URBAN TREE CANOPY

ASSESSMENT

CHARLOTTESVILLE, VIRGINIA

MARCH | 2022

PLANIT GEO™
mapping a greener future

AN ASSESSMENT OF URBAN TREE CANOPY IN CHARLOTTESVILLE, VIRGINIA

It's the little things citizens do.

That's what will make the difference.

My little thing is planting trees.

-Wangaari Mathai

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PREPARED FOR
City of Charlottesville, Virginia

COMPLETED
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2,771
ACRES OF CANOPY

40%
OF CHARLOTTESVILLE WAS COVERED BY TREE CANOPY IN 2018

EXECUTIVE SUMMARY

The urban forest in Charlottesville is a valuable asset providing residents and visitors with many environmental, social, and economic benefits. This assessment mapped urban tree canopy (UTC), possible planting area (PPA), and tree canopy changes from 2014 to 2018 and analyzed how they are distributed throughout the City and its property ownership, parcels, planning neighborhoods, and right-of-way.

PROJECT METHODOLOGY

The results, based on 2018 and 2014 imagery from the USDA's National Agriculture Imagery Program (NAIP), provide a current and historical look at land cover in Charlottesville and will allow the City to revise and develop existing and new strategies to protect and expand the urban forest. A prior land cover assessment (2014) used 2014 NAIP aerial imagery and object-based image analysis techniques to map and calculate tree canopy and land cover metrics.

However, this study used modern machine learning techniques to create land cover data that are more reproducible and will allow for a more even comparison the next time tree canopy and land cover are assessed.. A point-based analysis was also used to assess the canopy levels from the years 1974 and 1957.

CHARLOTTESVILLE'S URBAN FOREST

In 2018, Charlottesville had 40% urban tree canopy cover and 22% possible planting area, not including any surface water bodies within the city. The City's total land cover contained 40% tree canopy, 23% non-canopy vegetation; 1% soil/dry vegetation; 36% impervious surfaces, and >1% water. The 2,771 acres of tree canopy in Charlottesville provide a multitude of economic, environmental, and social benefits, valued at just under $15 million annually.

Of the 19 planning neighborhoods in Charlottesville, Barracks/Rugby had the highest canopy coverage at 58%. However, the Greenbrier neighborhood contained the most canopy, overall, containing 427 acres or 15% of all canopy in the City. The Ridge Street neighborhood contained the greatest potential for canopy expansion, offering 188 acres (26% PPA by area and 12% of the City's total plantable space).

URBAN TREE CANOPY CHANGE

Results from the 2014 assessment indicated there was 45% tree canopy cover in Charlottesville in 2014. This study found that canopy cover changed from 45 to 40% from 2014 to 2018 (-5% or 381 acres) using the current city boundary. Private lands saw a 7% decrease while canopy on public lands decreased in canopy by 3%. Canopy cover within the CRHA (Charlottesville Redevelopment and Housing Authority) decreased by 5%. The overall decrease is due, in part, to the City's stream restoration and Meadow Creek Interceptor projects, as well as development within several neighborhoods throughout the City. Parcels included in the stream line restoration area lost 3% canopy cover.

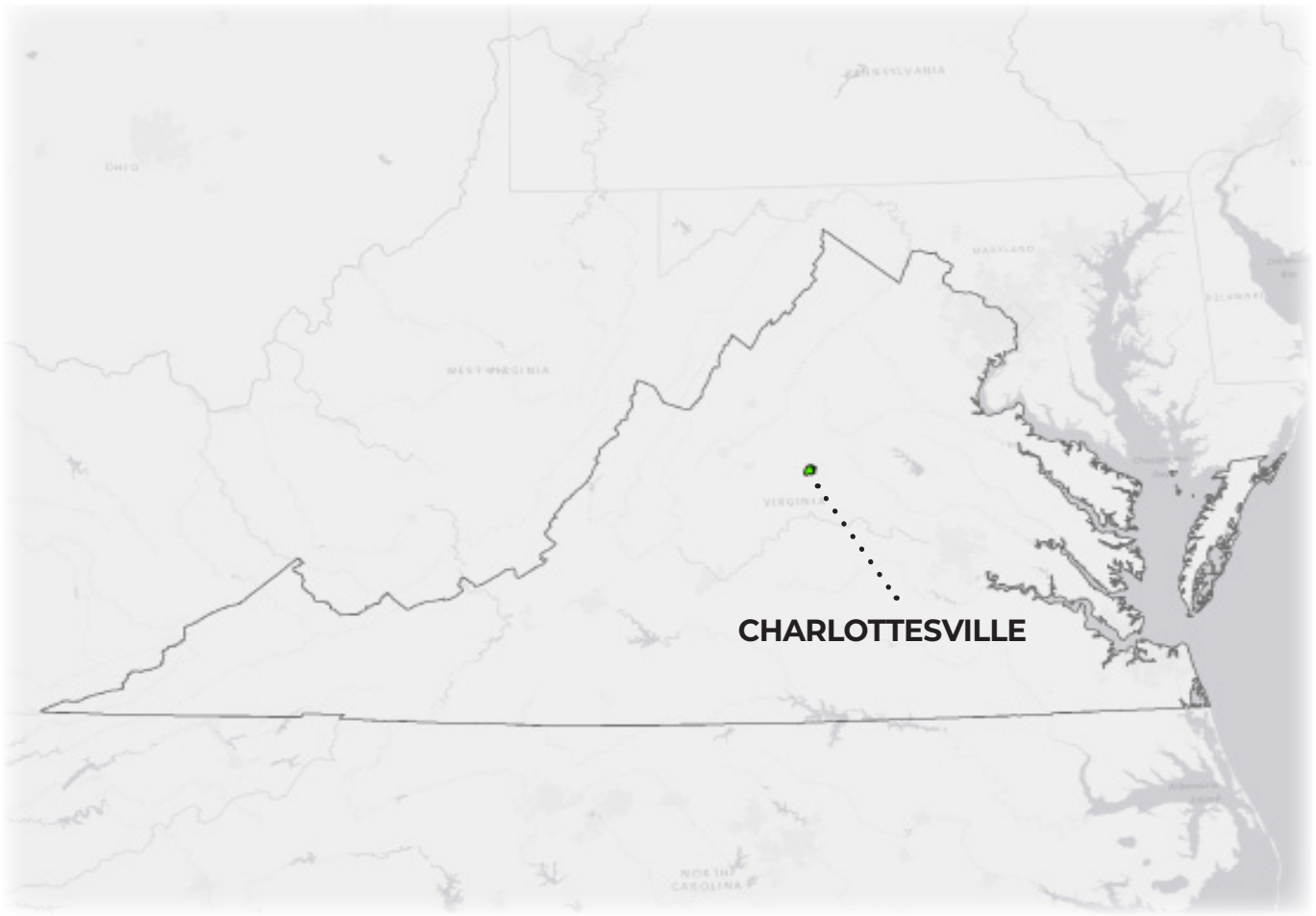


Figure 1. Charlottesville occupies approximately 10 square miles in central Virginia.

PUTTING THE DATA TO WORK

The results of this analysis can be used to develop plans to protect and expand the urban forest in Charlottesville. The UTC and PPA maps and data in this report can be used as a guide to determine where the City has been successful in protecting and expanding its urban forest while also targeting areas to concentrate future efforts based on needs, benefits, and available planting space. Charlottesville can use these results to ensure that their urban forest policies and management practices continue to prioritize its maintenance, health, and growth.

40%
URBAN TREE CANOPY

22%
POSSIBLE PLANTING AREA

36%
IMPERVIOUS SURFACE

Figure 2. Based on an analysis of 2018 high-resolution imagery, Charlottesville contains 40% tree canopy, 22% areas that could support canopy in the future, and 36% total impervious areas.

PROJECT METHODOLOGY

Land cover, urban tree canopy, and possible planting areas were mapped using the sources and methods described below. These data sets provide the foundation for the metrics reported at the selected geographic assessment scales.

DATA SOURCES

This assessment utilized high-resolution (60-centimeter) multispectral imagery from the U.S. Department of Agriculture's National Agriculture Imagery Program (NAIP) collected in 2018 to derive the land cover data set. The NAIP imagery was used to classify all types of land cover.

MAPPING LAND COVER

The land cover data set is the most fundamental component of an urban tree canopy assessment. Tree canopy and land cover data from the EarthDefine US Tree Map (https://www.earthdefine.com/treemap/) provided a five class land cover data set. The US Tree Map is produced using a modern machine learning technique to extract tree canopy cover and other land cover types from the latest available 2018 NAIP imagery. These five classes are shown in Figure 3 and described in the Glossary on page 24.

Figure 3. Five (5) distinct land cover classes were identified in the 2018 tree canopy assessment: urban tree canopy, other non-canopy vegetation, bare soil and dry vegetation, impervious (paved) surfaces, and water.

CLASSIFYING URBAN TREE CANOPY

The EarthDefine US Tree Map was then used as a mask to extract generalized tree species composition using a Normalized Difference Vegetation Index (NDVI), supervised training, and an iterative machine learning approach. Generalized tree species composition mapping was performed at a scale to classify larger groves of trees but not individual trees. There were no accuracy standards required or assessed for this classification.

IDENTIFYING POSSIBLE PLANTING AREAS AND UNSUITABLE AREAS FOR PLANTING

In addition to quantifying Charlottesville's existing tree canopy cover, another metric of interest in this assessment was the area where tree canopy could be expanded. To assess this, all land area in Charlottesville that was not existing tree canopy coverage was classified as either possible planting area (PPA) or unsuitable for planting.

Possible planting areas were derived from the non-canopy vegetation layer. Unsuitable areas, or areas where it was not feasible to plant trees due to biophysical or land use restraints (e.g. golf course playing areas, recreation fields, utility corridors, etc.) were manually delineated and overlaid with the existing land cover data set (Figure 4 on the next page).

Other PPA and planting site exclusions included varying width buffers around railroad right-of-way, existing trees and buildings, recent tree plantings, overhead and underground utilities, alleyways, and the Meadow Creek Interceptor. The final results were reported as PPA Vegetation, Unsuitable Vegetation, Unsuitable Impervious, Unsuitable Soil, and Water.

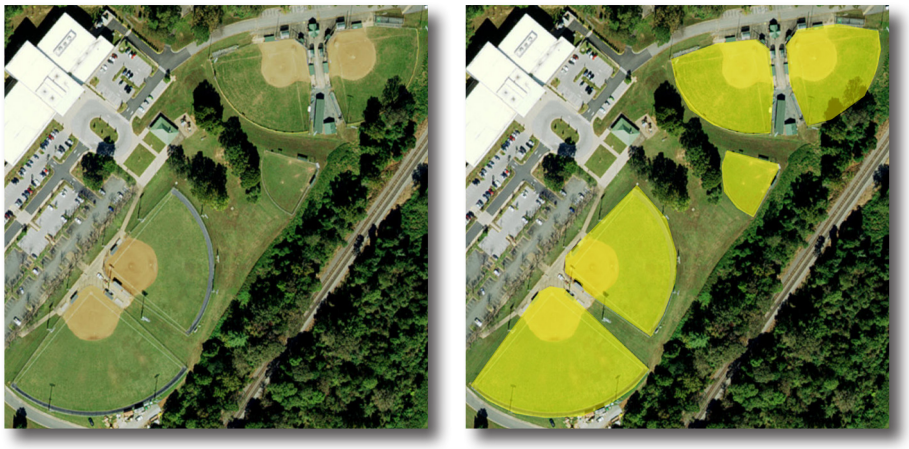


Figure 4.
Vegetated areas where it would be biophysically feasible for tree plantings but undesirable based on their current usage (left) were delineated in the data as "Unsuitable" (right). These areas included recreational sports fields, golf courses, and other open space.

URBAN TREE CANOPY CHANGE ANALYSIS

Tree canopy change between 2014 and 2018 was also analyzed across the same geographic assessment boundaries described in the previous section. The City hired PlanIT Geo in 2015 to perform a tree canopy assessment using 2014 NAIP aerial imagery. Results from that assessment indicated there was 45% tree canopy cover in Charlottesville at the time. To measure the changes that have occurred since then, the City decided to re-assess canopy and land cover data using 2018 NAIP imagery and a more modern and repeatable mapping technique that takes advantage of recent technological advancements in artificial intelligence, computer vision, and machine learning.

Urban tree canopy change was also assessed for the years 1957 and 1974 using a point-based analysis. This involved the use of 1,600 randomly distributed points to identify the presence or absence of canopy in both years using historical imagery obtained from the University of Virginia Library. Percent UTC cover was derived based on the total canopy points compared to non-canopy points, and change was assessed by the difference in canopy percentages. This technique yielded a 1.2% standard error in the UTC estimates for both 1957 and 1974.

URBAN HEAT MAP OVERLAY

Pre-existing urban heat island data from the Trust for Public Land was used to identify local hotspots where tree plantings can be focused to help cool hotter areas in the city. This heat map data set was created using the thermal band of a Landsat 8 satellite image collected in the summer of 2018 and 2019. The mean surface temperature within the City was calculated. Areas that are 1.25 F° or greater than the citywide average were then categorized from low to high severity based on a Jenks Natural Breaks classification scheme. Planting sites were created within a refined version of the PPA classification which removed utilities, railroad right of-way, and existing & recently planted trees. Each site was then assigned a value based on the heat severity of where the point was located. The average severity at the planning neighborhood scale was then calculated and correlated with tree canopy cover to identify areas that could benefit from the cooling shade that additional trees can provide.

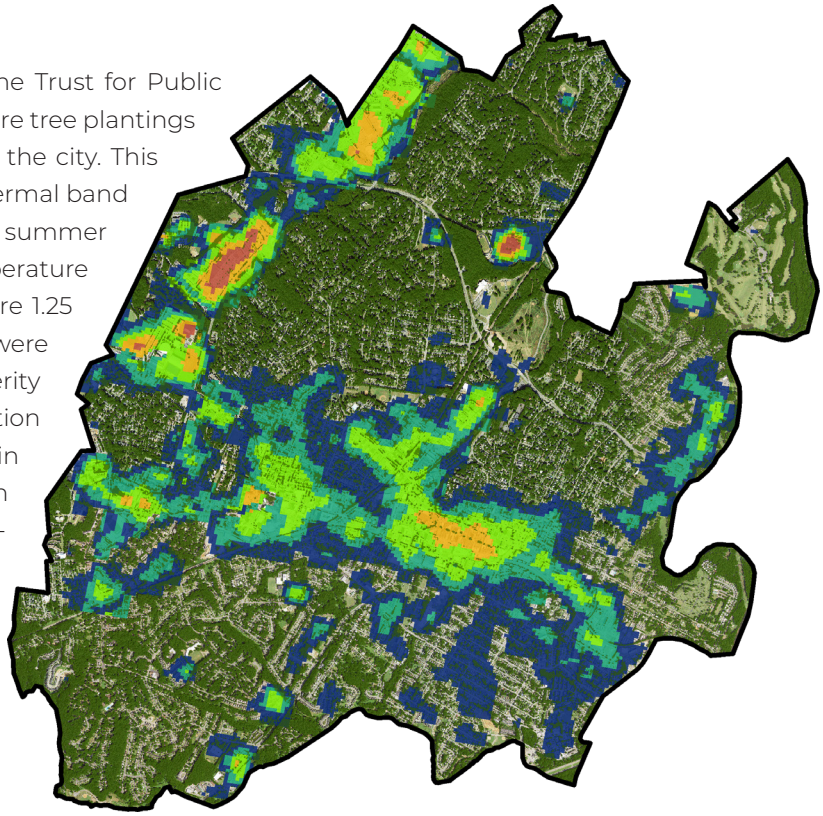
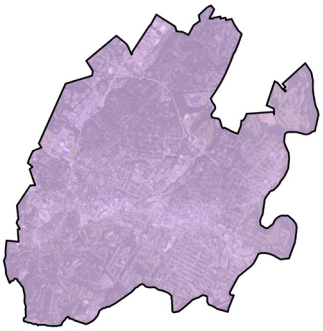


Figure 5. Trust for Public Land urban heat island severity.

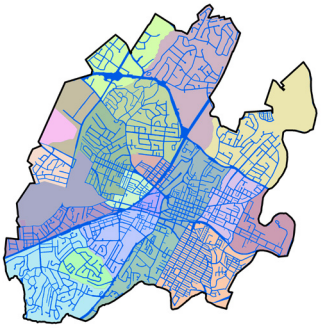
DEFINING ASSESSMENT LEVELS

In order to best inform the City of Charlottesville's various stakeholders, urban tree canopy and other associated metrics were tabulated across a variety of geographic boundaries. These boundaries include the city boundary, property ownership, planning neighborhoods, right-of-way (citywide and within each planning neighborhood), and parcels..



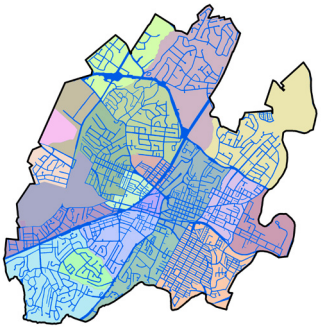
City Boundary

The City of Charlottesville **citywide boundary** is the one (1) main area of interest over which all metrics are summarized.



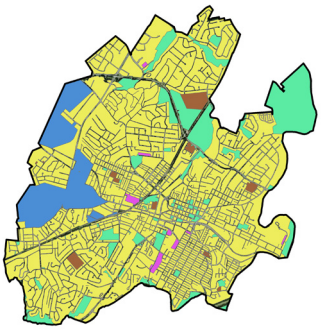
Planning Neighborhoods

Planning Neighborhoods include twenty one (21) areas for which the UTC results were summarized. This reflects the 19 Planning Neighborhoods of Charlottesville plus two remaining areas within the University of Virginia campus. While the UVA areas are not within the purview of the City to implement change, they were included since they are within the City limit.



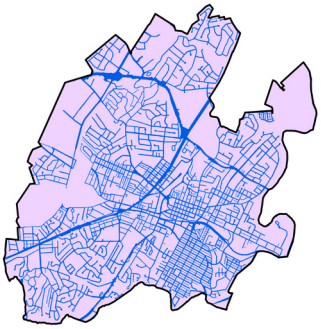
Right-of-Way by Planning Neighborhoods

Right-of-Way by Planning Neighborhoods further dissects the ROW areas by each of the twenty one Planning Neighborhoods so the City can get a better idea of where to focus efforts within the publicly managed land across these different boundaries.



Property Ownership

Property ownership summarizes parcels by ownership type, including schools, city-owned parcels, University of Virginia (UVA) campus property, Charlottesville Redevelopment & Housing Authority (CRHA), and privately owned lands. This allows for the distinction between public and private property, in addition to right-of-way.



Right-of-Way

Right-of-Way (ROW) reports the UTC results within ROW for the entire city, identified as any area not covered by parcels. It should be noted that not all space identified by this study as ROW is city-owned. Some of the area is private alleys and others may be VDOT or railroad company controlled which may limit potential planting area.

Parcels

The smallest unit of analysis was **parcels**, of which there were over thirteen thousand (13,937) in total. This unit is helpful for assessing the canopy on an individual piece of property.

STATE OF THE CANOPY AND KEY FINDINGS

The results and key findings of this study, including the tree canopy cover map and canopy analysis results, are presented below. These results can be used to design a strategic approach to identifying existing canopy and future planting areas. Land cover percentages are based on the total area of interest while urban tree canopy, possible planting area, and unsuitable percentages are based on land area. Water bodies are excluded from land area because they are typically unsuitable for planting new trees without significant modification.

Table 1. Land cover classes in acres and percent in the City of Charlottesville.

City of Charlottesville	Acres	% of Total
City Boundary	7,006	100%
Tree Canopy	2,771	40%
Non-Canopy Vegetation	1,610	23%
Impervious Surfaces	2,512	36%
Soil & Dry Vegetation	86	1%
Water	26	<1%

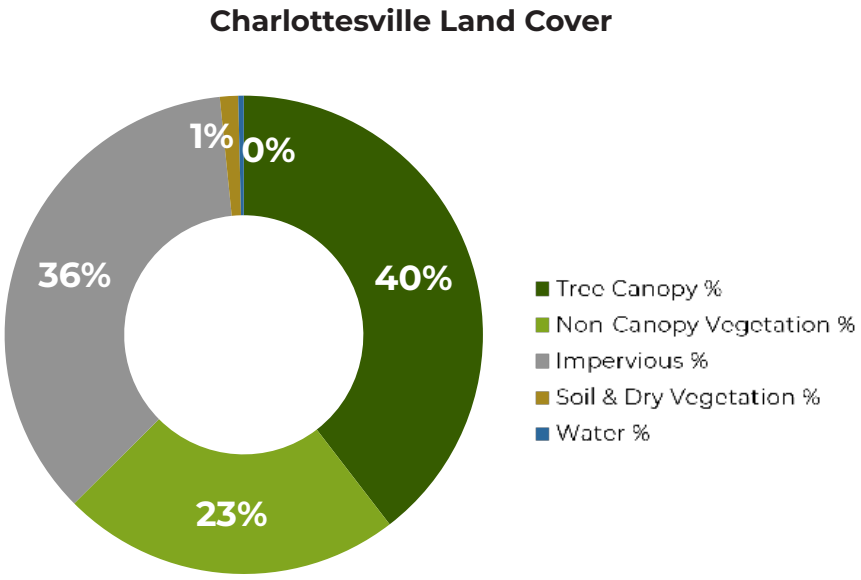
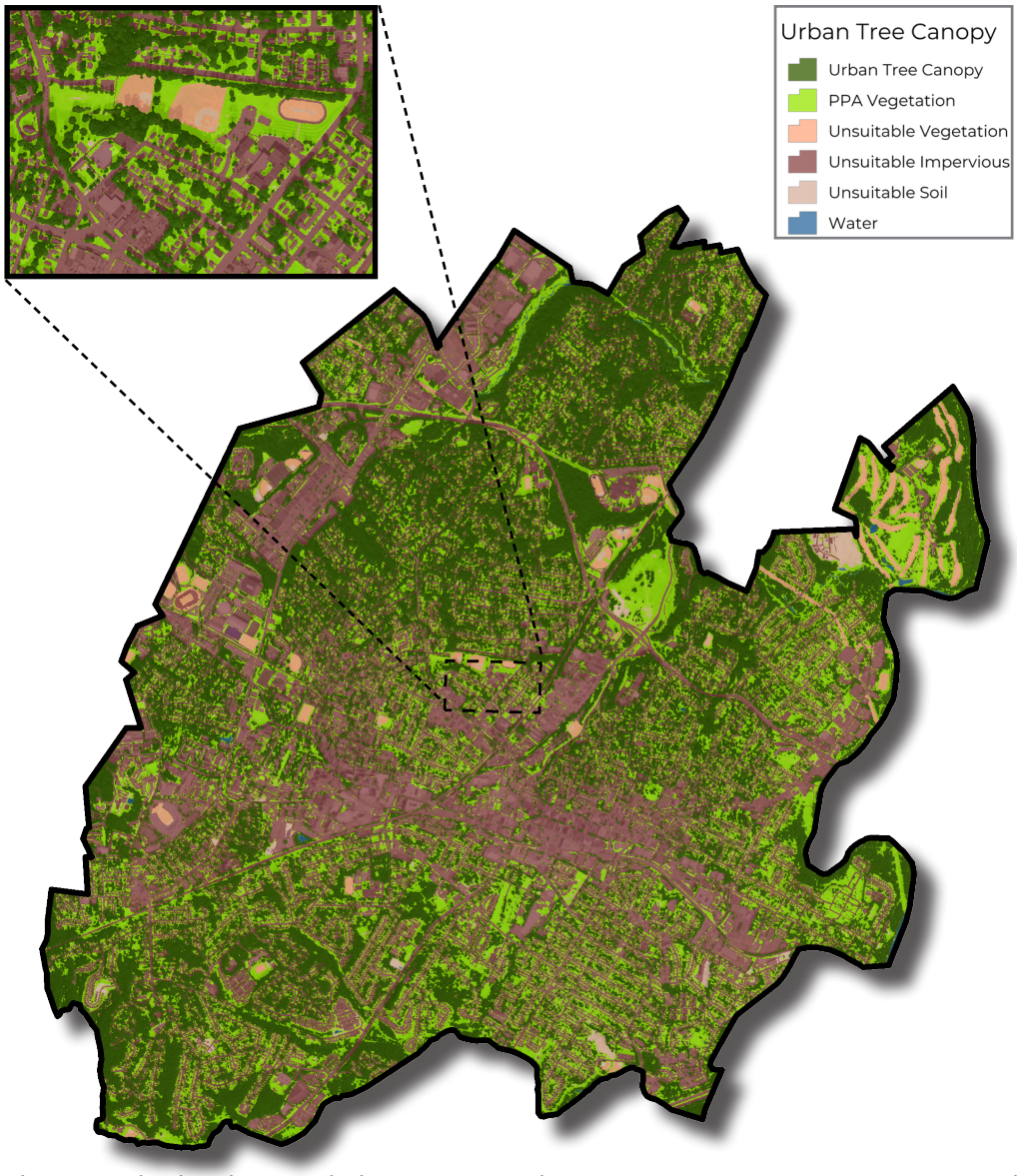


Figure 6. Land cover classes in percent of total area in Charlottesville, VA.

CITYWIDE URBAN TREE CANOPY

This urban tree canopy assessment utilized the land cover data as a foundation to determine possible planting areas throughout the City. Additional layers and areas to be excluded from plantable space were also incorporated into the analysis (e.g., 30 ft. buffer around the Meadow Creek Interceptor sewer line project). Note that the results of this study are based on land area, which excludes water bodies, as opposed to total area, which includes water bodies. Results of this study indicate that within the City of Charlottesville, 2,771 acres are covered with urban tree canopy, making up 40% of the City's 6,980 land acres; 1,505 acres are covered with other vegetation where it would be possible to plant trees (PPA), making up 22% of the City; and the other 2,716 acres were considered unsuitable for tree planting, making up 39% of the City. The unsuitable areas (other than PPA exclusions) include recreational sports fields, golf course playing areas, utility corridors, and impervious surfaces.

In addition to the total amounts of urban tree canopy and possible planting areas contained within each boundary by acres and percent, the City was also interested in the distribution of where it is located throughout the City's total area. Since land ownership plays a large role in the management actions the City can take, UTC and PPA distribution were evaluated by type of land (City-owned, private, Charlottesville Redevelopment & Housing Authority (CRHA), schools, and University of Virginia property). Total area was also evaluated by planning neighborhoods for further analysis into the City's important managed areas.



Currently, 1,896 acres of Charlottesville's urban tree canopy is found on privately owned property, accounting for 76% of all of the City's UTC. Overall, private property in Charlottesville contains 43% UTC, and City-owned property has 49% UTC.

Similarly, private land contains 75% of all PPA, 17% is found on City-owned property, and just 1% on CRHA property. Schools and University of Virginia property contained 27% and 35% UTC, respectively, with schools having 25% possible planting area (or 2% of the overall PPA in the City) and University of Virginia having 16% (or 6% overall PPA).

Figure 7. Distribution of existing and potential urban tree canopy throughout the City boundary.

The city's 2,771 acres of urban tree canopy were further divided into subcategories based on whether their canopy had an impervious or pervious understory. Tree canopy overhanging an impervious surface can provide many benefits through ecosystem services such as localized cooling provided by shading of impervious surfaces and increased stormwater absorption. Results indicated that Charlottesville's UTC was predominantly overhanging pervious understory at 87%, while 13% is overhanging impervious surfaces.

Table 2. Urban tree canopy assessment results by acres and percent. (Percentages based on land acres.)

City of Charlottesville	Acres	%
Total Area	7,006	100%
Land Area	6,980	99%
Urban Tree Canopy	2,771	40%
Total Possible Planting Area	1,505	22%
Total Unsuitable Area	2,716	39%

Table 3. Detailed urban tree canopy classifications.

City of Charlottesville	Acres	%
Overhanging Pervious Surfaces	2,425	87%
Overhanging Impervious Surfaces	347	13%
Totals	**2,771**	**100%**

Charlottesville Urban Tree Canopy Potential

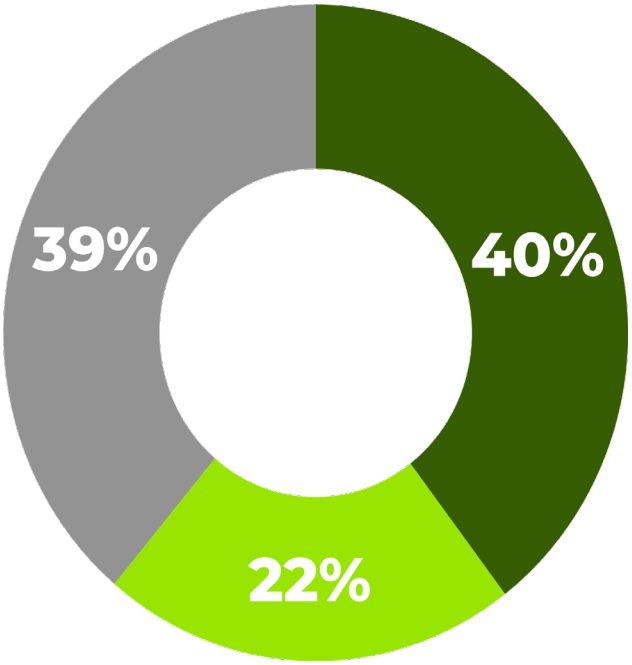


Figure 8. Urban tree canopy, possible planting area, and area unsuitable for UTC in the City of Charlottesville.

CITYWIDE URBAN TREE CANOPY CHANGE

There was a decrease in Charlottesville's tree canopy over the four-year study period. Tree canopy decreased by approximately 380 acres citywide, yielding a 5% raw decrease (12% relative to 2014 acreage) since 2014. This decrease in canopy can be attributed to development of certain areas around the City as well as stream restoration projects around the City and the Meadow Creek Interceptor sewer line project. Reforestation efforts associated with the project have yet to be measured and will appear in future assessments Although there was an overall decrease in canopy, further analysis revealed that there were also some small increases in certain parcels. The increase in tree canopy in Charlottesville can be attributed to crown growth of maturing trees and growth of newly planted trees since 2014.

Current levels of urban tree canopy in Charlottesville can be maintained with careful planning and planting efforts. Charlottesville's urban forest includes many large-stature mature trees which may eventually succumb to old age, stress, and other environmental factors. It is important that the City continue to plant tree species which have potential to reach a large stature. These will eventually replace current large-stature trees, help to maintain and grow current canopy levels and, the valuable ecosystem services provided. The City also contains thousands of smaller trees which must be cared for and maintained properly by the respective entity to ensure crown growth and maturity.

Using the point-based urban tree canopy change analysis, it was determined that the percentage of urban tree canopy from the years 1957 and 1974 were 45% and 29%, respectively. This shows that from 1957 to 2018 there was a 5% decrease in canopy and an 11% increase from 1974. Canopy levels showed to have been the same in 1957 as in 2014, at 45% UTC. To deter from a downward trend in canopy coverage, Charlottesville should focus on the possible planting areas in areas where the most canopy has been lost.

URBAN TREE CANOPY BY PLANNING NEIGHBORHOODS

UTC and PPA were assessed in Charlottesville's 21 planning neighborhoods. This reflects the 19 Planning Neighborhoods of Charlottesville plus two remaining areas within the University of Virginia (UVA) campus. While the UVA areas are not within the purview of the City to implement change, they were included since they are within the City limit and identified as UVA1 and UVA 2 to be consistent with the 2014 urban canopy assessment. The planning neighborhood with the highest UTC percent was the Barracks/Rugby neighborhoods at 58% UTC, while the lowest was Star Hill with 14% UTC. Possible planting area was highest in the Ridge Street and Woolen Hills neighborhoods which both contained 31% PPA, with the next highest being Belmont at 28%.

URBAN TREE CANOPY BY RIGHT-OF-WAY BY PLANNING NEIGHBORHOODS

The right-of-way (ROW) by planning neighborhood boundaries was also assessed for UTC and PPA. UTC in the ROW was shown to be relatively evenly distributed throughout the City. UVA1 and UVA2 were not included in the ROW analysis. Out of the 19 neighborhoods, Barracks/Rugby also had the highest UTC in the ROW at 20%, while Barracks Road had the lowest at 4%. The Belmont neighborhood contained the highest PPA at 11% which accounts for 16% of all PPA in the ROW. Barracks Road, the neighborhood with the lowest UTC, also contained 11% PPA within its ROW.

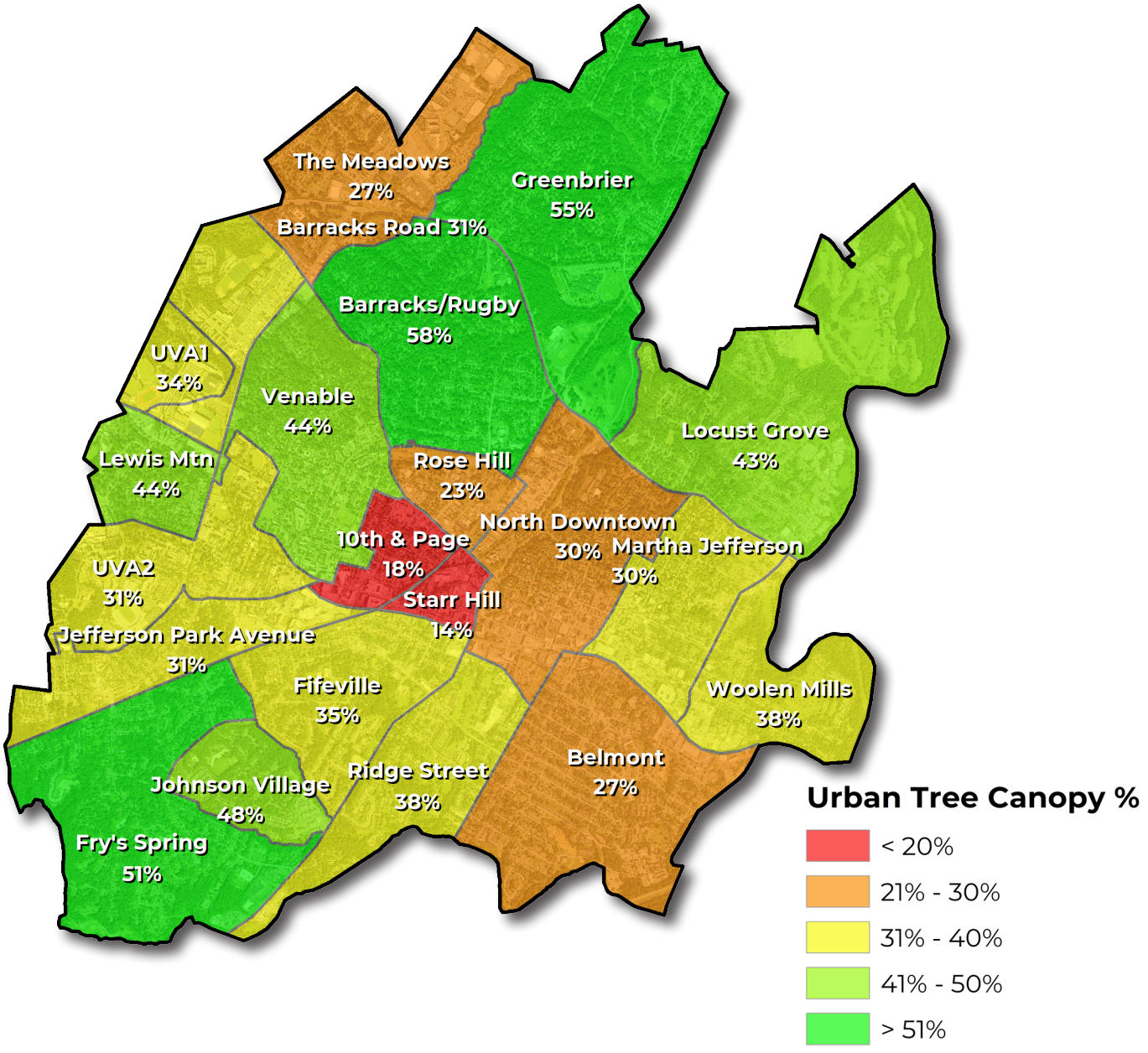


Figure 9. Urban tree canopy in Charlottesville's planning neighborhoods.

CANOPY CHANGE BY PLANNING NEIGHBORHOODS

Along with the decrease in overall city-wide canopy, planning neighborhoods also had a decrease in canopy. All 21 of the planning neighborhoods within Charlottesville had a small to moderate decrease in canopy. From 2014-2018, UTC in most planning neighborhoods decreased between 1 and 8%. The planning neighborhood with the largest amount of land area, Belmont, had a decrease in canopy of 10%, with Johnson Village having the largest decrease of 12%.

CANOPY CHANGE BY RIGHT-OF-WAY BY PLANNING NEIGHBORHOODS

The ROW in 18 of the 21 neighborhoods had decreases in canopy of between 1 and 7%. Three neighborhoods' ROW in the City had small increases in canopy; 10th & Page, Star Hill, and Venable at 2%, 2%, and 1%, respectively. Johnson Village ROW had the largest decrease in canopy at 7%, followed by Belmont and Woolen Mills at 6%. In the ROW, it will be especially important to plant in areas with the lowest UTC and highest amount of PPA due to the limited space available.

Table 4. Total urban tree canopy, right-of-way tree canopy, and tree canopy change from 2014-2018 in Charlottesville's Planning Neighborhoods.

Planning Neighborhoods	UTC %	ROW UTC %	UTC % Change
10th & Page	18%	9%	-1%
Barracks Road	31%	20%	-1%
Barracks/Rugby	58%	4%	-7%
Belmont	27%	12%	-10%
Fifeville	35%	10%	-9%
Fry's Spring	51%	15%	-8%
Greenbrier	55%	16%	-3%
Jefferson Park Avenue	31%	12%	-6%
Johnson Village	48%	7%	-12%
Lewis Mtn	44%	8%	-3%
Locust Grove	43%	10%	-8%
Martha Jefferson	30%	8%	-6%
North Downtown	30%	11%	-3%
Ridge Street	38%	9%	-8%
Rose Hill	23%	13%	-1%
Starr Hill	14%	10%	0%
The Meadows	27%	12%	-1%
UVA1	34%	0%	0%
UVA2	31%	5%	-2%
Venable	44%	10%	-2%
Woolen Mills	38%	12%	-7%
City of Charlottesville	**40%**	**12%**	**-5%**

URBAN TREE CANOPY BY PROPERTY OWNER

UTC and PPA were assessed across land ownership types including schools, city-owned parcels, University of Virginia (UVA) campus property, Charlottesville Redevelopment & Housing Authority (CRHA), and privately owned lands. UTC varied across the different land ownership types. City-owned property had 49% canopy coverage, while private property contained 43% UTC. University of Virginia property and CRHA both had 35% UTC while there was only 27% within the other school properties. PPA ranged from 16% on UVA property to 33% on CRHA property. Private properties contained 24% PPA , while City-owned property contained 30%. Private property makes up 75% of land area in Charlottesville and, thus, contained 1,896 acres or 75% of all UTC and 1,051 acres or 75% of all PPA in the City.

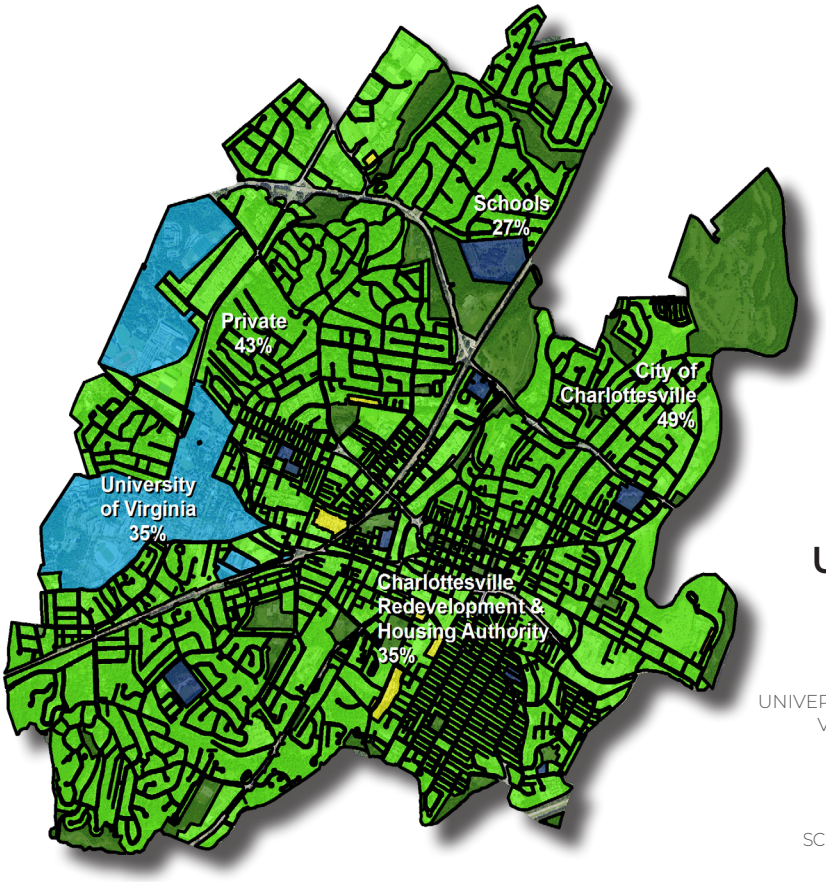


Figure 10. Urban tree canopy in Charlottesville by property ownership.

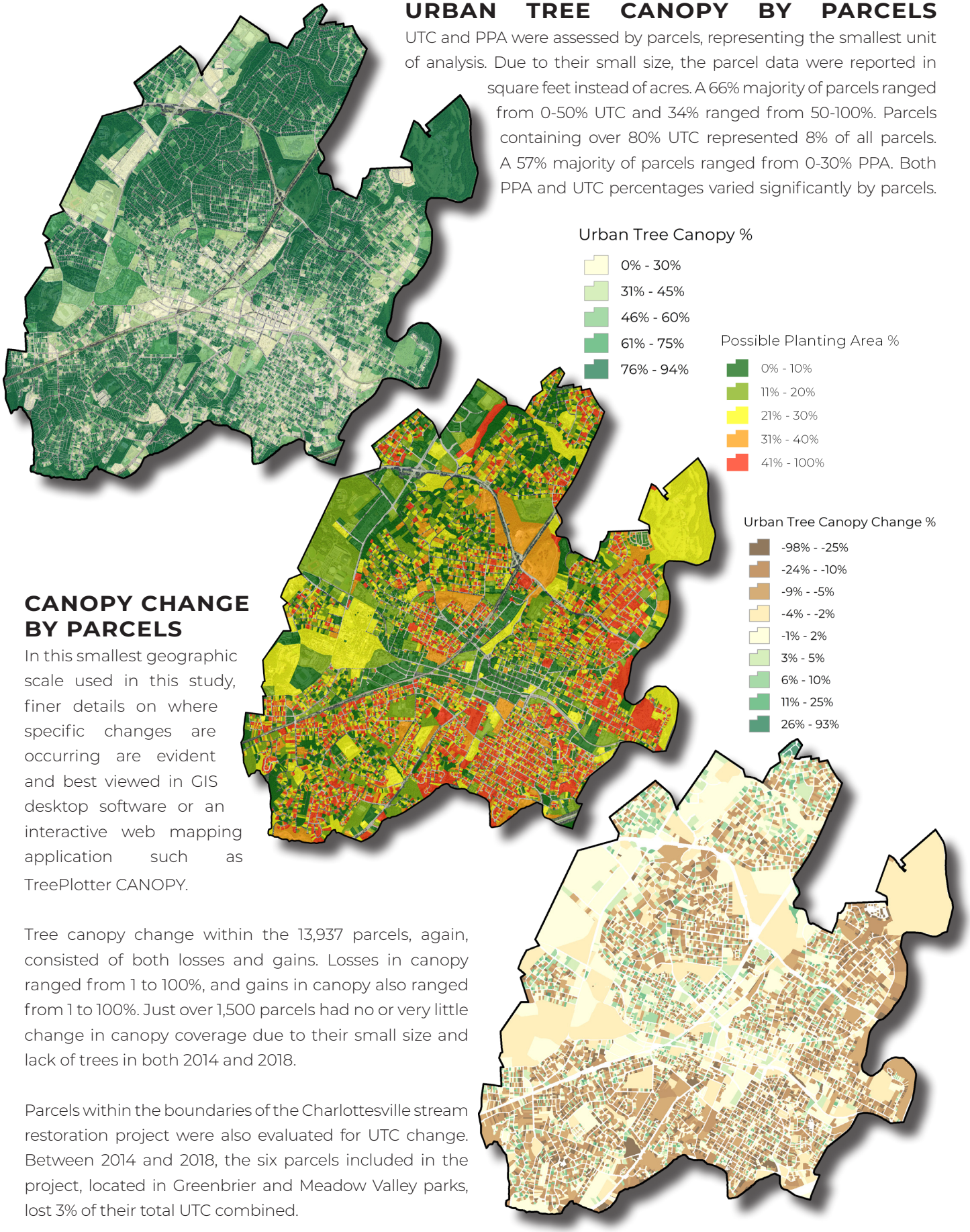
CANOPY CHANGE BY PROPERTY OWNER

When UTC change since 2014 was assessed, private property ownership had a decrease of 305 acres, or 7%, of tree canopy from 2014 to 2018. The 7% decrease in canopy on private properties was the highest percentage decrease in land ownership types, with the second largest decrease being on CRHA property. The decrease in canopy in these two areas highlights the amount of development that has occurred in the City since 2014. City-owned property had a decrease in canopy of 27 acres or 3%, while University of Virginia and schools had decreases of 2% and <1%, respectively.

Figure 11. Urban tree canopy change in Charlottesville by property ownership.

URBAN TREE CANOPY BY PARCELS

UTC and PPA were assessed by parcels, representing the smallest unit of analysis. Due to their small size, the parcel data were reported in square feet instead of acres. A 66% majority of parcels ranged from 0-50% UTC and 34% ranged from 50-100%. Parcels containing over 80% UTC represented 8% of all parcels. A 57% majority of parcels ranged from 0-30% PPA. Both PPA and UTC percentages varied significantly by parcels.



CANOPY CHANGE BY PARCELS

In this smallest geographic scale used in this study, finer details on where specific changes are occurring are evident and best viewed in GIS desktop software or an interactive web mapping application such as TreePlotter CANOPY.

Tree canopy change within the 13,937 parcels, again, consisted of both losses and gains. Losses in canopy ranged from 1 to 100%, and gains in canopy also ranged from 1 to 100%. Just over 1,500 parcels had no or very little change in canopy coverage due to their small size and lack of trees in both 2014 and 2018.

Parcels within the boundaries of the Charlottesville stream restoration project were also evaluated for UTC change. Between 2014 and 2018, the six parcels included in the project, located in Greenbrier and Meadow Valley parks, lost 3% of their total UTC combined.

Figure 12. Urban tree canopy, total plantable space, and canopy change percent by parcels.

ASSESSMENT OF ECOSYSTEM BENEFITS

Using the best available science from i-Tree tools, values were calculated for some of the benefits and functions provided by the urban tree canopy in Charlottesville. The urban forest holds millions of dollars of savings in avoided infrastructure costs, pollution reduction, and stored carbon. The following values were calculated using the USDA Forest Service's iTree Landscape tool with Charlottesville's total acres of urban tree canopy as the input data.

AIR QUALITY

Trees produce oxygen, indirectly reduce pollution by lowering air temperature, and improve public health by reducing air pollutants which cause death and illness. The existing tree canopy in Charlottesville removes 170K pounds of air pollution annually, valued at over $600K.

STORMWATER AND WATER QUALITY

Trees and forests mitigate stormwater runoff which minimizes flood risk, stabilizes soil, reduces sedimentation in streams and riparian land, and absorbs pollutants, thus improving water quality and habitats. The tree canopy in Charlottesville absorbs 44 million gallons of water per year. Extrapolated citywide, this means that Charlottesville's existing canopy provides over $395K annually in stormwater benefits.

CARBON STORAGE AND SEQUESTRATION

Trees accumulate carbon in their biomass; with most species in a forest, the rate and amount increase with age. Charlottesville's trees store approximately 169 million pounds of carbon, valued at over $14 million, and each year the tree canopy absorbs and sequesters approximately 169 million pounds of carbon dioxide, valued at over $460K.

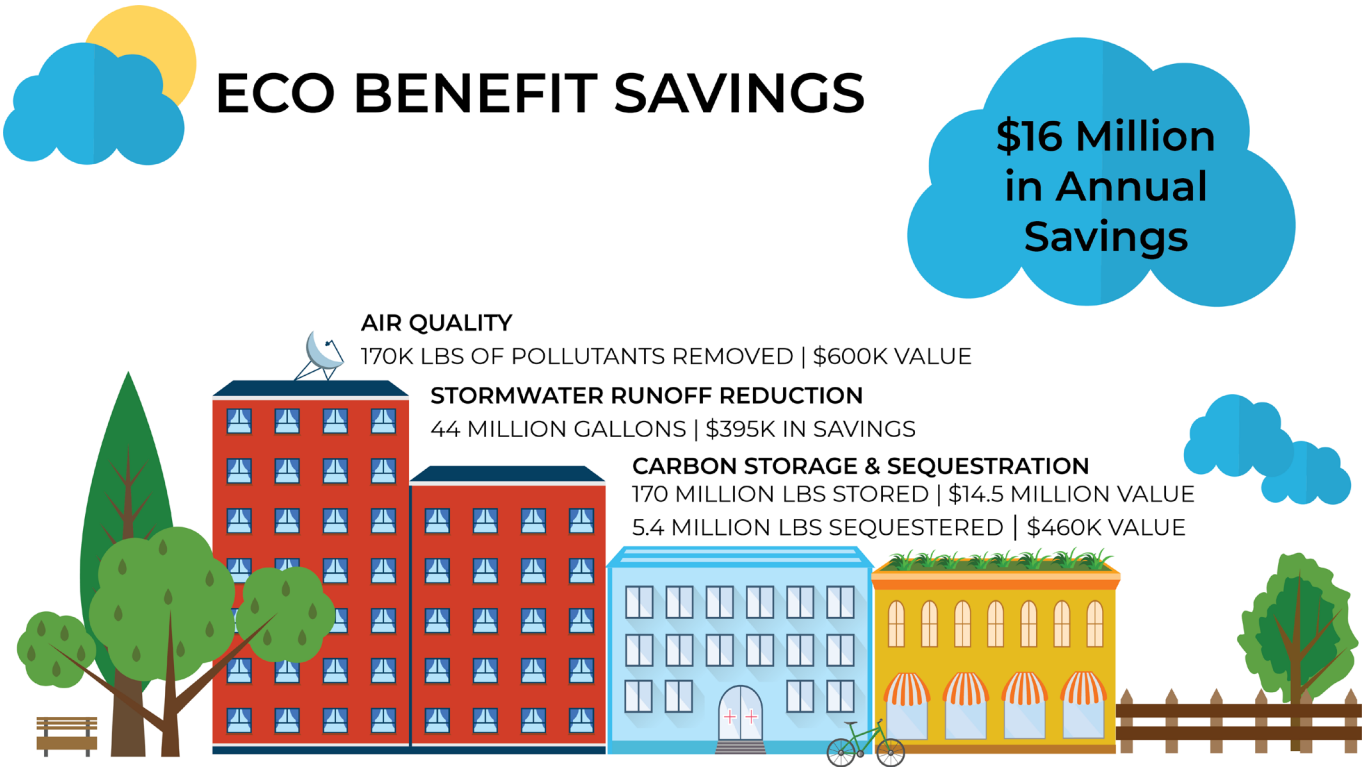


Figure 13. Eco-benefits of Charlottesville's urban forest.

Table 5. Comparison of selected urban tree canopy benefits in Charlottesville in 2014 and 2018.

City of Charlottesville	*2014 Canopy*		*2018 Canopy*	
	Amount (lbs)	Value ($)	Amount (lbs)	Value ($)
Carbon Monoxide	3,360	$2,240	3,245	$2,164
NO2	15,778	$4,116	14,865	$5,813
O3	143,144	$133,405	133,416	$224,216
PM2.5	5,850	$213,824	4,741	$345,149
SO2	5,736	$287	5,594	$469
PM10	30,977	$97,088	24,990	$78,327
CO2 Sequestration	30,190,551	$548,109	22,218,800	$516,744
Totals	**30,395,396**	**$990,071**	**22,405,653**	**$1,172,882**

BENEFITS OF PUBLIC TREES

In addition to assessing the value of ecosystem services provided by Charlottesville's generalized complete urban forest, values were also calculated for (some of) its individual trees. This assessment was performed using the iTree Eco tool with the City's public tree inventory as the input data. By estimating the benefits that specific trees are contributing, the City can both determine the approximate proportion of its total benefits that are derived from the trees that it directly manages (e.g. the public tree population), and also determine which species are giving the greatest benefits compared to other trees to inform future planting efforts. The full results with specific values per-tree have been provided.

The assessment of the vegetation structure, function, and value of the Charlottesville's urban forest was conducted using the i-Tree Eco model developed by the U.S. Forest Service, Northern Research Station and yielded the following results:

- Most common species of trees: Flowering dogwood, Eastern red cedar, Eastern white pine
- Pollution Removal: 2.622 tons/year ($26.8 thousand/year)
- Carbon Storage: 4.438 thousand tons ($757 thousand)
- Carbon Sequestration: 97.73 tons ($16.7 thousand/year)
- Oxygen Production: 260.6 tons/year
- Avoided Runoff: 285.2 thousand cubic feet/year ($19.1 thousand/year)
- Replacement values: $29.1 million

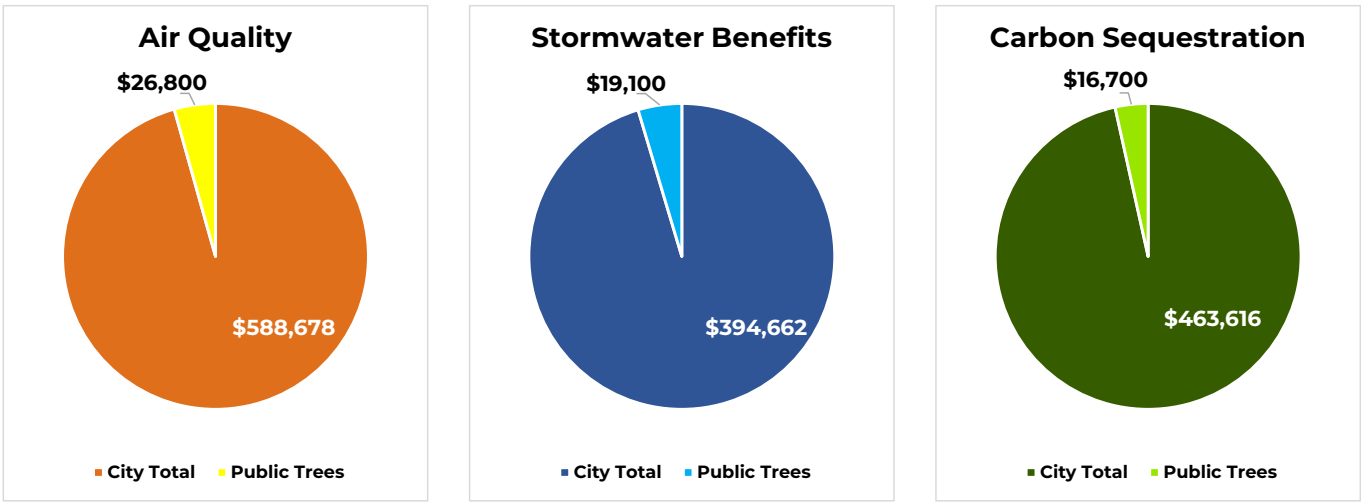


Figure 14. Eco-benefits of Charlottesville's full urban forest and public tree population.

TREE PLANTING PRIORITIZATION

PRIORITIZATION CRITERIA DESCRIPTIONS

Urban tree canopy provides a multitude of direct and indirect benefits. To provide the most complete understanding of where those benefits are lacking, tree planting priorities were identified based on environmental, socio-demographic, and public health data sets.

Tree planting prioritization ranking is needs-based and designed to rank each planning neighborhood based on each area's need for a particular benefit that trees can provide. Rankings are sorted from high (red) to low (green) and were calculated for each individual criteria as well as overall to show where multiple needs overlap. Viewing combined ranks show where tree canopy benefits can have the greatest impact by addressing multiple needs.

SOCIO-DEMOGRAPHIC

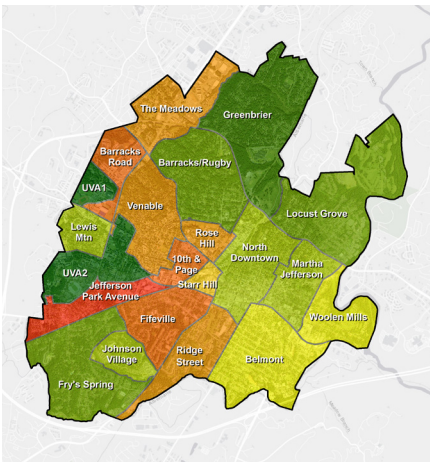
- **Population Below Poverty:** This indicator shows the percentage of residents living below the poverty level according to American Community Survey 2014-2019 5-year estimates

- **Public Property Ownership:** Possible planting area on City-owned, operated, or managed public and public/private land. Values equal the percentage of plantable space within public land within each geographic area.

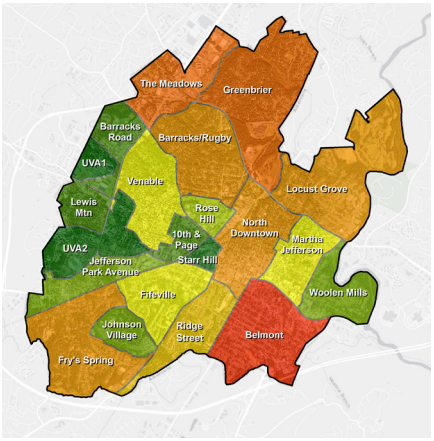
ENVIRONMENTAL

- **Right-of-Way:** Trees planted along roads can have greater benefits to air quality and noise.

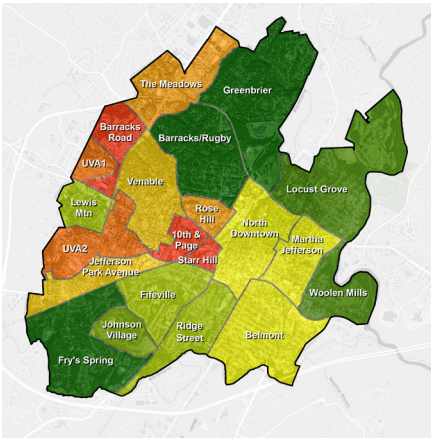
- **Urban Heat Island:** The average temperature value within each feature. Urban heat severity data from the Trust for Public Land derived using the thermal band of a Landsat 8 satellite image were used.



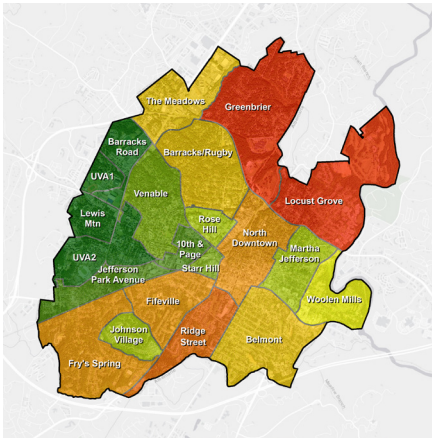
Population Below Poverty



Right-of-Way



Urban Heat Island



Public Lands

Overall Tree Planting Priority by Planning Neighborhoods

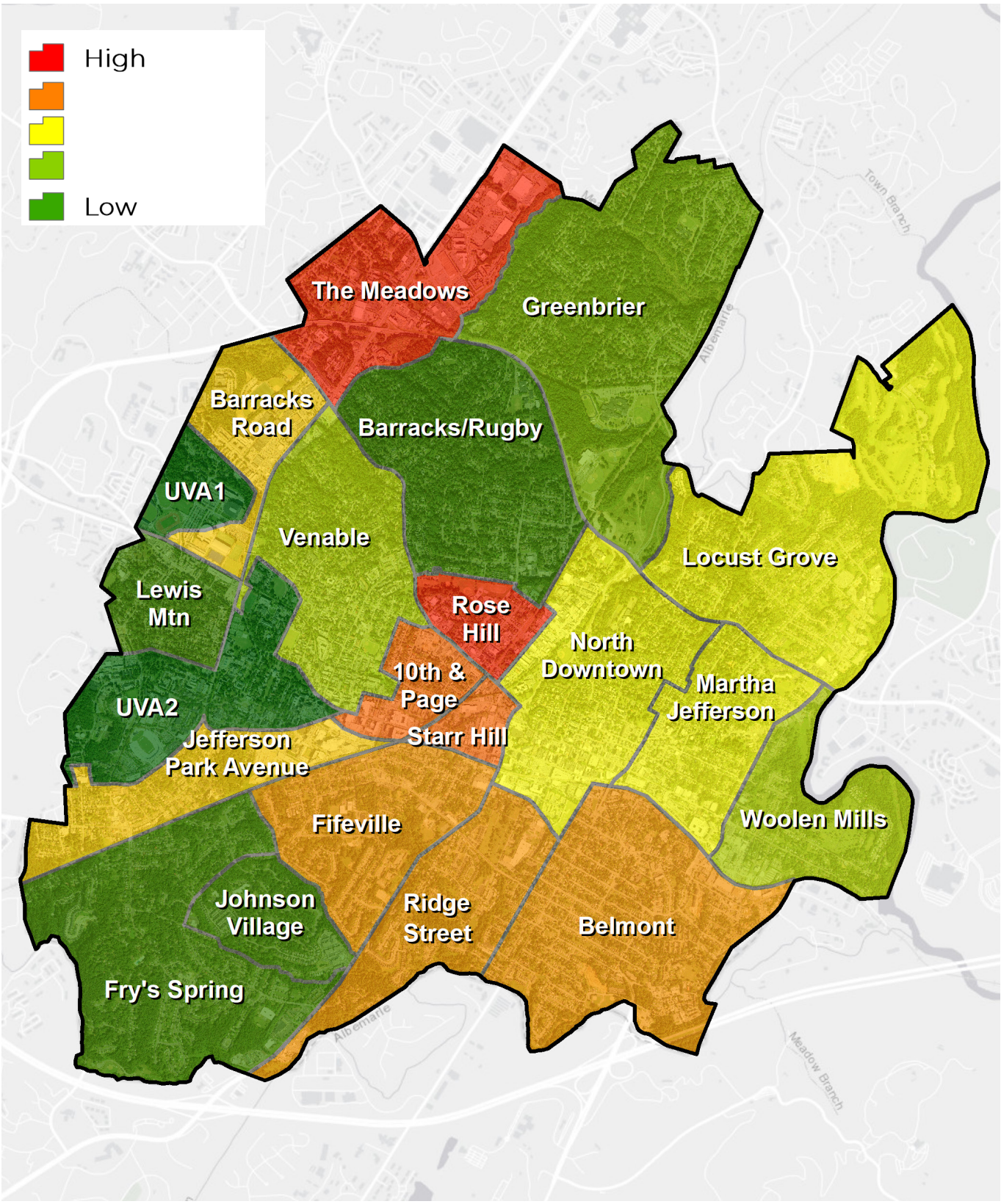


Figure 15. Combined planting prioritization by planning neighborhoods.

CONCLUSIONS AND RECOMMENDATIONS

The City of Charlottesville has demonstrated that it values its natural resources and wants to maintain a healthy and sustainable urban environment. Recurring assessments of the City's tree canopy represent important steps in ensuring the long-term health of its urban forest. A greater percent of canopy cover can be achieved with proper planning, investment, and care of existing trees. The City should continue to monitor the health of the urban forest and implement the following recommendations to ensure the urban forest is considered during future city planning and development to sustain and enhance the benefits that trees provide to the community.

Continue to monitor changes in the urban forest using regularly updated data

To preserve, protect, and maintain Charlottesville's tree canopy, the City should continue to have a tree canopy assessment performed at regular intervals such as through TreePlotter CANOPY subscription or continuing regular projects. As the City grows, they will be able to use these data to ensure that their urban forest policies and management practices prioritize its maintenance, health, and growth. The City's urban forest provides Charlottesville with a wealth of environmental, social, and even economic benefits which relate back to greater community pride and interest in citywide initiatives and priorities. These results can be used to identify where existing tree canopy cover should be preserved, where there are opportunities to continue to expand the City's canopy cover, and which areas would receive the greatest benefits from the investment of valuable time and resources into Charlottesville's urban forest.

1. Leverage the results of this assessment to promote the urban forest

The results of this assessment should be used to encourage investment in urban forest monitoring, maintenance, and management; to prepare supportive information for local budget requests/grant applications; and to develop targeted presentations for city leaders, planners, engineers, resource managers, and the public on the functional benefits of trees in addressing environmental issues. The land cover, tree canopy, and urban tree canopy change data should be disseminated to diverse partners for urban forestry and other applications while the data are current and most useful for decision-making and implementation planning. The information from this study can help establish new canopy cover goals for the short- and long-term to continue to expand Charlottesville's urban forest to its known potential.

2. Use the urban tree canopy change data to identify areas to prioritize canopy expansion

The City and its various stakeholders can utilize the results of the UTC, PPA, and urban tree canopy change analyses to identify the best locations on City-owned and private property to focus future tree planting and canopy expansion efforts. Trees can play a large role in improving public health by improving air quality, reducing temperatures, and addressing climate change. The City can acquire parcels for public use as part of redeveloped neighborhoods to be used as carbon sinks to address community access to nature, climate, human health, and equity. Plantable space in the right-of-way is often found close to high concentrations of impervious surfaces. Focus on planting the right tree in the right place and planting large-species trees where appropriate to maximize ecosystem services. Results revealed that 17% of all plantable space in Charlottesville is found on City-owned property where the City often has direct management. Planting trees near impervious surfaces can offset the urban heat island effect, stormwater runoff, and energy consumption. The priority planting analysis should be used to identify planting opportunities adjacent to high concentrations of impervious surfaces in these areas. Results revealed that 9% of plantable space is in the right-of-

way, adjacent to impervious surfaces. The City can develop a proactive street tree maintenance program to take on the responsibility of planting and managing street trees, ensuring healthy trees are distributed equitably across the city. Given the majority of tree loss was attributed to development, the City should evaluate city codes to increase tree preservation, create space for existing trees during the development process, and set aside space for new larger stature trees to be planted both on private property and within the public right-of-way to maximize the benefits of trees. It will also be important for the City to continue to replant and maintain areas involved in the City's stream restoration projects as well as the Meadow Creek Interceptor project to mitigate the 3% loss in canopy in those areas.

75%

OF ALL PLANTABLE SPACE IN CHARLOTTESVILLE IS LOCATED ON PRIVATE LAND

3. Develop outreach programs towards private landowners

In Charlottesville, 75% of PPA is found in areas designated as Private property. The City should focus on community outreach and education programs to better inform citizens and private landholders of the environmental, health, social, and financial benefits that trees provide and consider other strategies to help preserve existing trees and grow the tree canopy in the 1,000+ acres of plantable space on private properties. The City should explore options to develop grant programs for tree maintenance or removal of hazard or invasive trees within the city to remove barriers for overburdened communities which lack tree canopy. Tree giveaways, tree planting programs, and tree maintenance events can help to promote new tree plantings. To promote new plantings, expand the partnership with local contractors to plant more trees on redeveloped or newly developed property focusing on low-canopy and underserved neighborhoods. The City should also continue to develop partnerships with Community Based Organizations and individual champions throughout neighborhoods to build stewardship at the community level. In addition, the City should continue to conduct volunteer tree planting and tree maintenance events to increase awareness levels in the community.

4. Focus new plantings in high priority areas

To maximize impact, see greater return on investment, and provide the greatest number of benefits to the community, we recommend that the City focus planting and management efforts in areas with high weighted priority rankings. Planting priority maps and data, such as the map on page 16, show the areas of highest priority for all planting prioritization criteria and land cover metrics. The City should also use the GIS data provided to create unique weighted scenarios to focus efforts in targeted areas that meet specific criteria. For instance, the City could find areas that have low UTC, high PPA, and would offer the greatest benefits to temperature reduction (UHI). Focusing urban forest management resources on expanding and maintaining tree canopy in these areas will have positive impacts on multiple factors that the City has deemed important. Efforts should focus on outreach to the residents of these neighborhoods, as well as local business and land owners, in order to promote new tree plantings and continued maintenance of existing trees.

REPORT APPENDIX

ACCURACY ASSESSMENT

Classification accuracy serves two main purposes. Firstly, accuracy assessments provide information to technicians producing the classification about where processes need to be improved and where they are effective. Secondly, measures of accuracy provide information about how to use the classification and how well land cover classes are expected to estimate actual land cover on the ground. Even with high resolution imagery, very small differences in classification methodology and image quality can have a large impact on overall map area estimations.

The classification accuracy error matrix illustrated in Table A1 contain confidence intervals that report the high and low values that could be expected for any comparison between the classification data and what actual, on the ground land cover was in 2020. This accuracy assessment was completed using high resolution aerial imagery, with computer and manual verification. No field verification was completed.

THE INTERNAL ACCURACY ASSESSMENT WAS COMPLETED IN THESE STEPS:

1. Five hundred sample points, or approximately 50 points per square mile area in Charlottesville (10 sq. miles), were randomly distributed across the study area and assigned a random numeric value.
2. Each sample point was then referenced using the NAIP aerial photo and assigned one of five generalized land cover classes ("Ref_ID") mentioned above by a technician.
3. In the event that the reference value could not be discerned from the imagery, the point was dropped from the accuracy analysis. In this case, no points were dropped.
4. An automated script was then used to assign values from the classification raster to each point ("Eval_ID"). The classification supervisor provides unbiased feedback to quality control technicians regarding the types of corrections required. Misclassified points (where reference ID does not equal evaluation ID) and corresponding land cover are inspected for necessary corrections to the land cover.[1]
5. Accuracy is re-evaluated (repeat steps 3 & 4) until an acceptable classification accuracy is achieved.

SAMPLE ERROR MATRIX INTERPRETATION

Statistical relationships between the reference pixels (representing the true conditions on the ground) and the intersecting classified pixels are used to understand how closely the entire classified map represents Charlottesville's landscape. The error matrix shown in Table A1 represent the intersection of reference pixels manually identified by a human observer (columns) and classification category of pixels in the classified image (rows). The blue boxes along the diagonals of the matrix represent agreement between the two-pixel maps. Off-diagonal values represent the number of pixels manually referenced to the column class that were classified as another category in the classification image. Overall accuracy is computed by dividing the total number of correct pixels by the total number of pixels reported in the matrix (189 + 97 + 162 + 6+ 4 = 458 / 500 = 91.6%), and the matrix can be used to calculate per class accuracy percentage's. For example, 197 points were manually identified in the reference map as Tree Canopy, and 189 of those pixels were classified as Tree Canopy in the classification map. This relationship is called the "Producer's Accuracy" and is calculated by dividing the agreement pixel total (diagonal) by the reference pixel total (column total). Therefore, the Producer's Accuracy for Tree Canopy is calculated as: (189/197 = .959), meaning that we can expect that ~96% of all 2018 tree canopy in the Charlottesville, VA study area was classified as Tree Canopy in the 2018 classification map.

Conversely, the "User's Accuracy" is calculated by dividing the total number of agreement pixels by the total number of classified pixels in the row category. For example, 189 classification pixels intersecting reference pixels were classified as Tree Canopy, but 11 pixels were identified as Vegetation and 6 were identified as impervious in the reference map. Therefore, the User's Accuracy for Tree Canopy is calculated as: (189/206 = 0.917), meaning that ~92% of the pixels classified as Tree Canopy in the classification were actual tree canopy. It is important to recognize the Producer's and User's accuracy percent values are based on a sample of the true ground cover, represented by the reference pixels at each sample point. Interpretation of the sample error matrix results indicates this land cover, and more importantly, tree canopy, were accurately mapped in Charlottesville in 2018. The largest sources of classification confusion exist between tree canopy and vegetation.

1 Note that by correcting locations associated with accuracy points, bias is introduced to the error matrix results. This means that matrix results based on a new set of randomly collected accuracy points may result in significantly different accuracy values.

Table A1. | Error matrix for land cover classifications in Charlottesville, VA. (2018).

Classification Data	Reference Data: Tree Canopy	Vegetation	Impervious	Soil / Dry Veg.	Water	Total Reference Pixels
Tree Canopy	189	11	6	0	0	206
Vegetation	3	97	6	1	0	107
Impervious	5	10	162	0	0	177
Soil / Dry Veg.	0	0	0	6	0	6
Water	0	0	0	0	4	4
Total	197	118	174	7	4	500

Overall Accuracy = 92%

Producer's Accuracy	
Tree Canopy	96%
Veg./ Open Space	82%
Impervious	93%
Bare Ground / Soil	86%
Water	100%

User's Accuracy	
Tree Canopy	92%
Veg./ Open Space	91%
Impervious	92%
Bare Ground / Soil	100%
Water	100%

ACCURACY ASSESSMENT RESULTS

Interpretation of the sample error matrix offers some important insights when evaluating Charlottesville's urban tree canopy coverage and how well aligned the derived land cover data are with interpretations by the human eye. The high accuracy of the 2018 data indicates that regardless of how and when it was achieved, the City's current tree canopy can be safely assumed to match the figures stated in this report (approximately 40%).

GLOSSARY/KEY TERMS

Land Acres: Total land area, in acres, of the assessment boundary (excludes water).

Non-Canopy Vegetation: Areas of grass and open space where tree canopy does not exist.

Possible Planting Area - Vegetation: Areas of grass and open space where tree canopy does not exist, and it is biophysically possible to plant trees.

Total Possible Planting Area/Total Plantable Space: The combination of PPA Vegetation area and PPA Impervious area. In this project no impervious areas were identifies as plantable.

Soil/Dry Vegetation: Areas of bare soil and/or dried, dead vegetation.

Total Acres: Total area, in acres, of the assessment boundary (includes water).

Unsuitable Impervious: Areas of impervious surfaces that are not suitable for tree planting. These include buildings and roads and all other types of impervious surfaces.

Unsuitable Planting Area: Areas where it is not feasible to plant trees. Airports, ball fields, golf courses, etc. were manually defined as unsuitable planting areas.

Unsuitable Soil: Areas of soil/dry vegetation considered unsuitable for tree planting. Irrigation and other modifiers may be required to keep a tree alive in these areas.

Unsuitable Vegetation: Areas of non-canopy vegetation that are not suitable for tree planting due to their land use.

Urban Tree Canopy (UTC): The "layer of leaves, branches and stems that cover the ground" (Raciti et al., 2006) when viewed from above; the metric used to quantify the extent, function, and value of the urban forest. Tree canopy was generally taller than 10-15 feet tall.

Water: Areas of open, surface water not including

MARCH | 2022

URBAN TREE CANOPY

ASSESSMENT

CHARLOTTESVILLE, VIRGINIA

PLANIT GEO™
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