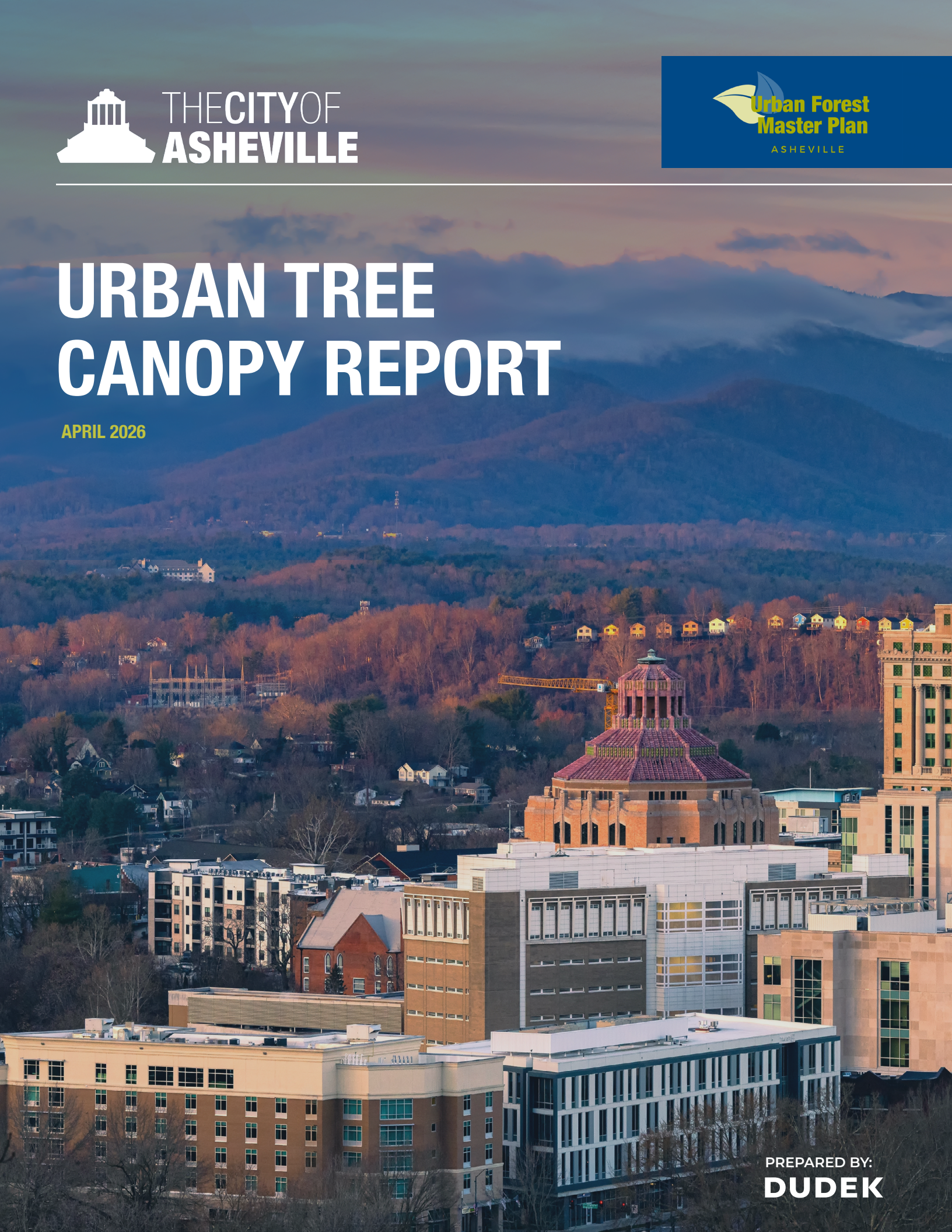
THE CITY OF ASHEVILLE

Urban Forest Master Plan
ASHEVILLE

URBAN TREE CANOPY REPORT

APRIL 2026



PREPARED BY:
DUDEK

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1. INTRODUCTION

Understanding how tree canopy cover has changed over time helps frame current conditions and guides long-term planning. The City of Asheville (City) completed an Urban Tree Canopy Study in 2019, which evaluated canopy cover in 2008 and 2018 and found a 6.4% decline (City of Asheville 2019). The current analysis uses 2022 National Agriculture Imagery Program (NAIP) imagery (USDA 2022) and a different classification approach to provide an updated estimate of existing canopy conditions and offer a reference point for understanding recent trends. Although this assessment provides valuable information to guide urban forest master plan (UFMP) strategies, the data are not directly comparable to previous estimates due to the differences in methods.

In addition, Hurricane Helene, which struck in September 2024, likely resulted in additional canopy loss across the City. The 2022 dataset therefore serves as a pre-storm baseline, and a follow-up assessment will be needed to evaluate storm-related impacts and guide future recovery and replanting efforts.

2. CITY WIDE CANOPY COVER

Land cover was mapped using 2022 NAIP aerial imagery at a 0.6-meter spatial resolution. A machine-learning classification process was applied to identify five land cover types: tree canopy, low to medium vegetation, bare earth or non-photosynthetic vegetation, impervious surfaces, and water. Results were summarized across the City's corporate limits to provide a comprehensive view of land cover distribution.

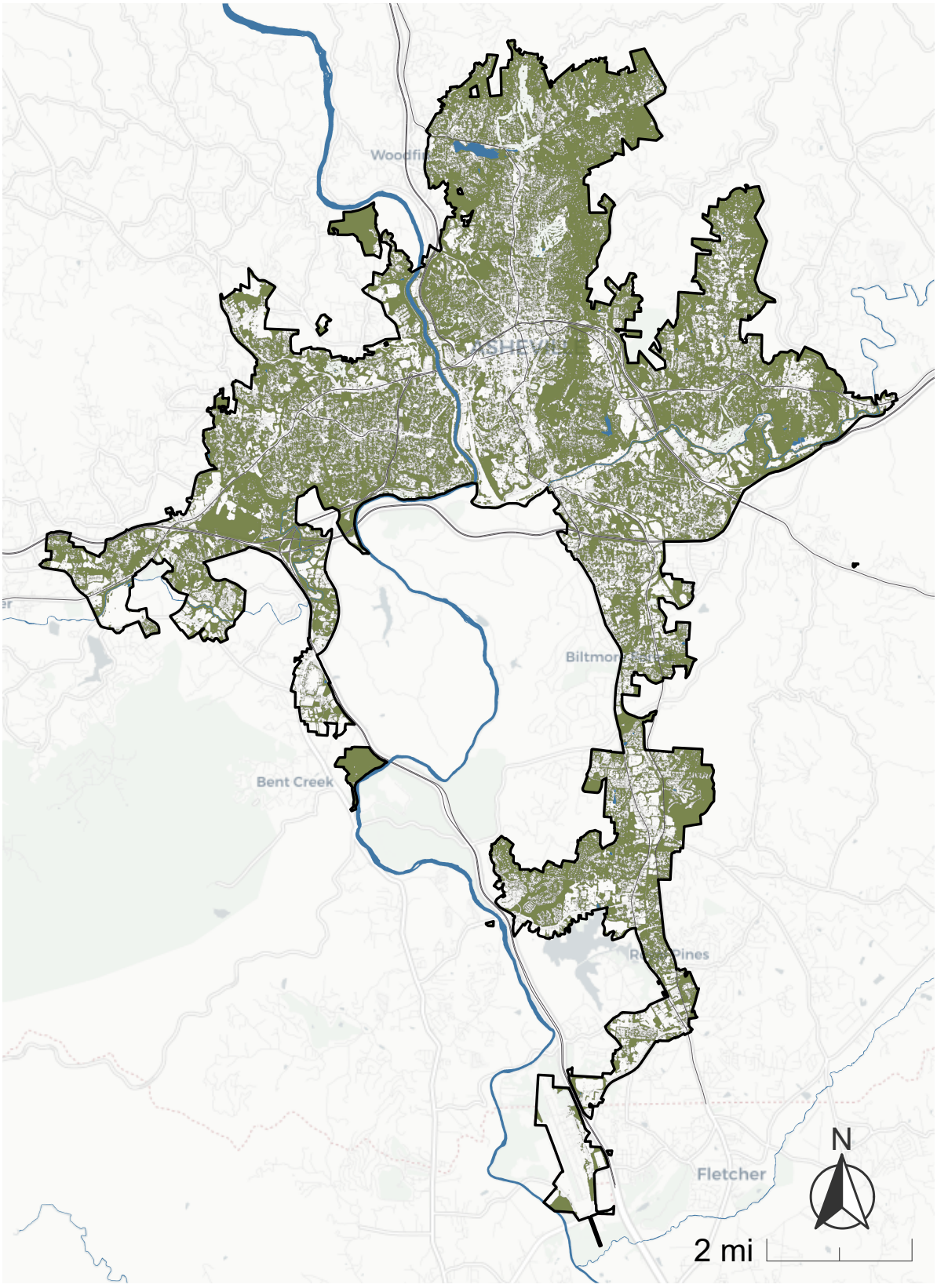
The corporate (or city) limit boundary defines the full extent of the City's jurisdiction and serves as the baseline for citywide canopy estimates. This summary provides an overview of tree canopy and other land cover types and establishes a consistent reference point for comparing canopy distribution across finer geographies such as census tracts and neighborhoods.

Using an accuracy-adjusted estimation method (see Section 6, Methods), tree canopy is estimated to cover approximately **15,909 acres,** or **54.3%** of the City's total area. A 95% confidence interval places the true canopy cover between **51.1%** and **57.5%**. These adjustments account for potential classification error using established best practices (Olofsson et al. 2014, 2021). **Table 1** presents the adjusted area and percent cover for each land cover class.

Table 1. Adjusted Land Cover Summary – Corporate Limits

Land Cover Class	Adjusted Area (acres)	Adjusted Percent Cover (percent)
Tree canopy	15,909	54.3%
Low to medium vegetation	4,463	15.2%
Bare earth/non-photosynthetic vegetation	449	1.5%
Impervious	8,268	28.2%
Water	191	0.7%

Exhibit 1. Asheville Canopy Cover (2022)



Source: Dudek 2026.

3. CANOPY COVER BY GEOGRAPHIC UNIT (2022)

Tree canopy cover was summarized across multiple geographic units, including census tracts, census blocks, neighborhoods, zoning districts, and parcels, to support urban forest planning and implementation. These boundaries provide insight into how canopy is distributed across different parts of the City and help identify opportunities for planting, protection, and equitable investment. Summarizing canopy at these scales also supports goal-setting, prioritization, and community engagement. Each subsection below highlights key findings for a specific geography, illustrating where canopy is most and least concentrated

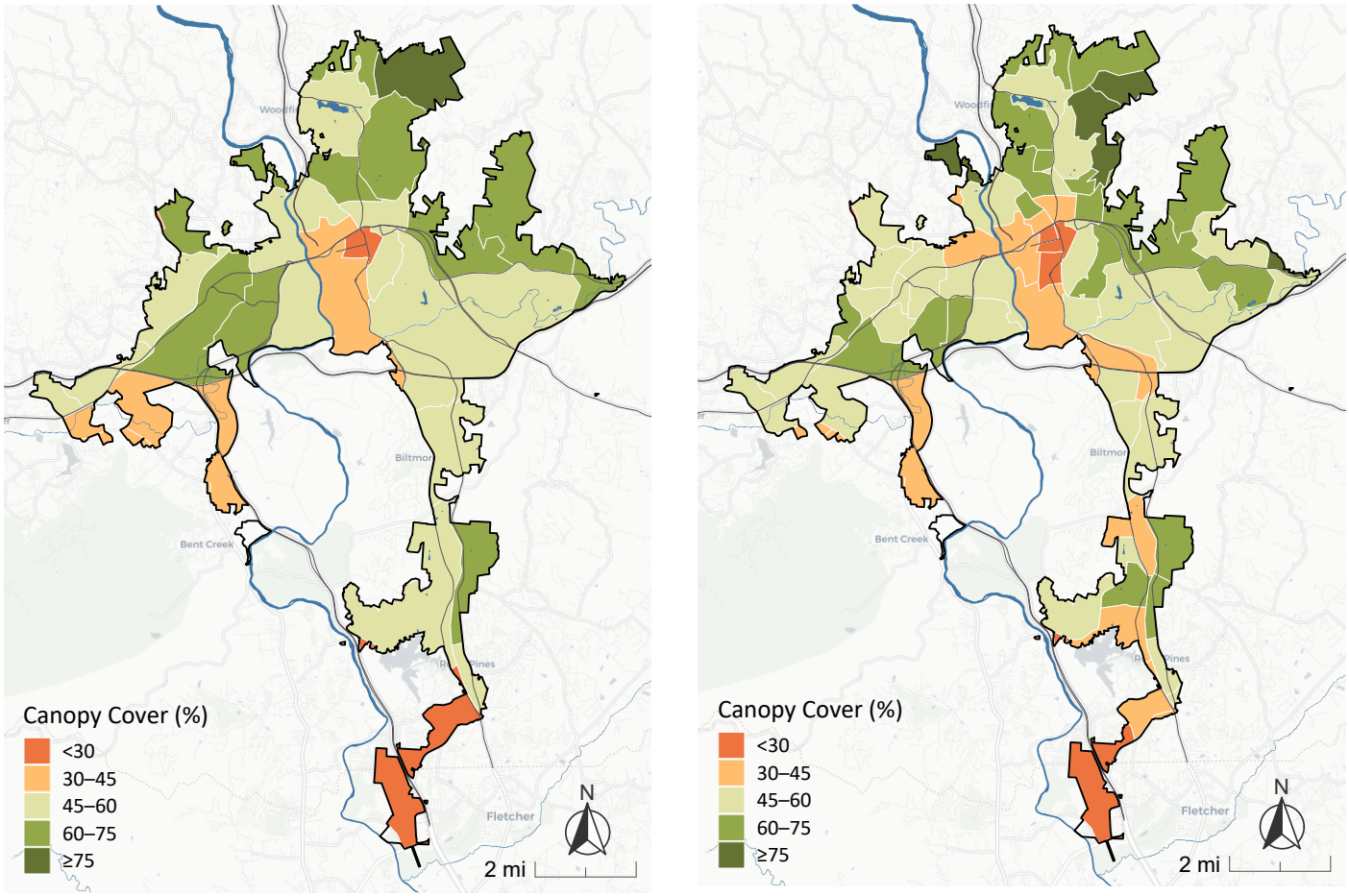
3.1 CENSUS TRACTS AND BLOCKS

Tree canopy was summarized across 34 census tracts and 80 census blocks to evaluate how tree cover aligns with population-based boundaries. These geographies are defined by the U.S. Census Bureau (2020) and are commonly used in environmental justice, public health, and grant funding analyses. They are especially valuable for identifying disparities and guiding equitable tree planting. Census tracts provide a broad view of canopy distribution across communities, while census blocks allow for finer analysis of localized gaps.

KEY FINDINGS

- Canopy cover across tracts ranged from 14.3% to 76.7%, with higher coverage in areas containing open space or lower-density development.
- Block-level canopy ranged from nearly 7.9% to 86.6%, revealing variation even within individual tracts.
- Canopy cover is lowest in central urban tracts and blocks, particularly around downtown Asheville, where dense development and impervious surfaces limit tree growth. The southernmost tracts and blocks, which include Asheville Regional Airport and commercial areas, also show low canopy due to paved and built surfaces.

Exhibit 2. Canopy Cover by Census Tract and Block



Source: Dudek 2026.



3.2 NEIGHBORHOODS

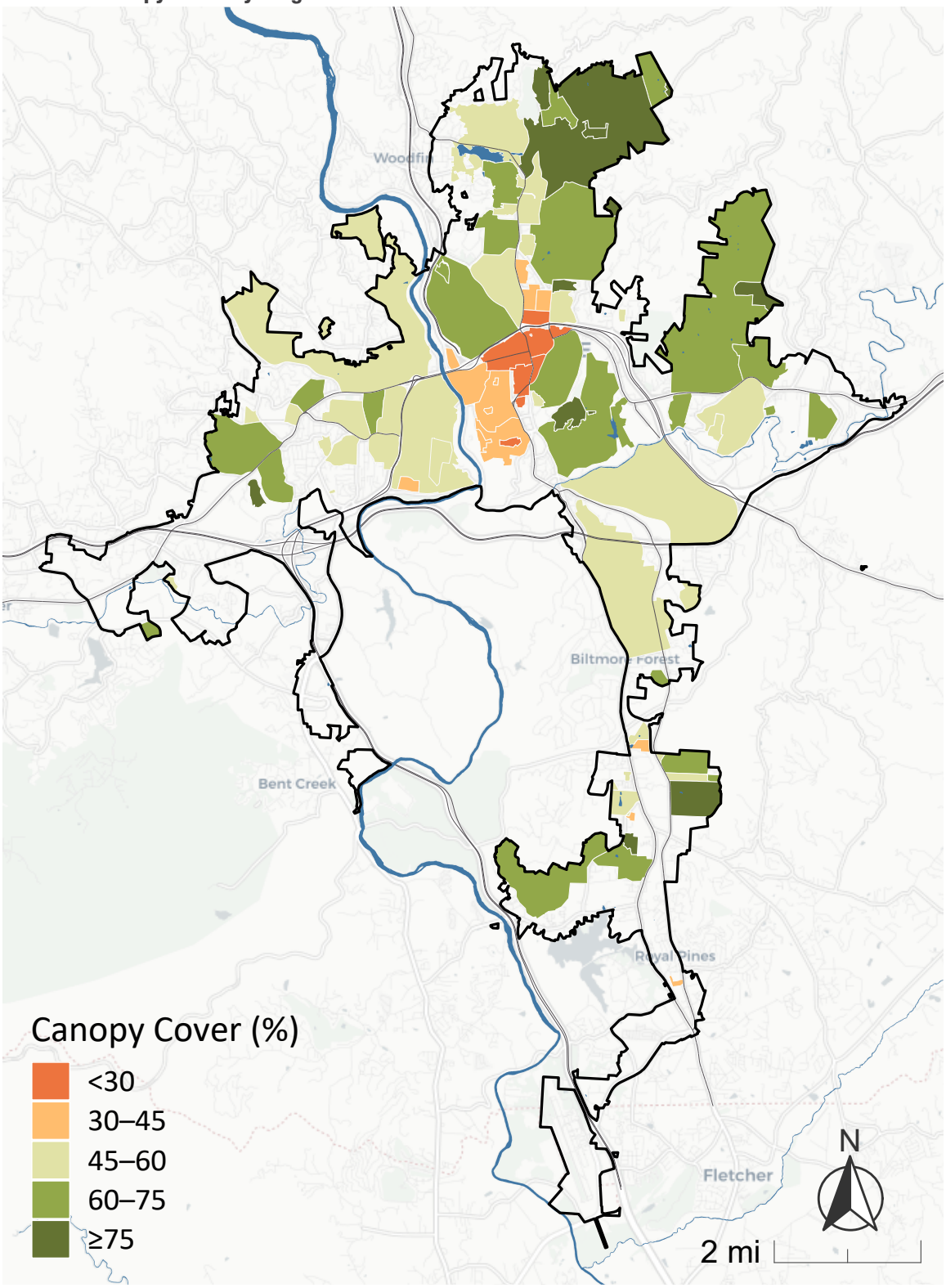
Tree canopy was assessed across 86 neighborhoods to understand how tree distribution relates to local community boundaries. Neighborhood-level summaries are useful for community engagement, localized outreach, and partnering with neighborhood associations or nonprofits on planting efforts. Neighborhoods offer a familiar scale for residents and provide meaningful context for planning initiatives.



KEY FINDINGS

- Canopy cover ranged from 13.0% in Downtown to 90.7% in Blake Mountain, showing wide variability in tree distribution across neighborhoods.
- Neighborhoods with the lowest canopy are concentrated around downtown, reflecting high development intensity and limited planting space; these areas could benefit from targeted greening efforts.
- High-canopy neighborhoods are mostly concentrated in the north, northwest, and southernmost neighborhoods.
- The average canopy cover across neighborhoods was 55.6%. A quarter of neighborhoods had less than 45% canopy cover, placing them in the lowest quartile. These areas may experience reduced access to tree-related benefits compared to neighborhoods in the upper quartile, where canopy exceeds 67%.

Exhibit 3. Canopy Cover by Neighborhood



Source: Dudek 2026.

3.3 ZONING DISTRICTS

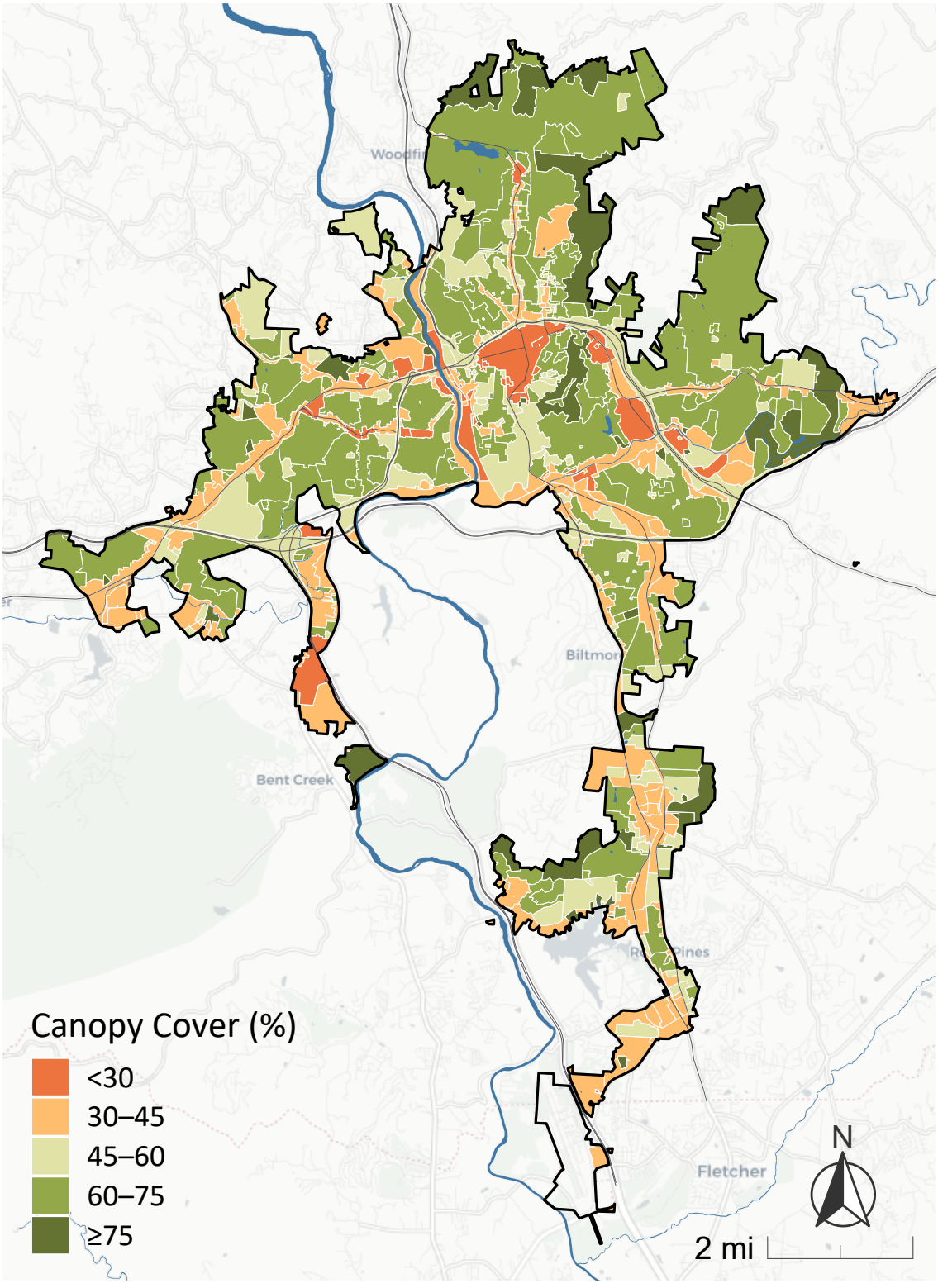
Tree canopy was summarized across 47 zoning types to evaluate how land use regulations relate to canopy distribution. Zoning reflects how land is planned and developed, influencing factors such as lot size, imperviousness, and landscaping requirements. This boundary is helpful for identifying regulatory opportunities to increase or preserve canopy.

KEY FINDINGS

- Canopy cover across zoning districts ranged from 3.8% to 92.2%, illustrating how development intensity and zoning regulations influence the amount of space available for trees.
- Urban and commercial zones had the lowest canopy cover. The Central Business District had 14.8% canopy cover, and its expansion zone dropped to 3.8%, the lowest in the City. Other commercial zones, including Urban Place at 19.8%, Regional Business at 25.7%, and Community Business II at 30.9%, also had relatively low canopy.
- Residential zoning districts supported the highest levels of canopy cover. Low-density single- and multi-family districts had the most canopy, with coverage ranging from 65.5% to 81.5%. Medium- and high-density multifamily districts also maintained relatively high canopy, with cover between 56.3% and 67.5%. These patterns suggest that residential zoning generally provides more space for tree canopy.
- Institutional zones had 55.4% canopy cover, placing them in the third quartile among all zoning districts. This relatively high coverage is likely due to the presence of parks, schools, and campus settings, which often provide space for trees and present opportunities for long-term stewardship partnerships.



Exhibit 4. Canopy Cover by Zoning District



Source: Dudek 2026.

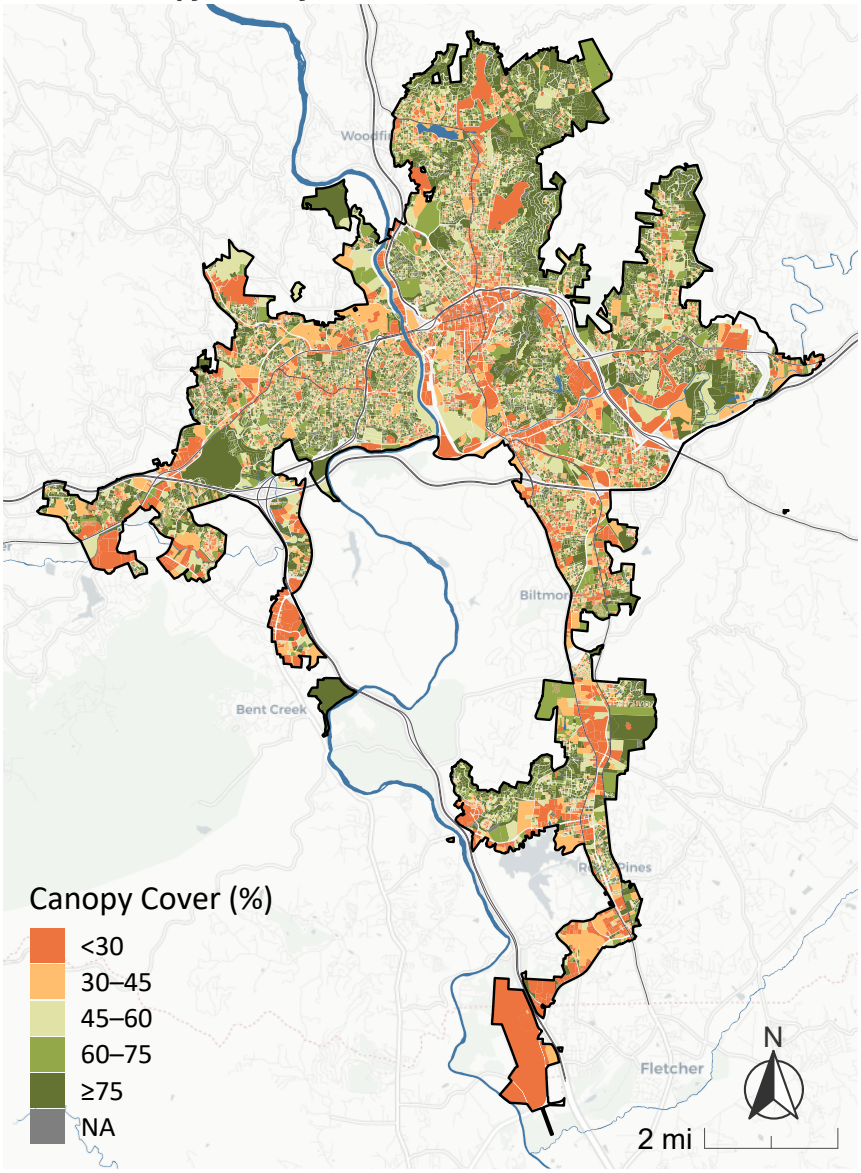
3.4 PARCELS

Tree canopy was summarized across more than 40,000 parcels to support site-specific planning, evaluate planting feasibility, and align tree data with ownership and land value. This highly detailed scale helps identify which properties already contribute substantial canopy and where new planting may be most feasible. Parcel-level summaries are useful for screening but should be interpreted with care due to limitations in the land cover classification process.

KEY FINDINGS

- Some parcels were nearly fully covered by tree canopy, often reflecting preserved land, forested areas, or large residential lots with mature trees.
- Most properties support some level of tree canopy, 94% of parcels had more than 5% canopy cover.
- Parcel-level analysis provides a useful screening tool for identifying potential planting or outreach areas, although site-specific review is needed to confirm on-the-ground conditions.

Exhibit 5. Canopy Cover by Parcel



Source: Dudek 2026.

4. CANOPY COVER CHANGE (2008–2022)

Tree canopy cover in the City has shifted over time due to factors such as development, natural disturbances, tree planting efforts, and the maturation or loss of existing trees. This section summarizes canopy estimates for 2008, 2018, and 2022.

Between 2008 and 2018, the City experienced a net loss of 891 acres of tree canopy, equivalent to a 3.0 percentage point decrease or a 6.4% relative reduction compared to 2008 levels. The 2018 estimate was derived from 0.6-meter NAIP imagery and processed using object-based image analysis (City of Asheville 2019). The resolution and source of the 2008 imagery used in that analysis were not specified in the report.

In 2022, Dudek conducted a new canopy assessment using 0.6-meter resolution NAIP imagery and a different classification approach. This analysis estimated that tree canopy covered 15,909 acres, or 54.3% of the City. Compared to 2018, this reflects an increase of 2,888 acres, a 9.8 percentage point gain, and a 22% relative increase. Due to methodological differences, the 2022 estimate is not directly comparable to earlier results. However, it provides a snapshot of canopy conditions and serves as a baseline for evaluating future changes.

A major storm, Hurricane Helene, in September 2024 likely caused additional canopy loss. A follow-up assessment will be needed to understand the extent of storm-related impacts and to inform future tree planting efforts.

Tree canopy change was evaluated using two metrics: absolute change and relative change.

- **Absolute change** refers to the difference in acres or percentage points between two time periods.
- **Relative change** measures the percent increase or decrease relative to the original value.



Table 2 summarizes canopy cover metrics for each year.

Table 2. Urban Tree Canopy Cover Change in Asheville (2008–2022)

Year	Source	Canopy Area (acres)	Canopy Cover (percent)	Absolute Change (acres)	Absolute Change (percentage points)	Relative Change (percent)
2008	Davey	13,912	47.5%	N/A	N/A	N/A
2018	Davey (2018 0.6-meter NAIP)	13,021	44.5%	−891	−3.0	−6.4%
2022	Dudek (2022 0.6-meter NAIP)	16,244	55.5%	3,223	11	25%
2022*	Dudek (accuracy-adjusted estimate)	15,909	54.3%	2,888	9.8	22%

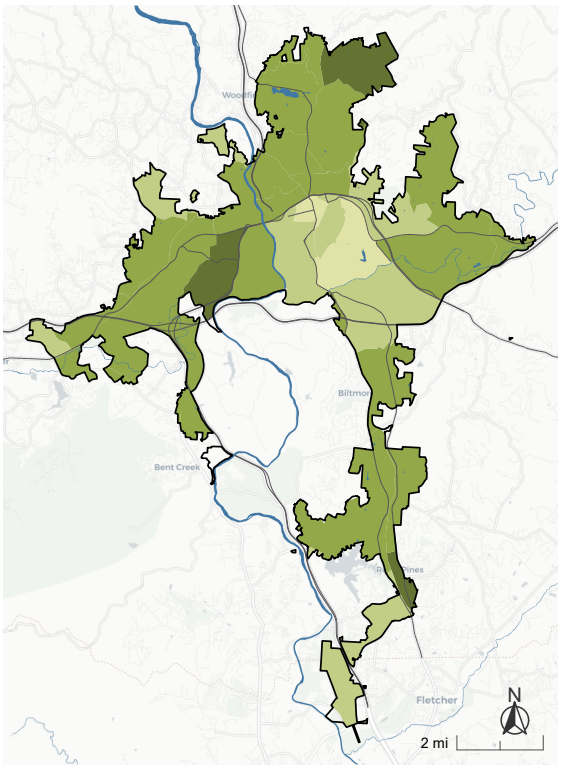
Note: NAIP = National Agriculture Imagery Program.
* The 2022 adjusted estimate incorporates classification accuracy and reflects a statistically corrected estimate of canopy cover.

KEY FINDINGS

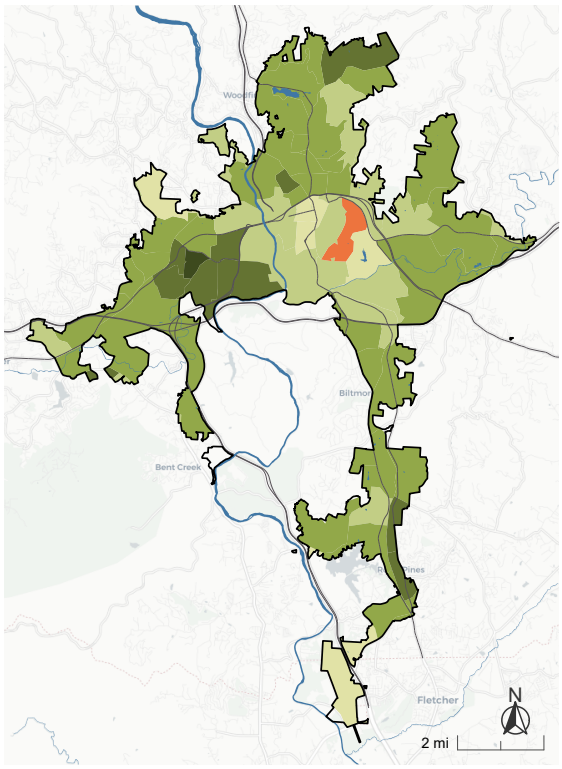
- All census tracts experienced an increase in canopy cover, ranging from 2.4 to 20.4 percentage points.
- Census blocks showed changes ranging from a decrease of 0.1 to an increase of 25.9 percentage points, with the majority experiencing increases.
- Neighborhood-level changes in canopy cover ranged from a decrease of 22.9 to an increase of 29.8 percentage points. All neighborhoods experienced gains except for Maple Crest Apartments, which saw a 22.8% decrease due to redevelopment.
- Zoning districts experienced changes in canopy cover ranging from a decrease of 16.9 to an increase of 23.6 percentage points, reflecting variation in land use and development activity. The largest increases occurred in residential districts, while the Central Business Expansion, Lodging Expansion, and Light Industrial districts saw decreases.
- Comparisons across parcels are not recommended. Due to their small size, percent changes can be exaggerated and may not reflect meaningful trends.

Exhibit 6. Canopy Change by Geographic Unit (2018–2022)

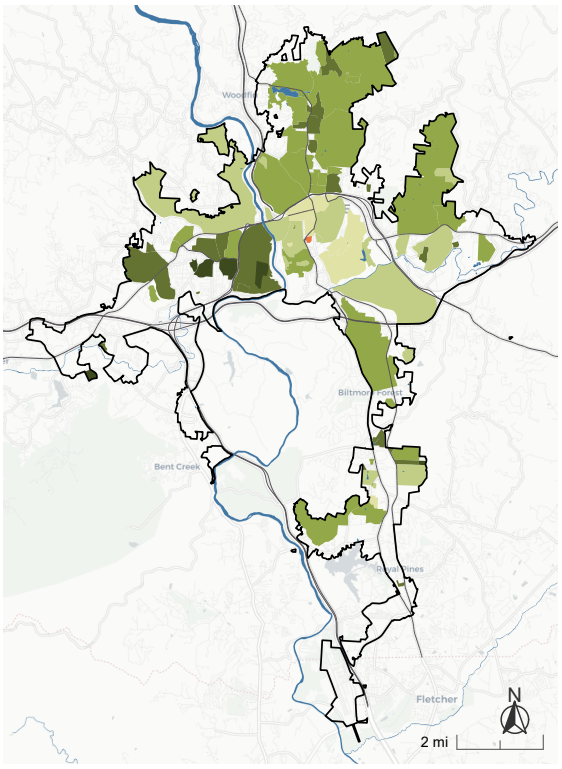
CENSUS TRACTS



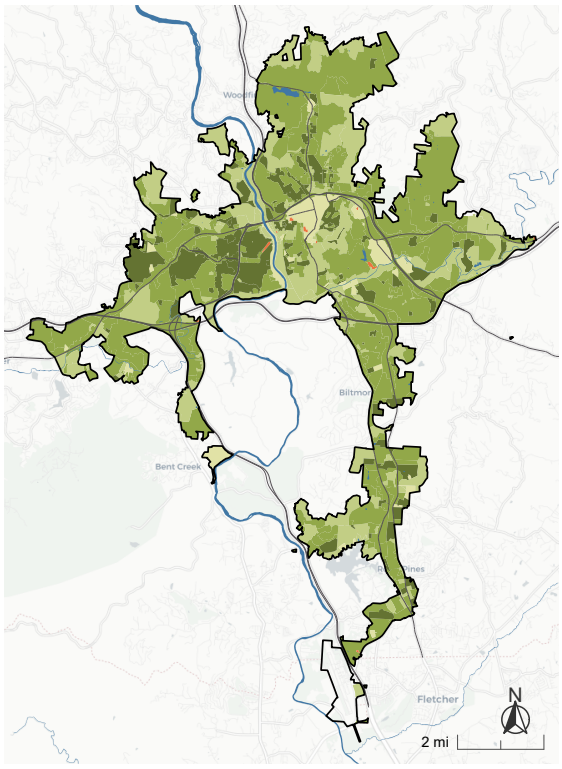
CENSUS BLOCKS



NEIGHBORHOODS



ZONING DISTRICTS



Canopy Change (%)

Loss | 0–5 | 5–10 | 10–15 | 15–25 | ≥25

Source: Dudek 2026.

5. CONCLUSION AND RECOMMENDATIONS

The 2022 canopy assessment provides an updated estimate of tree cover across the City and serves as a foundational input to the UFMP. Using high-resolution NAIP imagery and a machine-learning classification approach, the analysis found that approximately 54.3% of the City is covered by tree canopy, after adjusting for classification accuracy. This estimate reflects a new classification method and establishes a baseline for understanding current conditions and informing future urban forest strategies.

Canopy distribution varies across the City. Areas with high development intensity, such as downtown and commercial zones, generally have lower canopy cover. Residential and institutional zones support higher canopy levels. These patterns highlight opportunities for targeted investment in neighborhoods with limited access to tree-related benefits.

The dataset represents pre-storm conditions prior to Hurricane Helene in September 2024. A follow-up assessment will be needed to evaluate canopy loss from the storm and guide recovery planning.

RECOMMENDED NEXT STEPS

INTEGRATE FINDINGS INTO THE UFMP:

Apply the 2022 canopy data to guide UFMP goals, planting strategies, and community engagement. Use insights at the census, neighborhood, and zoning levels to support planting prioritization and equity-focused investment. Begin discussions on setting a citywide canopy cover target informed by these results.

PLAN FOR A POST-STORM CANOPY ASSESSMENT:

Conduct a follow-up analysis using post-2024 imagery to evaluate the impacts of Hurricane Helene. Results will help identify areas most affected and inform replanting and recovery strategies.

DETERMINE A PREFERRED METHODOLOGY FOR LONG-TERM MONITORING:

As part of the UFMP, select a consistent classification approach and update interval to support future assessments. Establishing a repeatable method will enable more reliable tracking of canopy change over time.

6. METHODS

6.1 LAND COVER CLASSIFICATION

Land cover classification was performed using 2022 NAIP aerial imagery at a 0.6-meter spatial resolution. Imagery included red, green, blue (RGB), and near-infrared (NIR) bands and was processed using a machine-learning classification approach. Five land cover types were mapped: tree canopy, low to medium vegetation, bare earth/non-photosynthetic vegetation, impervious surfaces, and water.

To prepare the dataset, the imagery was pre-processed to correct for any spatial distortions and enhance alignment. A composite image was created using the RGB and NIR bands, including the normalized difference vegetation index (NDVI), which was derived using the red and NIR bands. Texture metrics were derived by calculating the local standard deviation for each spectral band, capturing variation in surface patterns within a neighborhood of pixels. These metrics provide additional information to distinguish land cover types that may appear spectrally similar. Segmentation techniques were used to group pixels into homogeneous regions for more accurate training sample collection.

A deep-learning classifier based on U-Net architecture was trained using manually labeled training samples. The classified output was then reviewed and manually edited to correct misclassifications, particularly along tree canopy boundaries. The water class was not predicted by the model and was instead added manually using publicly available water feature datasets.

CLASSIFICATION WORKFLOW

1. **Obtain Data:** Acquire high-resolution aerial imagery.
2. **Pre-Process Imagery:** Apply atmospheric correction, band alignment, and spatial enhancement.
3. **Create Secondary Products:** Calculate NDVI, derive texture metrics, and generate composite imagery.
4. **Collect Training Samples:** Use segmented composite image to collect representative samples for each land cover class.
5. **Train Model:** Input composite imagery and training samples into a U-Net deep-learning classifier.
6. **Classify Imagery:** Generate predicted land cover raster.
7. **Manual Editing:** Refine misclassified areas.
8. **Accuracy Assessment:** Perform stratified random sampling and generate a confusion matrix.

ACCURACY ASSESSMENT

An accuracy assessment was conducted using a stratified random sample of 251 validation points, approximately 50 for each of the five land cover classes, to evaluate the reliability of the land cover classification. Each point was visually interpreted using high-resolution aerial imagery (reference data) to determine its true class and was compared to the corresponding classified output.

The results were compiled into a confusion matrix (Table 3) and used to calculate standard accuracy metrics, including user's accuracy, producer's accuracy, overall accuracy, and the Kappa coefficient:

Table 3. Confusion Matrix

Classification Data	Reference Data					Total	User's Accuracy
Classes	Canopy	Veg	Bare	Impervious	Water		
Canopy	48	2	0	0	0	50	96%
Veg	4	46	0	0	0	50	92%
Bare	0	4	47	0	0	51	92%
Impervious	0	1	1	48	0	50	96%
Water	0	0	0	0	50	50	100%
Total	52	53	48	48	50	—	—
Producer's Accuracy	92%	87%	98%	100%	100%	—	—
						Overall Accuracy:	95%
						Kappa Coefficient	0.94

- **Overall Accuracy** represents the proportion of all validation points that were correctly classified. It was calculated by dividing the total number of correctly classified points by the total number of samples:
  - $Overall\ Accuracy = \frac{48+46+47+48+50}{251} = \frac{239}{251} = 95\%$
- **User's Accuracy (commission error)** describes the likelihood that a pixel classified as a given class is actually that class in the reference data. It is calculated by dividing the number of correctly classified pixels for a class by the total number of pixels classified as that class. In this assessment, User's Accuracy ranged from 92% for Veg and Bare to 100% for Water.

- **Producer's Accuracy (omission error**) measures how well reference data for a class was correctly identified in the classification. It is calculated by dividing the number of correctly classified pixels for a class by the total number of reference pixels in that class. Values ranged from 87% for Vegetation to 100% for Impervious and Water.
- **Kappa Coefficient** measures how well the classification agrees with the reference data, while adjusting for agreement that could occur by chance. It provides a more robust assessment than overall accuracy alone, especially when class distributions are unbalanced. In this analysis, the observed agreement (overall accuracy) was 0.95, and the expected agreement by chance was 0.20. A Kappa value of 0.94 indicates almost perfect agreement, based on the interpretation scale from Landis and Koch (1977):
    - $Kappa\ Coefficient = \frac{0.95-0.2}{1-0.2} = \frac{0.75}{0.8} = 0.94$

The classification achieved an overall accuracy of 95%, indicating strong agreement with the reference data. The greatest confusion occured between Canopy and Vegetation classes, suggesting some difficulty distinguishing tree canopy from tall shrubs or dense herbaceous cover in aerial imagery. Canopy and Impervious were classified with high accuracy, with minimal confusion. These results indicate the classification is reliable for city-scale analysis of canopy and land cover.

6.2 CANOPY COVER CALCULATIONS

Canopy cover metrics were summarized by geographic unit to understand the distribution of canopy across the City. For each defined boundary of interest, the total area and percent cover of tree canopy were calculated. The 2022 analysis was based on a classified raster dataset, where each pixel represents a known ground area of approximately 0.6 meters. Pixel counts were extracted for the canopy class, then converted to acres to determine total canopy area. Percent cover was calculated using the following formula:

$$Canopy\ Cover\ (\%) = \left(\frac{Area\ of\ Canopy\ Class\ in\ Acres}{Total\ Area\ in\ Acres}\right) X\ 100$$

A post-classification area adjustment was applied to each land cover class based on the user's accuracy derived from the confusion matrix to improve accuracy. This approach follows established best practices for accuracy-based estimation (Olofsson et al. 2014, 2021). Adjusted area was calculated by multiplying the classified area by the user's accuracy. Confidence intervals (95%) were also calculated using standard error. **Table 4** summarizes this information for each class.

Table 4. Land Cover Summary with Accuracy Adjustments

Land Cover Class	Classified Area (acres)	Adjusted Area (acres)	95% Confidence Interval (± acres)	Adjusted Percent Cover
Tree canopy	16,244	15,909	± 940	54.3%
Low to medium vegetation	3,932	4,463	± 999	15.2%
Bare earth/ non-photosynthetic vegetation	301	449	± 338	1.5%
Impervious	8,613	8,268	± 473	28.2%
Water	191	191	± 0	0.7%

6.3 CANOPY COVER CHANGE

To evaluate how canopy cover changed over time, canopy data from 2018 was analyzed using the same geographic boundaries as the 2022 assessment. The 2018 dataset was provided as a vector layer with canopy features already delineated. Canopy area was calculated by intersecting the 2018 canopy layer with each boundary and converting the results to acres. Percent cover was calculated using the same formula as above.

Absolute change in canopy cover was calculated by subtracting the 2018 values from the 2022 values for each geographic unit. This produced the net change in both canopy area and percent cover between the two time periods.

All spatial analyses were completed using ArcGIS Pro, and R. Boundary datasets were obtained from the City's Open Data Portal in 2024 (City of Asheville 2024).

6.4 DATA LIMITATIONS

Although this assessment applied a high-resolution classification method and achieved strong accuracy metrics, several sources of uncertainty should be acknowledged. Visual interpretation of aerial imagery can be affected by factors such as shadowing, relief displacement, and the difficulty of distinguishing between trees and low vegetation (Richardson and Moskal 2014). These effects may lead to minor over- or underestimation of canopy extent, particularly in areas with mixed vegetation types or dense development.

Reported canopy and land cover metrics may differ from other studies due to variations in data sources, classification methods, geographic boundaries, and validation techniques. For example, this study used 2022 NAIP imagery at a 0.6-meter resolution and applied a machine-learning classification approach. Other assessments may rely on different imagery sources, such as satellite data or lidar, or use field-based sampling and visual interpretation methods. Additionally, the analysis boundary used here is approximately 29,280 acres, which may differ slightly from other published figures due to differences in source data or spatial alignment.

Differences in data format and processing between years also limit comparability. The 2018 dataset was provided as a vector shapefile containing canopy polygons and was used as-is, without reclassification, post-processing, or validation. In contrast, the 2022 canopy dataset was classified from raster imagery using a machine-learning model. These differences in input format and classification method may introduce inconsistencies when comparing canopy values over time.

Although the accuracy assessment for the 2022 classification indicated a high level of agreement with reference data (overall accuracy: 95%; Kappa coefficient: 0.94), these metrics only reflect the performance of the 2022 model and do not capture all sources of spatial or thematic uncertainty. In areas with dense development or transitional vegetation, mixed pixels and edge effects may influence classification results and contribute to small inaccuracies.

This assessment does not account for storm-related canopy loss. The 2022 dataset reflects pre-storm conditions prior to Hurricane Helene, which occurred in September 2024. Canopy loss resulting from the storm is not captured in this analysis.



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THE CITY OF ASHEVILLE

CITY OF ASHEVILLE
70 Court Plaza,
Asheville, North Carolina 28801
Contact: Keith Aitken

PREPARED BY:
DUDEK

DUDEK
225 South Lake Avenue
Pasadena, California 91101

Urban Forest Master Plan
ASHEVILLE