INSTRUCTIONS FOR DATA PREPARATION AND USE OF TSW SPREADSHEET DATA TOOL

ABSTRACT

This manual describes the technical steps to prepare new data to use in the Trees to Offset Stormwater Calculator Tool developed by the Green Infrastructure Center Inc.

Stuart Sheppard

May 24, 2019

Contents

This is the technical manual for the Trees to Offset Stormwater Project funded by the USDA Forest Service Southern Region. The Green Infrastructure Center Inc. is the technical services consultant for this project and the author of the methodology described in this document.

The work upon which this publication is based was funded in whole or in part through an Urban and Community Forestry grant awarded by the Southern Region, State and Private Forestry, U.S. Forest Service and administered by the Virginia Department of Forestry.

The Trees and Stormwater Calculator Tool

The Trees and Stormwater Calculator Tool is intended to simulate the impact of increasing or decreasing urban tree canopies upon stormwater runoff yield. The tool integrates average rainfall event data from local weather stations with high-resolution spatial (GIS) data representing land cover and soils to approximate the complex interactions of tree canopies, land surface cover, soils and storm events. The curve number method developed by the US Department of Agriculture's Natural Resources Conservation Service (NRCS) forms the basis of the model, with modifications suggested by recent studies conducted for the Chesapeake Bay Conservation program.[1] The tool was tested in 12 communities across the south and the summary report as well as case studies for each community can be found at http://www.gicinc.org/trees_stormwater.htm

Method to Determine Water Interception, Uptake and Infiltration

This study used the Natural Resources Conservation Service (NRCS) TR-55 curve number method to calculate stormwater runoff. The TR-55 method calculates stormwater runoff and absorption for different land covers, e.g. pavement, lawn, forest. This approach is widely recognized and utilized by stormwater engineers to determine stormwater runoff volumes and most cities use the TR-55 curve numbers to generate expected runoff amounts for land cover changes. It also accounts for the infiltration rate for various soils.

Major factors determining CN are:

- The hydrologic soil group (defined by surface infiltration rates and transmission rates of water through the soil profile, when thoroughly wetted)
- Land cover types
- Hydrologic condition – density of vegetative cover, surface texture, seasonal variations
- Treatment – design or management practices that affect runoff

This method used a modified TR-55 curve number equation to include a factor for canopy interception (see following equation). Trees capture some of the rainfall before it reaches the ground, while some of the rainfall goes through the branches (through fall) and down the branches and trunk of the tree (trunk flow). Ordinarily, the runoff calculation is based on soils and ignores the role that trees play in rainwater interception and evaporation. Accounting for the role that trees play in capturing, absorbing and evaporating rainfall is critical in understanding how much water is running off the land and how much is retained.

A canopy interception factor is added to the runoff equation to account for the role trees play in interception of rainfall based on location and planting condition (e.g. trees over pavement versus trees over a lawn or in a forest). Tree canopy reduces the proportion of precipitation that becomes stream and surface flow, also known as water yield. Hynicka and Divers (2016) modified the water yield equation of the NRCS model by adding a canopy interception term (Ci) to account for the role that canopy plays in capturing stormwater, resulting in:

$$R = \frac{(P - Ci - Ia)2}{(P - Ci - Ia) + S}$$

- Where R is runoff
- P is precipitation (inches)
- Ia is the initial abstraction for captured water, which is the fraction of storm depth after which runoff begins

[1] https://www.chesapeakebay.net/documents/Urban_Tree_Canopy_EP_Report_WQGIT_approved_final.pdf

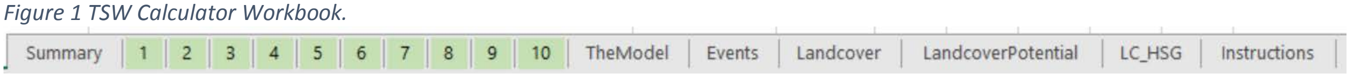
- S is the potential maximum retention after runoff begins for the subject land cover (S = 1000/CN – 10).
- Canopy interception (Ci) is subtracted from precipitation (P) to account for the water that trees take up.

In order to use the equation and model scenarios for future tree canopy and water uptake, the GIC first developed a highly detailed land cover analysis to account for the land conditions in which the trees are found (trees overhanging pavement versus trees over a lawn). This is important because rain falling though a tree (throughfall) onto a pervious surface, such as a lawn, can still be absorbed, while rain throughfall to a street or parking lot will become runoff.

The stormwater runoff model provides estimates of the capture of precipitation by tree canopies and the resulting reductions in runoff yield. It takes into account the interaction of land cover and soil hydrologic conditions. The Trees and Stormwater Calculator Tool also be used to run 'what-if' scenarios, specifically losses of tree canopy from development and increases in tree canopy from tree planting programs.

Cities can use the modified TR-55 CN from this study for modeling and development design reviews, watershed plans or for setting urban canopy goals. The Trees and Stormwater Calculator Tool makes it very easy for the user to change the curve numbers if they wish to. This TSW Calculator is also a tool for setting goals at the watershed scale for planting trees and for evaluating consequences of tree loss as it pertains to stormwater runoff. The Trees and Stormwater Calculator Tool allows the user to hypothetically add or reduce tree canopy to see what are the effects for stormwater capture or runoff. However, in order to create a calculator for a city or other area, a detailed land cover map is needed to create the inputs used in the calculator. This document describes how to do this and its intended audience is GIS analysts. For those communities who already have a TSW Calculator Tool (created by the GIC), this document provides technical details and instructions to use or modify the tool.

Figure 1 TSW Calculator Workbook.



Introduction to Calculator Setup

The TSW calculator is a Microsoft Excel Workbook with multiple tabs and fields. The calculator is built to require little input from the user, and once set up, it requires only manipulation of key variables to assess different scenarios. Scenarios can be based on amount of rainfall and potential future predictions and plans for tree canopy loss and gain.

TSW Calculator Basics

The trees and stormwater calculator requires four tables that are a result of field work, remote sensing, GIS data management and analysis. To fully achieve the potential of the calculator, high resolution inputs and multiple spatial analyses and data processes are required.

The following four tables are necessary for the TSW calculator formulas to work. There are four corresponding tabs in the workbook where these values must be pasted.

The project area in these tables should be stratified – for example by watershed or drainage basin.

1. Land Cover (by stratification unit, in acres)
2. Land Cover Potential (by stratification unit, in acres)
3. Landcover intersected with hydrologic soil groups (by stratification unit, in acres)

4. Average precipitation amounts for various storm scenarios (from the nearest weather station, in inches)

Figure 2 TSW Input table: LC by WS

LANDCOVER CROSS TABULATIONS

acres

No	AREA	TREE CANOPY	TC OVER IMPERV	PERVIOUS	WATER	IMPERVIOUS	BARE_EARTH	FORESTED OPEN SPACE	FORESTED WETLANDS	WETLAND	SAND	TOTAL
	TOTALS	55,894	3,650	109,637	63,296	83,928	5,814	187,777	3,272	30,885	876	545,057
1	Black Creek-St. Johns River	189	8	260	84	408	31	218	28	-	-	1,226
2	Doctors Lake-St. Johns River	5,655	439	9,086	7,610	8,643	511	23,043	367	18	93	55,465
3	Lower Nassau River Frontal	1,390	23	3,172	7,939	905	404	10,131	122	14,868	513	39,466
4	North Fork of Black Creek	3,527	49	12,340	710	2,779	624	24,451	223	30	-	44,733
5	Ortega River-St. Johns River	14,647	1,136	20,509	17,390	23,774	923	20,796	462	104	7	99,747
6	St. Johns River-Atlantic Ocean	14,382	1,059	26,849	20,885	25,114	1,289	38,120	1,011	14,079	253	143,042
7	Thomas Creek	1,205	21	6,722	458	1,195	442	23,960	478	589	-	35,071
8	Tolomato River	91	3	156	13	166	3	250	2	-	2	686
9	Trout Creek-St. Johns River	12,786	882	22,271	7,538	19,400	866	24,033	464	1,072	9	89,322
10	Upper St. Marys River	2,023	29	8,273	668	1,543	722	22,775	142	125	-	36,299

Figure 3 TSW Input table: LC Potential by WS

LANDCOVER POTENTIAL CROSS TABULATIONS

acres

No	BASIN	TREE CANOPY	TC OVER IMPERV	PERVIOUS	WATER	IMPERVIOUS	BARE_EARTH	FORESTED OPEN SPACE	FORESTED WETLANDS	WETLANDS	Sand	TOTAL
	TOTALS	81,154	4,730	75,545	63,163	82,795	5,676	197,195	3,042	30,871		545,038
1	Black Creek-St. Johns River	262	12	178	83	404	30	229	25	-	-	1,224.8
2	Doctors Lake-St. Johns River	7,846	539	6,142	7,596	8,537	499	23,857	335	18	92	55,460.6
3	Lower Nassau River Frontal	2,195	41	1,964	7,923	885	398	10,558	117	14,864	510	39,454.1
4	North Fork of Black Creek	5,275	97	9,644	702	2,727	611	25,434	212	29	-	44,730.6
5	Ortega River-St. Johns River	20,819	1,439	12,795	17,374	23,458	882	22,446	424	104	7	99,746.4
6	St. Johns River-Atlantic Ocean	20,862	1,358	18,411	20,843	24,804	1,257	40,233	952	14,073	248	143,041.3
7	Thomas Creek	2,185	41	5,315	453	1,175	436	24,444	436	588	-	35,072.2
8	Tolomato River	119	4	126	12	165	2	252	2	-	2	685.4
9	Trout Creek-St. Johns River	18,516	1,142	14,216	7,516	19,128	842	26,473	410	1,069	9	89,321.8
10	Upper St. Marys River	3,075	58	6,753	661	1,513	717	23,268	132	124	-	36,300.4

Figure 4 TSW Input table: LC with HSG by WS

LANDCOVER BY HYDROLOGIC SOIL GROUPS

acres

		TreeCanopy							
No	BASIN	A	A/D	B	B/D	C	C/D	D	X
	TOTALS	16,346	5,922	4,795	8,276	12,602	5,806	107	-
1	Black Creek-St. Johns River	74.97	51.43	9.96	3.40	33.54	4.71	-	
2	Doctors Lake-St. Johns River	1,798.06	618.30	601.20	457.19	1,387.17	468.84	-	
3	Lower Nassau River Frontal	856.77	135.54	132.60	10.21	204.04	-	-	
4	North Fork of Black Creek	1,067.32	1,048.89	320.73	752.94	155.30	10.48	3.69	
5	Ortega River-St. Johns River	3,421.12	1,781.32	1,366.13	1,291.51	3,946.56	2,498.23	15.78	
6	St. Johns River-Atlantic Ocean	4,868.26	998.94	926.43	1,933.34	4,125.19	671.31	8.32	
7	Thomas Creek	655.79	39.42	114.97	308.67	50.13	0.32	20.77	
8	Tolomato River	64.75	-	6.18	0.91	17.74	-	-	
9	Trout Creek-St. Johns River	3,136.39	772.92	1,118.22	2,714.45	2,631.43	2,151.80	55.69	
10	Upper St. Marys River	402.88	475.11	198.67	803.61	50.44	-	3.00	

		TreeCanopyImperv							
No	BASIN	A	A/D	B	B/D	C	C/D	D	X
	TOTALS	830	260	282	480	1,202	509	2	-
1	Black Creek-St. Johns River	3.60	0.62	0.20	0.09	3.26	0.37	-	
2	Doctors Lake-St. Johns River	156.10	46.38	37.68	27.59	113.45	40.08	-	
3	Lower Nassau River Frontal	17.22	1.42	1.71	0.24	2.52	-	-	
4	North Fork of Black Creek	11.88	15.88	3.49	11.65	5.30	0.42	-	
5	Ortega River-St. Johns River	173.54	69.06	96.39	113.55	435.59	239.11	0.66	
6	St. Johns River-Atlantic Ocean	293.34	80.75	65.40	134.78	381.65	52.92	0.18	
7	Thomas Creek	13.10	0.45	1.72	5.01	0.59	0.01	0.27	
8	Tolomato River	2.23	-	0.31	-	0.50	-	-	
9	Trout Creek-St. Johns River	151.45	38.57	72.77	176.74	258.25	176.43	0.45	
10	Upper St. Marys River	7.45	7.03	2.43	9.93	1.04	-	0.00	

		Pervious							
No	BASIN	A	A/D	B	B/D	C	C/D	D	X
	TOTALS	39,997	15,437	9,251	15,978	17,968	4,574	779	-
1	Black Creek-St. Johns River	119.64	68.36	11.63	2.99	35.62	3.69	-	
2	Doctors Lake-St. Johns River	3,447.06	730.55	1,132.86	805.63	1,850.91	340.87	-	
3	Lower Nassau River Frontal	1,718.45	219.51	334.83	26.29	599.43	-	-	
4	North Fork of Black Creek	3,918.85	3,367.21	1,093.54	2,918.70	411.47	21.07	8.94	
5	Ortega River-St. Johns River	6,779.79	4,162.71	1,461.52	1,175.92	4,480.65	1,650.39	74.97	
6	St. Johns River-Atlantic Ocean	11,171.72	2,542.91	1,841.17	2,370.81	5,836.23	566.35	117.91	
7	Thomas Creek	3,453.39	174.32	601.95	1,701.34	446.60	2.71	278.86	
8	Tolomato River	97.76	-	6.09	1.53	45.62	-	-	
9	Trout Creek-St. Johns River	7,645.38	1,960.91	1,991.53	3,806.77	4,038.05	1,988.88	283.73	
10	Upper St. Marys River	1,644.83	2,210.58	776.23	3,168.02	223.36	-	14.53	

Figure 5 TSW Input table: Storm event scenarios

Design Events & Misc Parameters		
Design Event	**P**	**Source**
1 yr / 24 hour	4.06	JACKSONVILLE INTL AP
2 yr / 24 hour	4.7	JACKSONVILLE INTL AP
5 yr / 24 hour	5.9	JACKSONVILLE INTL AP
10 yr / 24 hour	7.05	JACKSONVILLE INTL AP
25 yr / 24 hour	8.87	JACKSONVILLE INTL AP
50 yr / 24 hour	10.4	JACKSONVILLE INTL AP
100 yr / 24 hour	12.2	JACKSONVILLE INTL AP
Modeling Parameters		
Set CN Adjustments for Tree Canopy Cover	-2	our recommendation is -2
Set Canopy Interception Term	0.050	our recommendation .050
		Name: Jacksonville, Florida, USA*
		Station name: JACKSONVILLE INTL AP
		Site ID:
NOAA Precipitation Frequency Data Server (PFDS)		

The prior tables are linked to existing tabs and critical cells are referenced in calculations throughout the workbook, resulting in key rain water run off calculations by stratification unit and summarized for the entire project area. Each stratification unit in the example tables above will have a tab that is numbered corresponding to the line it references in the input table.

Note: If there are not enough tabs for the number of stratification units, simply copy and paste an existing tab then 1) rename to the tab to the number in corresponding line of the input tables 2) change cell A1 to match this number

Figure 6. TSW Table: Stratification Unit Calculations tab in the TSW Calculator.

1 Black Creek-St. Johns River

Event	P (in)	Source
10 yr / 24 hour	7.05	JACKSONVILLE INTL AP

Existing Landcover	acres	%	Q Runoff (in)	Runoff (TCF)	Capture (TCF)
Tree Canopy	189	15.4%	3.95	2,704	243
Tree Canopy over Impervious	8	0.7%	6.41	191	11
Pervious	260	21.2%	2.19	2,063	
Water	84	6.9%	7.05	2,152	
Impervious	408	33.3%	6.77	10,031	
Bare Earth	31	2.5%	4.72	530	
Forested Open Space	218	17.8%	0.96	757	2,972
Forested Wetlands	28	2.3%	4.15	426	58
Wetlands	-	-	-	-	
Sand	-	-	-	-	
totals	1,226			18,855	3,284

Potential Landcover -Increased Tree Cover	acres	%	Runoff / acre (cf)	Capture (MCF)
Tree Canopy	262	21.4%	3,765	338
Tree Canopy over Impervious	12	1.0%	274	16
Pervious	178	14.6%	1,418	
Water	83	6.8%	2,134	
Impervious	404	33.0%	9,934	
Bare Earth	30		517	
Forested Open Space	229		797	3,127
Forested Wetlands	25	2.1%	380	52
Wetlands	-	0.0%	-	
Sand	-	0.0%	-	
totals	1,225		19,220	3,534

	Formula components								
	Composite CN's	CN	S	Ia	Q	*CN*	*S*	*Ia*	*Q*
1	Tree Canopy	75.8	3.19	0.69	3.95	*77.81*	*2.85*	*0.57*	*4.31*
2	Tree Canopy over Impervious	96.0	0.42	0.13	6.41	*98.00*	*0.20*	*0.04*	*6.78*
3	Pervious	57.9	7.26	1.45	2.19				
4	Water	100.0	-	-	7.05				
5	Impervious	98.0	0.20	0.04	6.77				
6	Bare Earth	81.9	2.21	0.44	4.72				
7	Forested Open Space	43.1	13.22	2.64	0.96				*4.72*
8	Forested Wetlands	77.0	2.99	0.60	4.15				*4.72*
9	Wetlands	0.0	-	-	-				
10	Sand	0.0	-	-	-				

Matrix of Runoff Increases (inches) by Landcover Change

	Changed Landcover					
Original Landcover	P	I	W	P	I	W
Tree Canopy	-	2.82		-	0.58	
Tree Canopy over Impervious		0.37			0.02	
Forested Open Space	1.23	5.81		-	-	
Forested Wetlands		2.62	2.90		-	-

Summary Results				
Percent tree canopy			existing	38.8%
Percent Impervious			existing	35.7%
Percent of rainfall captured by trees			10 yr / 24 hour	17.4%
Rainfall captured by trees (million gallons)			10 yr / 24 hour	24.57

Summary Results				
Percent tree canopy			max	46.3%
Percent Impervious			min	35.4%
Percent of rainfall captured by trees			max	18.4%
Rainfall captured by trees (million gallons)		max	max	26.43

GOAL: Added canopy (% of total area)		42.6%
Increased H2O Capture	million gallons	0.93

What-If Scenarios

Urban tree canopy loss	10%	% UTC loss
	40%	<- Set % impervious
Additional stormwater runoff	0.60	million gallons
Forested open space loss	0%	% FOS loss
	40%	<- Set % impervious
Additional stormwater runoff	-	million gallons
TOTAL TREE CANOPY SUMMARY	4%	total canopy loss
Additional stormwater runoff	0.60	million gallons

Supporting Calcs

	acres
Area Minus Wetland and Water and Sand	1,141
Total Tree Canopy	443
Total Potential Tree Canopy	529
Total Impervious Area (inclding under TC)	416
Total Pervious Area (including TC)	697
Additional Planting Area Available	86
Urban Tree Canopy Loss	19.67
Forest Open Space Loss	-

Once the tables are in place, the calculator can be explored and changes to the variables made in the summary tab.

Figure 7: TSW Table: The summary table gives averages for the entire project area along with key fields from the stratification unit's tab.

Jacksonville,FL | Urban Tree Canopy Stormwater Model | version

The Green Infrastructure Urban Tree Canopy Stormwater Model estimates stormwater runoff yields for methodology is based upon the NRCS TR-55 method for small urban watersheds. It is used to provide t cover and modeling of potential canopy area.

				million gallons				
	TOTALS	55.8%	15.4%	13,778.6	187.2	444.7	59.7%	
	Statistics by Drainage Basin (current settings)							
	Area	Current Tree Cover	Current Impervious Cover	Tree H20 Capture	Increased H2O w/xx% tree loss	Added H2O Capture w/xx% PPA	Tree Cover Goal	Pick an Event
		%		*million gallons*			%	Event
1	Black Creek-St. Johns River	38.8%	35.7%	24.57	0.60	0.93	43%	10 yr / 24 hour
2	Doctors Lake-St. Johns River	61.8%	18.1%	1,779.38	19.53	40.04	65%	10 yr / 24 hour
3	Lower Nassau River Frontal	72.3%	5.6%	465.25	4.42	12.86	76%	10 yr / 24 hour
4	North Fork of Black Creek	64.2%	6.3%	2,137.17	10.90	49.95	67%	10 yr / 24 hour
5	Ortega River-St. Johns River	45.0%	28.9%	1,954.13	50.18	100.91	50%	10 yr / 24 hour
6	St. Johns River-Atlantic Ocean	50.6%	23.3%	2,399.51	48.55	91.58	55%	10 yr / 24 hour
7	Thomas Creek	75.4%	3.5%	1,385.82	3.73	17.52	78%	10 yr / 24 hour
8	Tolomato River	51.6%	24.7%	5.11	0.29	0.15	54%	10 yr / 24 hour
9	Trout Creek-St. Johns River	47.3%	24.0%	1,679.28	42.72	105.46	52%	10 yr / 24 hour
10	Upper St. Marys River	70.3%	4.3%	1,948.42	6.26	25.32	73%	10 yr / 24 hour

Variable			
Pick an Event	Pick a loss scenario		Converted Land
Event	% UTC loss	% FOS Loss	% Imperv
10 yr / 24 hour	10%	0%	40%
10 yr / 24 hour	10%	0%	40%
10 yr / 24 hour	10%	0%	40%
10 yr / 24 hour	10%	0%	40%
10 yr / 24 hour	10%	0%	40%
10 yr / 24 hour	10%	0%	40%
10 yr / 24 hour	10%	0%	40%
10 yr / 24 hour	10%	0%	40%
10 yr / 24 hour	10%	0%	40%
10 yr / 24 hour	10%	0%	40%

The calculator can be used to model runoff for different storm events by watershed. A drop down menu is provided and a % of urban tree canopy (UTC) loss is established by the user. So if a development plans to remove 50 percent of the trees; the impact can be determined by each storm. This approach was taken because stormwater management plans are usually created for specific storm events (e.g. the 10 year storm). However, a city could also look at impacts from larger storms, such as 25 year storm, or a much larger event.

Getting Started

The workbook includes an instructions tab which will tell a user exactly which cells or tabs need to be changed in order to customize the workbook for a specific area of interest. In other words, it shows the specific cell address that would need to be changed.

Figure 8 The TSW Calculator provides a detailed tab for instructions on how to set the workbook up and cells that require explanation have a comment field with additional information.

How to use this model

	Steps for a new analysis	Sheet	Cell
1	Enter community name	Summary	A1
2	Load landcover data	Landcover	B5:K68
3	Load landcover potential data	LoandcoverPotential	B5:K68
4	Load landcover/soils data	LC_HSG_Data	B6:CE69
5	Enter storm event data	Events	B3:D9
6	Set canopy interception parameter	Events	C12
7	Set curve number adjustment parameter	Events	C13
9	Copy basin spreadsheets	1	

NOTES

This model allows the user to modify some assumptions, drainage basin by drainage basin, and see the impact upon stormwater runoff yield and precent tree canopy.

To run different scenarios the user can change, for one or more drainage basins, the following parameters. Within each drainage basin

Parameter	Cell	Description
Storm event	C3	Precipitation from a given storm event
Ci	F14	canopy interception term
CN adjust	L64	CN adjustment for tree impact on soil
% loss	I16	Canopy loss %
% impervious	I15	% impervious of landcover after loss of
Tree canopy goal	Q16	% tree canopy set as a goal (constrained

The results will be updated autimatically on the summary tab.

Cell format legend

- Data Input
- Changeable Default (not recommended)
- Calculations
- *Explanatory*

Once the calculator inputs are in place, there are several variables that can be set to assess different scenarios. For example, to plan for the future, a user can set how much of the Potential Planting Area (PPA) they propose to plant. The GIC suggests that usually no more than 50 percent of open space might realistically be planted. From these variables, calculations will be made throughout the workbook. The variables are essentially modifiers to the calculator formulas.

Notes and instructions are provided in the workbook itself and formulas are open for inspection or editing as desired.

Figure 9 Variables have an orange background and can be set in the summary tab.

Variable						
Pick an Event	Pick a loss scenario		Converted Land			anopy Added
Event	% UTC loss	% FOS Loss	% Imperv			of Land
10 yr / 24 hour	10%	0%	40%	46.3%	7.5%	3.8%
10 yr / 24 hour	10%	0%	40%	68.2%	6.4%	3.2%
10 yr / 24 hour	10%	0%	40%	80.0%	7.7%	3.9%

For loss scenarios set % of converted land that becomes impervious. (if not sure what to use - the Current % Imperivous Cover is good estimate)

Interpreting results

The TSW calculator provides approximate estimates of stormwater runoff yield, as sheet flow before becoming channel flow, under different land cover scenarios. Soil moisture before a storm event, tree canopy density and health, types and connectedness of impervious surfaces, are among the factors that may increase or decrease the actual stormwater runoff yields and their impacts.

The Summary tab is meant to enable the user to manage scenarios and see summary results for all watershed/stratification units and the study area as a whole.

Nutrients and Sediment Loads

Tree canopy also serves to reduce nutrient loadings by both increases in nutrient uptake by additional vegetative growth and by reduction in quantity of runoff. The TSW calculator uses conservative estimates by assuming that reductions in nitrogen, phosphorus and sediment are proportional to the reduction in water yield. This likely underestimates the actual reductions by a small degree.

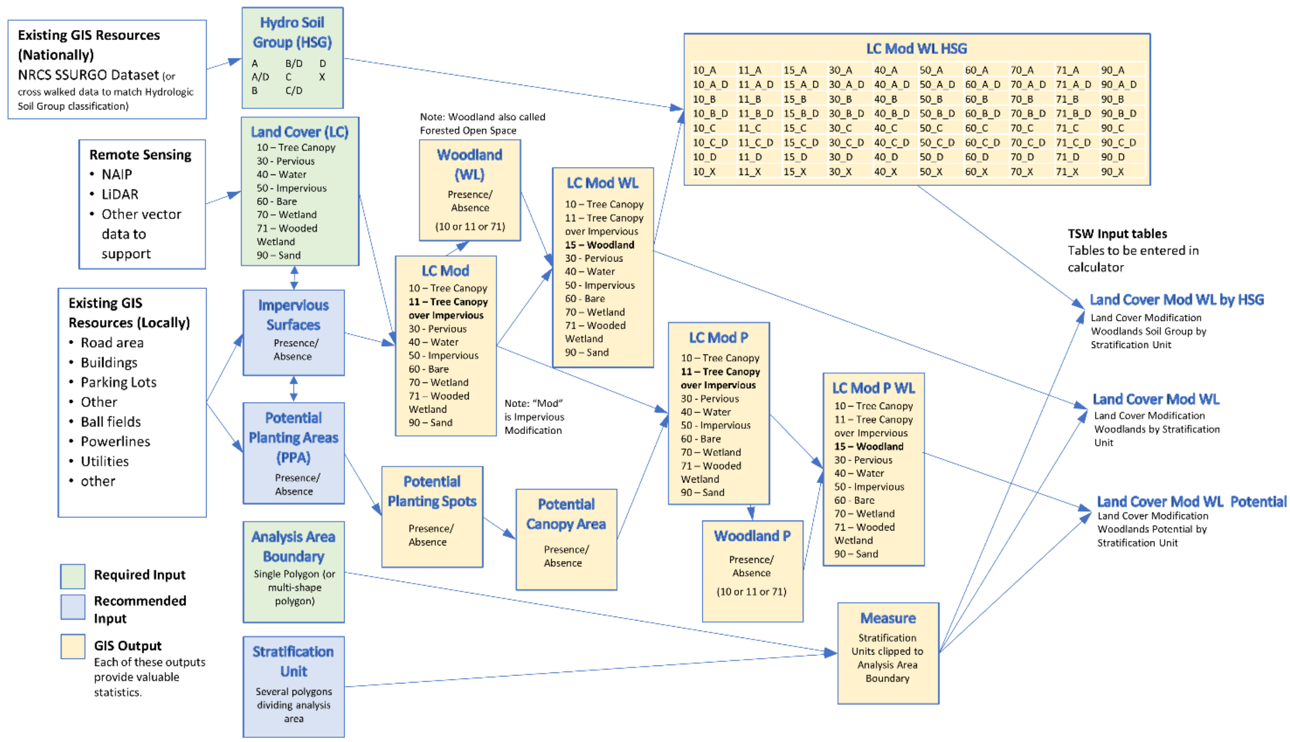
2.9%	2.9%	2.9%	1.3%	1.3%	1.3%
Statistics by Drainage Basin (current settings)					
Canopy Pollution Load % Reduction			Additional Canopy Pollution Load % Reduction		
N	P	Sed	N	P	Sed
4.1%	4.1%	4.1%	1.5%	1.5%	1.5%
2.9%	2.9%	2.9%	1.1%	1.1%	1.1%
1.1%	1.1%	1.1%	0.6%	0.6%	0.6%
1.9%	1.9%	1.9%	0.9%	0.9%	0.9%
4.4%	4.4%	4.4%	1.8%	1.8%	1.8%

Building the Trees and Stormwater Analysis and Database

The Landcover, Landcover Potential, and Landcover/Soils (LC_HSG) tabs are results of producing statistics on the intersection of the Stratification units and the land cover datasets involved. These data come from external landcover and spatial analysis. While high-resolution (1m cells) land cover data are best, useful scenarios can be run with existing landcover data even if it is not at high-resolution or lacks all the land cover classes. Detailed tree canopy classes (tree canopy over impervious, tree canopy over pervious, forested open space, and forested wetland) provide greater granularity and accuracy to the estimates, but they can be collapsed into fewer, or even one, tree canopy category if that is the only available data.

Stratification units are typically watersheds or drainage basins because they are most relevant for determining the relationship between forest cover in a watershed and impacts to the receiving waters where stormwater ends up. However, other units of analysis may be substituted, such as neighborhoods, council districts, municipal boundaries, and zoning districts.

Figure 10 Workflow for creating final TSW tables



Introduction to the Trees and Stormwater Data Preparation

The TSW Database is the GIS dataset used to create the key tables for the TSW Calculator. Key to the TSW Calculator model's results is a good landcover dataset. This project used leaf-on [2]NAIP 4-band aerial imagery, available existing planimetric vector data, and where available, LiDAR data. The project used ArcGIS 10.6 and Feature Analyst image processing tools to perform an *object-based classification.

*Object-based Classification. Object-based or object-oriented classification involves categorization of pixels based on the spatial relationship with the surrounding pixels Object based classification methods were developed relatively recently compared to traditional pixel based classification techniques.

Acquiring existing datasets

There are existing data layers publicly available to get started in building the dataset. These include the following:

[2] NAIP refers to National Agricultural Imagery Project data that consist of aerial imagery during the growing season for the United States. NAIP data are available through: https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/

- Storm event precipitation amounts provided by NOAA's Hydro meteorological Design Studies Center, Precipitation Frequency Data Server (PFDS)
- Soil hydrologic data, specifically hydrologic soils groups (HSG), are available from the USDA Natural Resources Conservation Service's SSURGO Database.
- Many states, counties or cities either host built infrastructure on their websites or support a partner in distributing building footprints, roads and other infrastructure datasets. The data available can range from basic to extensive in both classification and scale.

Other datasets such as Land Cover and Potential Planting Area usually must be created in order to use the most up to date information. In the Potential Planting Area process, a complete impervious surfaces layer is compiled from the newly created Land Cover layer and existing vector datasets. This compiled impervious surface layer is important for building detailed "planting exclusions" such as a buffer from road or buildings. Further detail can be added to the PPA process by using underground utilities and any other features that might interfere with a tree's growth or be obstructed by a tree.

Minimum and recommended GIS Inputs

The following six data layers are the recommended minimum GIS datasets that should be acquired for this analysis. Results can be achieved with only the first three datasets (HSG, LC and Analysis Boundary) however accuracy and resolution will be sacrificed as data layers are omitted and depending on implementation plan and scale will most likely not be enough.

Figure 11 Required and Recommended minimum data layers

Data Layer	Description
Hydrologic Soil Groups Required	• NRCS Natural Resources Conservation Service, United States Department of Agriculture hydrologic soils groups provided in the SSURGO database. • Will be intersected with Land Cover types and their combination will calculate the Curve Number used for estimating runoff rates.
Land Cover Required	• Basic Land Cover layer - created from Leaf-on imagery. • Methods section will discuss the Land Cover process and classification.
Analysis Boundary Required	• The boundary polygon for the analysis area. One single polygon (or multipart polygon) that represents the area that will be the denominator for percent values. (i.e.: the area is 35% Tree Canopy for the city of X)
Stratification Units Recommended	• This layer is optional because the calculator will still get results without it. The results will be only to the analysis boundary extent if no stratification units are used. • Stratification units are sub-boundary polygons that divide the area into manageable sub-units. For example, Watersheds or Neighborhoods.
Impervious Surfaces Recommended (expected basic Impervious surfaces are in Land Cover)	• This layer is optional because results can still be achieved without it. However, the "Tree Canopy over Impervious" detail will be lost and although it only influences the TSW calculations a little – this value can also be thought of as a quality of life indicator.

Data Layer	Description
	• This layer represents any concrete or otherwise impervious surface; such as buildings, roads and parking lots. This layer will be used to create a land cover class called Tree Canopy over Impervious. • Possible to use Road Centerlines to estimate road width so can get tree canopy over impervious features that were not visible in creation of land cover map if road areas do not exist. • Not all impervious surfaces exist in planimetric data and not all impervious surfaces are visible with leaf on imagery. Therefore a combination of the two is most informative.
Potential Planting Area Recommended	• This layer is listed as optional because it is essentially an intermediate data layer for creating the potential canopy. At the very minimum, the "pervious" and "bare earth" features from the landcover layer can be used instead of the relatively intensive process necessary to create the potential planting area. • The PPA is created from intersecting possible areas to plant then subtracting obstacles (or exclusion areas) that would impede a tree's growth. • The methods section will go into detail for creating a PPA layer. At the very minimum, it can be created from the Land Cover classes Pervious and Bare. In other words use, Pervious or Bare earth as the potential planting area.

Creating the Minimum GIS inputs

Hydrologic Soil Groups (HSG)

The hydrologic soil group is from NRCS (Natural Resources Conservation Service) dataset. The field hydrgrpcd gives values based on soil type's runoff potential.

Hydrgrpcd (from SSURGO Database) can be acquired by joining MUPOLGON to table MUAGGATT using MUSYM field. The field you will need is called Hydgrpdcd with Alias Hydrologic Group - Dominant Conditions. The Natural Resource Conservation Service classifies soils into four Hydrologic Soil Groups based on their runoff potential. The Hydrologic Soils Groups are A, B, C and D ranging from A with the smallest runoff potential up until D soils with the greatest. For more see 'Urban Hydrology for Small Watersheds' at https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf published by the Engineering Division of the Natural Resource Conservation Service, United States Department of Agriculture, Technical Release–55.

- Group A is sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission.
- Group B is silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly or moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

- Group C soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.
- Group D soils are clay loam, silty clay loam, sandy clay, silty clay or clay. This HSG has the highest runoff potential. They have 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 clay pan or clay layer at or near the surface and shallow soils over nearly impervious material.

Land Cover (LC)

The Land Cover dataset uses a simple classification scheme that is appropriate for stormwater analysis. It is based on land cover rather than a more generalized land use classification (e.g. commercial, residential, open space, etc.).

To prepare data for the Trees and Stormwater Calculator Tool, land cover was created using 1-meter spatial resolution NAIP four-band aerial imagery and existing vector data from published sources. LiDAR was very valuable for mapping tree canopy and impervious surfaces – such as new buildings. LiDAR also allows for clarification of differences between trees and small bushes with tree canopy. For example, by using a height threshold, vegetation can be classed as over or under 20 feet. If LiDAR is close to the same data as the NAIP image it is possible to use the NIAP alone to calculate vegetation presence. Then LiDAR can be used to show- vegetative features above X ft. (e.g. 15 feet) tall and then classify those features as trees. If it shows a feature that is below that height but green, it is pervious. If not vegetation and above threshold height, it is a building, and if below, then it is pavement.

GIC used ArcGIS Feature Analyst (by Textron Systems) and ArcGIS 10.6. Scripts were created using ArcGIS model builder and are available with the Trees and Stormwater Calculator Toolbox.

Following is a description of initial landcover classification. Class 11. Tree Cover over Impervious and 71. Forested Open Space/Woodland will be added in future steps. When creating the land cover map, one can use more classes than the following and collapse the categories to this simple classification during post processing. This is because some features might have local variables that can affect how they should be considered in the TSW calculator. For example, sandy hard packed trail is no different than impervious surface in terms of water infiltration.

Class Code	LC Class	Notes
10	Tree Canopy	• ‘Canopy over impervious’ class will be added later • If LiDAR data are available, during the remote sensing process classify any vegetation (possibly calculated by NDVI) above a certain height (for example 12 feet) as Tree Canopy and vegetation below 12 feet as the general class of pervious.
30	Pervious	• Any vegetation not ‘Tree Cover’.
40	Water	• If vector data already exist, it is useful to add existing water class. • Using NDVI can produce good results for finding standing water such as small ponds that could complement existing data. • Sometimes, using both of above inputs with manual verification is necessary.

		There may be significant confusion between water and dark pavement, shadows and sometimes the accuracy of existing data – such as NHD Waterbodies – of an insufficient scale in the area of interest.
50	Impervious surfaces	• This layer is usually created by combining existing vector data and remote sensing results. • The vector data here are the same as that found when creating the PPA exclusions – make sure the 'Impervious' class is coincident in both the PPA Exclusions and the Land Cover data layers.
60	Bare earth	• Bare earth is a class that can be interpreted as several different features. Spectrally, several different features might be identified as bare ground, but practically, they might be very different. For example, unplanted crop land vs land cleared for a construction site. • A good practice is to identify critical differences. Assign bare earth features that are NOT PPA a class of 61 so they can easily be pulled from the Land Cover data and put into the PPA dataset.
70	Wetland	• Wetland data are available from the National Hydrography Dataset as Wetland (and Wooded Wetland) classes. Both of these classes can be used in the final land cover dataset and Wooded Wetland will be counted as Tree Canopy. This can be revised using LiDAR if available. (If a feature classified as wooded wetland does not meet tree height requirement, then re-class simply as wetland). Check this dataset carefully against imagery and other resources. • The National Wetlands Inventory can also be used but it misses many wetlands and misidentifies other open waters.
71	Wooded Wetland	• Wooded Wetland can sometimes be identified spectrally but can be identified where Tree Cover is over wetland vector data. (for example from NWI as stated above) • The NHD dataset has a class called wooded wetland.
90	Sand	• Sand (e.g. bare ground) can be many features. In the beginning of the mapping process it is important (as for any class) to plan what features are identifiable, where there might be confusion, and then define a rule for it. For example, a sand road is different than sand on the beach – A sand road or parking lot is best classified as impervious or pervious depending on its' local context - and beach sand (or sand on a golf course) should be classified as sand.

Analysis Boundary

The analysis boundary is most commonly a municipal boundary (such as a city, town or county) but can be as small as city block. An analysis boundary may be an area for an implementing agency or for a plan, such as a watershed boundary or a master plan.

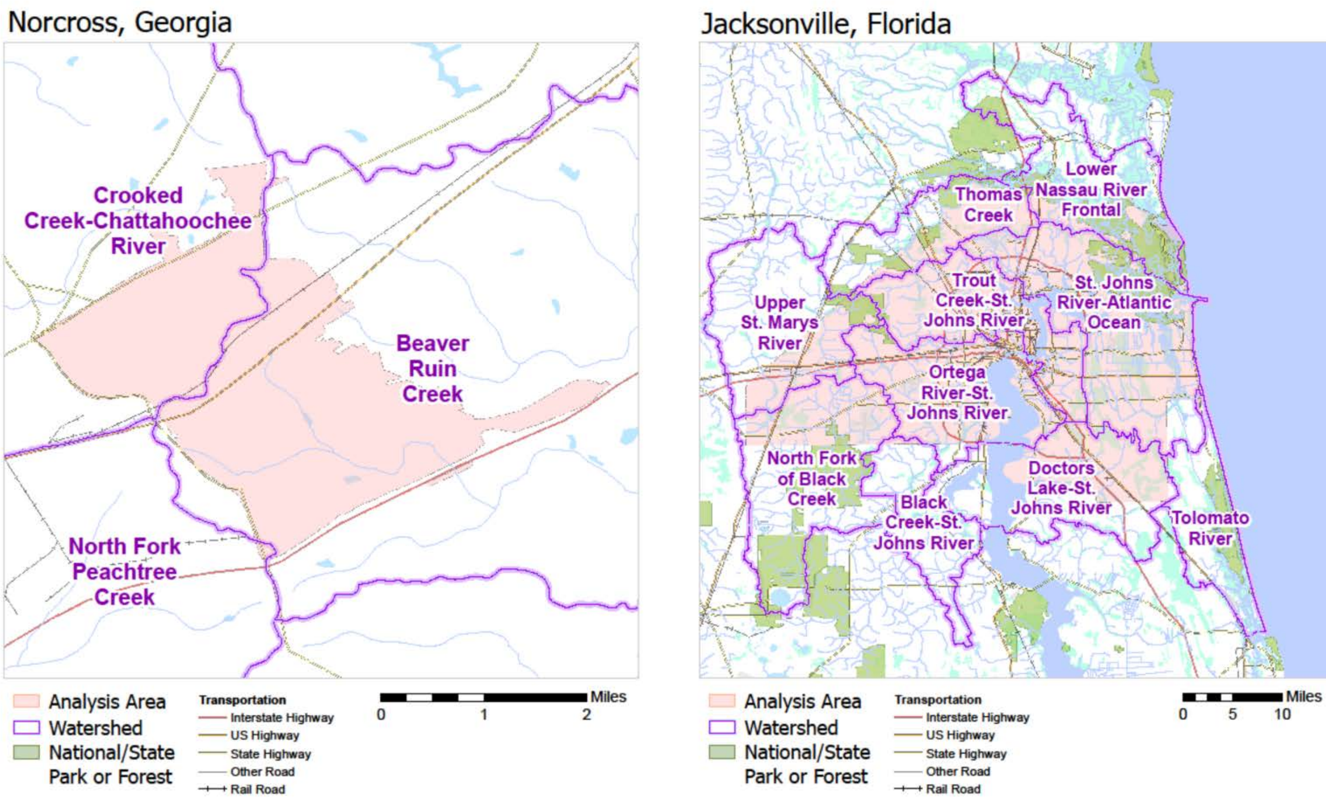
In selecting the Analysis Boundary and Stratification units, the relationship can be thought of at multiple scales. A stratification unit (such as a watershed) can also be used as an analysis boundary at a smaller scale.

Stratification Units

If the analysis boundary is too large, then interpreting results might not be useful. A reasonable number of smaller stratification units can be useful for computational efficiency and providing information about spatial differences in tree canopy and stormwater impacts across the analysis area. Project goals and implementation strategies should be thought of when choosing stratification units. The TSW calculator tool creates average curve numbers across a watershed so the smaller the unit of analysis (e.g. using a Hydrologic Unit Code (HUC) 10 instead of a HUC 6) may produce more accurate results.

Watersheds were the stratification units used for the TSW study. HUC 12 was the most often used boundary, but HUC 10 was used for large areas.

Figure 12 Norcross used HUC 12 vs Jacksonville using HUC10



Impervious Surfaces

This layer represents any paved or otherwise impervious surface, such as buildings, roads and parking lots. It is used to create a land cover class called 'Tree Canopy Over Impervious' and is also used in the PPA process.

This data layer can be compiled from existing planimetric datasets. In the land cover mapping process, its inputs can inform the land cover map. Also, the impervious surfaces layer itself might be expanded as features are extracted from the satellite imagery. The final "impervious surfaces" layer can be created most efficiently in the PPA process when selecting both the vector inputs and relevant impervious classes from land cover classification.

This feature is identified as a separate layer because it can be compiled from and contributes to other datasets.

Potential Planting Area (PPA)

The PPA process begins by determining land cover types that can be planted. Usually this includes pervious land cover and bare earth (depending on how the bare earth class was defined). These plantable land cover features are then buffered "in" to a safe plantable distance from surrounding features. From that the infrastructure, utilities and other features to be excluded from possible planting spots are buffered "out" and then subtracted from the plantable land cover features.

Although PPA could be created simply by using the pervious land cover features and applying a buffer of about 10 feet or 3 pixels (or shrink in raster analysis) in order to avoid conflicts with other features, this is not sufficient for detailed planning.

Creating an accurate PPA layer can involve intense analysis. Data layers from utilities and public works are necessary and ultimately could include every dataset that represents features on, under or above the ground that might interfere with a tree's growth, such as overhead power lines. The data are then buffered depending on various criteria (set buffer distances such as 10 feet from a building) and subtracted from the pervious land cover features that would otherwise be available for planting.

Planimetric data should exist in a city database but these data are usually out of date. The existing planimetric data represent areas where trees should not be planted. These features should be buffered based on existing regulations.

Following is a list of possible inputs. Since every city operates and manages their data differently, this list can vary. Some features can be identified in the land cover mapping process.

- Digitized Exclusions
    - Manual Exclusions – Any areas manually digitized that are known to be inappropriate for planting trees (e.g. land just outside an airport runway).
- Infrastructure and Impervious Surfaces
    - Buildings
    - Railroads
    - Road Area – Can model road area estimates from centerline if necessary
    - Other Impervious Surfaces – any impervious surfaces.
- Sports and Recreation Areas– Established Ball fields and school playgrounds where trees cannot be planted.
    - Athletic fields
    - Golf courses
- Utilities and Restricted Land Use– Utilities underground or above ground that might interfere with tree growth.
    - Sewer line
    - Storm water pipes
    - Best management practices (e.g. those that interfere with trees)
    - Overhead transmission lines
    - Landfills

Data Layer	Description
Leaf-on - Satellite/Aerial Image	✓ This project used NAIP 1-meter resolution 4 band leaf on imagery to create the landcover map. It is free from USDA.
Hydrologic Soil Groups	✓ NRCS Natural Resources Conservation Service
Land Cover	✓ If existing land cover does not exist it can be created from the leaf-on imagery. o Features/LC Classification ▪ Tree Canopy* ▪ Pervious ▪ Bare earth ▪ Impervious ▪ Water ▪ Wetlands ▪ Wooded Wetlands* * Used in calculating Tree Canopy. (Note Water and Wetlands are not used in the denominator for calculating percent of land area that is Tree Canopy.)
Analysis Boundary	✓ e.g. city boundary or some other area of interest
Stratification Units	✓ Watersheds ✓ Other zones of interest
Impervious Surfaces	✓ Road area ✓ Buildings ✓ Parking lots ✓ Any other impervious surfaces data
PPA Exclusions	✓ Impervious surfaces ✓ Digitized Exclusions ▪ Any areas manually digitized that are known to be a bad place for planting trees such as a fairground. ✓ Infrastructure and Impervious Surfaces ▪ Buildings ▪ Railroads ▪ Road area – Can model road area estimates from centerline if necessary ▪ Other impervious surfaces ✓ Sports and Recreation Areas– Established Ball fields and school playgrounds where trees cannot be planted. ▪ Athletic fields ▪ Golf courses ✓ Utilities and Restricted Land Use– Utilities underground or above ground that might interfere with tree growth. ▪ Sewer line ▪ Storm water pipes ▪ BMPs ▪ Overhead transmission lines ▪ Landfills
Optional: **LiDAR**	✓ Not required but highly recommended if available (even if old data)
Optional: **Existing Outdated Land Cover map**	✓ Often much of the base data can be extracted (e.g. roads and water)
Optional: Supporting **vector base data** that can be used in Land Cover or PPA mapping process	✓ Tree inventories ✓ Water (lakes and large rivers) ✓ Any other land use data that could support or verify classification

GIS Data Checklist

At the beginning of a project it is important to determine any data limitations and available resources needed to fill critical gaps. The following is a checklist for a complete dataset to compile when starting the process. If all data are not available, there are “work arounds” which will be discussed.

GIS Outputs and resulting tables

Once the above minimum inputs are created, the following outputs can be developed.

Figure 13 Output datasets and brief on process

Dataset	Description
LCMod	Land Cover Impervious Modification is the land cover dataset intersected with impervious surfaces dataset to create a class that shows where Tree Canopy is over Impervious surfaces. o Features/LC Classification ▪ Tree Canopy* ▪ Tree Canopy over impervious* ▪ Pervious ▪ Bare earth ▪ Impervious ▪ Water ▪ Wetlands * Used in calculating Tree Canopy. (Note Water and Wetlands are not used in denominator for calculating percent of areas that is Tree Canopy.)
Woodlands / Forested Open Space	Tree Canopy where the core area of the forest block is greater than 1 acre. Also known as forested open space (FOS).
LCModWL	Land Cover Impervious Modification with woodlands added manually. Note the woodlands class will be created from the core area of Tree Canopy, Tree Canopy over Impervious and wooded wetland. o Features/LC Classification ▪ Tree Canopy* ▪ Tree Canopy over impervious* ▪ Pervious ▪ Bare earth ▪ Impervious ▪ Water ▪ Wetlands ▪ Wooded Wetlands* ▪ Woodland/Forested Open Space* (includes forest cores greater than 1 acre made up from TC, TC over Impervious and Wooded Wetland) * Used in calculating Tree Canopy. (Note Water and Wetlands are not used in denominator for calculating percent of areas that is Tree Canopy.)
PPA	The Potential Planting Area (PPA) is created by selecting the land cover features that have space available for planting trees, then eliminating areas that would interfere with existing infrastructure.
PPS	The Potential Planting Spots (PPS) are created from the PPA. The potential planting areas (PPA) is run through a GIS model that selects spots a tree can be planted depending on the size trees desired.

	Potential Planting Spots spacing for future tree canopy to be 20 and 40 ft diameter. (used to estimate number of trees possible to plant) Scenario used was 20 and 40 ft diameter trees with 30% overlap in the full grown canopy.
PCA	The Potential Canopy Area (PCA) is created from the PPS. Once the possible planting spots are given a buffer around each point that represents a tree's mature canopy is created. For this analysis they are given a buffer radius of 10 or 20 ft that results in 20 and 40 ft tree canopy. Potential Canopy Area is the result of buffering the potential planting spots to get the projected canopy area.
LCModP	Land Cover Impervious Modification has the Potential Canopy Area burned in. o Features/LC Classification ▪ Potential Tree Canopy* ▪ Potential Tree Canopy over impervious* ▪ Pervious ▪ Bare earth ▪ Impervious ▪ Water ▪ Wetlands * Used in calculating Potential Tree Canopy. (Note Water and Wetlands are not used in denominator for calculating percent of areas that is Tree Canopy.)
WoodlandsP (Potential)	Where Tree Canopy block will be greater than 1 acre once grown to fullest extent
LCModPWL	Land Cover Impervious Modification Potential with woodlands burned in**. (TSW calculator input)** o Features/LC Classification ▪ Potential Tree Canopy* ▪ Potential Tree Canopy over impervious* ▪ Pervious ▪ Bare earth ▪ Impervious ▪ Water ▪ Wetlands ▪ Wooded Wetlands* ▪ Potential Woodland/Forested Open Space* (includes forest cores greater than 1 acre made up from TC, TC over Impervious and Wooded Wetland) * Used in calculating Tree Canopy. (Note Water and Wetlands are not used in denominator for calculating percent of areas that is Tree Canopy.)
LCModWLHSG	Land Cover Impervious Modification with woodlands intersected with hydrologic soil group. Result is every combination that exists in nature between landcover types and soil types.
Measure	Analysis area stratified for reporting purposes.

Figure 14 TSW Input tables

Table	Description
LCModWLHSG byStrat	LCModWLHSG stratified by user defined units.
LCModWL byStrat	LC Mod WL stratified by user defined units.
LCModPWL byStrat	LC Mod P WL stratified by user defined units.

Processing the data

The following section details methods used in data creation. These notes can be used as reference but are not necessarily a complete script. Data differences and availability need to be addressed on a case by case basis.

LCMod (Land Cover Impervious Modification)

LCMod is created by intersecting the Land Cover's Tree Canopy class with Impervious Surfaces to get new class called Tree Canopy over Impervious.

The Impervious Surface features for this process usually does not come from the remote sensing data alone – in the land cover mapping process only impervious surfaces that are visible from the platform of the camera are mapped. Road Area and buildings are the two most important datasets to acquire because they are the ones most frequently under canopy. If parking and other planimetric data exist this is preferred, but those classes (which are visible to sensor above) can come from the remotely sensed land cover layer.

- If Land Cover = "Impervious Surface" and ("Tree Canopy" or "Wooded Wetland") THEN Calc "Tree Canopy over Impervious Surfaces"

Figure 15 Tree Canopy over Impervious surfaces is added to land cover classification.

Woodlands / Forested Open Space

Woodlands are created by selecting classes (10,11 and 71) Tree Canopy, Tree Canopy over Impervious and Wooded Wetland from the LCMod layer. These features are then dissolved to represent continuous forest blocks. (Note at this point a decision can be made to include or exclude tree canopy over impervious – if Tree Canopy over impervious is included it could result in less and/or smaller woodland polygons) The forest blocks are then buffered in 30 feet (10 meters) and then buffered out the same amount. From the buffered area only greater than 1 acre is kept. This is in order to isolate large blocks from thin "fingers" that are not highly viable forest.

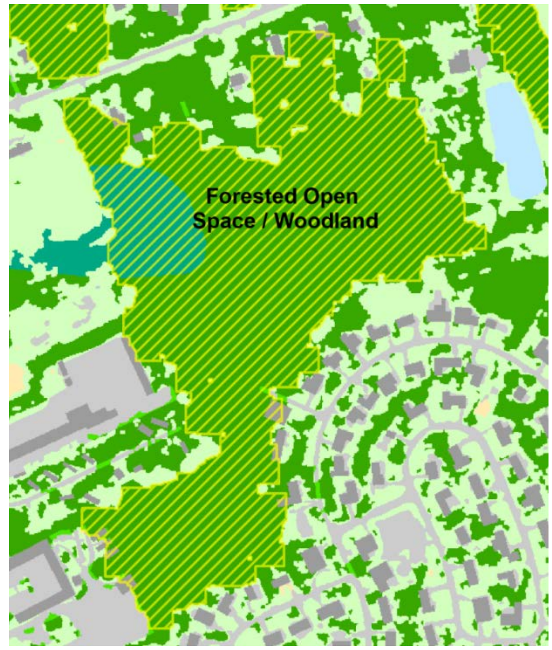


Figure 16 Forest Open Space are large blocks of continuous forest.

LCModWL

Woodlands are then burned into the LCMod classification. The LCMODWL is the dataset that will go into the TSW Calculator. Note Wooded Wetland, Tree Canopy and Tree Canopy over Impervious are possible to be reclassified as Woodland.

Potential Planting Spots - PPS

Potential planting spots are created by resampling the pixel size for potential planting area raster to the projected diameter of the trees expected to be planted. For the TSW process we modeled to achieve 20 and 40-foot diameter canopy's when fully grown and a 30% overlap.

To do this:

1. Resample the PPA raster twice; once to be 16 foot and a second to be 32 foot pixels with nearest neighbor resampling method. (note 16 and 32 are 30% of 20 and 40) The resampled data will have a pixel only if its center is over the finer resolution PPA pixel. This means small areas will not have a new pixel. The results for 16 foot pixels will cover more small places than the 32-foot pixel results.
2. Keep all 40 foot pixels and all 20 foot pixels where there is no 40-foot pixel.
3. Convert the rasters to points (center of pixel) and then merge the two point layers for the final PPS.

Potential Canopy Area - PCA

The PCA is created by buffering the Potential Planting Spots out to their fullest grown potential. So the points that come from the 16ft pixel process will be buffered to 20ft and the 32ft pixel results will be buffered to 40ft. (use buffer option with attribute value). Then dissolve this layer for the final modeled tree canopy.

In order to model the tree canopy for coming years (rather than one date in future) a multiring buffer process can be used.

LCModP

The land cover mod potential dataset is created by merging the PCA with the existing LCMOD dataset. Impervious that has modeled canopy over it should be changed to Tree Canopy over impervious.

WoodlandsP (Potential)

Woodlands are created by selecting classes (10,11 and 71) Tree Canopy, Tree Canopy over Impervious and Wooded Wetland from the LCModP layer. These features are then dissolved to represent continuous forest blocks. The forest blocks are then buffered in 30 feet (10 meters) and then buffered out the same amount. From the buffered area only greater than 1 acre is kept. This is in order to isolate large blocks from thin "fingers" that are not highly viable forest.

LCModPWL

Potential Woodlands are then burned into the LCMod classification. The LCMODPWL is the dataset that will go into the TSW Calculator. Note Wooded Wetland, Tree Canopy and Tree Canopy over Impervious are possible to be reclassified as Woodland.

LCModWLHSG

This layer is created by intersecting (or combine in raster) the LCMODWL layer and the Hydrologic Soils Group layer. A new field is then created and the attributes of each layer are concatenated into a unique new field. For example: Tree Canopy_A, Tree Canopy_B….

Creating the TSW input tables

There are four input tables necessary for the calculator to give results. Three of those tables come from the GIS datasets above. LCModWL, LCModPWL and LCModWLHSG.

The stratification units clipped by the analysis boundary will create a "measures" layer that can be used with a GIS command comparable to Tabulate Areas in ArcGIS. The result is a matrix format with stratification units along the vertical axis and the land cover or potential land cover or the land cover/HSG combination along the top.

LCModWL, LCModPWL will look like this:

	Tree Canopy	Tree Canopy over impervious	Pervious	Bare earth	Impervious	Water	Wetlands	Wooded Wetlands	Woodland/Forested Open Space
Stratification Unit 1									
Stratification Unit 2									
Stratification Unit 3									

LCModWLHSG will look like this

	Tree Canopy				Tree Canopy over Impervious				Continued……
	A	B	C	D	A	B	C	D	A
Stratification Unit 1									
Stratification Unit 2									
Stratification Unit 3									

The fourth table must be populated from the data found at the NOAA Precipitation Frequency Data Server (PFDS) website.

Figure 177 Events table with information for TSW Calculator Events table..

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.292** (0.264-0.325)	**0.349** (0.315-0.389)	**0.424** (0.381-0.471)	**0.477** (0.427-0.528)	**0.543** (0.483-0.601)	**0.590** (0.521-0.653)	**0.635** (0.557-0.706)	**0.678** (0.589-0.756)	**0.729** (0.624-0.818)	**0.767** (0.649-0.867)
10-min	**0.467** (0.421-0.519)	**0.559** (0.503-0.622)	**0.678** (0.610-0.754)	**0.763** (0.683-0.845)	**0.865** (0.770-0.957)	**0.939** (0.830-1.04)	**1.01** (0.885-1.12)	**1.08** (0.934-1.20)	**1.15** (0.988-1.29)	**1.21** (1.02-1.37)
15-min	**0.584** (0.527-0.649)	**0.702** (0.632-0.782)	**0.858** (0.772-0.954)	**0.965** (0.864-1.07)	**1.10** (0.976-1.21)	**1.19** (1.05-1.32)	**1.28** (1.12-1.42)	**1.36** (1.18-1.51)	**1.45** (1.24-1.63)	**1.52** (1.28-1.71)
30-min	**0.800** (0.722-0.889)	**0.970** (0.874-1.08)	**1.22** (1.10-1.36)	**1.40** (1.25-1.55)	**1.62** (1.45-1.80)	**1.79** (1.58-1.98)	**1.95** (1.71-2.17)	**2.11** (1.84-2.35)	**2.31** (1.98-2.59)	**2.45** (2.08-2.77)
60-min	**0.998** (0.900-1.11)	**1.22** (1.10-1.36)	**1.56** (1.41-1.74)	**1.82** (1.63-2.02)	**2.16** (1.93-2.39)	**2.43** (2.15-2.69)	**2.69** (2.36-2.99)	**2.96** (2.57-3.30)	**3.31** (2.84-3.72)	**3.58** (3.04-4.05)
2-hr	**1.16** (1.05-1.29)	**1.41** (1.28-1.57)	**1.82** (1.65-2.02)	**2.13** (1.92-2.37)	**2.55** (2.28-2.82)	**2.87** (2.55-3.18)	**3.20** (2.82-3.56)	**3.54** (3.09-3.95)	**3.98** (3.41-4.47)	**4.31** (3.65-4.88)
3-hr	**1.25** (1.14-1.39)	**1.51** (1.37-1.69)	**1.94** (1.76-2.16)	**2.27** (2.05-2.52)	**2.71** (2.43-3.01)	**3.06** (2.72-3.40)	**3.42** (3.02-3.81)	**3.78** (3.30-4.23)	**4.27** (3.66-4.81)	**4.64** (3.92-5.26)
6-hr	**1.57** (1.42-1.75)	**1.88** (1.71-2.11)	**2.38** (2.15-2.66)	**2.78** (2.50-3.10)	**3.34** (2.99-3.72)	**3.80** (3.37-4.24)	**4.28** (3.75-4.78)	**4.78** (4.13-5.37)	**5.48** (4.64-6.20)	**6.03** (5.02-6.86)
12-hr	**1.92** (1.74-2.18)	**2.31** (2.08-2.61)	**2.90** (2.61-3.29)	**3.41** (3.04-3.85)	**4.14** (3.66-4.67)	**4.75** (4.15-5.36)	**5.41** (4.66-6.13)	**6.13** (5.19-6.96)	**7.16** (5.91-8.22)	**8.01** (6.48-9.27)
24-hr	**2.39** (2.22-2.59)	**2.89** (2.68-3.13)	**3.67** (3.40-3.97)	**4.31** (3.98-4.66)	**5.23** (4.82-5.65)	**6.01** (5.49-6.48)	**6.83** (6.21-7.37)	**7.72** (6.96-8.32)	**8.99** (8.01-9.69)	**10.0** (8.84-10.8)
2-day	**2.80** (2.60-3.02)	**3.38** (3.14-3.65)	**4.27** (3.96-4.60)	**4.99** (4.61-5.37)	**6.02** (5.54-6.48)	**6.86** (6.29-7.38)	**7.75** (7.06-8.33)	**8.69** (7.87-9.36)	**10.0** (8.97-10.8)	**11.1** (9.84-12.0)
3-day	**2.99** (2.77-3.23)	**3.62** (3.35-3.91)	**4.55** (4.21-4.91)	**5.31** (4.90-5.72)	**6.38** (5.87-6.88)	**7.27** (6.65-7.82)	**8.19** (7.45-8.83)	**9.17** (8.29-9.89)	**10.5** (9.42-11.4)	**11.6** (10.3-12.6)
4-day	**3.19** (2.95-3.44)	**3.85** (3.56-4.16)	**4.83** (4.47-5.22)	**5.63** (5.20-6.08)	**6.75** (6.20-7.28)	**7.67** (7.01-8.27)	**8.64** (7.85-9.32)	**9.65** (8.70-10.4)	**11.1** (9.87-12.0)	**12.2** (10.8-13.2)
7-day	**3.69** (3.43-3.96)	**4.43** (4.12-4.76)	**5.51** (5.12-5.92)	**6.37** (5.90-6.82)	**7.55** (6.97-8.09)	**8.50** (7.81-9.10)	**9.47** (8.66-10.2)	**10.5** (9.53-11.3)	**11.9** (10.7-12.8)	**13.0** (11.6-14.0)
10-day	**4.23** (3.96-4.51)	**5.07** (4.74-5.40)	**6.21** (5.80-6.61)	**7.08** (6.60-7.53)	**8.25** (7.67-8.77)	**9.16** (8.49-9.75)	**10.1** (9.31-10.7)	**11.0** (10.1-11.7)	**12.2** (11.2-13.1)	**13.2** (12.0-14.1)
20-day	**5.67** (5.36-6.03)	**6.75** (6.37-7.18)	**8.09** (7.62-8.60)	**9.14** (8.59-9.71)	**10.5** (9.87-11.2)	**11.6** (10.9-12.4)	**12.7** (11.8-13.6)	**13.8** (12.8-14.7)	**15.3** (14.0-16.3)	**16.3** (14.9-17.6)
30-day	**7.02** (6.65-7.40)	**8.29** (7.86-8.75)	**9.74** (9.21-10.3)	**10.8** (10.2-11.4)	**12.3** (11.6-12.9)	**13.4** (12.6-14.1)	**14.4** (13.5-15.2)	**15.4** (14.4-16.3)	**16.7** (15.5-17.7)	**17.7** (16.3-18.8)
45-day	**8.86** (8.43-9.29)	**10.4** (9.92-10.9)	**12.1** (11.5-12.6)	**13.3** (12.6-13.9)	**14.8** (14.1-15.5)	**16.0** (15.1-16.7)	**17.1** (16.1-17.9)	**18.1** (17.0-19.0)	**19.4** (18.1-20.4)	**20.3** (18.9-21.4)
60-day	**10.6** (10.1-11.1)	**12.4** (11.9-13.0)	**14.1** (13.5-14.8)	**15.4** (14.7-16.1)	**17.0** (16.2-17.8)	**18.2** (17.3-19.0)	**19.2** (18.3-20.1)	**20.2** (19.2-21.2)	**21.4** (20.2-22.4)	**22.1** (20.9-23.3)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Defining the planning unit and stratification boundary

In defining the planning area and stratification units used it is important to address implementation vs ecological influences. Levels of detail in watersheds HUC 10 vs HUC12 were dependent on local scales.

Data Layer	Option1	Option2
Analysis Boundary	Political Unit - Town/City - County - Neighborhood	Single Watershed
Stratification Units	Watersheds	-Micro Watersheds -Neighborhoods -Planning Areas
Hydrologic Soil Groups	HSG	HSG
Potential Planting Area	PPA	PPA
Land Cover	LC	LC

Each project's analysis boundary and stratification units used in the 12-community study were decided on in consultation with the implementing team.

Figure 18. Stratification Units used for TSW Analysis in each locality.

Locality	Analysis Boundary	Stratification Units
APH	City	Watershed HUC 12
APX	City	Watershed HUC 12
AUB	City	Watershed HUC 12
CHS	City	City Provided Watersheds at various scales throughout city
HBG	City	Watershed HUC 12
JAX	Duval County (including municipalities)	Watershed HUC 10
LBG	City	Watershed HUC 12
MIA	City	Based on Islands
NRC	City	Watershed HUC 12
NRF	City	City Provided Watersheds at various scales throughout city
ORA	County	City Provided Watersheds at various scales throughout city
WLM	City	Watershed HUC 12

Data classification and quality notes

It's important to note the inputs for the TSW Calculator can be developed depending on data availability, project needs and implementation strategies. Even if there is an existing land cover map, it needs to have been created with imagery that is taken when trees are not dormant – leaf on – so that canopy can be determined.

Data such as Land Cover and Potential Planting Areas follow the "what you put in is what you get out" rule although if there are limitations in funding or personnel the best available data can provide a good starting point to be updated as data collection is available to fill in gaps identified in the first iteration.

Land Cover

Cross walking an existing land cover dataset will give results but scale and data currency must be considered. Most importantly, any land cover dataset will need to be classified to ensure that tree canopy is broken out by the settings in which the trees are found. Classes such as Tree Cover over Impervious will need to be specified so they can be input into the calculator tool.

Figure 19 Levels in LC Classification

<table>
<tr><th>Land Cover</th><th>Land Cover Impervious Modification</th><th colspan="2">Land Cover Impervious Modification with Woodlands</th></tr>
<tr><td rowspan="2">Tree Canopy</td><td>Tree Canopy</td><td>Tree Canopy</td><td rowspan="3">Forested open space / woodland</td></tr>
<tr><td>Tree Canopy over Impervious</td><td>Tree Canopy over Impervious</td></tr>
<tr><td>Wooded Wetland</td><td>Wooded Wetland</td><td>Wooded Wetland</td></tr>
<tr><td>Pervious</td><td>Pervious</td><td colspan="2">Pervious</td></tr>
<tr><td>Impervious</td><td>Impervious</td><td colspan="2">Impervious</td></tr>
<tr><td>Bare earth</td><td>Bare earth</td><td colspan="2">Bare earth</td></tr>
<tr><td>Sand</td><td>Sand</td><td colspan="2">Sand</td></tr>
<tr><td>Wetland</td><td>Wetland</td><td colspan="2">Wetland</td></tr>
<tr><td>Water</td><td>Water</td><td colspan="2">Water</td></tr>
</table>

Note: Wooded wetland can be created by intersecting where there is Tree Cover and where vector data shows wetland. (This is noted because otherwise the land cover may become "swamp (as it was classified in Norfolk) or "tree canopy" and it's important to not underestimate canopy just because it occurs within a wetland.

Although the calculator is meant to use the Land Cover Impervious Modification with Woodlands, it is possible to get results if classes are missing 1) because they just don't exist and 2) if some classes have been collapsed.

The land cover map was combined with a map of hydrologic soil groups (source: NRCS SSURGO) to calculate areas of landcover within each soil hydrologic group. The area counts were used to assign composite curve numbers for each drainage basin and landcover combination. The table below provided the curve numbers used for each land cover/soil group combination.

Curve Number

The runoff curve number is used in the NRCS TR-55 formula for estimating surface runoff yield. This nonlinear formula estimates runoff yield for a given precipitation event using a parameter, referred to as the curve number, which varies with existing land cover category and soil type. Lower curve numbers result in lower amounts of runoff, <u>so lower is better with curve numbers</u> when looking to

Major factors determining CN are:

- The hydrologic soil group (defined by surface infiltration rates and transmission rates of water through the soil profile, when thoroughly wetted)
- Land covers types – bare earth, pavement, trees etc.
- Hydrologic condition – density of vegetative cover, surface texture, seasonal variations
- Treatment – design or management practices that affect runoff

This study modified the TR-55 curve number equation to include a factor for canopy interception (see following equation). Trees capture some of the rainfall before it reaches the ground, while some of the rainfall goes through the branches (throughfall) and down the branches and trunk of the tree (trunk flow). Ordinarily, the runoff calculation is based on soils and ignores the role that trees play in rainwater interception and evaporation. Accounting for the role that trees play in capturing, absorbing and evaporating rainfall is critical in understanding how much water is running off the land and how much is retained.

When comparing two land covers, one with and one without tree canopy (and on the same soil), the differences in the curve number parameter can be used to approximate the relative effectiveness of trees in mitigating stormwater runoff. For example, we could compare a forested land cover before development with the same area after development that is now 40% buildings and pavement, 30% open lawns, and 30% tree cover. For a well-drained soil (Group A) the pre-development forest would have an estimated curve number of 30 and the post-development area a curve number of 62, an increase of 32. For a 4-inch storm, the runoff yield would increase from 0.3 inches pre development, to 3.5 inches post-development.

Land Cover	*Curve Numbers from TR-55*						
	A	A/D	B	B/D	C	C/D	D
Tree Canopy	**78**	**78**	**59**	**78**	**72**	**78**	**78**
Trees over Impervious	**96**	**96**	**96**	**96**	**96**	**96**	**96**
Forested wetland	77	77	77	77	77	77	77
Forested open space	30	77	55	77	70	77	77
Pervious	39	80	61	80	74	80	80
Impervious	98	98	98	98	98	98	98
Bare Earth	77	94	86	94	91	94	94
Wetlands	100	100	100	100	100	100	100
Water	100	100	100	100	100	100	100
Sand	77	94	86	94	91	94	94

Curve numbers assigned to the calculator tool may be changed by the user when there is adequate reason to do so such as knowledge of different soil types or other local situations.

If there are questions on the data preparation methods in this document please contact sheppard@gicinc.org To learn more about the Trees to Offset Stormwater Project please visit:

http://www.gicinc.org/trees_stormwater.htm