TOWN OF VIENNA
Parks and Recreation

VIENNA, VIRGINIA
URBAN TREE CANOPY ASSESSMENT REPORT

DAVEY Resource Group

ACKNOWLEDGMENTS

This project supports the vision of the Town of Vienna to promote and enhance community well-being through tree conservation and improved forestry management practices. This Urban Tree Canopy Assessment Report offers expertise in preserving and expanding urban canopy so the environmental, economic, and social benefits it provides may continue for generations.

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EXECUTIVE SUMMARY

The Vienna Urban Tree Canopy (UTC) Assessment is the first of its kind for the community. The primary goals of this assessment are to establish baseline data on the extent and function of Vienna's existing urban forest, compare current canopy data (2021) to levels seen in the past, and provide a resource to guide Vienna's future community forest management efforts.

This assessment was completed using the most recently acquired USDA one-meter resolution National Agriculture Imagery Program (NAIP) imagery and geographic information systems (GIS) data layers. The assessment resulted in a GIS map layer that identifies the location and extent of existing tree canopy. Ecosystem benefits and functions provided by Vienna's trees were quantified using i-Tree Eco modeling equations.

Analysis of current aerial imagery demonstrates that currently **tree canopy covers 38.7% of Vienna**, approximately 1,090 acres of land. Impervious surfaces cover 33.0%. The remaining percentages consist of grass and low-lying vegetation, bare soil, and open water.

In comparison to 2011 imagery, Vienna's current tree canopy cover has been reduced by approximately 163 acres, **a percent change loss of 13.0%**. However, opportunities exist to mitigate this trend. Suitable areas were analyzed for future planting and ranked based on the benefits that additional canopy coverage would provide. Approximately 214 acres of planting areas were identified as *Very High* and *High* classifications of potential canopy. If these areas were to be planted, this would represent a percent change increase in canopy cover of 19.6%.

Tree canopy cover removes pollutants and carbon from the air and reduces peak stormwater flows, in part mitigating the effects of increased urbanization and development. The annual benefits Vienna receives from its tree cover **are approximately $4.3 million**. These improvements to air quality, reductions in energy costs, and increased property values all contribute to the livability and sustainability of the Town.

Ensuring that Vienna's tree canopy will thrive in the future requires a multifaceted, leadership-driven approach. Strong planting efforts in the areas of town that can benefit the most is certainly part of this. However, it is not enough to simply plant more trees to increase canopy cover and benefits. Planning and funding for tree care and management, public outreach, and education must accompany planting efforts. This tactical approach is designed to increase the chance of success for newly planted trees and to ensure that the desired benefits are being realized through strategic urban forest management and partnerships. To make a difference, Vienna, its residents, and its partners can support the urban forestry program by promoting the benefits that trees offer to the community, fulfilling routine maintenance for both public and private trees, and maximizing the space available for new trees.

INTRODUCTION

The Town of Vienna, situated in Fairfax County, Virginia, is home to an estimated 16,329 people (U.S. Census Bureau, 2020). The town features its sustainability initiatives prominently on its website, including conservation information, sustainability challenges for businesses and organizations, and efforts to protect the Potomac River and Chesapeake Bay (Town of Vienna, 2022).

Perhaps the most comprehensive of these initiatives are the efforts that Vienna puts into planting, protecting, and honoring its urban forest. Vienna:

- Has been recognized by the Arbor Day Foundation as a Tree City USA for 21 years.
- Enacted a Tree Canopy Coverage ordinance on January 6, 2014.
- Sets forth tree protection and replacement requirements, including tree protection bonds for street trees.
- Provides street tree planting guidelines and an approved species list dictated by planting space size and overhead utilities.
- Maintains a list of its oldest trees, some of which are estimated to be close to 300 years old, and offers services to donate or dedicate trees and benches through the Parks and Recreation Department.
- Is currently reviewing all tree-related procedures and standards for review by Town Council and Town Leadership.
- Involves and solicits support from community partners as part of the tree management program.

The Town is also supported by the Conservation and Sustainability Commission (CSC), which addresses issues related to energy, environmental, and natural resources. This group is composed of ten community members including two student representatives. The CSC promotes education and outreach for sustainability initiatives and recommends policies and programs to the Town Council.

To further all these sustainability efforts, Vienna performed this Urban Tree Canopy (UTC) Assessment. The information presented in this report can be used to better understand the distribution of tree canopy within Vienna, the benefits it provides, and where expansion of the tree canopy can provide the greatest impact.

THIS REPORT PRESENTS SPECIFIC DATA, ANALYSIS, AND MAPS ORGANIZED INTO THE FOLLOWING SECTIONS:

SECTION 1

Examines Vienna's tree canopy and other land cover classifications as it relates to land use and census block groups.

SECTION 2

Explores canopy changes over time and looks at how development and human activity has affected the urban tree canopy.

SECTION 3

Describes a priority planting methodology based on what areas may benefit the most from increased planting efforts.

SECTION 4

Presents the benefits as analyzed by i-Tree Eco provided by the tree canopy.

WHAT IS AN URBAN FOREST?

The urban forest consists of all trees growing on public and private land within a given boundary. For Vienna, this includes all trees within 2,817 acres of the town limits. All trees in parks, open spaces, backyards, commercial lands, along streets, and other areas are considered. All trees within Vienna contribute to its overall tree canopy percentage.

SECTION 1

LAND COVER MAPPING AND METRICS

LAND COVER

The baseline of the analyses that follow rely on determining Vienna's various types of land cover. Based on current data, the town occupies a total of 2,817 acres. The classification divided the land into the following categories:

- Tree canopy
- Impervious surfaces (i.e., concrete, buildings)
- Grass and other low-lying vegetation
- Bare soils
- Open Water

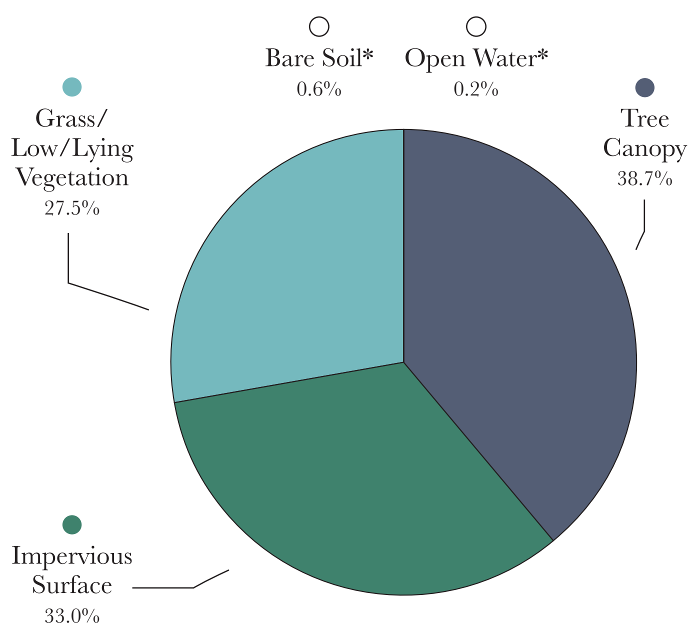
The following table and map show the breakdown of the overall land cover classification. As expected, the greatest concentration of canopy cover is found in residential areas, parks, and otherwise lower-level developed areas. Conversely, the highest percentage of impervious surfaces are found in commercial, industrial, and otherwise higher-level developed areas of the town. Full details of classification methodology and accuracy assessment can be found in Appendix A.

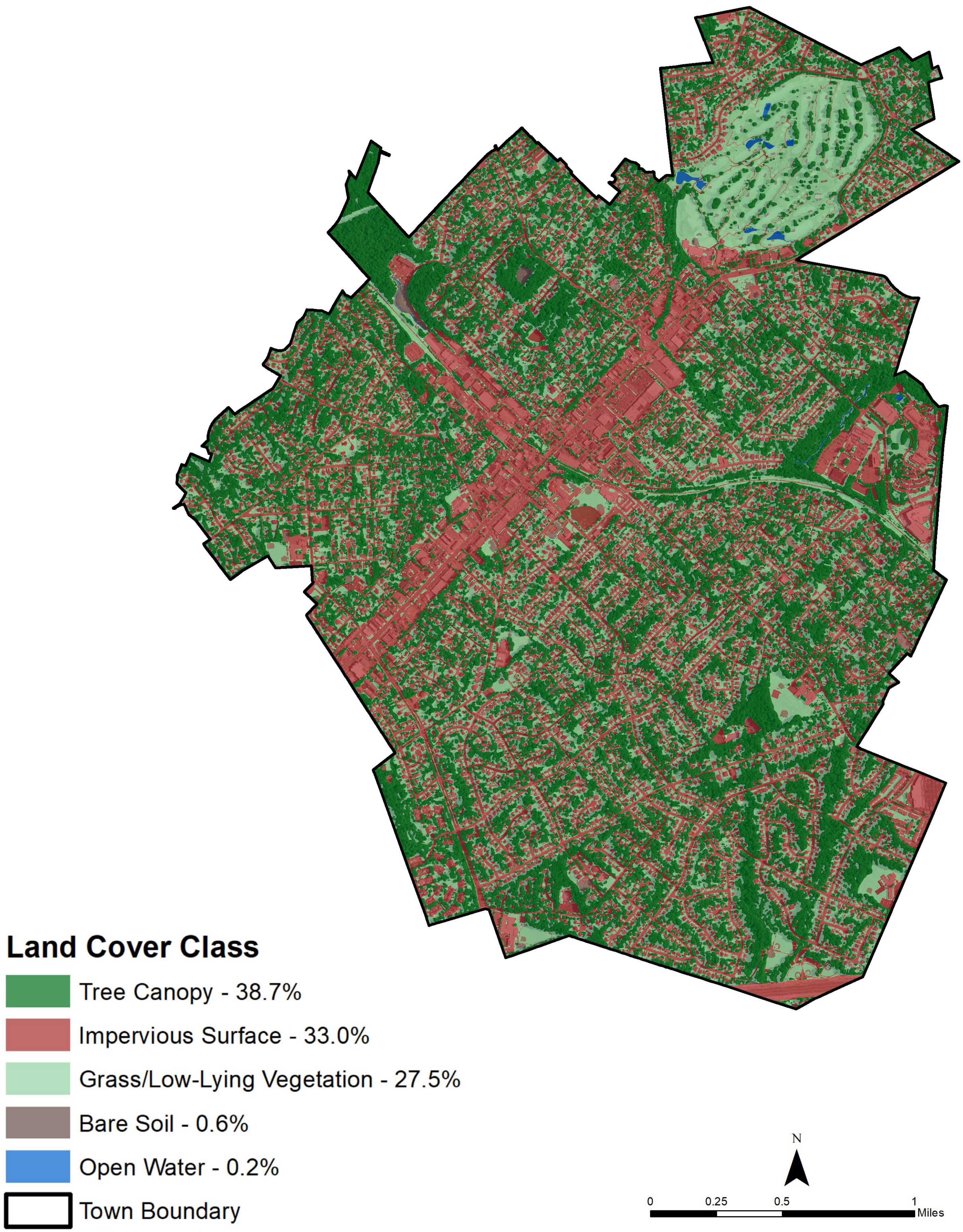
Table 1. Vienna, VA Land Cover Classification

	Acres	Percent
Tree Canopy	1,090	38.7%
Impervious Surface	930	33.0%
Grass/Low-Lying Vegetation	775	27.5%
Bare Soil	17	0.6%
Open Water	5	0.2%
Total	2,817	100%

*Due to low percentage, these values do not show on the chart.

Figure 1. Land Cover Classification




Land Cover Class
Tree Canopy - 38.7%
Impervious Surface - 33.0%
Grass/Low-Lying Vegetation - 27.5%
Bare Soil - 0.6%
Open Water - 0.2%
Town Boundary
N
0
0.25
0.5
1
Miles

TREE CANOPY BY LAND USE

Vienna has a **canopy percentage of 38.7%**. Examining how this tree canopy is distributed across land use can provide additional insight into where trees are and where they are most needed. Classification was first determined by categories described by Fairfax County's land use layer and then vetted by Town of Vienna staff for accuracy compared to local knowledge. Table 2 and Figure 2 show the levels of canopy and other land classifications present across the various land use types.

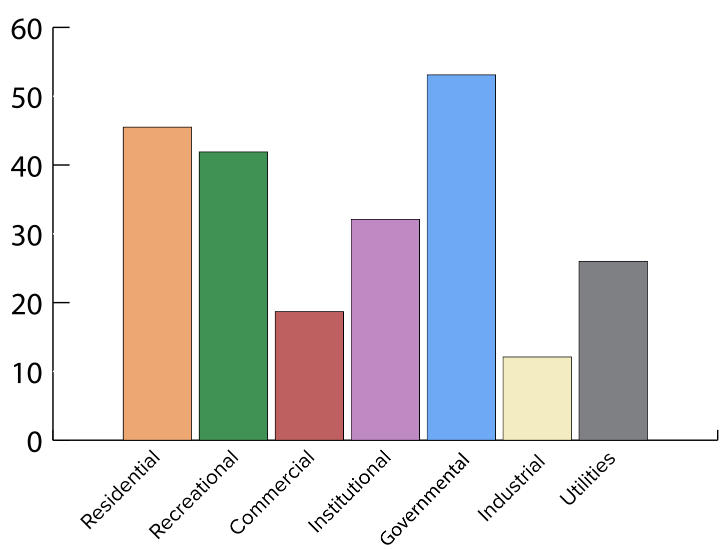
Table 2. Land Cover Classification by Land Use

Land Use	Total Land		Land Cover Classification Percent				
	Acres	Percent	Tree Canopy	Impervious Surface	Grass/Low-Lying Vegetation	Bare Soil	Open Water
Residential	1,682	59.7%	45.5%	23.4%	30.7%	0.4%	0.0%
Recreation	320	11.4%	41.9%	10.5%	45.1%	1.4%	1.1%
Commercial	204	7.3%	18.7%	71.1%	9.9%	0.1%	0.1%
Institutional	97	3.4%	32.1%	34.5%	31.4%	1.9%	0.1%
Governmental	38	1.4%	53.1%	25.0%	11.3%	9.9%	0.7%
Industrial	19	0.7%	12.1%	84.1%	3.8%	0.0%	0.0%
Utilities	4	0.1%	26.0%	48.2%	23.0%	2.7%	0.0%
Uncategorized	453	16.1%					
Total	**2,817**	**100%**					

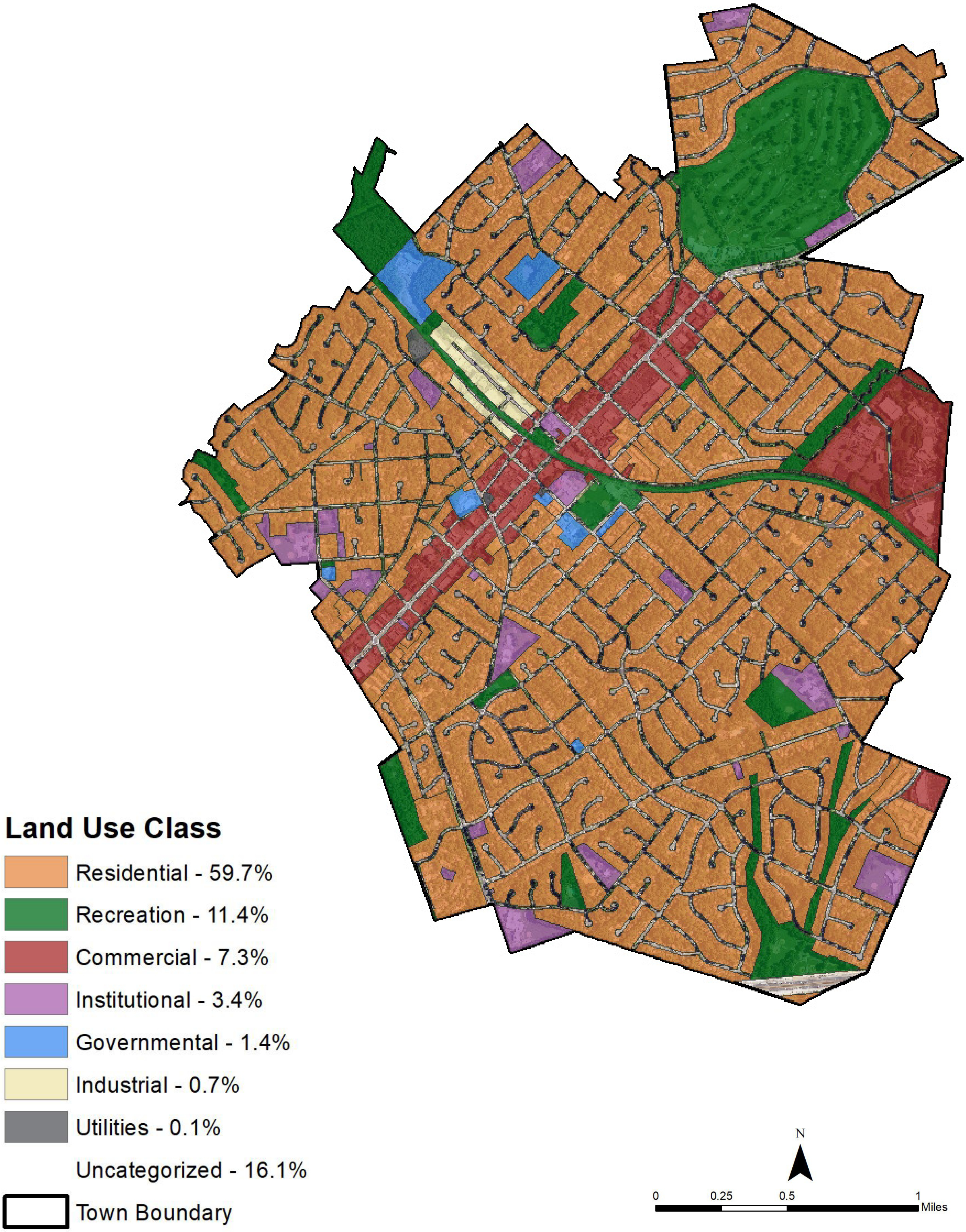
Of the total 2,817 acres within the town limit, 2,364 acres can be categorized by land use. The remaining 453 acres of uncategorized land includes streets, resource protection areas (RPAs), and areas that are otherwise not assigned a particular land use. These areas were not included in this land use data analysis but are considered in other sections of the plan. Residential areas make up the majority of land use (59.7% of the town) and have one of the highest tree canopy percentages (45.5%). The highest canopy percentage exists on land classified as Governmental at 53.1%, but this land use only occupies 1.4% of the total town acreage. The lowest percentage of canopy exists on land classified as Industrial (12.1%) and Commercial (18.7%).

In terms of impervious surfaces, the highest percentages exist in Industrial (84.1%), Commercial (71.1%) as well which correlates to the lower tree canopy and likely fewer opportunities for additional planting. The following map shows the locations of the various land use classifications in Vienna.

Figure 2. Tree Canopy Percent by Land Use



MAP 2. LAND USE



TREE CANOPY BY BLOCK GROUP

In addition to land use, tree canopy can be examined by census block groups. Block groups are a smaller delineation of census tracts and determined by population count. In other words, the number of people in each block group dictates the boundaries. A few block groups usually fall inside each census tract. Given the relatively small size of Vienna, block groups provide a more granular look where tree canopy is located.

As visible in the following map, the majority of tree canopy is concentrated on the northwest and south side of town. The lowest level of canopy cover is located on the central west side of town, where much of the commercial property is located.

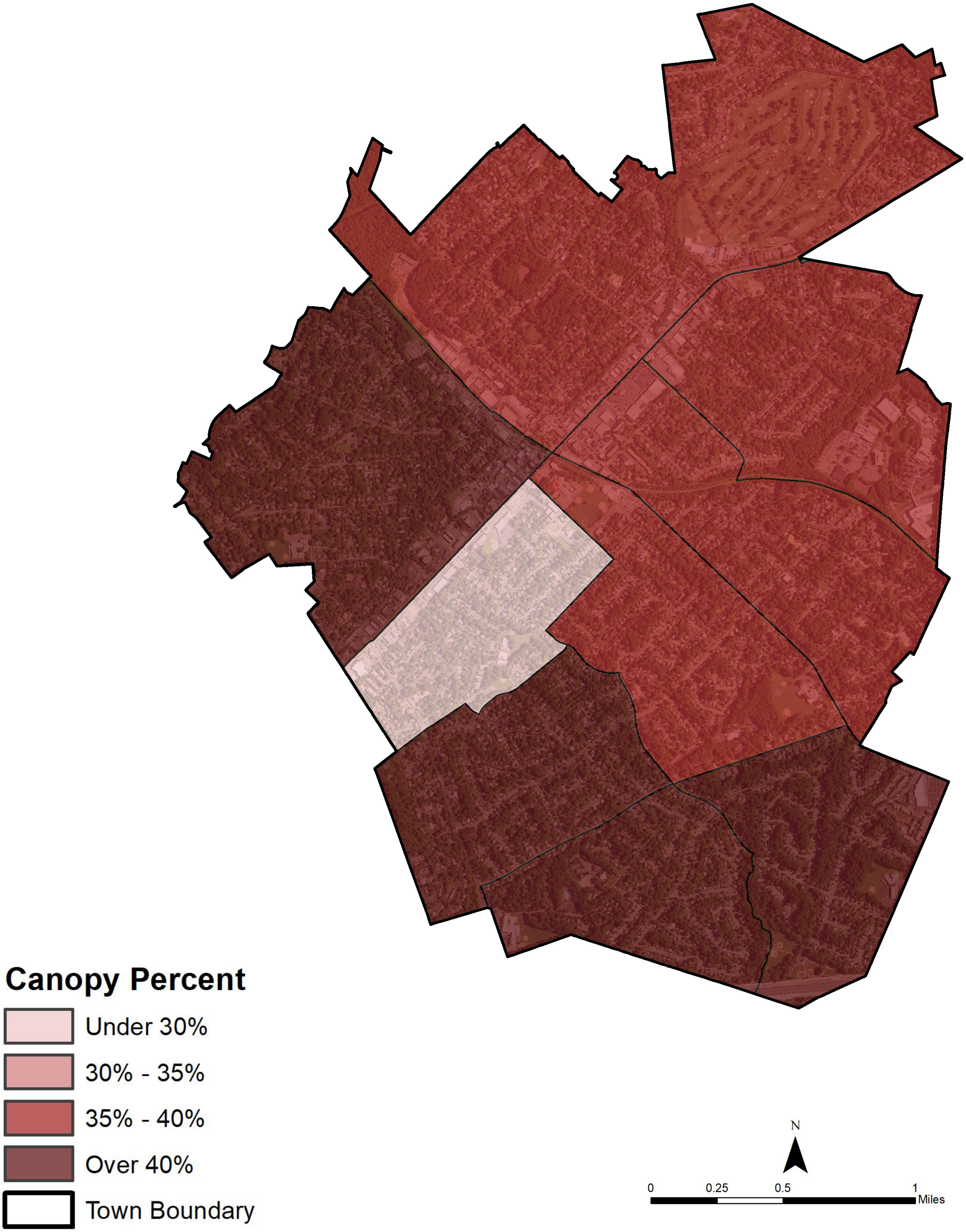
HOW DOES VIENNA COMPARE?

Table 3 compares Vienna's canopy percentage of 38.7% to that of communities in Virginia. Although this canopy data is from various sources, it provides some point of reference to how Vienna compares. Research has noted that canopy percentages of 40–60% are attainable (Leahy, American Forests, 2017). Recognizing where opportunities for planting exist across land uses, census block groups, and other delineations is key to increasing Vienna's canopy coverage. More information discussing opportunities and canopy goals can be found in Section 3.

Table 3. Canopy Percentage by Community

Location	Date	Canopy Coverage[1]
Town of Vienna	2022	38.7%
Fairfax County[a]	2016	51.2%
Falls Church[b]	2012	46%
Fairfax City[g]	2018	37.6%
Alexandria[c]	2018	32.5%
Arlington[f]	2017	38%
Washington DC[i]	2020	33%
Winchester[b]	2012	21%
Fredericksburg[d]	2012	44%
Charlottesville[b]	2012	27%
Waynesboro[h]	n/a	43%
Richmond[h]	2015	42%
Norfolk[h]	2009	26%
Harrisonburg[e]	2021	26.5%
Blacksburg[h]	n/a	30%
Roanoke[b]	2012	25%

MAP 3. TREE CANOPY BY BLOCK GROUP



SECTION 2

CANOPY CHANGE ANALYSIS

HISTORIC CHANGE ASSESSMENT

Historic imagery of Vienna from 2011 and 1990 was analyzed to compare canopy levels in the past to that seen in 2021. Importantly, the 1990 imagery was 'leaf-off' whereas the 2011 and 2021 data were 'leaf-on'. This means that the 1990 imagery was captured during a month in which most trees do not have leaves (excluding evergreens and other trees that still bear leaves in the off-season). Data validation and editing were performed with this leaf-off imagery in mind, but the lack of leaves can cause a minor variance in the canopy percent as it is not always possible to capture the exact extent of the canopy without the leaves. Despite this variance, this data is still a valid reference for comparison's sake.

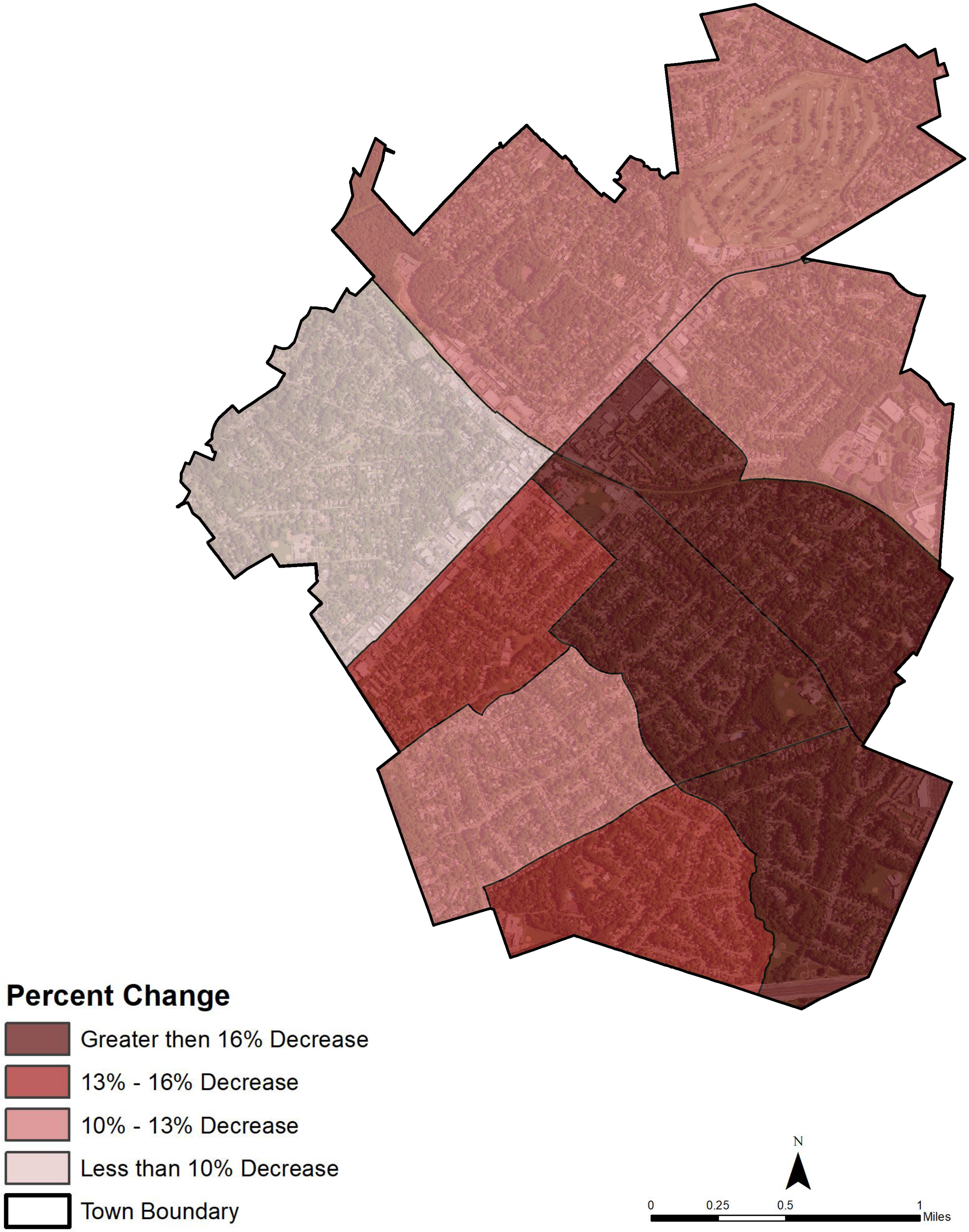
The comparison between 2011 and 2021 revealed a 13.0% decrease in Vienna's tree canopy within that 10-year timeframe. This loss represents an overall decrease of 163 acres of tree canopy. Conversely there was an increase in canopy coverage between 1990 and 2011. The findings of historic change assessments typically reveal a decrease in overall canopy in recent history, which can often be a direct result of increased development activities. This trend could indicate that Vienna has experienced similar, typical increases in the last 10 years.

Table 4. Historic Change Assessment—1990, 2011, 2021

Time Span	Total Town Acres	Acres of Canopy		Difference in Acres of Canopy from Beginning to End of Timeline	Percent Change from the Beginning of Timeline
		Acres at Beginning	Acres at End		
1990–2011	2817	952	1,253	301	31.6%
Canopy Coverage		33.8%	44.5%		
2011–2021	2817	1,253	1,090	-163	-13.0%
Canopy Coverage		44.5%	38.7%		
1990–2021	2817	952	1,090	138	14.5%
Canopy Coverage		33.8%	38.7%		

Looking at block groups and comparing data between 2011 and 2021, the largest decrease in canopy—a decrease greater than 30%—occurred on the southeast side of town. The lowest percentage of canopy loss occurred in the northwest-most block group, with a decrease of 0–15%. The reasons for these differences could be due to variations in patterns of development or, conversely, stronger planting and preservation efforts in those parts of town, where lower levels of canopy loss were noted.

MAP 4. CANOPY CHANGE BY BLOCK GROUP



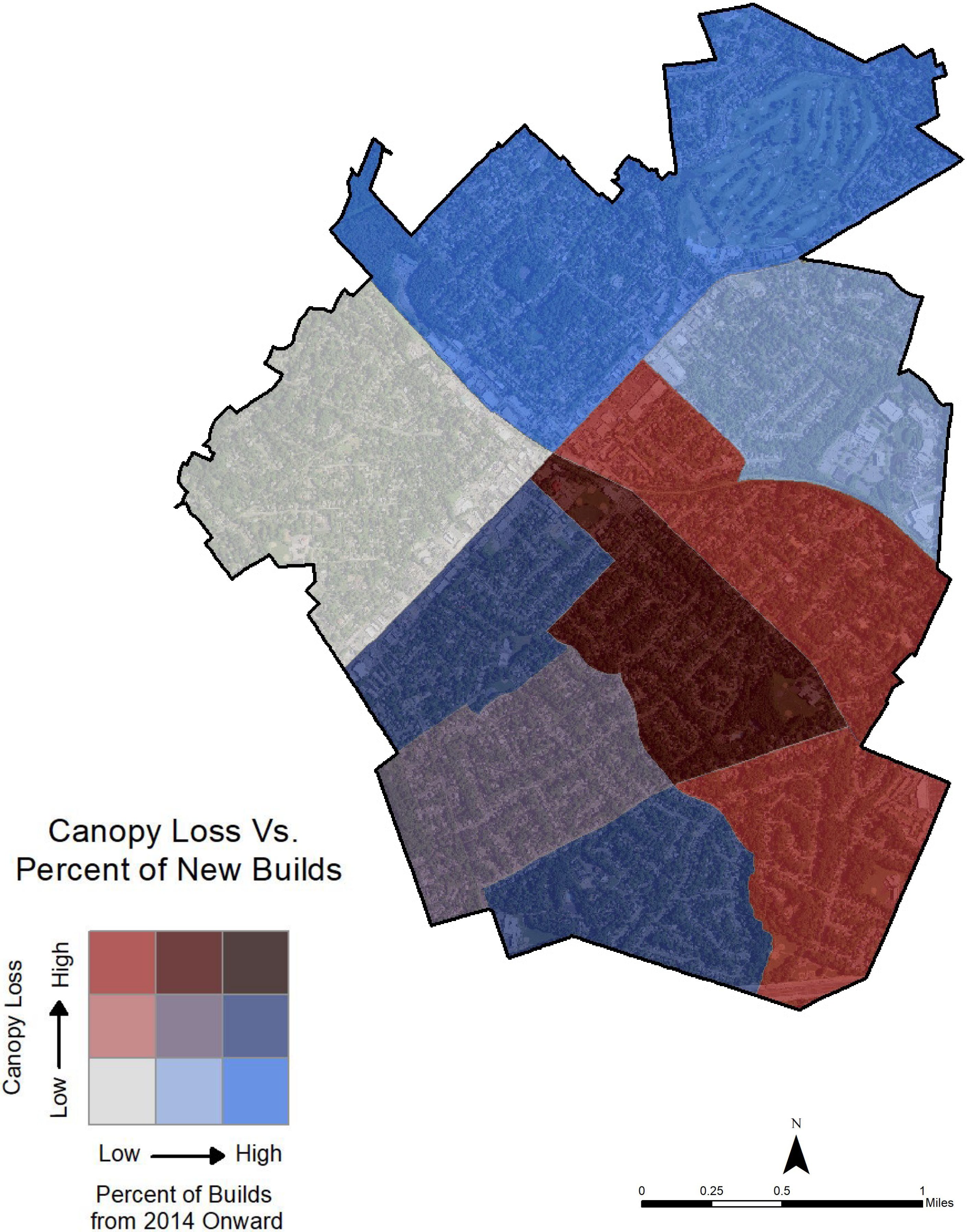
CANOPY LOSS BY PERCENT OF NEW BUILDS

Comparing the percentage of newly constructed buildings with the percentage of canopy loss underscores another way development can affect trees. To illustrate this, information on when buildings were constructed in Vienna was analyzed. Data regarding building age was present in two categories: those built earlier than 2014, and those built from 2014 to the present, referred to as new builds.

The following bivariate map compares the percentage of new builds (X axis) and the canopy loss percentage between 2011 and 2021 (Y axis) for each block group. This shows that block groups with more development activity (more new builds) are some of the areas where the canopy loss between 2011 and 2021 was the greatest.

The most impacted block group is in the center of town, where canopy loss was rated *High* and new builds rated *Moderate*. Areas on the southwest side were noted with moderate levels of canopy loss and high levels of new builds. The central western block group contained a low impact on tree canopy and lower levels of new builds.

MAP 5. NEW BUILDS AND CANOPY LOSS



PRIORITIZED PLANTING ANALYSIS

Increasing canopy cover to meet targets can be daunting without a plan. By assessing open spaces for viability of planting, Vienna can determine which areas would be best served with increasing canopy cover. Planting locations were created by combining all grass/open space and bare soil areas and removing non-feasible planting areas, such as agricultural, recreational fields, and major utility corridors. Note that even though this identification took place, not all sites identified will be suitable for tree planting. Vienna can, however, use this data as a starting point to identify areas for tree planting and field check the sites for tree planting suitability.

Once identified, these potential planting locations were assigned a ranking based on the following environmental factors as they relate to stormwater mitigation: proximity to hardscape, proximity to canopy, floodplain proximity, slope, and soil erosion factor (K-SAT). Full details of the methodology of this prioritization can be found in Appendix B.

A total of approximately 653 acres of suitable planting areas were identified. Table 5 shows the priority ranking across the town based on that stormwater mitigation prioritization.

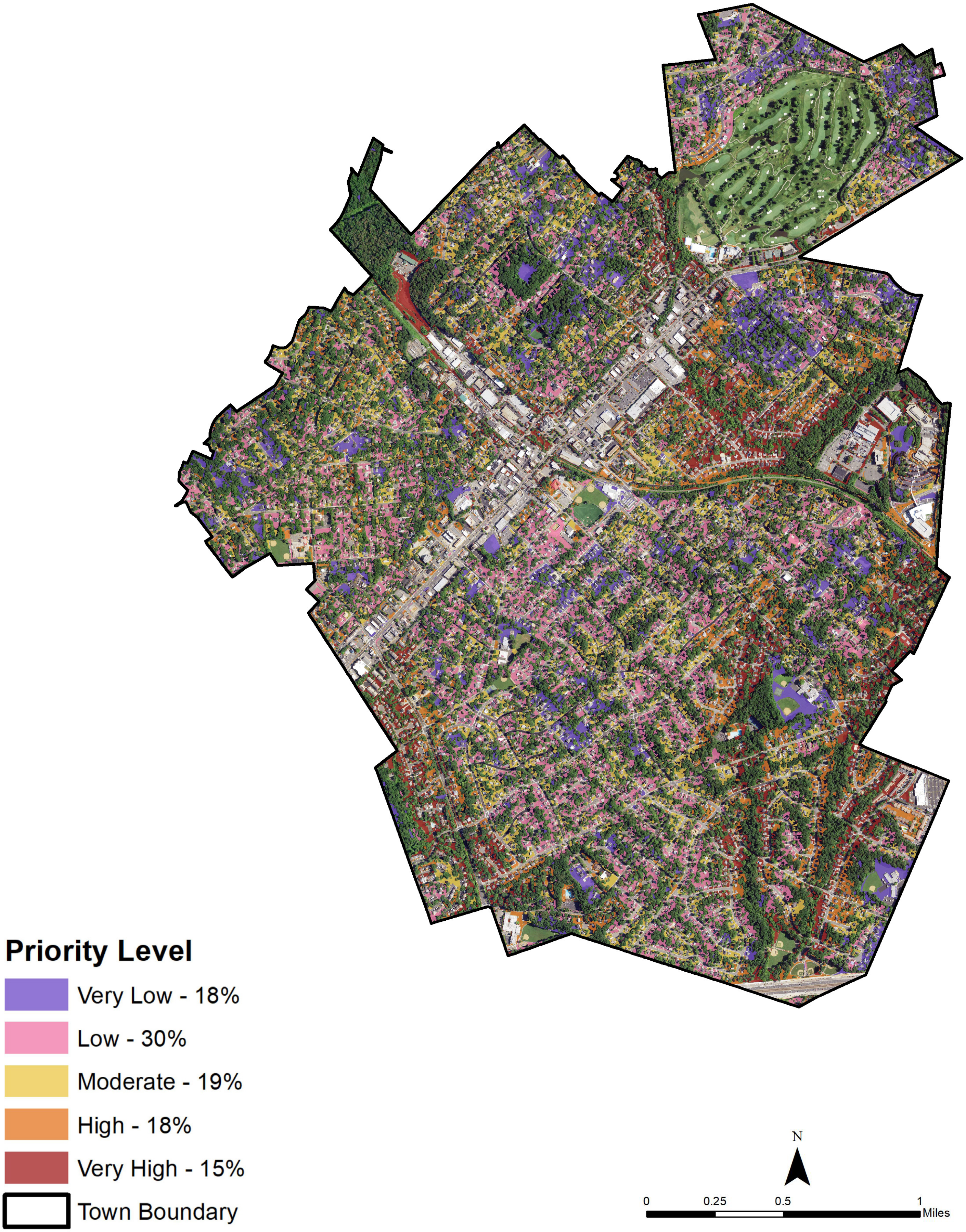
Table 5. Priority Planting Analysis

Priority Rank	Acres	Percent
Very High	99	15%
High	115	18%
Moderate	125	19%
Low	199	30%
Very Low	116	18%
Total	**653**	**100%**

The highest concentration of *Very High* and *High* classifications of planting areas are located in residential neighborhoods in the southwest and southeast parts of town. Another area with higher classification is in the neighborhood south of the Westwood Country Club.

The *Very High* and *High* classifications represent approximately 214 acres of potential canopy. If these areas were to be planted, the overall canopy level of Vienna would rise from its 2021 level of 1,090 acres to 1,303. This would bring the canopy level to 46.3%, a percent change of 19.6% when compared to 2021's 38.7%.

MAP 6. PRIORITY PLANTING ANALYSIS



WHAT IS AN ACCURATE CANOPY GOAL?

Historically, canopy goals of 40% have been touted by industry professionals, but recent data and science asks urban forestry managers to give more context than one catch-all goal. American Forests notes that 40–60% canopy goals are attainable given that the area in question is in a thoroughly forested region and that ideal conditions are present (Leahy, American Forests, 2017). Currently, Vienna is at 38.7% canopy.

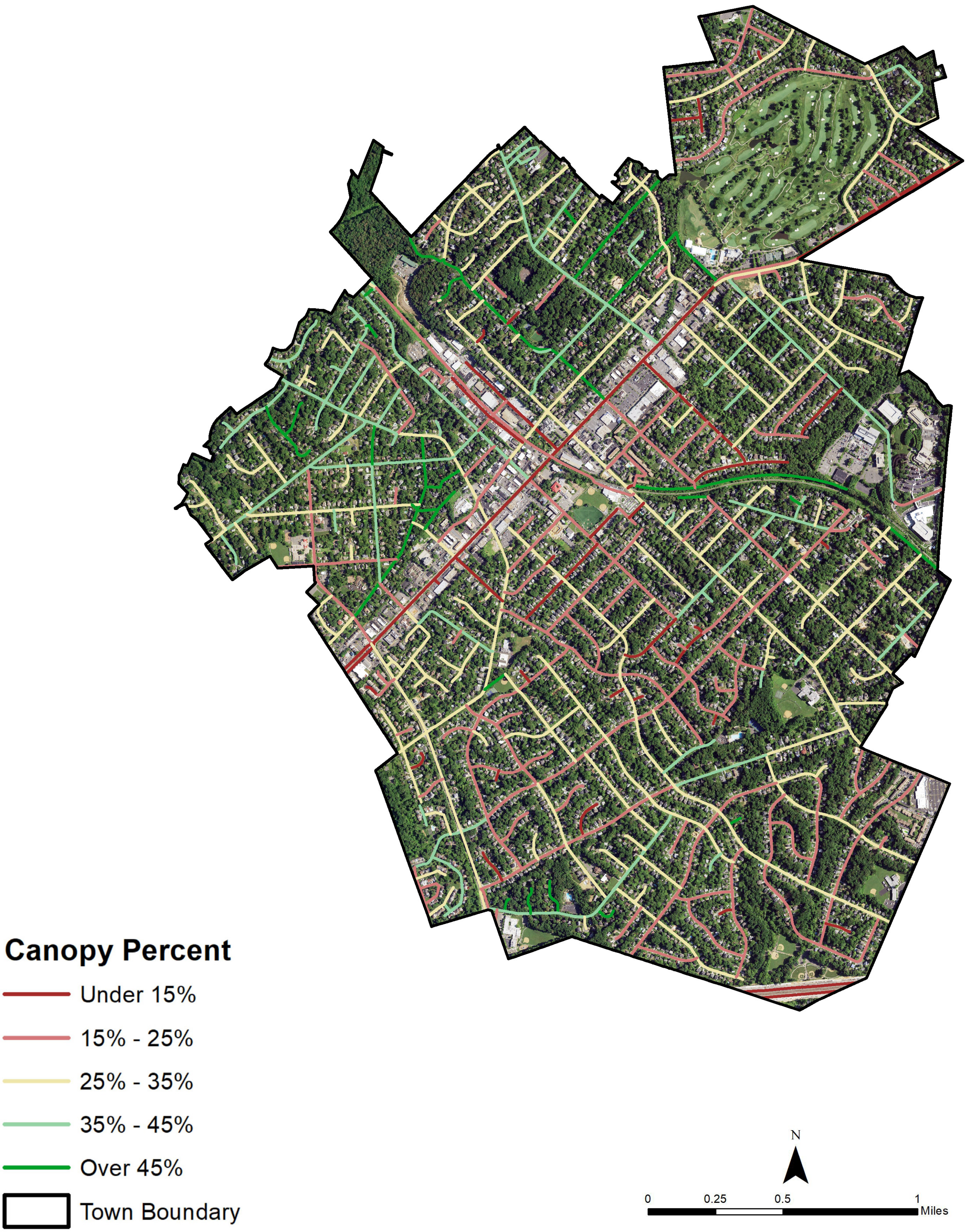
Setting a tree canopy goal is a key step in the planning process as it provides metrics to measure performance throughout the coming years. Methods of increasing canopy cover should include tree preservation and maintenance efforts, in addition to tree planting. As trees mature, their canopy increases often to degrees that cannot be realized with planting efforts alone.

TREE CANOPY IN THE STREET ROW

Another metric that can aid in the prioritization of planting efforts is the location of tree canopy within the town-maintained street right-of-way (ROW). The following map shows the percentage of canopy cover within 25 feet of the street centerline.

Streets with a lower canopy level are present through the main commercial corridor but are also present in some of the residential neighborhoods. From a planning perspective, the Town ROW is one of the areas where Vienna urban forest managers have more direct control over where and what trees are planted. Accordingly, Vienna may benefit by prioritizing tree planting in the Town ROW.

MAP 7. TREE CANOPY IN THE ROW



SECTION 4

BENEFITS OF THE URBAN FOREST

Vienna and the surrounding area of Fairfax County are considered a humid subtropical climate. This is marked by hot summers with high humidity and relatively mild springs, falls, and winters. The town is in USDA Hardiness Zone 7a, which is described as a minimum average temperature of 0° to 5° F. Temperatures in the peak of the summer average a range of 73° to 90° F.

The trees of Vienna play a vital role in not only mitigating these high temperatures, but also offering a variety of other benefits. Trees provide essential services, including (Bastin, et al., 2019; Ulmer, et al., 2019; and CUFR, n.d.):

- Removing ozone from the air, which helps reduce atmospheric warming and improves air quality and the public health effects of air pollution.
- Storing carbon and reducing the amount returning to the atmosphere as a greenhouse gas.
- Shading and cooling streets and buildings, mitigating the urban heat island effect, and reducing the use of air conditioning.
- Intercepting and absorbing stormwater, which reduces flooding and the amount entering a municipality's stormwater system.
- Improving water quality by filtering and removing pollutants.
- Providing homes, food, and shelter for wildlife.
- Beautifying the community.
- Positively impacting the overall health of urban residents and lessening the negative impacts of urbanization.

Annual Value of Vienna's Tree Canopy: $4.3 million

Vienna's tree canopy cover provides **a cumulative, annual value of $4,316,837** by providing the following ecosystem benefits to the community (USDA Forest Service, i-Tree Tools). Table 6 breaks down the following benefits.

Carbon. The trees sequester 1,440 tons of carbon, reducing the amount returning to the atmosphere as a greenhouse gas. **Annual value: $245,235** Additionally, the trees currently store over 37,710 tons of carbon which provides an estimated benefit valued at $6.4 million.

Stormwater. The trees intercept and absorb about 23.6 million gallons of stormwater, reducing the amount entering the storm sewer system. **Annual value: $4,018,115**

Air Pollution. The trees remove 437 pounds of carbon monoxide, 8,004 pounds of nitrogen dioxide, 35,485 pounds of ozone, and 2,922 pounds of sulfur dioxide from the atmosphere, helping to reduce atmospheric warming, improve air quality, and mitigate the public health effects from air pollution. **Annual value: $27,193**

Air Quality. Vienna's urban forest removes 11,141 pounds of dust, smoke, and other particles from the air, directly improving air quality and respiratory health (e.g., asthma). **Annual value: $26,294**

Table 6. Total Estimated Ecosystem Benefits Provided by the Tree Canopy

Ecosystem Benefits	Annual Ecosystem Benefits	
	Quantity	**Value**
Air: CO (carbon monoxide) removed	437 lbs	$218
Air: NO_2 (nitrogen dioxide) removed	8,004 lbs	$2,216
Air: O_3 (ozone) removed	35,485 lbs	$24,559
Air: SO_2 (sulfur dioxide) removed	2,921 lbs	$200
Air: PM_{10} particulate matter (dust, soot, etc.) removed	11,140 lbs	$26,294
Carbon sequestered	1,440 tons	$245,235
Stormwater: reduction in runoff	23,635,971 gal	$4,018,115
Total Annual Benefits		**$4,316,837**
Current stored carbon*	37,710 tons	$6,432,015
Total		**$10,748,852**
*Carbon storage is an estimation of the total carbon stored by trees at a given point in time. The estimation is based on a measurement of total carbon contribution over the life of the tree canopy.		

The largest annual ecosystem benefit that Vienna's trees provide is the reduction of approximately 23.6 million gallons of stormwater ($4.0 million in benefits). Considering the 1,090 acres of tree canopy and assuming that there are 50 mature trees per acre, this is about **420 gallons of stormwater taken up annually by each tree**. The largest overall benefit is the **37,710 tons of carbon stored within the trees of Vienna, valued at $6.4 million**. However, this is not measured on an annual basis and therefore is only included in the Total Value figure.

Nevertheless, this benefit represents a great boon to Vienna with carbon stored in the roots, stems, and foliage of the town's trees instead of being released or circulating in the atmosphere. As Vienna moves forward, it is important to consider the effects that each tree planted, preserved, or removed will have on the community. As development continues, the need for trees will become even more critical. Full details on ecosystem services methodology can be found in Appendix C.

CONCLUSION

A high percentage of canopy cover can be a strong indicator of a sustainable urban forest. Based on the 2021 data, canopy coverage in Vienna is 38.7%. However, tree canopy changes over time. Sometimes gradually and sometimes abruptly with weather, climate, disease, economic, and development events. Although overall canopy percentages of Vienna have decreased in the past 10 years, there exists many opportunities to plant, preserve, and maintain the trees within the town. The next steps will determine the course for The Town of Vienna's tree management program. Considerations should include (but are not limited to):

- Establishing a percentage for the Town's tree canopy goal.
- Providing support for tree planting and preservation programs and activities.
- Engaging and educating the residents and stakeholders in Vienna to support and participate in tree-related activities.
- Developing a program to encourage planting of trees on private property.
- Writing an Urban Forest Master Plan (UFMP) for Vienna.
- Conducting an inventory of the Town's public trees (street ROW, parks, and other public property).
- Continuing to compile and maintain data on the annual expenditures on tree planting and number of trees planted to maintain Vienna's "Tree City USA" status.

With a goal and prioritization plan, leadership can move forward promoting urban forestry initiatives with a data-driven approach. Regardless of whether trees and planting spaces are located on public or private land, the support of the community is needed to ensure Vienna can meet its canopy goals. This assessment is the first step of many to continue to foster a sense of tree stewardship in Vienna that can continue for generations to come.

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APPENDICES

APPENDIX A.
CLASSIFICATION METHODOLOGY AND ACCURACY ASSESSMENT

APPENDIX B. PRIORITIZED PLANTING METHODOLOGY

APPENDIX C. ECOSYSTEM SERVICES METHODOLOGY

APPENDIX A. CLASSIFICATION METHODOLOGY AND ACCURACY ASSESSMENT

DAVEY RESOURCE GROUP CLASSIFICATION METHODOLOGY

Davey Resource Group utilized an object-based image analysis (OBIA) semi-automated feature extraction method to process and analyze current high-resolution color infrared (CIR) aerial imagery and remotely-sensed data to identify tree canopy cover and land cover classifications. The use of imagery analysis is cost-effective and provides a highly accurate approach to assessing your community's existing tree canopy coverage. This supports responsible tree management, facilitates community forestry goal-setting, and improves urban resource planning for healthier and more sustainable urban environments.

Advanced image analysis methods were used to classify, or separate, the land cover layers from the overall imagery. The semi-automated extraction process was completed using Feature Analyst, an extension of ArcGIS®. Feature Analyst uses an object-oriented approach to cluster together objects with similar spectral (i.e., color) and spatial/contextual (e.g., texture, size, shape, pattern, and spatial association) characteristics. The land cover results of the extraction process was post-processed and clipped to each project boundary prior to the manual editing process in order to create smaller, manageable, and more efficient file sizes. Secondary source data, high-resolution aerial imagery provided by each UTC city, and custom ArcGIS® tools were used to aid in the final manual editing, quality checking, and quality assurance processes (QA/QC). The manual QA/QC process was implemented to identify, define, and correct any misclassifications or omission errors in the final land cover layer.

CLASSIFICATION WORKFLOW

1. Prepare imagery for feature extraction (resampling, rectification, etc.), if needed.

2. Gather training set data for all desired land cover classes (canopy, impervious, grass, bare soil, shadows). Water samples are not always needed since hydrologic data are available for most areas. Training data for impervious features were not collected because the City maintained a completed impervious layer.

3. Extract canopy layer only; this decreases the amount of shadow removal from large tree canopy shadows. Fill small holes and smooth to remove rigid edges.

4. Edit and finalize canopy layer at 1:2000 scale. A point file is created to digitize-in small individual trees that will be missed during the extraction. These points are buffered to represent the tree canopy. This process is done to speed up editing time and improve accuracy by including smaller individual trees.

5. Extract remaining land cover classes using the canopy layer as a mask; this keeps canopy shadows that occur within groups of canopy while decreasing the amount of shadow along edges.

6. Edit the impervious layer to reflect actual impervious features, such as roads, buildings, parking lots, etc. to update features.

7. Using canopy and actual impervious surfaces as a mask; input the bare soils training data and extract them from the imagery. Quickly edit the layer to remove or add any features. Davey Resource Group tries to delete dry vegetation areas that are associated with lawns, grass/meadows, and agricultural fields.

8. Assemble any hydrological datasets, if provided. Add or remove any water features to create the hydrology class. Perform a feature extraction if no water feature datasets exist.

9. Use geoprocessing tools to clean, repair, and clip all edited land cover layers to remove any self-intersections or topology errors that sometimes occur during editing.

10. Input canopy, impervious, bare soil, and hydrology layers into Davey Resource Group's Five-Class Land Cover Model to complete the classification. This model generates the pervious (grass/low-lying vegetation) class by taking all other areas not previously classified and combining them.

11. Thoroughly inspect final land cover dataset for any classification errors and correct as needed.

12. Perform accuracy assessment. Repeat Step 11, if needed.

AUTOMATED FEATURE EXTRACTION FILES

The automated feature extraction (AFE) files allow other users to run the extraction process by replicating the methodology. Since Feature Analyst does not contain all geoprocessing operations that Davey Resource Group utilizes, the AFE only accounts for part of the extraction process. Using Feature Analyst, Davey Resource Group created the training set data, ran the extraction, and then smoothed the features to alleviate the blocky appearance. To complete the actual extraction process, Davey Resource Group uses additional geoprocessing tools within ArcGIS®. From the AFE file results, the following steps are taken to prepare the extracted data for manual editing.

1. Davey Resource Group fills all holes in the canopy that are less than 30 square meters. This eliminates small gaps that were created during the extraction process while still allowing for natural canopy gaps.

2. Davey Resource Group deletes all features that are less than 9 square meters for canopy (50 square meters for impervious surfaces). This process reduces the amount of small features that could result in incorrect classifications and also helps computer performance.

3. The Repair Geometry, Dissolve, and Multipart to Singlepart (in that order) geoprocessing tools are run to complete the extraction process.

4. The Multipart to Singlepart shapefile is given to GIS personnel for manual editing to add, remove, or reshape features.

ACCURACY ASSESSMENT PROTOCOL

Table 7. Land Cover Classification Code Values

Land Cover Classification	Code Value
Tree Canopy	1
Impervious	2
Pervious (Grass/Vegetation)	3
Bare Soil	4
Open Water	5

Determining the accuracy of spatial data is of high importance to Davey Resource Group and our clients. To achieve to best possible result, Davey Resource Group manually edits and conducts thorough QA/QC checks on all urban tree canopy and land cover layers. A QA/QC process will be completed using ArcGIS® to identify, clean, and correct any misclassification or topology errors in the final land cover dataset. The initial land cover layer extractions will be edited at a 1:2000 quality control scale in the urban areas and at a 1:2500 scale for rural areas utilizing the most current high-resolution aerial imagery to aid in the quality control process.

To test for accuracy, random plot locations are generated throughout the city area of interest and verified to ensure that the data meet the client standards. Each point will be compared with the most current NAIP high-resolution imagery (reference image) to determine the accuracy of the final land cover layer. Points will be classified as either correct or incorrect and recorded in a classification matrix. Accuracy will be assessed using four metrics: overall accuracy, kappa, quantity disagreement, and allocation disagreement. These metrics are calculated using a custom Excel® spreadsheet.

LAND COVER ACCURACY

The following describes Davey Resource Group's accuracy assessment techniques and outlines procedural steps used to conduct the assessment.

1. **Random Point Generation**—Using ArcGIS, 1,000 random assessment points are generated.

2. **Point Determination**—Each point is carefully assessed by the GIS analyst for likeness with the aerial photography. To record findings, two new fields, CODE and TRUTH, are added to the accuracy assessment point shapefile. CODE is a numeric value (1–5) assigned to each land cover class (Table 7) and TRUTH is the actual land cover class as identified according to the reference image. If CODE and TRUTH are the same, then the point is counted as a correct classification. Likewise, if the CODE and TRUTH are not the same, then the point is classified as incorrect. In most cases, distinguishing if a point is correct or incorrect is straightforward. Points will rarely be misclassified by an egregious classification or editing error. Often incorrect points occur where one feature stops and the other begins.

3. Classification Matrix—During the accuracy assessment, if a point is considered incorrect, it is given the correct classification in the TRUTH column. Points are first assessed on the NAIP imagery for their correctness using a "blind" assessment—meaning that the analyst does not know the actual classification (the GIS analyst is strictly going off the NAIP imagery to determine cover class). Any incorrect classifications found during the "blind" assessment are scrutinized further using sub-meter imagery provided by the client to determine if the point was incorrectly classified due to the fuzziness of the NAIP imagery or an actual misclassification. After all random points are assessed and recorded; a classification (or confusion) matrix is created. The classification matrix for this project is presented in Table 8. The table allows for assessment of user's/producer's accuracy, overall accuracy, omission/commission errors, kappa statistics, allocation/quantity disagreement, and confidence intervals (Figure 3 and Table 9).

Figure 3

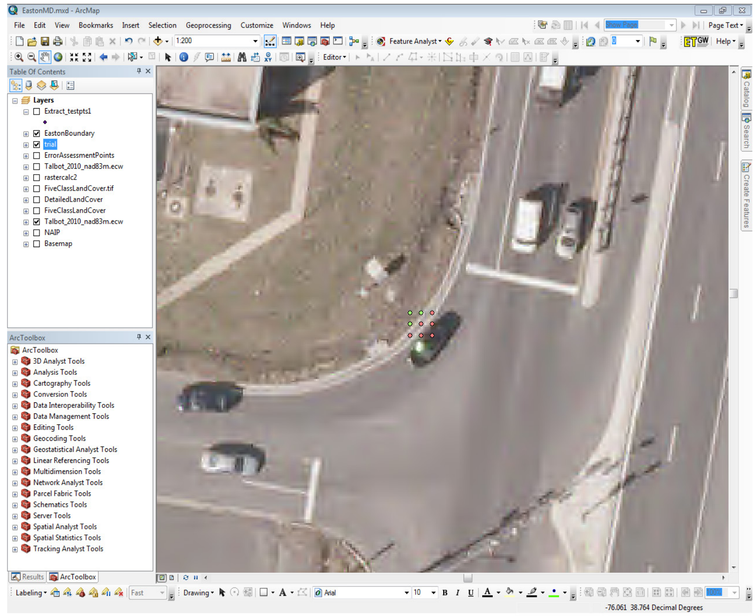

Table 8. Classification Matrix

Reference Data	Classes	Tree Canopy	Impervious Surfaces	Grass & Low-Lying Vegetation	Bare Soils	Open Water	Row Total	Producer's Accuracy	Errors of Omission
	Tree Canopy	351	2	12	0	0	365	96.16%	3.84%
	Impervious	2	320	18	0	0	340	94.12%	5.88%
	Grass/ Vegetation	13	9	262	0	0	284	92.25%	7.75%
	Bare Soils	0	0	0	9	0	9	100.00%	0.00%
	Water	0	0	0	0	2	2	100.00%	0.00%
	Column Total	366	331	292	9	2	1000		
	User's Accuracy	95.90%	96.68%	89.73%	100.00%	100.00%		Overall Accuracy	94.40%
	Errors of Commission	4.10%	3.32%	10.27%	0.00%	0.00%		Kappa Coefficent	0.9165

Following are descriptions of each statistic as well as the results from some of the accuracy assessment tests.

Overall Accuracy—Percentage of correctly classified pixels; for example, the sum of the diagonals divided by the total points ((351+320+262+9+2)/1,000 = 94.40%).

User's Accuracy—Probability that a pixel classified on the map actually represents that category on the ground (correct land cover classifications divided by the column total [351/366 = 95.90%]).

Producer's Accuracy—Probability of a reference pixel being correctly classified (correct land cover classifications divided by the row total [351/365 = 96.16%]).

Kappa Coefficient—A statistical metric used to assess the accuracy of classification data. It has been generally accepted as a better determinant of accuracy partly because it accounts for random chance agreement. A value of 0.80 or greater is regarded as "very good" agreement between the land cover classification and reference image.

Errors of Commission—A pixel reports the presence of a feature (such as trees) that, in reality, is absent (no trees are actually present). This is termed as a false positive. In the matrix below, we can determine that 4.10% of the area classified as canopy is most likely not canopy.

Errors of Omission—A pixel reports the absence of a feature (such as trees) when, in reality, they are actually there. In the matrix below, we can conclude that 3.84% of all canopy classified is actually classified as another land cover class.

Allocation Disagreement—The amount of difference between the reference image and the classified land cover map that is due to less than optimal match in the spatial allocation (or position) of the classes.

Quantity Disagreement—The amount of difference between the reference image and the classified land cover map that is due to less than perfect match in the proportions (or area) of the classes.

Confidence Intervals—A confidence interval is a type of interval estimate of a population parameter and is used to indicate the reliability of an estimate. Confidence intervals consist of a range of values (interval) that act as good estimates of the unknown population parameter based on the observed probability of successes and failures. Since all assessments have innate error, defining a lower and upper bound estimate is essential.

Table 9. Confidence Intervals

Class	Acreage	Percentage	Lower Bound	Upper Bound
Tree Canopy	1,090.3	38.7%	37.8%	39.6%
Impervious Surfaces	929.3	33.0%	32.1%	33.9%
Grass & Low-Lying Vegetation	775.1	27.5%	26.7%	28.4%
Bare Soils	17.3	0.6%	0.5%	0.8%
Open Water	4.5	0.2%	0.1%	0.2%
Total	2,816.5	100.00%		

Statistical Metrics Summary	
Overall Accuracy =	94.40%
Kappa Coefficient =	0.9165
Allocation Disagreement =	5%
Quantity Disagreement =	1%

Accuracy Assessment

Class	User's Accuracy	Lower Bound	Upper Bound	Producer's Accuracy	Lower Bound	Upper Bound
Tree Canopy	95.9%	94.9%	96.9%	96.2%	95.2%	97.2%
Impervious Surfaces	96.7%	95.7%	97.7%	94.1%	92.8%	95.4%
Grass & Low-Lying Vegetation	89.7%	87.9%	91.5%	92.3%	90.7%	93.8%
Bare Soils	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Open Water	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

APPENDIX B.
PRIORITIZED PLANTING METHODOLOGY

PRIORITIZED PLANTING—PLANTING LOCATION

The planting location polygons were created by taking all grass/open space and bare ground areas and combining them into one dataset. Non-feasible planting areas such as agricultural fields, recreational fields, major utility corridors, airports, etc. were removed from consideration. This layer was reviewed and approved by the City of Vienna before the analysis proceeded. The remaining planting space was consolidated into a single feature and, then, exploded back out to multipart features creating separate, distinct polygons for each location. Using zonal statistics, the priority grid raster was used to calculate an average value for each planting location polygon. The averages were binned into five (5) classes with the higher numbers indicating higher priority for planting. These classes ranged from Very Low to Very High.

HOW SITES WERE PRIORITIZED

To identify and prioritize planting potential, Davey Resource Group assessed a number of environmental features, including proximity to hardscape, canopy fragmentation, floodplain proximity, slope, and urban heat island index. Each factor was assessed using data from various sources and analyzed using separate grid maps. Values between zero and four (with zero having the lowest priority) were assigned to each grid assessed. The grids were overlain and the values were averaged to determine the priority levels at an area on the map. A priority ranging from Very Low to Very High was assigned to areas on the map based on the calculated average of all grid maps.

Once the process of identifying priority was completed, the development of planting strategies was the next task. All potential planting sites were not treated equal as some sites were considered to be more suitable than others. Through prioritization, sites were ranked based on a number of factors pertaining to storm water reduction and a relative urban heat island index. While available planting sites may ultimately be planted over the next several decades, the trees that are planted in the next several years, should be planned for areas in most need, and where they will provide the most benefits and return on investment.

Table 10. Priority Ranking Variables

Dataset	Source	Weight
Proximity to Hardscape	Urban Tree Canopy Assessment	0.3
Floodplain Proximity	National Hydrologic Dataset	0.2
Slope	National Elevation Dataset	0.1
Proximity to Canopy	Urban Tree Canopy Assessment	0.1
Soil Permeability	Natural Resource Conservation Service	0.15
Soil Erosion (K-factor)	Natural Resource Conservation Service	0.15

APPENDIX C. ECOSYSTEM SERVICES

METHODOLOGY:

1. HOW TREE CANOPY BENEFITS ARE CALCULATED:

1.1 Air Quality

The i-Tree Canopy v7.1 Model was used to quantify the value of ecosystem services for air quality. i-Tree Canopy was designed to give users the ability to estimate tree canopy and other land cover types within any selected geography. The model uses the estimated canopy percentage and reports air pollutant removal rates and monetary values for carbon monoxide (CO), nitrogen dioxide (NO2), ozone (O3), sulfur dioxide (SO2), and particulate matter (PM) (Hirabayashi 2014).

Within the i-Tree Canopy application, the U.S. EPA's BenMAP Model estimates the incidence of adverse health effects and monetary values resulting from changes in air pollutants (Hirabayashi 2014; US EPA 2012). Different pollutant removal values were used for urban and rural areas. In i-Tree Canopy, the air pollutant amount annually removed by trees and the associated monetary value can be calculated with tree cover in areas of interest using BenMAP multipliers for each county in the United States.

To calculate ecosystem services for the study area, canopy percentage metrics from UTC land cover data performed during the assessment were transferred to i-Tree Canopy. Those canopy percentages were matched by placing random points within the i-Tree Canopy application. Benefit values were reported for each of the five listed air pollutants.

1.2 Carbon Storage and Sequestration

The i-Tree Canopy v7.1 Model was used to quantify the value of ecosystem services for carbon storage and sequestration. i-Tree Canopy was designed to give users the ability to estimate tree canopy and other land cover types within any selected geography. The model uses the estimated canopy percentage and reports carbon storage and sequestration rates and monetary values. Methods on deriving storage and sequestration can be found in Nowak et al. 2013.

To calculate ecosystem services for the study area, canopy percentage metrics from UTC land cover data performed during the assessment were transferred to i-Tree Canopy. Those canopy percentages were matched by placing random points within the i-Tree Canopy application. Benefit values were reported for carbon storage and sequestration.

1.3 Stormwater

The i-Tree Hydro v6.0 Model was used to quantify the value of ecosystem services for stormwater runoff. i-Tree Hydro was designed for users interested in analysis of vegetation and impervious cover effects on urban hydrology. This most recent version (v6.0) allows users to report hydrologic data on the city level rather than just a watershed scale giving users more flexibility. For more information about the model, please consult the i-Tree Hydro v6.0 manual (http://www.itreetools.org).

To calculate ecosystem services for the study area, land cover percentages derived for the project area and all municipalities that were included in the project area were used as inputs into the model. Precipitation data from 2005-2012 was modeled within the i-Tree Hydro to best represent the average conditions over an eight year time period. Model simulations were run under a Base Case as well as an Alternate Case. The Alternative Case set tree canopy equal to 0% and assumed that impervious and vegetation cover would increase based on the removal of tree canopy. Impervious surface was increased 1.9% based on a percentage of the amount of impervious surface under tree canopy and the rest was added to the vegetation cover class. This process was completed to assess the runoff reduction volume associated with tree canopy since i-Tree Hydro does not directly report the volume of runoff reduced by tree canopy. The volume (in cubic meters) was converted to gallons to retrieve the overall volume of runoff avoided by having the current tree canopy.

Through model simulation, it was determined that tree canopy decreases the runoff volume in the project area by 23,635,971 gallons per year using precipitation data from 2005-2012. This equates to approximately 21,679 gallons per acre of tree canopy (23,635,971 gals/1090.3 acres).

To place a monetary value on storm water reduction, the cost to treat a gallon of storm/waste water was taken from McPherson et al 1999. This value was $0.17 per gallon. Tree canopy was estimated to contribute roughly $4,018,115 to avoided runoff annually to the project area.

APPENDIX C REFERENCES

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