceedence

Avg. Annual Runoff Depth (in)

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

Figure 2.5 Results for Current, Post-developed w/o LID, and Post-developed with LID

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



Avg. Runoff Depth by Specific Landuse

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

Average Annual Rainfall Depth (in) 34.02

NONPOINT SOURCE POLLUTANT RESULTS

Nitrogen (lbs)

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

Also view Annual Variation and Probability of Exceedence

Phosphorous (lbs)

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

Figure 2.6 NPS results sample.

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

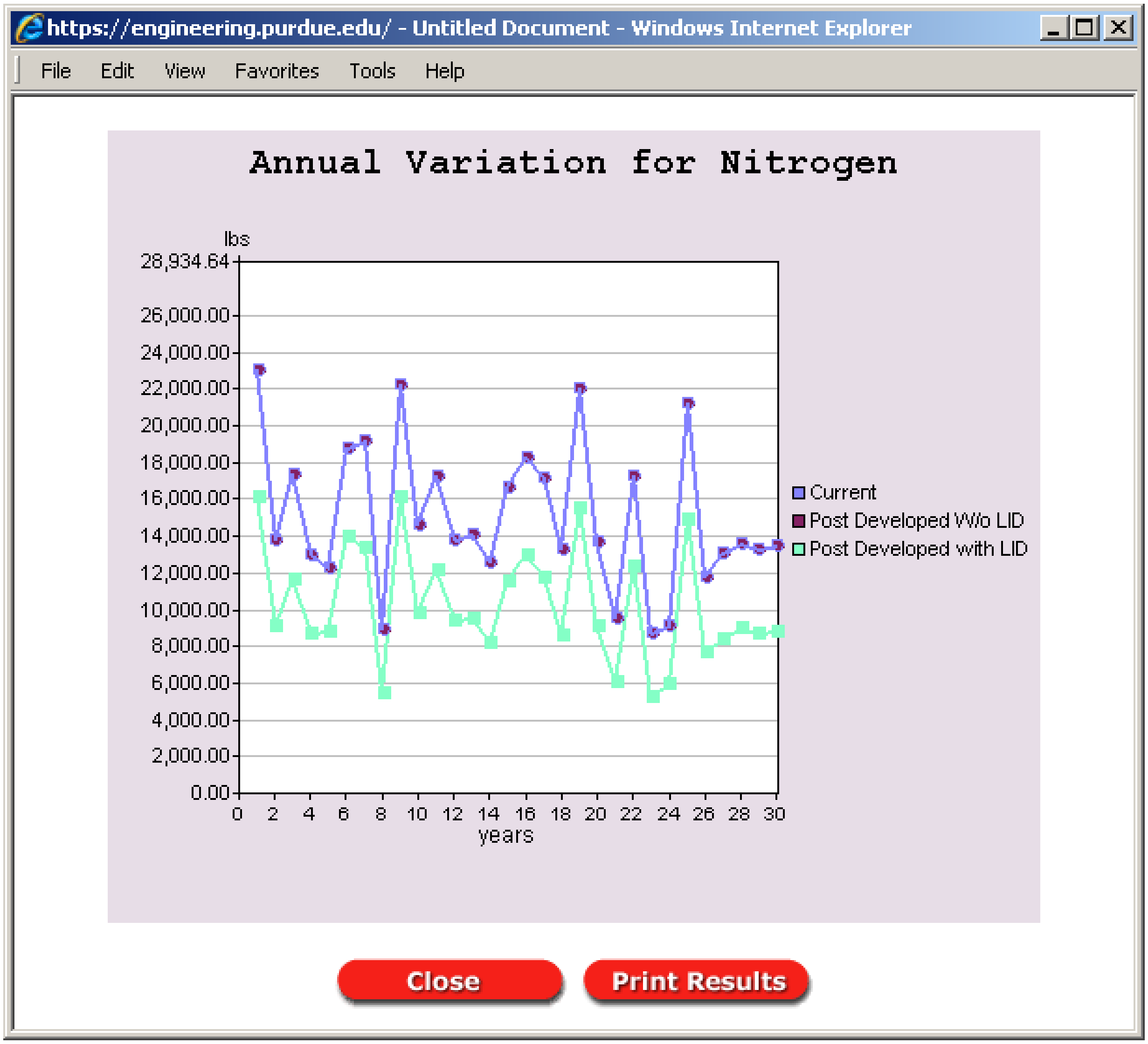


Figure 2.7 Annual Variation for Nitrogen graph created from link in results tables.

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