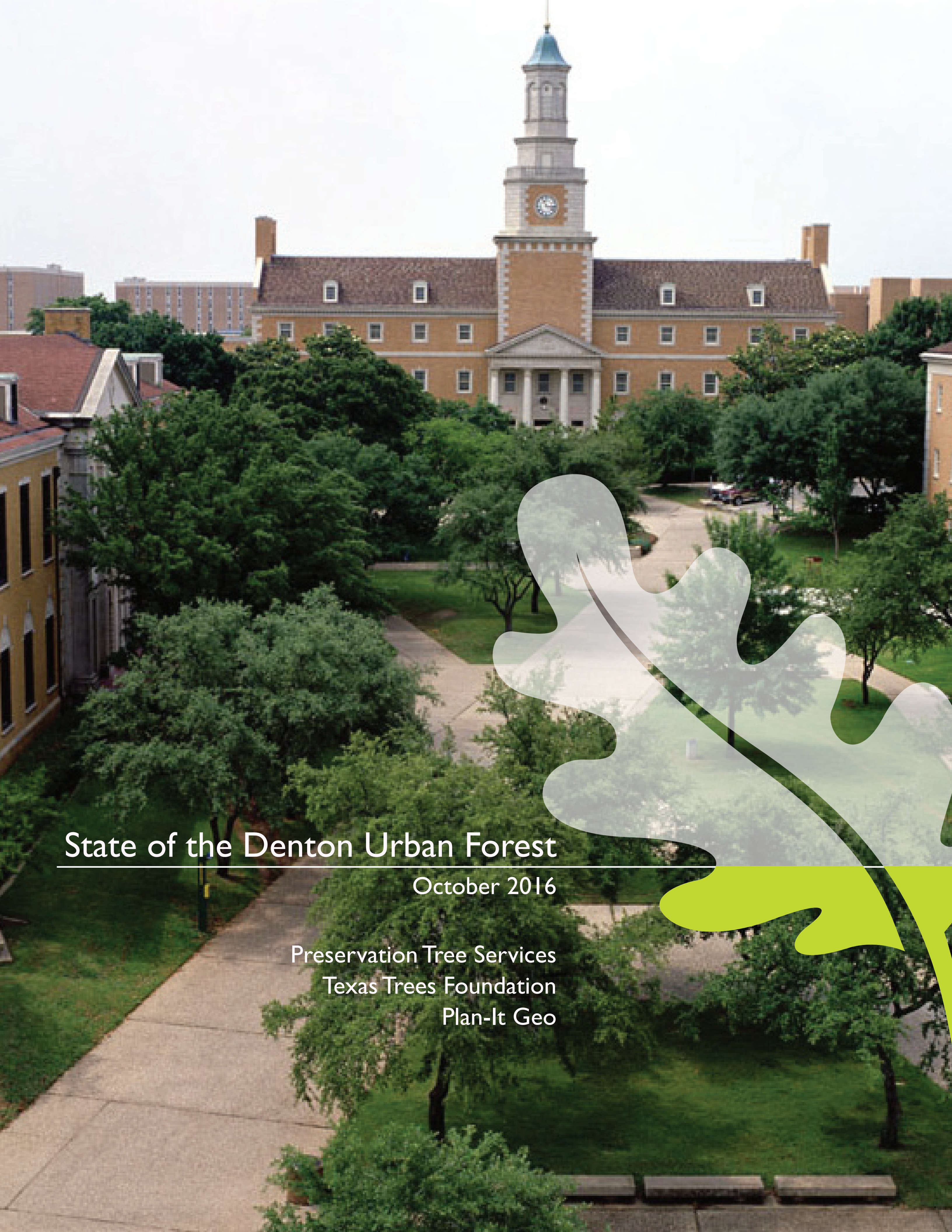

State of the Denton Urban Forest

October 2016

Preservation Tree Services
Texas Trees Foundation
Plan-It Geo

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Keep Denton Beautiful
Program Manager
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(Project Lead)

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Preservation Tree

Preservation Tree Services, Inc. is a Dallas-based, full-service tree care company that employs sustainable practices for use in tree care, preservation and urban forestry management. Their Urban Forestry Division provides a wide range of professional consultation and management services. Clients include residential, commercial corporations, local municipalities, and higher education institutions.

Texas Trees Foundation

The Mission of the Texas Trees Foundation is to preserve, beautify and expand parks and other public natural green spaces, and to beautify public streets, boulevards and rights of-way by planting trees and encouraging others to do the same through educational pr grams that focus on the importance of building and protecting the "urban forest" today and for generations to come. Their vision is shared nationally, but efforts and loyalties are focused among communities in North Central Texas.

plan-it GEO

Plan-It Geo (PG) is a geospatial consulting and software development company specializing in innovative solutions for natural resource management. PG offers a full range of services including GIS, remote sensing, cost/benefit analysis, urban forest planning, water resources analysis, decision tools, and web-based software. They are recognized nationally as a trusted source in progressive geospatial analysis and reporting related to urban forestry and green infrastructure.

Photos Provided By Keep Denton Beautiful

City Manager's Office

Howard Martin, Interim City Manager
Jon Fortune, Assistant City Manager
Brian Langley, Assistant City Manager
John Cabrales, Assistant City Manager

Denton City Council

Chris Watts, Mayor
Kevin Roden, Mayor Pro Tem/District 1
Keely Briggs, District 2
Kathleen Wazny, District 3
Joey Hawkins, District 4
Dalton Gregory, At Large Place 5
Sara Bagheri, At Large Place 6

For Questions on the State of the Denton Urban Forest Report, Please Contact:

Micah Pace – Project Lead
Urban Forestry Specialist
Preservation Tree Services, Inc.
micahp@preservationtree.com
214.662.6086

Haywood Morgan – City Urban Forester
City of Denton
haywood.morgan@cityofdenton.com
940.349.8337

Lauren Barker – Project Administrator
Program Manager, Keep Denton Beautiful
lauren.barker@cityofdenton.com
940.349.8739

City of Denton Staff Contributors

JoEtta Dailey, Watershed Protection Coordinator
Jason Donnell, Parks & Recreation Crew Leader
Kevin Babcock, GIS Administrator
Shannon Brajer, GIS/Engineering Tech
Vance Kemler, Director of Solid Waste & Recycling
Melissa Kraft, Chief Technology Officer
Jim Mays, Parks & Recreation Superintendent of Planning and Construction
Ron Menguita, Long Range Planning Administrator
Haywood Morgan, Urban Forester
John Schubert, Parks & Recreation Superintendent
Tony Smith, GIS Supervisor
Deborah Viera, Environmental Compliance Coordinator
Emerson Vorel, Director of Parks & Recreation
Cody Yates, GIS Analyst

Keep Denton Beautiful, Inc. Board of Directors

Chris Henry, President
Mannix O'Connor, Vice President
Kathy Glasschroeder, Treasurer
Christa Crowe, Secretary
Lancine Bentley
Kiersten Dieterle
Karen McDaniels
Haywood Morgan
Ali Silva
Sonny Solis
Katharine Wilcox

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Executive Summary

The urban forest of Denton plays a crucial role in the livability and sustainability of the city. Denton's 3.5 million trees impact everything from economic development to the overall health of the people that live, work, and play in Denton every day.

A more comprehensive understanding about the urban forest's structure, function, and associated value can promote effective policy development, sound management planning, and help set and anticipate future budgetary requirements. During the summer of 2016 the City of Denton and Keep Denton Beautiful partnered with Preservation Tree Services, Inc., Texas Trees Foundation, and Plan-It Geo, Inc. to perform the most detailed and comprehensive study of Denton's urban forest resource ever completed.

Two state-of the art urban forestry assessments were conducted. Each one independently only tells half the story, but combined provide the most accurate and detailed urban forest data available. The two assessments completed were:

1) i-Tree Eco Assessment: i-Tree Eco is one tool in a suite of tools that provides a broad picture of the entire urban forest, both on public and private property. i-Tree is a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that can be used to provide an urban and community forestry analysis and environmental benefits assessments. i-Tree tools help communities of all sizes to strengthen urban forest management and advocacy efforts by quantifying both the structural and environmental services trees provide.

2) Urban Tree Canopy (UTC) Assessment: UTC assessments utilize detailed land cover data derived from high-resolution aerial imagery to determine a very precise and accurate picture of the extent of the tree canopy, impervious surfaces, and available planting space, even down to parcel level.

The following (5) recommendations will help protect and promote the Denton urban forest:

Recommendation 1: Utilize assessment results to preserve and promote urban tree canopy, especially in Undeveloped and Single-family Residential land use classes.

Recommendation 2: Perform further UTC analyses, especially comparing publicly and privately owned parcels in the Undeveloped land use class.

Recommendation 3: Utilize assessment to help drive policy and management decisions that both strengthen tree protection during development and professional care annually.

Recommendation 4: Utilize assessment results to enhance current tree planting initiatives through strategic tree and planting location selection and through development of public/private partnerships.

Recommendation 5: Utilize trees and other green infrastructure to off-set the urban heat island effect and reduce impact of stormwater.

The State of the Denton Urban Forest Report provides detailed information to help Denton advance their understanding of their urban tree population and provides the framework to make more informed decisions about the future management of this important community asset. The data provided here lays the ground work for Denton becoming a more resilient city that is greener, cleaner, and cooler.

Key Findings

The key findings for the 2016 City of Denton Urban Forest Resource Assessment are below. These data represent a snapshot of both the structural and functional characteristics and values of the city's urban trees. They are provided to aid in the planning and management of this increasingly important resource. The quantification of the benefits of Denton's urban forest should serve as a reliable advocacy tool to help educate community leaders and the general public about the importance of investing in professional planning and management for Denton's trees.

- Denton's 3,463,000 trees had a structural value of $2.06 billion.
- Denton's trees provided $7.2 million annually in environmental services.
- Trees cleaned the air by storing 458,000 tons of carbon valued at $61 million.
- Trees provided over 52 thousand tons of Oxygen per year.
- Trees provided annual energy savings of $1.6 million annually.
- Denton's average tree canopy was 30%.
- 46% of Denton's urban tree canopy was located on undeveloped land.
- Within Denton's ETJ there was an increase in canopy of 2.2% from 2008 to 2014.
- 14% of the surface area in Denton was covered with impervious surface such as buildings, cement, roads and parking lots.
- 44% of the current land area was suitable for future tree planting.
- Denton's most common tree species was Sugarberry, Cedar Elm, Post Oak.

Ton: short ton (U.S.) (2,000 lbs)
Carbon storage: the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation
Carbon sequestration: the removal of carbon dioxide from the air by plants
Carbon storage and carbon sequestration values are calculated based on $133 per ton
Pollution removal value is calculated based on the prices of $1136 per ton (carbon monoxide), $1,671 per ton (ozone), $528 per ton (nitrogen dioxide), $165 per ton (sulfur dioxide), $8,897 per ton (particulate matter less than 10 microns and greater than 2.5 microns), $7,1337 per ton (particulate matter less than 2.5 microns)
Energy saving value is calculated based on the prices of $1,14.9 per MWH and $10.15 per MBTU
Rainfall Interception is calculated by the price $0.067/ft^3
Structural value: value based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree)
Monetary values ($) are reported in US Dollars throughout the report except where noted

For an overview of i-Tree Eco methodology, see Appendix I.

Introduction

Located in northern Texas, the City of Denton is the county seat of Denton County. The city straddles both the Grand Prairie and Eastern Cross Timbers sub-regions of the Cross Timbers Ecoregion (Griffith 2004). Denton was incorporated in 1866, twenty years following a land grant by the State. The arrival of the Texas and Pacific Railway fifteen years later in 1881 helped spur the growth of the city and, later, the establishment of the University of North Texas in 1890 and Texas Woman's University in 1901.

The increase in commercial activity, literally carried by the railroad, along with the increase in population associated with the development of two higher-learning institutions, helped the City of Denton become an important community in North Texas. Over half a century later, the city saw even more rapid growth with the completion of the Dallas/Fort Worth International Airport in 1974. As of 2011, Denton was the seventh fastest-growing city in the country with a population over 100,000.

Subsequently, the city's infrastructure also grew. Throughout this growth, the City of Denton has sustained a history of environmental consciousness. Through reforestation and wetland reconstruction efforts in any one of its 26 parks or preserves, such as the 2,900-acre nature preserve known as the Clear Creek Natural Heritage Center, or through community education programs, such as the city's Sustainable Schools Program, Denton has prioritized both the practice and education of sustainable land use and the preservation of open space on behalf of its citizens.

The city strives for effective land management that can reduce development pressure, especially in environmentally sensitive areas (ESA), while also enhancing resource and transportation efficiency without compromising air and water quality; all characteristics of a thriving, healthy urban community.

The State of the Denton Urban Forest Report reaffirms this commitment to responsible resource management and builds upon other important city accomplishments, including:

- *Adoption of the city's comprehensive plan in 1999*
- *Denton 2030 Plan*
- *25 consecutive years as a Tree City USA community*
- *Recipient of 8 Tree City USA Growth Awards*
- *First established Public Tree Care Ordinance in 2004*
- *First urban forester hired in 2008*

The following report defines both the scale and diversity of Denton's urban forest, highlights the monetary value of this tremendous community asset, and provides relevant management concerns and strategies to enhance the resource and its many benefits.

Methods

The area of interest (AOI) for this urban forest assessment was the city limits of Denton, Texas, located at 33°13'01.8"N 97°07'51.1"W. The AOI has an area of 116 mi^2 or 74,492 acres in size. Study area for the Eco study portion of this project did not include the city's extraterritorial jurisdiction (ETJ), however the urban tree canopy (UTC) portion of this study did incorporate the ETJ area in the analysis (Figure 1).

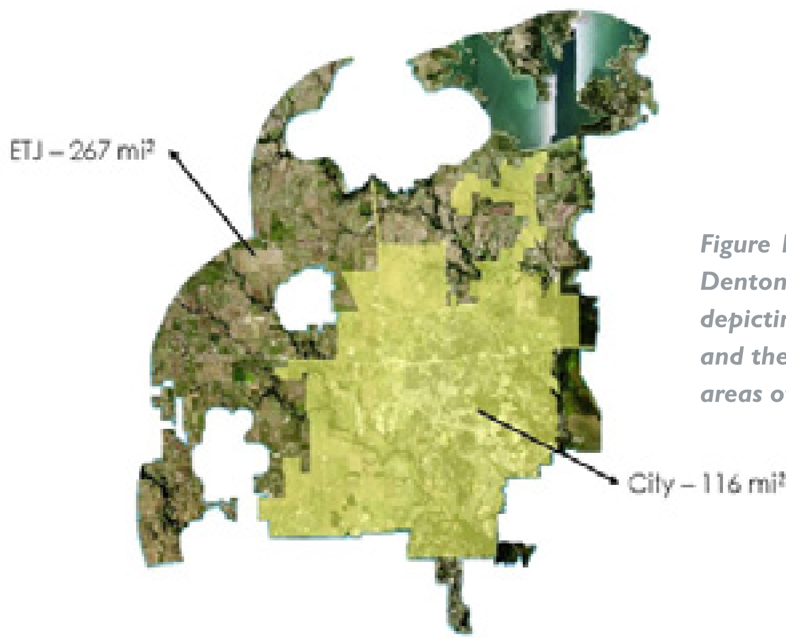


Figure 1: Area of Interest (AOI) for the City of Denton Urban Forest Ecosystem Assessment depicting both the city limits (shaded area) and the extraterritorial jurisdiction (ETJ) areas of the project

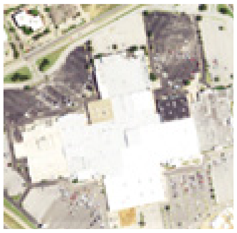
This section also describes the methods through which land cover, urban tree canopy, and possible planting areas (PPA) were mapped and the protocol for how i-Tree Eco field data was collected. UTC analyses were completed within five specific target geographies and included: citywide, zip codes, census blocks, voter districts, and parcels.

Mapping Land Cover

An essential component of this UTC assessment is the creation of an initial land cover data set. High-resolution (1-meter) aerial imagery flown in 2014 from the USDA's National Agricultural Imagery Program (NAIP) was overlaid with LiDAR elevation data (2015) within the city limits. An object-based image analysis (OBIA) software program called Feature Analyst (ArcGIS Desktop) was used to classify land cover types through an iterative approach, analyzing spectral signatures across four bands (blue, green, red, and near-infrared) as well as elevation, texture, and spatial patterns. This process resulted in five initial land cover classes as shown in Figure 2. After manual classification improvement and quality control, additional data layers from the city, such as buildings, roads, and other impervious surfaces, were utilized to capture finer feature detail and further categorize the land cover data set.

Urban Tree Canopy
Tree cover when viewed and mapped from above

Non-Canopy Vegetation
Grass and open space vegetation



Impervious Surfaces
Hard surfaces where rainfall cannot permeate

Bare Soil
Not included in possible planting areas

Water Bodies
Bodies of water removed from total land cover

Figure 2: Five Primary Land Cover Classes generated from Aerial Imagery-based Analysis

Identifying Possible Planting and Unsuitable Areas

Possible Planting Areas (PPA) for both vegetation and impervious surfaces were then derived from the Non-Canopy Vegetation and Impervious land cover classes. "Unsuitable" areas were incorporated into the data set to identify where it is not feasible to plant trees. The City of Denton provided GIS data delineating these unsuitable areas, which included sports fields, utility easements, and stormwater detention ponds (as shown in Figure 3). Roads and buildings, also provided by the city, were isolated from the impervious surfaces and identified as "unsuitable impervious." Thus, the final results are reported with vegetated possible planting areas (PPA-Veg), impervious possible planting areas (PPA-IA), total possible planting areas (To-PPA), unsuitable impervious (roads and buildings), other unsuitable (sports fields, etc.), and total unsuitable.

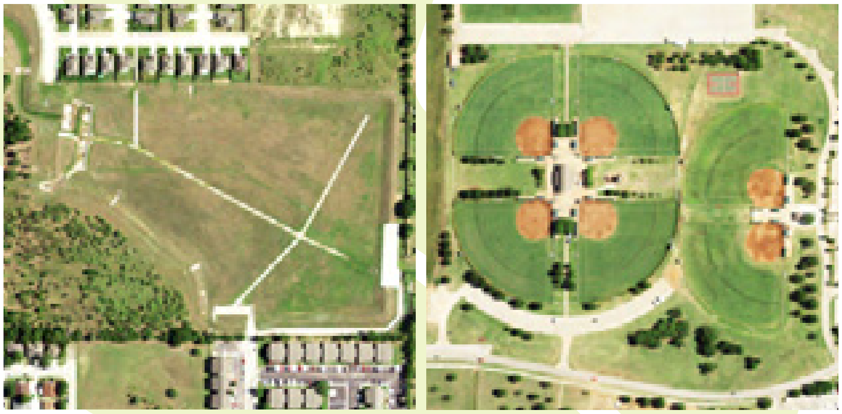
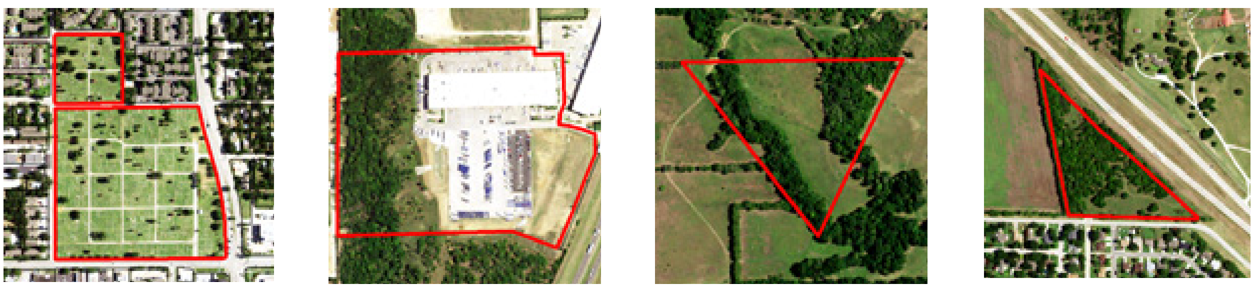


Figure 3: Sports fields and stormwater detention ponds are considered unsuitable for planting

Visualizing Urban Tree Canopy Results

Maps showing UTC in this report express relative levels of canopy as a percentage of land area (not including water). UTC levels are divided into meaningful categories for each of the assessment area boundaries and may vary slightly depending on the distribution within the target geographies. For parcels, UTC levels are broken up into four classes: 20% or Less UTC, 21-40% UTC, 41-70% UTC, and Greater than 70% UTC. Figure 4 provides visual examples of what the varying levels of UTC look like against the aerial imagery, all shown at the same scale of 1:10,000.

Figure 4: Examples of Relative Canopy Coverage by Parcel

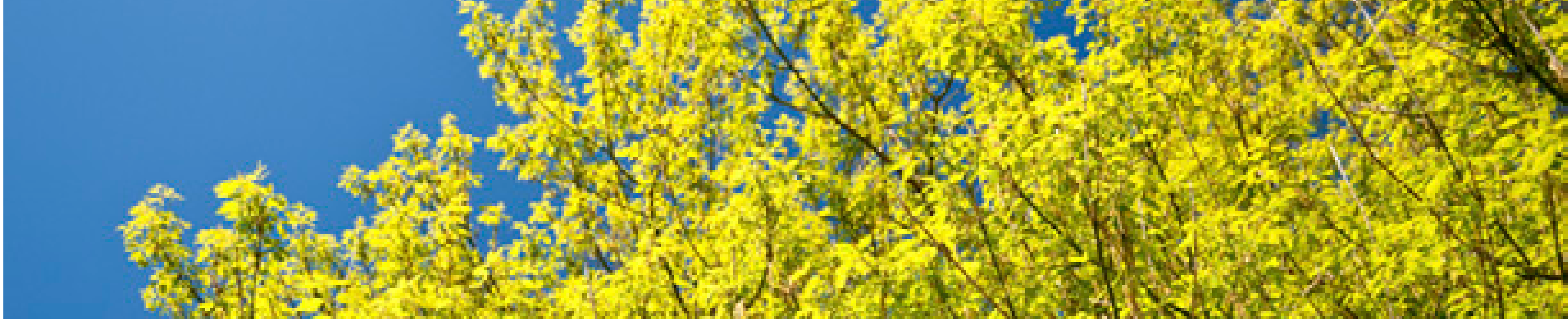


14% UTC (low) | *27% UTC* | *56% UTC* | *82% UTC (high)*

Defining Assessment Levels

In order to better inform various stakeholders (city officials, city staff, and citizens alike), UTC and associated information were calculated for a variety of geographic boundaries. These include the ETJ, city limits, census block groups, land use classes, parcels, voter districts, and zip codes. Outputs include total area (in acres or square feet) and percentages for each assessment type: UTC, PPA, impervious surfaces, and unsuitable areas. Assessment levels include the following geographic boundaries:

- *The ETJ boundary is the largest area of interest. Only canopy cover was mapped and summarized for this area, as land cover and LiDAR data were not available (Figure 5).*
- *The City Limit of Denton, for which all metrics are summarized, unless otherwise stated, for the ETJ (Figure 5).*
- *Five Voter Districts were evaluated to identify the amount of tree canopy as it relates to the individual voter districts and potentially to inform the council members and citizens residing in them.*
- *Zip Codes provide an additional visualization for the distribution of land cover and tree canopy.*
- *The City's Land Use Classes were categorized and analyzed to represent current human uses and land characteristics, totaling 12 classifications.*
- *Census Block Groups originate from the U.S. Census Bureau and are used for statistical consistency when tracking populations throughout the U.S. They can be used to provide indicators of environmental justice (Figure 6).*
- *Parcels are the finest level of detail for which metrics were generated. UTC and PPA are reported for over 38,000 individual properties, including residential and commercial (Figure 7).*



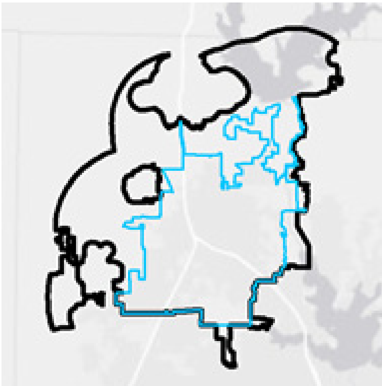


Figure 5: Extraterritorial Jurisdiction (black) and the City of Denton (blue) (scale = 1:900,000)

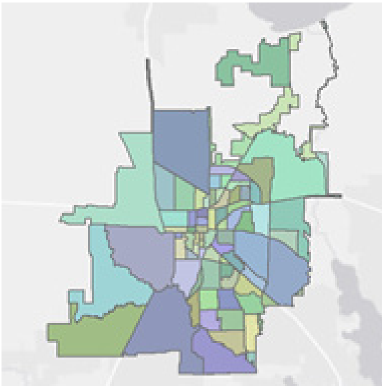


Figure 6: Census Block Groups within the Denton City Limit (scale = 1:600,000)

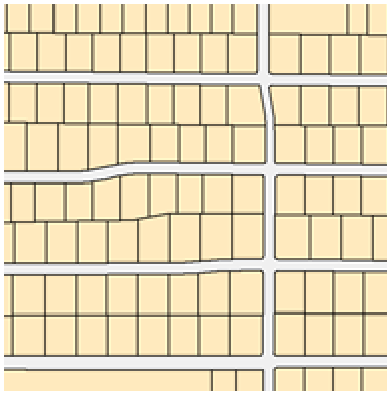


Figure 7: Parcel Level Target Geography (scale = 1:8,000)

i-Tree Eco

Study design and field data collection protocol for the Eco study portion of this project were developed by the U.S. Forest Service, Northeast Research Station (Appendix I). Using geographical information system (GIS) technology, 275 1/10th-acre circular plots were created and randomly established within the city limits of Denton encompassing both public and private property.

There were a total of twelve land use classes identified within Denton. Land use categories used include: Agriculture, Commercial, Government, Industrial, Infrastructure, Institution, Parks/Open Space, ROW, Religious, Single-Family Residential, Multi-Family Residential, and Undeveloped/Vacant. For logistical and operational planning, the study area was geographically divided into quadrants with all 275 study plots randomly located across all four quadrants (Figure 8).

Study plots were located in the field using a combination of orienteering with known lat/long coordinates of plot centers and aerial imagery for each plot listed in map books for each respective quadrant. Where plots or portions of plots fell on private property, permission to access private properties for plot measurement was obtained prior to data collection.

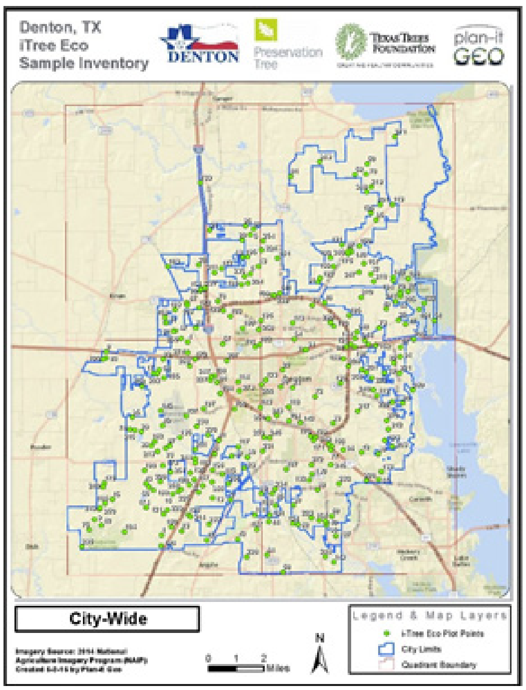


Figure 8. Area of Interest (AOI): City of Denton displaying the location of 275 randomly located 1/10th-acre study plots across city limits

Plot and tree level data were recorded on paper forms and archived following data entry. In addition, study plots were designed as permanent measurement locations through the use of global positioning system (GPS) units by recording exact plot center locations, the reference points for all measurements.

Plot centers can be relocated for future measurements using either recorded latitude and longitude values or by triangulating their positions by using the distance and direction of two reference points measured for each plot center (except for many plots in Vacant land use where no reference objects were available). Plot centers for Forested plots and Agricultural plots were exclusively located by latitude and longitude. In addition, a minimum of two (2) photos were taken of plot center for each plot (Figure 9).

See Appendix I for details on i-Tree Eco methodology and the environmental benefits estimation models used for this assessment or visit http://itreetools.org/eco/resources/UFORE%20Methods.pdf.

Figure 9: Examples of study plot center pictures in Single-Family Residential (left), Undeveloped (center), and Agricultural (right) land use classes. Photo credit Micah Pace, Urban Forester, Preservation Tree Services

Assessment Results

The urban forest of the City of Denton had an estimated 3.5 million trees with a tree cover of 30%. This section presents the key findings and results of both assessments, including the land cover base map, as well as the canopy analysis results, which were analyzed across various geographic assessment boundaries. These results, or metrics, provide a benchmark of the current forest cover and can assist in developing a strategic approach towards identifying future planting areas. Complete UTC assessment results for all target geographies, including maps and graphs can be found in Appendix II.

Urban Tree Canopy Assessment Results

Citywide Land Cover

In 2016, 30% of Denton was covered by tree canopy, 45% was non-canopy vegetation, and 14% was impervious. Further dividing the impervious surface areas into more detailed classifications shows that 3% of the city was covered by buildings, 3% was covered by roads, 2% was covered by parking lots, and 0.2% was covered by sidewalks, leaving 5% classified as "Other Impervious" (Table 1). With this amount of impervious surface, issues such as the urban heat island effect and flash flooding could increase if new tree planting isn't strategically planned to help support future development. Figure 10 below illustrates a detailed city land cover classification map used for this assessment.

Table 1: Urban Tree Canopy Assessment - 5-Class Land Cover Results

Total Acres	Tree Canopy (acres)	Tree Canopy %	Non-Canopy Vegetation (acres)	Non-Canopy Vegetation %	Impervious (acres)	Impervious %	Water (acres)	Water %	Soil/Dry Vegetation (acres)	Soil/Dry Vegetation %
74,492	22,540	30%	33,321	45%	10,506	14%	730	1%	7,394	17%

Land cover refers to the physical and biological cover over the surface of the land, including water, vegetation, bare soil, and/or artificial structures. It differs from land use, which is the physical use of the site. Urbanization tends to increase the rate of ground cover change, making sustainable land practices essential to the sustainable management of the urban forest. This assessment revealed not only that 14% of all surfaces in Denton are covered with an impervious material, but that 36% was also covered with ornamental turf/maintained grasses (Figure 11). This indicated that 50% of all available land is covered by impervious or semi-impervious surfaces, making it very difficult to manage storm water flow.

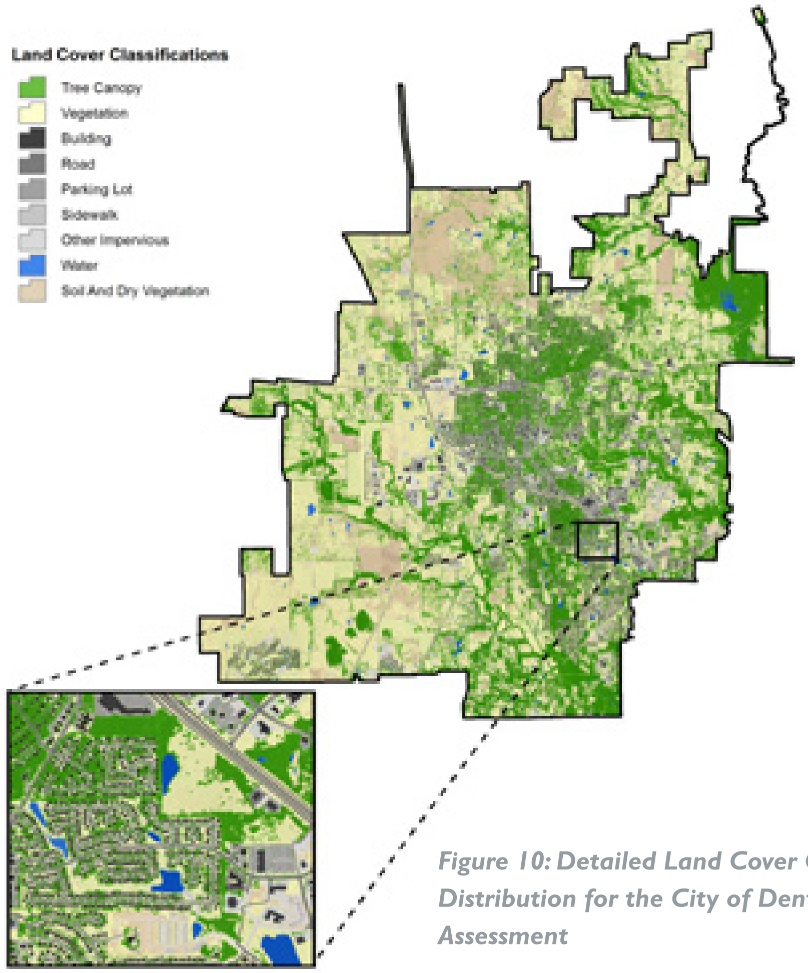


Figure 10: Detailed Land Cover Classifications and Distribution for the City of Denton Urban Forest Assessment

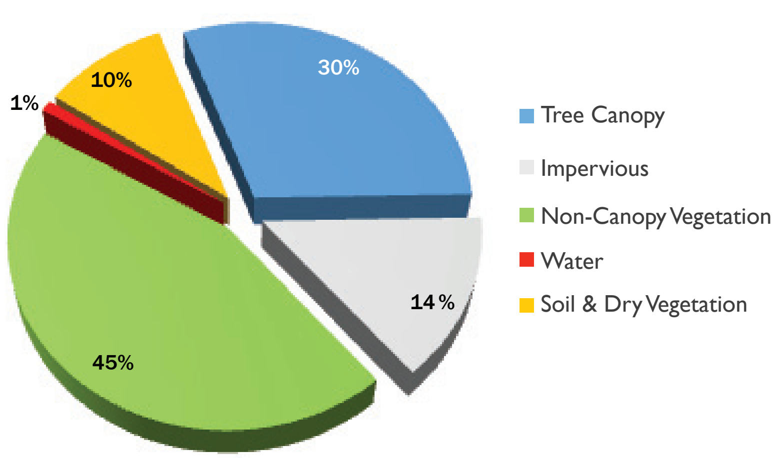


Figure 11: Land cover percentages for City of Denton

Citywide Urban Tree Canopy and Possible Planting Areas (PPA)

While 22,540 acres of Denton were covered by urban tree canopy, making up 30% of the 73,761 total land acres, an additional 32,609 acres of land were identified as non-canopy vegetation, which provides the possibility for addition tree canopy (Table 2). This Possible Planting Area (PPA Vegetation) makes up 44% of the city. Non-building and non-road impervious areas cover 5,418 acres that may also offer additional planting opportunity (PPA Impervious), while 19% of the city's land has been identified as unsuitable for planting. This includes sport fields, golf course fairways, buildings and roads, and soil/dry vegetation.

Table 2: Urban Tree Canopy and Possible Planting Areas (PPA)
**Note: Percentages are based on Land Area*

*Land Area (acres)	UTC (acres)	UTC %	PPA Vegetation (acres)	PPA Vegetation %	PPA Impervious (acres)	PPA Impervious %	Total Possible Planting (acres)	Total Possible Planting %	Unsuitable UTC* (acres)	Unsuitable UTC* %
73,761	22,540	30%	32,609	44%	5,418	7%	38,028	52%	13,923	19%

Land Use

Many of the policies, regulations, ordinances, and actions influencing tree canopy in Denton are dependent on land use classes. To provide data that advances UTC policy and management, 12 land use classes were assessed (Figure 12).

The Single-Family Residential and Undeveloped land use classes had the highest individual canopy coverage with 45% and 38%, respectively. These two classes combined constituted 74% of all the UTC in the city, while Industrial, Agricultural, Multi-Family Residential, and Parks/Open Space land use classes only accounted for 22%. The six other classes, including Commercial and Government property, made up the remaining 5% of UTC coverage (Figure 13). 46% of total citywide urban tree canopy was located on undeveloped property placing a large portion of Denton's urban forest at risk during future develop, especially that portion of UTC located on privately owned undeveloped parcels.

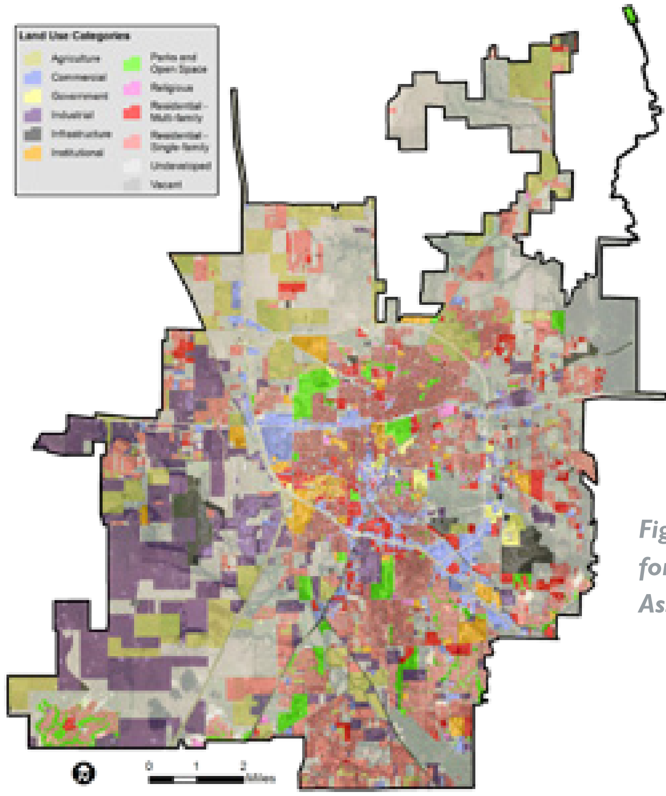


Figure 12: Land Use Categories for City of Denton Urban Forest Assessment

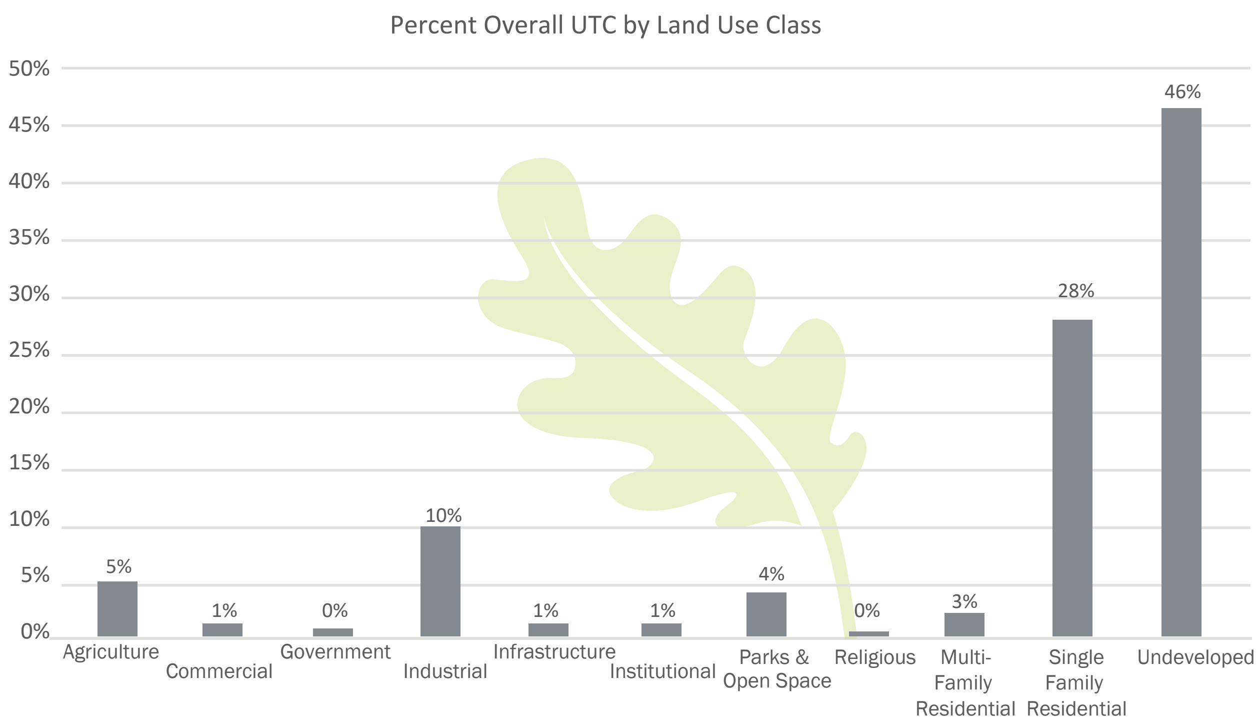


Figure 13: Percent Canopy Coverage in Denton by Land Use Class

Parcels

The most detailed assessment geography analyzed for this study was the parcel layer. This study calculated UTC totals and Possible Planting Areas (Vegetation, Impervious, and Total PPA) for each individual property (parcel) with over 38,000 records (Figure 14). Due to the size of the data set, comprehensive data have been provided to the city in GIS format, and are not included in tabular format in this report. The parcel dataset can be queried to find specific areas in the city that have low UTC, high PPA, particular land use types, or a certain amount of impervious area.

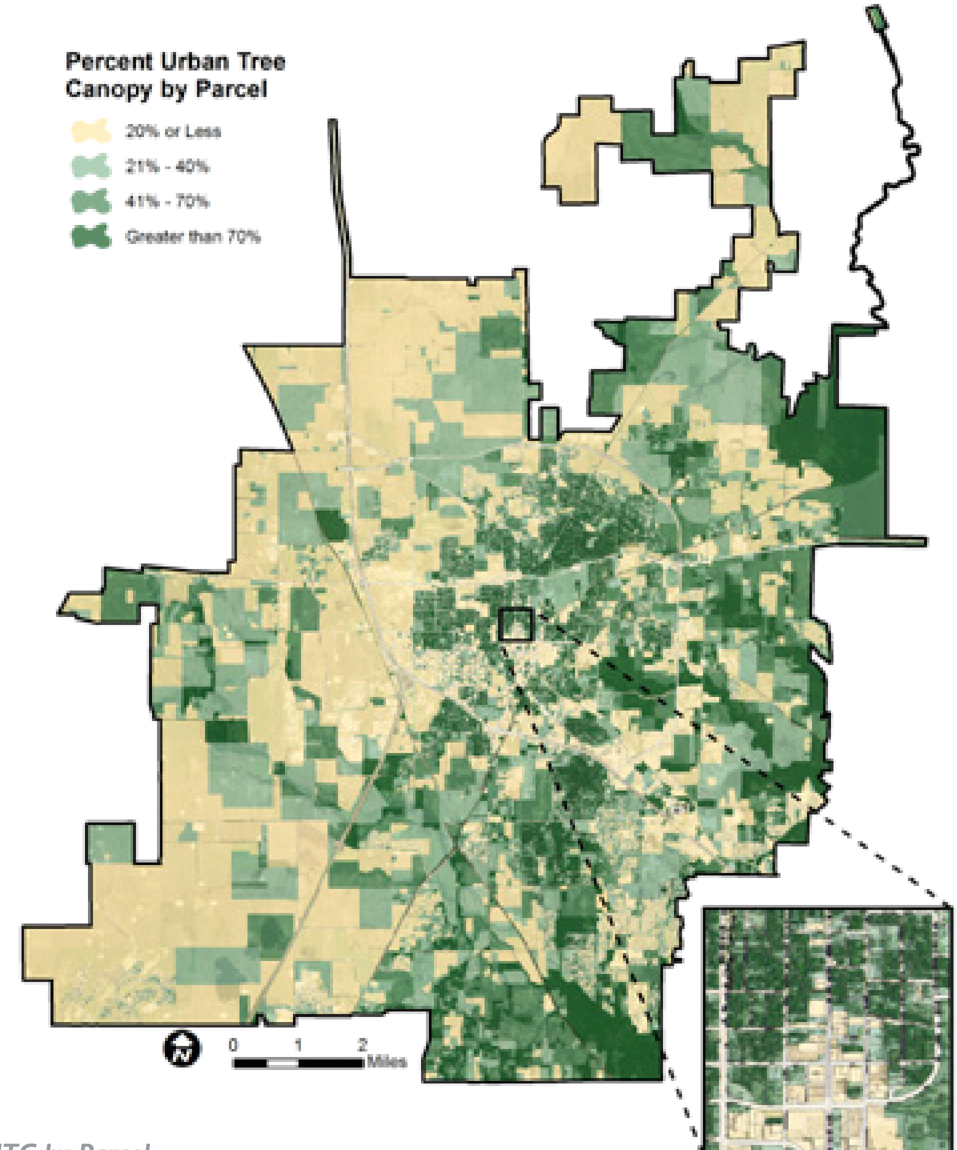


Figure 14: UTC by Parcel

In addition to parcel, this report also examines the Urban Tree Canopy (UTC) and Possible Planting Areas (PPA) by zip codes, census block groups and City Council Districts. More information about these sub groups and maps can be found in Appendix II.

Canopy Change

Denton's urban tree canopy was not only assessed within the city limits, but also within the city's 170,938 acres of ETJ. Canopy change analysis between 2008 and 2014 was completed to better understand the dynamics of the urban tree cover and urban development (growth). Although similar methods were used for the analysis there was a difference in available image quality between 2008 and 2014. Data from 2014 were produced using high resolution LiDAR data collected in 2015. Using LiDAR data in conjunction with aerial imagery helped to increase overall mapping accuracy for the 2014 data set.

Canopy cover in 2008 equaled 34,810 acres, comprising 20.4% of the city and ETJ. Canopy cover in 2014, totaled 38,561 acres, comprising 22.6% of the city and ETJ. This means that the UTC in the city and ETJ increased by 3,751 acres or 2.2% in the six years between 2008 and 2014 (Table 3).

Table 3: Urban Tree Canopy Change Analysis Results: Years 2008 – 2014

Total Acres	UTC Area 2008 (acres)	UTC 2008 %	UTC Area 2014 (acres)	UTC 2014 %	Percent Change 2008-2014
170,938	34,810	20.4%	38,561	22.6%	2.2%

Despite the overall marginal gain in canopy cover between 2008 and 2014, there were many areas within the city and ETJ that experienced loss in canopy cover. Some of the loss was clearly attributed to development, such as the northern expansion of the Denton airport runway (Figure 15), while other canopy loss may be related to natural tree loss from prolonged drought stress (Figure 16).

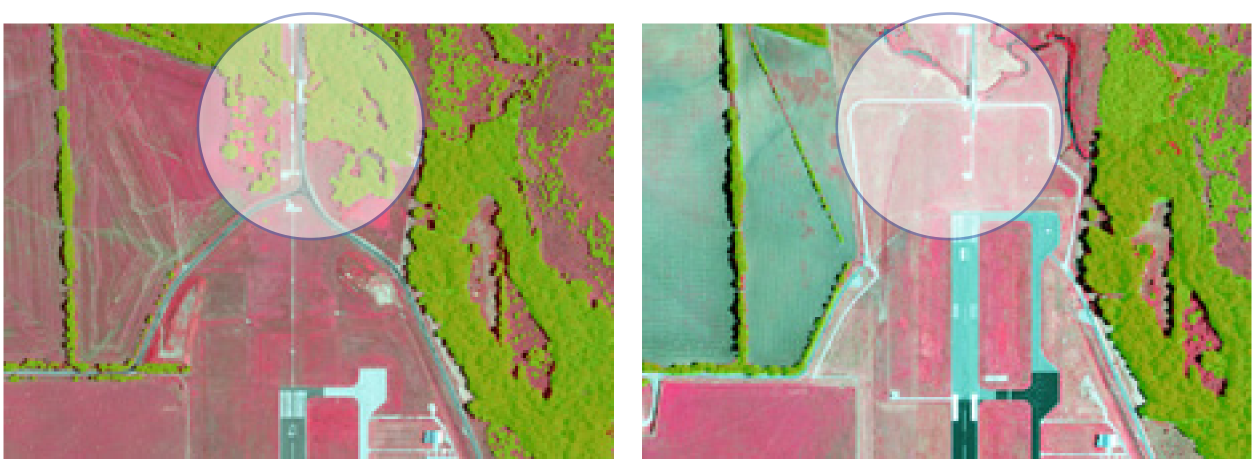


Figure 15: Extension of the runway on the north side of the Denton Enterprise Airport led to major tree and canopy loss between 2008 (left) and 2014 (right)

Figure 16: A prolonged drought period in much of Texas during the early 2010's caused the water level at Lake Ray Roberts to drop significantly between 2008 (left) and 2014 (right). As a result, many trees experienced natural thinning and a decrease in canopy cover

In other areas of the city, recent growth and development of previously agricultural land actually led to an increase in canopy cover. The area around the CH Collins Athletic Complex, for example, was first developed in 2004. Figure 17 shows the growth of recently planted trees in the past six years, as well as the addition of new trees at the educational facilities to the west.

Figure 17: Growth and development of undeveloped lands led to increased canopy cover from 2008 (left) to 2014 (right)

Finally, the canopy cover also increased between 2008 and 2014 as a result of natural growth and maturation of trees. Figure 18, below, illustrates how trees that were planted in newly developed neighborhoods in 2008 grew and expanded their canopy coverage over the 6-year analysis period.

Figure 18: Maturation of newly planted trees led to increased canopy cover from 2008 (left) to 2014 (right)

It is important to note that there were slight inaccuracies and differentiations in data quality between the 2008 and the 2014 canopy mapping. While accuracy assessments for both years of mapping revealed over 97% accuracy for canopy cover, it is difficult to accurately compare data produced with differing data sources. The 2008 canopy mapping lacked the extra detail provided by the LiDAR elevation data. Canopy mapping in 2014 showed a slight overestimation due to subtle shifts between the 2014 NAIP aerial imagery and the 2015 LiDAR data. In future studies, it is recommended that data be derived from sources collected concurrently.

i-Tree Eco Results

Denton's Urban Forest Tree Characteristics

While the UTC assessment focused on the overall canopy cover for the city using LIDAR data and high resolution imagery, the i-Tree Eco assessment requires direct measurements through the collection of field data in order to better understand the species, size, health and overall composition of Denton's urban forest.

Urban forests by nature have a higher tree diversity than surrounding native landscapes, often with a mix of native and exotic tree species. The level of species diversity can have major implications on resource management. Increased tree diversity, for example, can minimize the overall impact or destruction by a host-specific insect or disease. However, it can also pose risk to native plants if some of the exotic species are invasive plants that potentially out-compete and displace more desirable native species. In Denton, about 96% of the trees are species that are both native to North America and the State of Texas. Species exotic to North America make up only 5% of the total population, an indicator of the overall good health of Denton's urban forest (Appendix III).

The three most common species in Denton were sugarberry (*Celtis laevigata*) (21.2%), cedar elm (*Ulmus crassifolia*) (18.3%), and post oak (*Quercus stellata*) (8.7%) (*Figure 19*). Sugarberry, while highly valuable for wildlife and water quality in native wetland/riparian areas, are not the most sustainable choice for an urban area due to their short life spans and tendency to be weak-wooded. Cedar elms and post oaks were the second and third most common species citywide, however, their respective levels of importance varied by land use (Figures 20 and 21). These two valuable native trees were primarily located in Undeveloped, Single-Family Residential, and Multi-Family Residential land use classes. The city would benefit from the protection and planning of these species' individual contributions to the future Denton urban forest canopy.

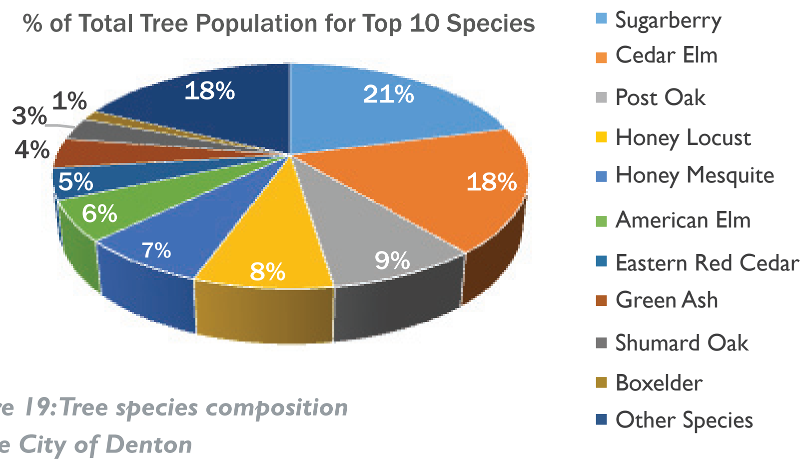


Figure 19: Tree species composition in the City of Denton

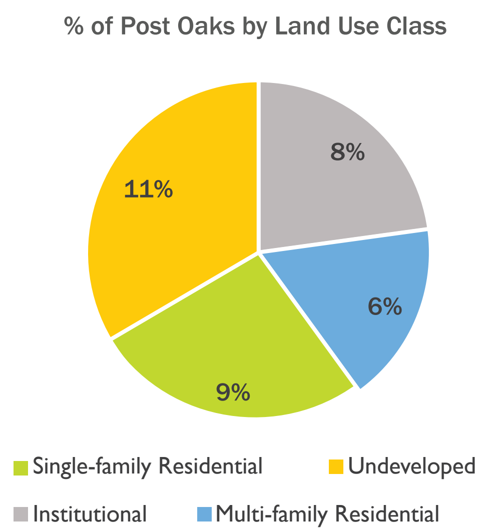


Figure 20: Percentage of Post Oaks by Land Use Class in the City of Denton

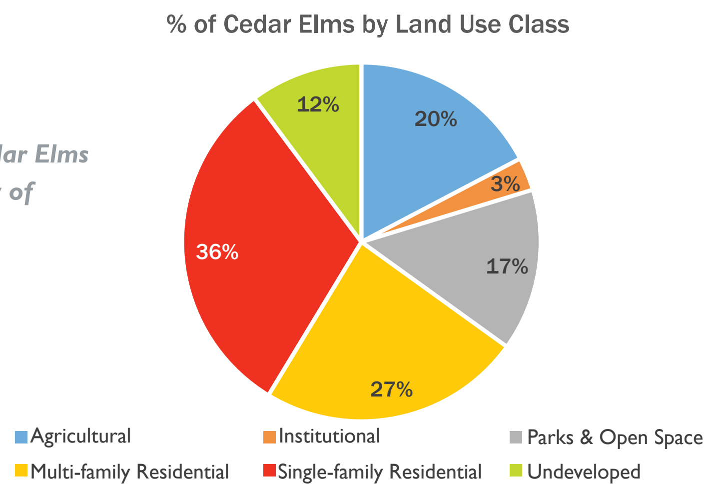


Figure 21: Percentage of Cedar Elms by Land Use Class in the City of Denton

Relative Tree Age and Size

The size of Denton's trees can be a good prediction for future trends in the structure and composition of the urban forest. While larger trees provide more ecosystem benefits, the space to grow and maintain large trees in an urban setting can be limited. In addition, trees will only grow to the size that current environmental conditions will allow. This study revealed that of all of Denton's trees, 58% had a diameter less than 6 inches (Figure 22). The relative size/age of trees in a community, combined with other observable species trends, enables more informed management and planning for future planting projects. For example, of the 58% of the tree population that had less than 6-inches in trunk diameter, approximately 42% were species that will attain a relatively large size at maturity if properly protected and cared for.

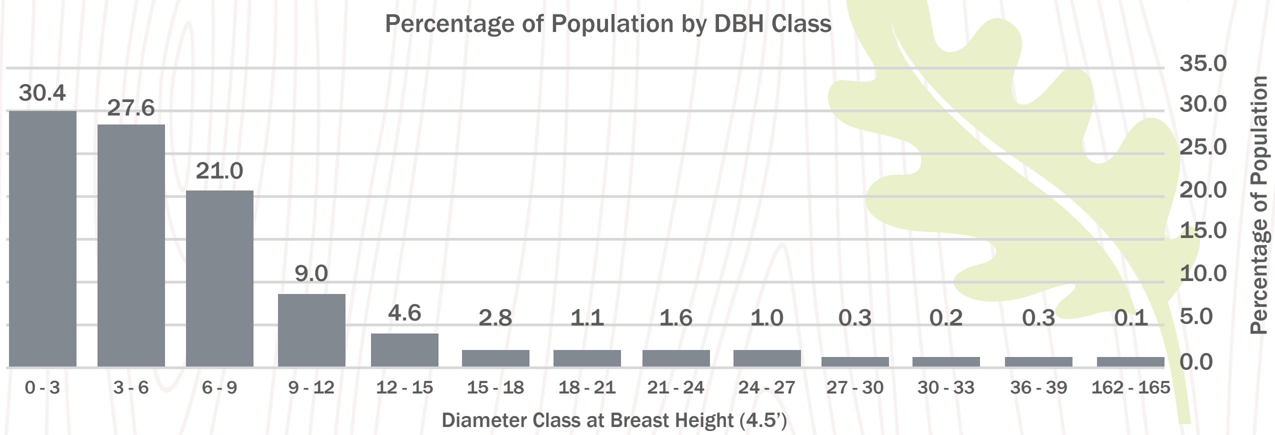


Figure 22: Percentage of Denton tree population by diameter class (DBH=stem diameter at 4.5 feet)

Invasive plant species are often characterized by their vigor, ability to adapt, reproductive capacity, and general lack of natural enemies. These abilities enable them to displace native plants and make them a threat to natural areas. Three of the 46 tree species sampled in the City of Denton are identified as invasive on the state invasive species list. These invasive species comprise 0.7% of the tree population, and thus may only have a minimal level of impact. These three invasive species were chinaberry (*Melia azedarach*) (0.3% of the population), Chinese pistache (*Pistacia chinensis*) (0.3% of population), and tallow tree (*Triadica sebifera*) (0.1%) (see Appendix IV for details of invasive species).

The Value of Denton's Urban Forest

Pollution Removal

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation.

Pollution removal by trees and shrubs in the City of Denton was estimated using field data and recent available pollution and weather data. Pollution removal was greatest for ozone. It is estimated that trees remove 404.86 tons of air pollutants (ozone, carbon monoxide, nitrogen dioxide), particulate matter less than 2.5 microns, and sulfur dioxide per year with an associated valued of $759,000 (Figure 23). See Appendices I and V for more details.

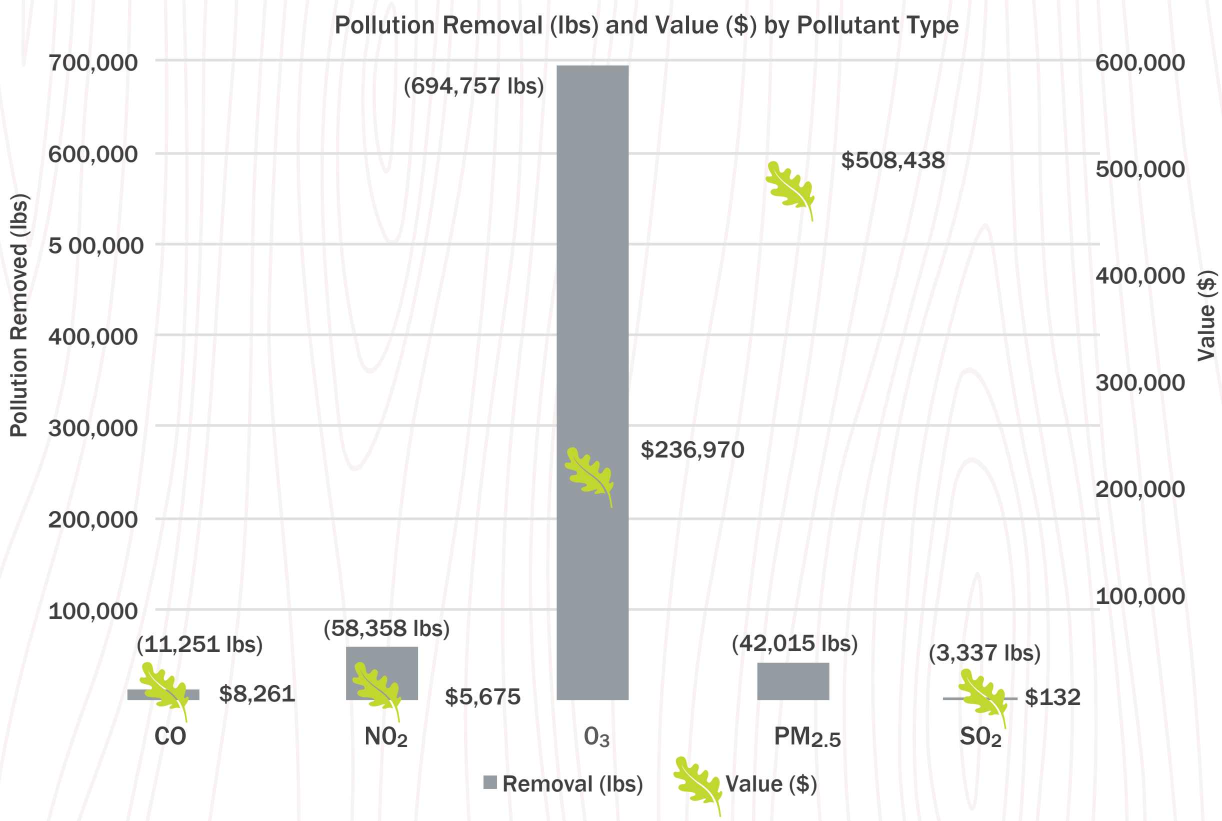


Figure 23: Pollution removal (bars) and associated value (leaf icons) for trees in Denton

In 2016, trees within the City of Denton emitted an estimated 441.9 tons of volatile organic compounds (VOCs) (388.7 tons of isoprene and 53.2 tons of monoterpenes). Emissions vary among species based on species characteristics (e.g. some genera such as oaks are high isoprene emitters) and amount of leaf biomass. 59% of the urban forest's VOC emissions (precursor chemicals to ozone formation) were from post oak and Shumard oak. We mention this because it is a fact that trees do produce these VOC, but it's important to remember the numerous studies that have shown that increasing tree cover in an area can actually reduce ozone levels. "Vegetation can absorb as much as 20% of the global atmospheric ozone production, so the potential impact on air quality is substantial," says Dr. Emberson, a senior lecturer in the Environment Department at the University of York and director of SEI's York Center. For general recommendations on improving air quality see Appendix VI. A table displaying the Top Oxygen Producing Species is available in Appendix VII.

Carbon Sequestration and Storage

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power plants.

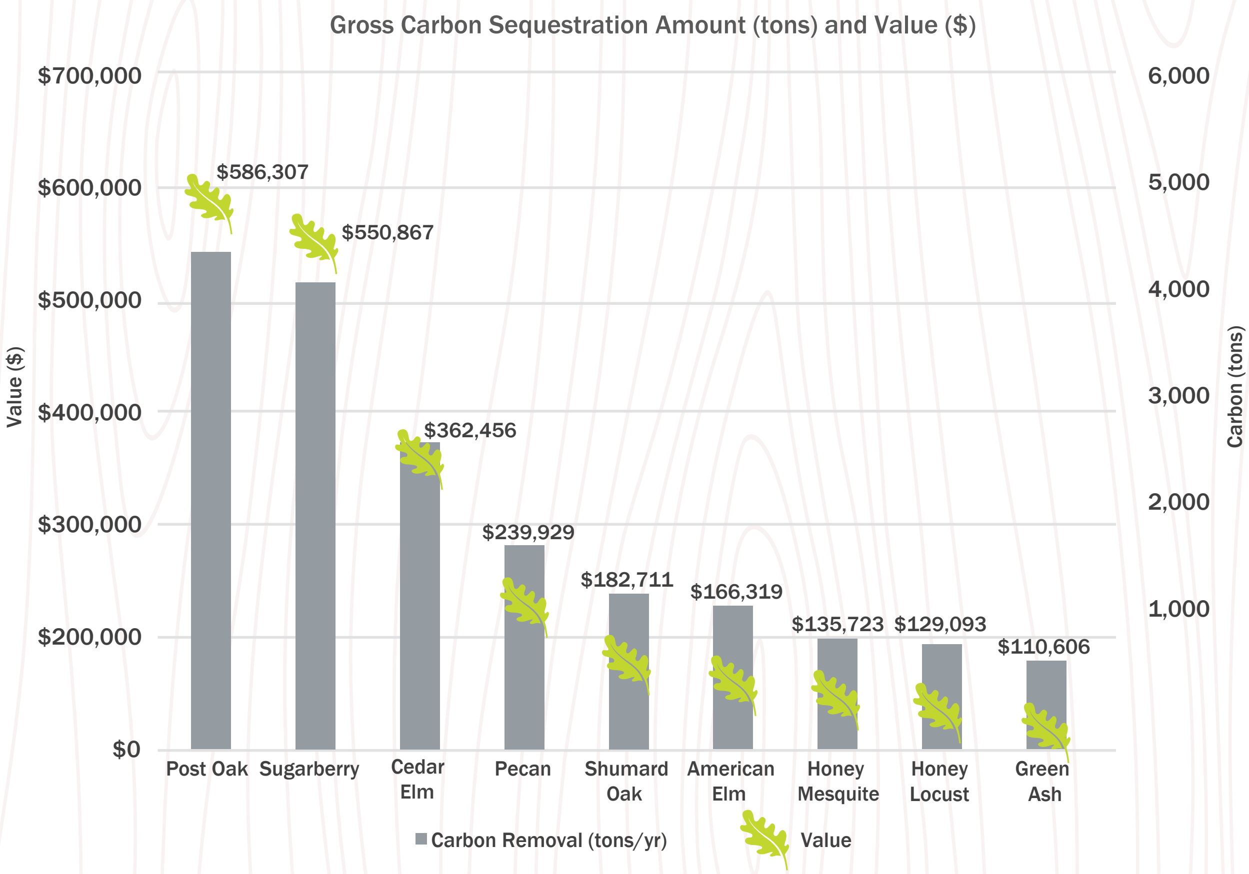


Figure 24: Carbon sequestration/value for species with greatest overall carbon sequestration in Denton

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of City of Denton trees is about 23,000 tons of carbon per year with an associated value of $3.06 million. Net carbon sequestration in the urban forest is about 19,795 tons (Figure 24). Carbon storage and carbon sequestration values are calculated based on $133 per ton (see Appendices I and V for more details).

As trees grow they store more carbon as incorporated wood. As trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in the City of Denton are estimated to store 458,000 tons of carbon ($61 million) (Figure 25). Of the species sampled, post oak stores and sequesters the most carbon (approximately 23.5% of the total carbon stored and 19.2% of all sequestered carbon) though it is only the third most populous species with approximately 9% of all trees.

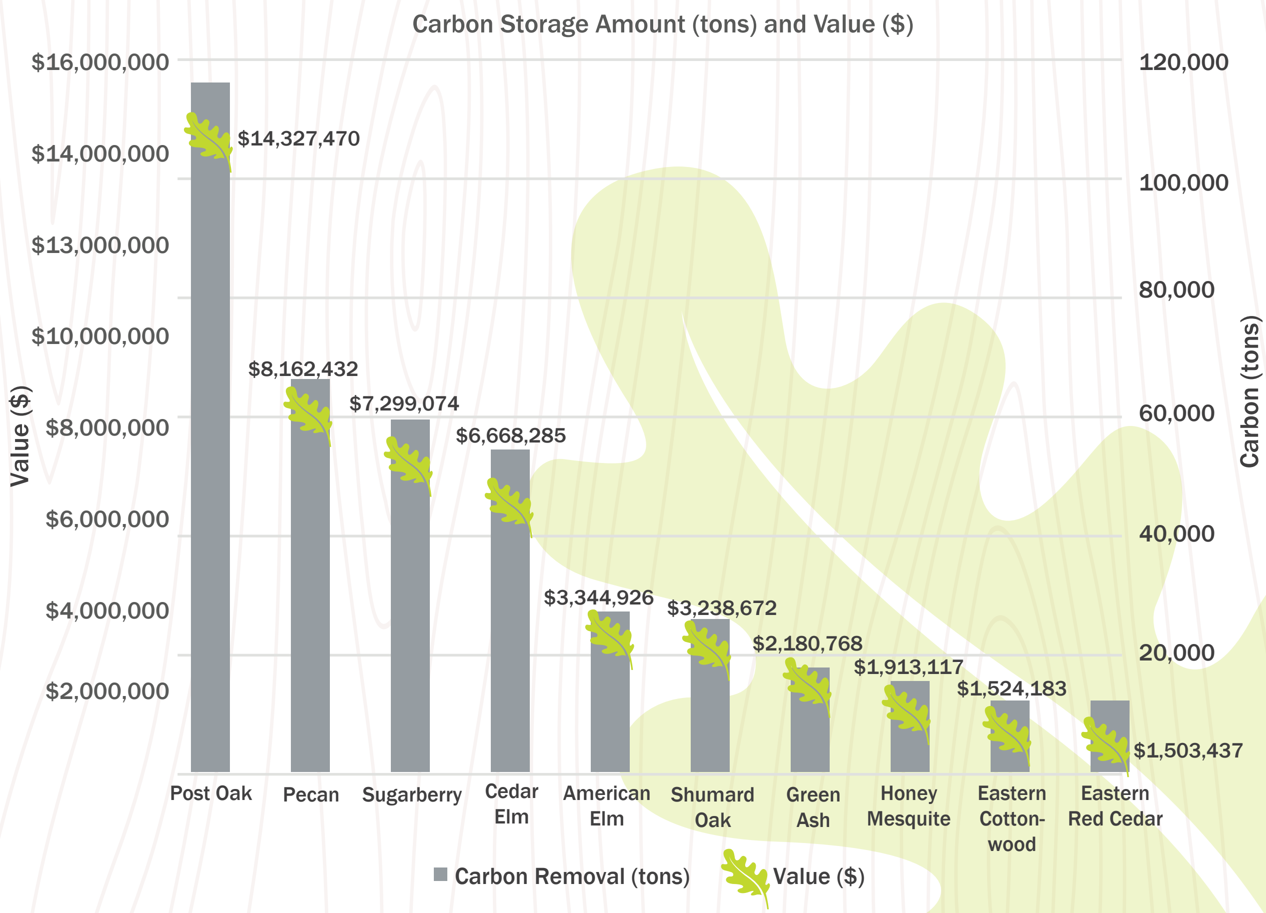


Figure 25: Carbon storage/value for species with greatest overall carbon storage in Denton

Energy Savings

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the location of trees around the building. Estimates of tree effects on energy use are based on field measurements of tree distance and direction to space conditioned residential buildings.

Trees in the City of Denton are estimated to reduce energy-related costs from residential buildings by $1.6 million annually. Trees also provide an additional $452,000 in value by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 3,400 tons of carbon emissions annually) (Tables 4 and 5).

Table 4: Annual energy savings by energy unit due to trees near residential buildings
Note: negative numbers indicate an increased energy use or carbon emission

	Heating	Cooling	Total
MBTU[a] MWH[b] Carbon avoided (t[3])	-52,906 -2,066 -1,252	n/a 21,184 4,649	-52,906 19,117 3,396

aMBTU = one million British Thermal Units
bMWH = megawatt-hour

Table 5: Annual savings ($) in residential energy expenditure during heating and cooling seasons.
Note: negative numbers indicate a cost due to increased energy use or carbon emission

	Heating	Cooling	Total
MBTU[b] MWH[c] Carbon avoided[d]	-572,048 -230,581 -166,640	n/a 2,363,933 618,476	-572,048 2,133,352 451,837
Totals	-$969,269	$2,982,409	$2,013,141

bBased on the prices of $111.59 per MWH and $10.81 per MBTU (see Appendix I for more details)
cMBTU = one million British Thermal Units
cMWH = megawatt-hour
dCarbon avoided value is based on $133.05 per ton

Stormwater Management

The Federal Clean Water Act regulates municipal stormwater discharge that enters public water sources. Municipal governments are required to outline and submit Best Management Practices for avoiding and reducing pollutant discharge. Fortunately, municipal trees aid in reducing stormwater runoff by intercepting and storing rainfall on their leaves and branches. Reducing the volume of runoff during a storm event helps to minimize both soil erosion potential and peak flow levels. More specifically, healthy urban trees play an important role in stormwater management in three key ways:

1. *Reducing the overall volume of water entering the storm system by leaf and branch absorption.*
2. *Increased soil health and structure due to the process of root growth and decomposition, thus increasing water infiltration rates that ultimately reduce overland water flow.*
3. *Reduction of rainfall velocity and the soil impact rate of raindrops through tree canopy interception which reduces soil erosion potential and surface transport rates of water.*

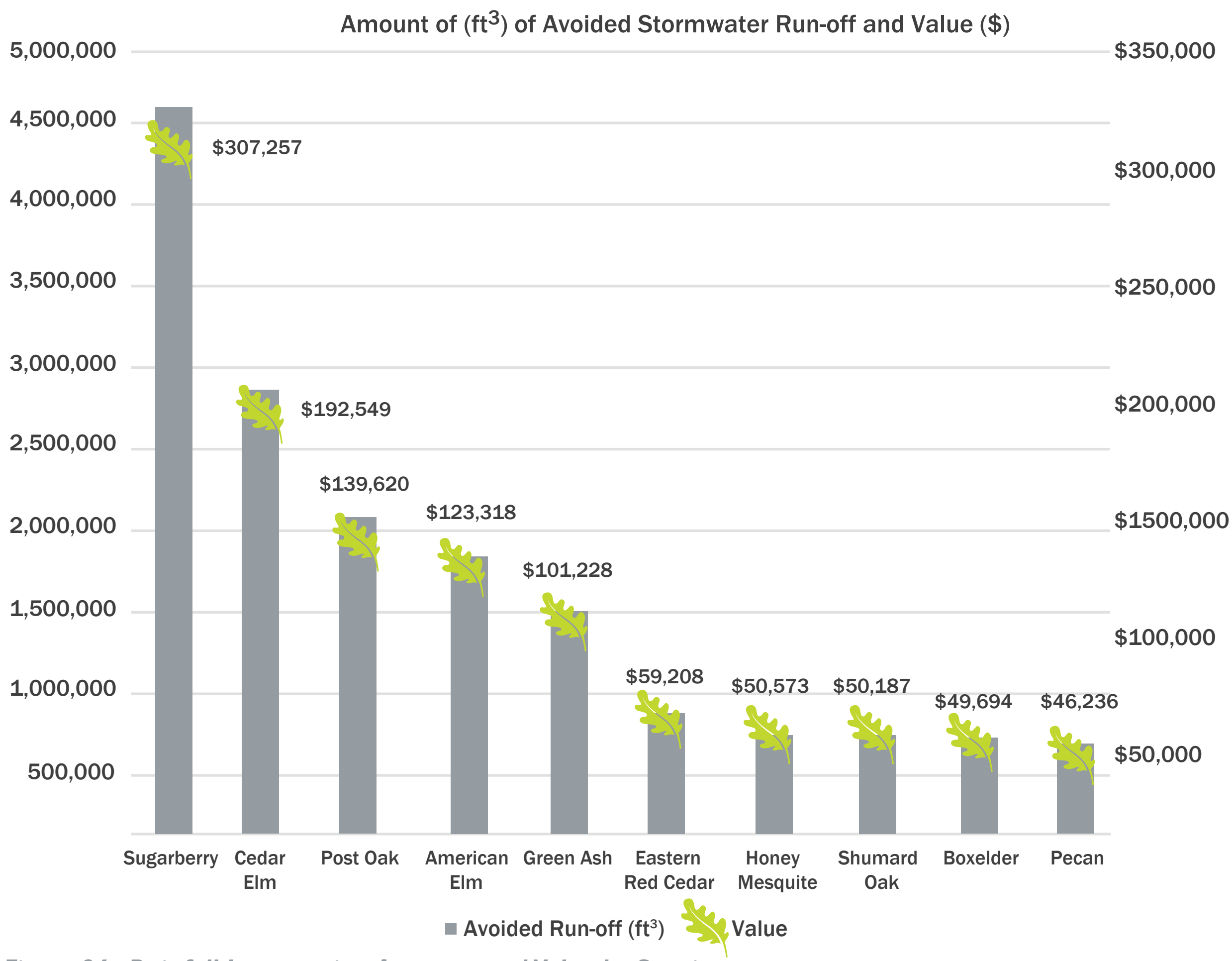


Figure 26: Rainfall Interception Amounts and Value by Species

The Trees of the City of Denton provide a total of 20.2 million ft^3/yr of stormwater reduction which has a total monetary savings of more than $1.3 million annually. As with all benefits these values will continue to increase as the trees grow and increase their canopy coverage, especially over impervious surfaces such as sidewalks, parking lots and streets. The top three species for rainfall interception were sugarberry, cedar elm, and post oak (Figure 26).

Functional Value of Denton's Urban Forest

Overall Denton's 3.5 million trees provide a total functional value of $7.2 million annually. The relative value of each species' contribution to the total benefits provided is seen in Figure 27 below. Pecan had the largest percent-benefits to percent-population ratio of any species and provided approximately 13% of the total value of all benefits with only 1% of the total population. Post oak represented 23% of the citywide benefit value with only 9% of the population.

Annual Functional Values:

- *Carbon sequestration: $3.06 million*
- *Avoided run-off: $1.35 million*
- *Pollution removal: $759,000*
- *Energy costs and Carbon emission reductions: $2.01 million*

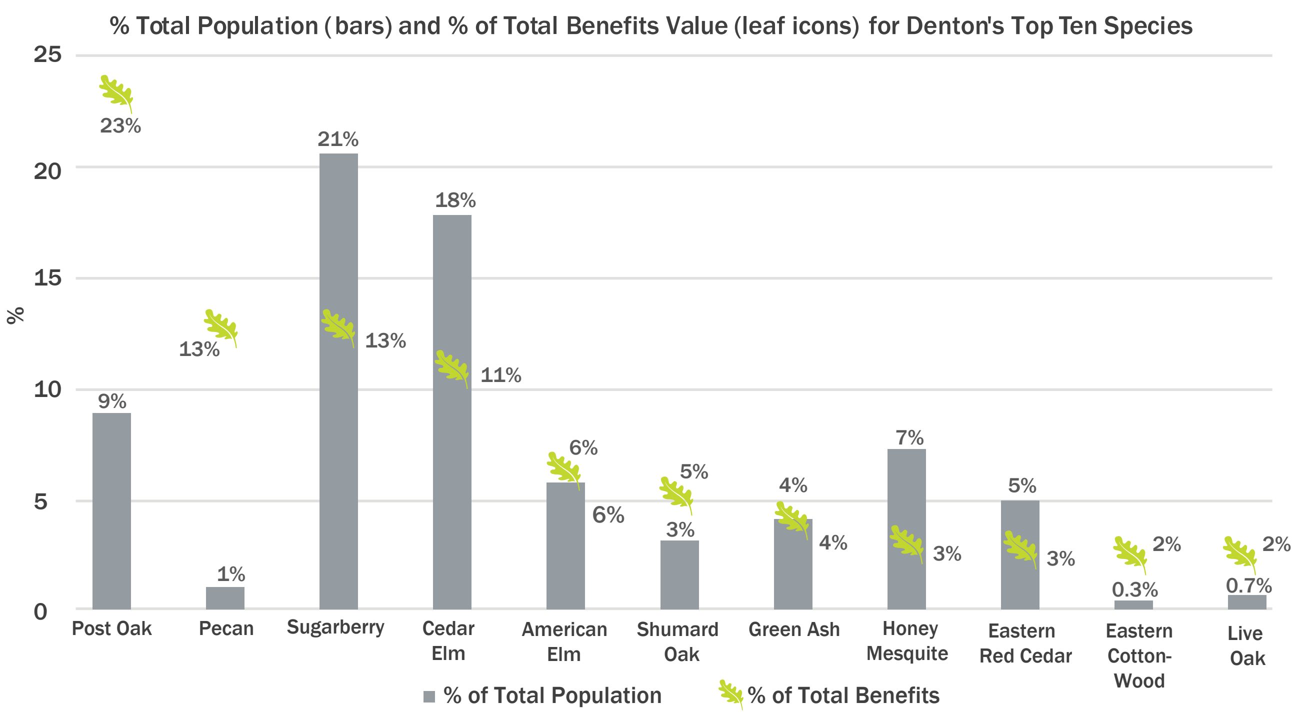


Figure 27: Percentage of Total Population (bars) and Percentage of Total Benefits Value (leaf icons) for Denton's Top Ten Species

Structural Value of Denton's Trees

Urban forests have a structural value based on the trees themselves (e.g., the cost of having to replace a tree with a similar tree). The urban forest also has functional values, either positive or negative, based on functions the trees perform.

The structural value of an urban forest tends to increase with a rise in the number and size of healthy trees. Annual functional values also tend to increase with increased number and size of healthy trees, and are usually on the order of several million dollars per year. Through proper management, urban forest values can be increased; however, the values and benefits also can decrease as the amount of healthy tree cover declines.

Structural Values:

- *Replacement value: $2.06 billion*
- *Carbon storage: $61 million*

The replacement value of the Denton urban forest was $2.06 billion. Post oak was the most valuable tree species with an estimated replacement value of $344 million, which represented 17% of total replacement value for the entire urban forest. Pecan provided 12% of the forest's structural value with only 1% of the population while sugarberry and cedar elm represented nearly 40% of the population with only 22% of the replacement value combined (Figure 28).

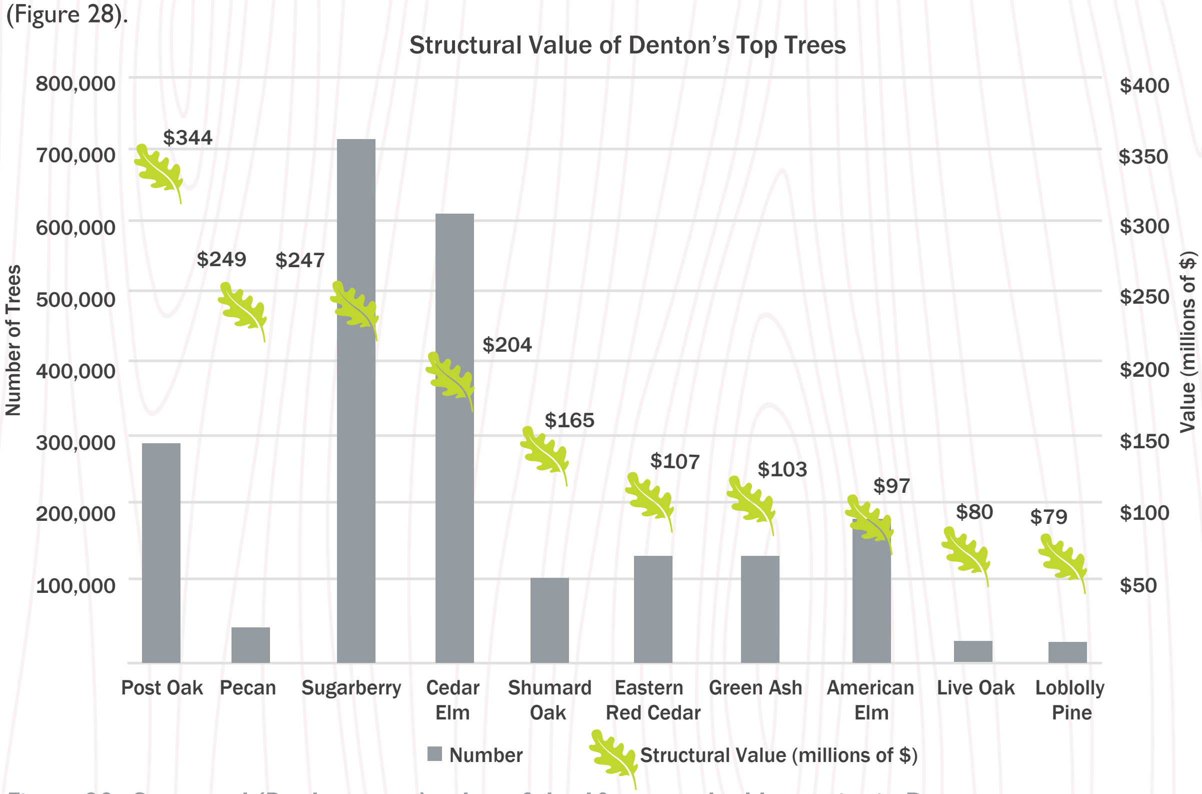


Figure 28: Structural (Replacement) value of the 10 most valuable species in Denton

Potential Pest Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, structural value and sustainability of the urban forest. As pests tend to have differing tree hosts, the potential damage or risk of each pest will differ among cities. Thirty-six pests were analyzed for their potential impact and compared with pest range maps (Forest Health Technology Enterprise Team 2014) for the conterminous United States to determine their proximity to Denton County. Two of the thirty-six pests analyzed are located within the county. For a complete analysis of all pests, see Appendix VIII.

Figure 29 depicts the three most serious pest/disease threats to Denton's urban forest. Two of these health issues (Dutch elm disease and oak wilt) are currently present in the community and contribute to tree losses annually. Emerald ash borer is a new threat to DFW and Texas.

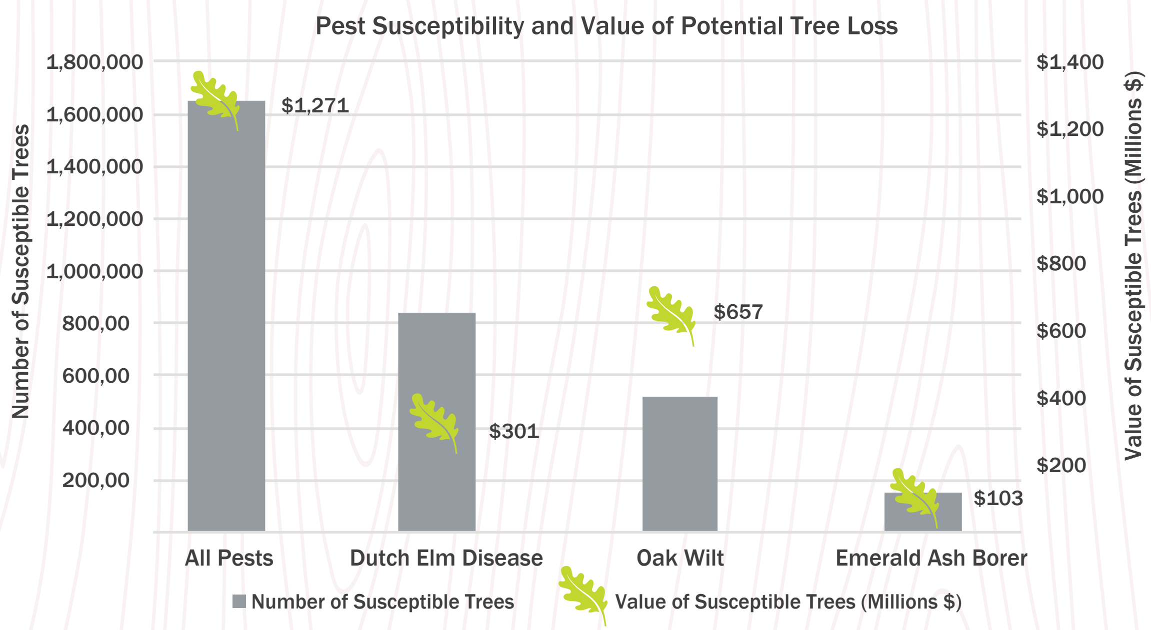


Figure 29: Susceptibility of the City of Denton's tree population and structural value by pest

In the City of Denton, the greatest opportunity for loss related to pests and associated diseases is from Dutch elm disease and oak wilt disease, potentially affecting 24% and 15% of the total population worth $301 million and $657 million, respectively.

Emerald ash borers have caused the death of tens of millions of ash trees in the Midwest and should be a serious concern for tree managers in the DFW region, as the presence of the pest was recently confirmed in East Texas (Harrison County) in early 2016. While the impact of losing Denton's ash population may not be as devastating as it has been in Michigan and Ohio cities, green ash is the eighth most populous species in Denton with approximately 4% of all trees. The potential loss of value, should Denton lose its ash trees, was estimated to be $102.6 million. Thus, protecting high value landscape specimens of this species might be a priority. See Appendix VIII for more potential pest risk information.

Discussion

The Denton urban forest provides multiple social and environmental benefits to the residents of the city and helps create a sense of community that has continued to make Denton a desirable destination. An increase in the understanding of these benefits and their associated economic values can improve both local planning and management and ultimately improve the overall condition or quality of the forest leading to increased benefits. With an average canopy cover of 30% across the city, Denton possesses a substantial natural resource worth protecting during future growth and development. In fact, since a majority of the city's trees are 6 inches or less in diameter, most trees are relatively young, but with proactive care should, over time, grow and expand both the community's UTC and the essential benefits it provides. However, the sustainability of this forest is in direct relation to the quality and extent by which it is managed. Sound urban forestry programs based in science, technology, and research will allow the city to maximize the return on this investment.

The Structure of Denton's Urban Forest

The structure of the urban forest (e.g. number of trees, number of different species, diameter size distribution, leaf area, etc.) is an important factor in making sound management decisions. As a general rule, urban foresters recommend having no more than 10% of the total tree population made up of any single species, and no more than 20% made up of any one tree genus (i.e. the oaks or elms, etc.). Sugarberry and cedar elm both supersede the 10% individual species threshold and combined make-up 40% of the urban forest population. Having a relatively high proportion of the forest in only a few species heightens the risk of catastrophic loss in the event of host-specific pest outbreaks. Furthermore, sugarberry tends to be a weak-wooded and short-lived species. Planning for this species' gradual replacement over time will help sustain and grow Denton's urban tree canopy long-term. See Appendix IX for more information regarding species importance values as it relates to percent population and leaf area.

Three examples of major pest problems threating trees in the Dallas-Fort Worth Metroplex include: oak wilt, Dutch elm disease, and (as of 2016) emerald ash borer. 43% of Denton's trees were elms, oaks, and ash (24%, 15%, and 4% respectively). The impact of the potential loss [as a result of a pest/disease epidemic] of one of the these structurally important species in Denton is highlighted by the fact the elms and oaks together make up 44% of the overall structural value of the entire community forest. A major loss of either of these species would have a tremendous impact on the function of Denton's urban forest.

Diversity in both species type and size distribution is ultimately a sign of a healthy tree resource. Nearly half (48%) of the City of Denton urban forest is represented by only three species. Thus, diversifying species selection in future planting initiatives, as well as improved management of existing trees in order to grow current trees into larger diameter classes, is recommended in order to enhance the forest's overall quality, resiliency, and benefits.

Denton has a relatively young urban forest with 58% of all trees less than 6 inches in diameter. This is a trend seen throughout the Metroplex communities. While it is important to have a relatively high proportion of younger trees to replace dying older trees, it requires purposeful management in order to grow smaller/younger trees into maturity where benefits are maximized.

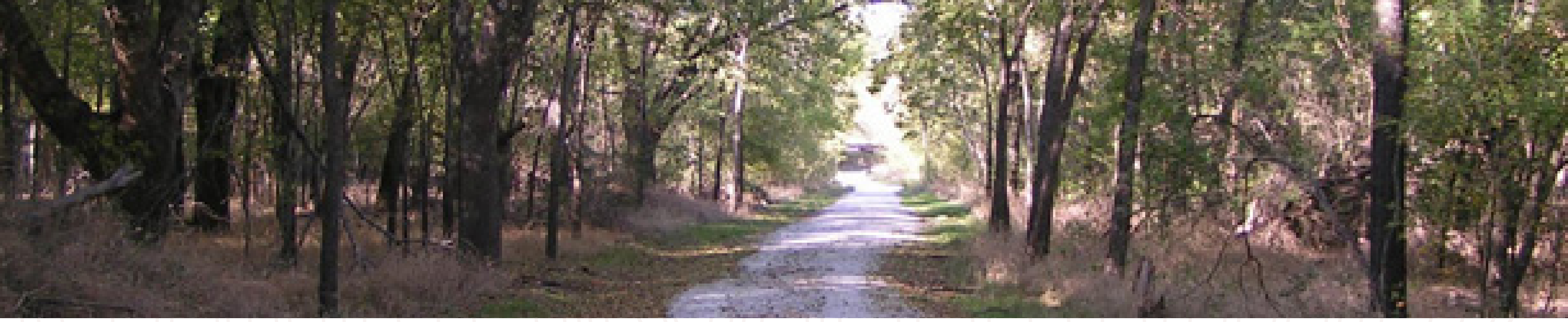
The geographic distribution of trees and canopy cover across the city is also an important characteristic for effective urban forest management. While differences in tree and leaf area densities across land use classes is not unexpected, an understanding of which land uses contribute more significantly to the city's overall urban forest canopy is essential for long-term resource management.

Of the various land use classes analyzed in this study, Undeveloped and Single Family Residential had the highest densities in terms of trees per acre (Figure 13) making tree protection in these land uses a key strategy for enhancing Denton's urban forest canopy. Since the Undeveloped land use class also had the largest percentage of leaf area per acre of any land use class in the city (46%), it therefore has the most to lose during development. However, with data collected in this study, the city can now have a better understanding of the relative contribution individual land use classes provide in terms of number of trees and existing canopy cover.

The Function of Denton's Urban Forest

The function of the urban forest is also an important factor that helps resource managers make management decisions and set well-defined goals. These goals may be aimed at specific environmental services such as reducing air pollution in high traffic congestion areas or to improve stormwater management in areas with relative high proportions of impervious surfaces. The function of the urban forest is directly linked to its structure since some species provide more benefits within a certain category (e.g. pollution removal) than other species and larger trees generally provide more benefits than smaller trees. Knowing which species are providing more benefits in a particular community can aid the municipal tree manager in planning for the urban forest via more strategic planting plans.

For example, post oaks sequester 20% of all the carbon in Denton yet make up only 9% of the total population. This provides a good example of how important tree size is with respect to the level of environmental benefits individual trees/species can have in Denton. Denton can more effectively manage its carbon foot print by either increasing the number of post oaks across the city or, better still, increasing the canopy coverage of existing post oaks through proactive management.



Pecans also outperformed the majority of the top species that define the Denton urban forest population. While they made up only 1% of the forest, pecans contributed 3% of the total leaf area of the urban forest canopy and provided a significant 13% of the total value of all environmental benefits. Pecans also represented 12% of the total replacement value for all species across Denton. High performing species, such as pecans and post oaks should be promoted and professionally managed to best maximize their role in the urban forest ecosystem.

As shown, species selection will be of major importance to the value of Denton's future tree canopy. With over 40% of the city's canopy at risk to future development, the importance of having a comprehensive tree protection code will help to ensure the protection of the biggest and best trees in the city. Development will continue to increase with over 1,000 people moving to Texas a day. It is unavoidable that Denton's land use will change dramatically over the coming years. Future landscape codes, canopy cover goals, and green infrastructure practices will determine what Denton will look like in the future.

Comparing the Denton Urban Forest

Denton represents only the sixth community in the state to complete an i-Tree Eco study and only the fifth in the DFW Metroplex. Comparing the structural or functional values of urban forests across various communities requires converting the various structural and functional values to per tree and/or per acre values to allow for the best comparison across communities (Table 6).

While a direct comparison to other communities is interesting on an empirical basis, it is important to recognize the many physical (e.g. types of infrastructure, level/extent of development, etc.), social (e.g. political support for program, etc.), and natural (e.g. species availability and growth rates, climate, etc.) attributes that control the level and quality of any community's urban forest. Furthermore, the year each study is completed may impact the results to a small degree since regression equations that provide leaf area estimates and benefit values, as well as other local inputs such as energy costs and replacement cost values, are periodically adjusted following new research and updates to estimation models.

See Appendix X for a comparison of Denton's urban forest with other North American cities.

Per Tree Benefit Values for Several i-Tree Eco Studies in Texas

Table 6. Per tree and per acre structural and functional values for i-Tree Eco studies in Texas

Location	Year	Scale	# of Trees	Acres	Tree/Acre	# of Species	Canopy Cover (%)	Carbon Storage ($)	Carbon Sequestration ($/yr)	Energy Savings ($/yr)	Air Quality ($/yr)	Rainfall Interception ($/yr)	Average of All Benefits ($)	Structural / Replacement Value ($)
Houston	2005	Region (8 County)	663,000,000	4,851,840	137	67	28	1.87	0.04	0.20	0.45	NA	0.64	$311
Arlington	2009	City	2,965,000	65,889	45	77	22	2.87	0.15	0.99	0.98	1.44	1.29	$927
Mesquite	2012	City	2,091,000	29,568	71	54	24	4.92	0.44	0.37	0.74	0.96	1.49	$476
El Paso	2013	City	1,281,000	164,032	13	50	5	5.16	0.41	2.11	0.19	1.72	1.92	$1272
Plano	2014	City	1,690,000	46,030	37	60	16	8.99	0.62	1.1	1.02	0.26	2.39	$947
Dallas	2014	City	14,700,000	218,240	67	80	29	9.32	0.56	0.61	1.03	0.27	2.36	$613
Denton	2016	City	3,463,000	74,492	47	46	30	17.61	0.88	0.58	0.22	0.39	3.93	$595

Per Acre Benefit Values for Several i-Tree Eco Studies in Texas

Table 6. Per tree and per acre structural and functional values for i-Tree Eco studies in Texas

Location	Year	Scale	# of Trees	Acres	Tree/Acre	# of Species	Canopy Cover (%)	Carbon Storage ($)	Carbon Sequestration ($/yr)	Energy Savings ($/yr)	Air Quality ($/yr)	Rainfall Interception ($/yr)	Average of All Ben-efits ($)	Structural / Replacement Value ($)
Houston	2005	Region (8 County)	663,000,000	4,851,840	137	67	28	148.60	5.98	27.00	61.00	NA	60.65	$42,458
Arlington	2009	City	2,965,000	65,889	45	77	22	129.00	6.94	44.54	44.00	65.36	57.97	$42,496
Mesquite	2012	City	2,091,000	29,568	71	54	24	348.35	31.35	26.14	52.08	67.98	105.18	$33,685
El Paso	2013	City	1,281,000	164,032	13	50	5	40.30	3.22	16.46	1.47	13.41	14.97	$9,937
Plano	2014	City	1,690,000	46,030	37	60	16	330.22	22.59	40.41	37.58	9.67	88.09	$34,977
Dallas	2014	City	14,700,000	218,240	62	80	29	627.75	37.53	41.24	69.65	18.33	158.90	$41,330
Denton	2016	City	3,463,000	74,492	47	46	30	818.87	41.08	20.94	10.19	18.12	181.84	$27,654

Recommendations

Denton's urban forest is an increasingly valuable community resource. However, to best support the appreciation of its value, explicit, professional care must be a priority. A commitment of continued investment in Denton's Urban Forestry Program will help to increase this important community asset's role in developing a more livable Denton for both residents and visitors alike. As such, the city should use these suggestions, along with the key findings in this report, as a tool for an interdisciplinary goal-setting process and determination of priorities and strategies.

Recommendation 1: Utilize assessment results to preserve and promote urban tree canopy.

With the recent increase in both commercial and residential housing markets, the focus of tree protection and professional tree management has never been more important. Working with city planners and developers to both protect existing trees, as well as, incorporate future trees in new and creative ways will help to enhance the benefits of the city's urban forest into the future.

This assessment report provides detailed information about current UTC and possible planting areas, both city-wide and at various geographic scales. These results should be utilized to enhance and promote forest preservation and management efforts, including the establishment of a baseline urban tree canopy cover percentage. The City of Denton should disseminate the data from this study to diverse partners for urban forestry and other applications while they are current and most useful for decision-making and implementation planning.

Recommendation 2: Perform further analyses on assessment results.

Much of Denton's UTC lies on undeveloped/vacant land. As Denton continues to grow, UTC will be under increasing pressure in order to make room for new development. Further analysis of the assessment results should be performed in order to support the case for a stronger tree ordinance. Specifically, the city should assess the relative UTC percent for public versus private lands within the Undeveloped land use class. Evaluating land ownership (e.g. public vs. private) by parcel within the Undeveloped land use class will help the city identify at-risk-properties.

Recommendation 3: Utilize assessment to help drive policy and management decisions.

As Denton continues to sprawl, UTC will be under increasing pressure in order to make room for new development.

It is recommended that the city of Denton develop an Urban Forest Management Plan which outlines goals and the tasks necessary to reach them. Establishing measureable program goals and staff-defined responsibilities will allow the urban forestry program to enhance channels of communication regarding professional tree care within the community, set work priorities, monitor progress, and develop appropriate budgets annually.

One way to do this is to revisit the city's tree protection ordinance. Specifically, canopy coverage goals and/or recommendations designed for specific land-use such as parking lots, industrial, and commerical areas should be addressed, especially with 14% of the city's ground cover in impervious suface.

Recommendation 4: Utilize assessment to develop strategic tree planting initiatives.

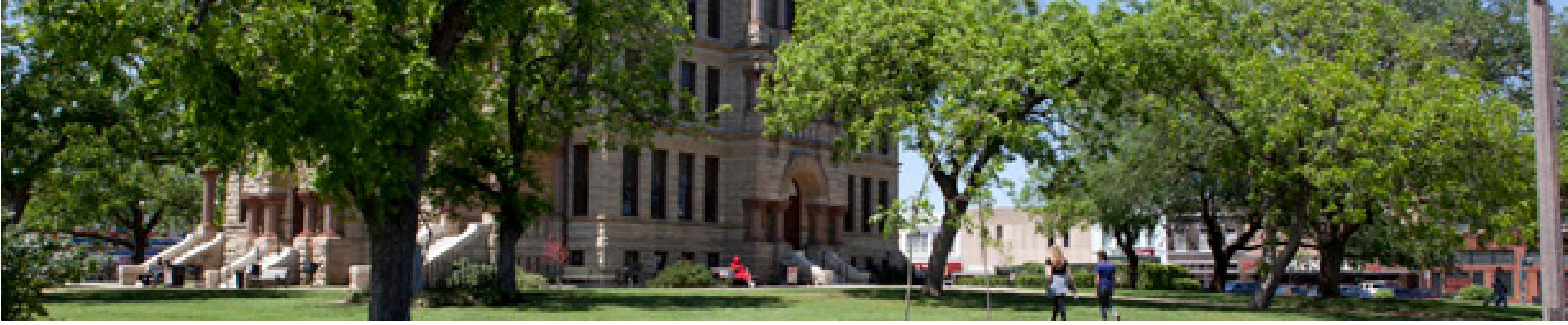
Even though Denton's canopy cover measured 30%, a majority of the canopy is located on the east side of town and additionally 46% is on undeveloped property. Improved landscape requirements and maintenance standards will help grow the next generation of forest canopy. With 37% of all single family residential homes having available planting spaces, expanding tree planting on private property would be a good place to start while avoiding increased cost to the city. In the long-term, strategic tree planting programs must include expanded species selection, updated landscape requirements, maintenance requirements and costs.

Recommendation 5: Utilize trees and other green infrastructure to offset the urban heat island effect and control stormwater.

43% of the commercial district of Denton is available for tree planting. By strategically planting trees within the commercial district as well as other land uses with relatively high amounts of impervious surfaces, the city can reduce both stormwater and the urban heat island effect.

It is also recommended to further examine any change in impervious surfaces between 2008 and the present. Although the 2% increase of canopy coverage between 2008 and 2014 is positive, anecdotal evidence suggests that the amount of impervious surface across the city may have increased at an even higher rate.

Therefore, stormwater impact fees and other development guidelines should also be reviewed and strengthened to ensure that they are as current and comprehensive as they can be. Strategies that combine smart regulation with urban tree canopy enhancement within the commercial district of Denton will promote sustainability for generations.



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Appendix I: i-Tree Eco Model & Field Measurements

i-Tree Eco is designed to use standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects (Nowak and Crane 2000), including:

- *Urban forest structure (e.g., species composition, tree health, leaf area, etc.).*
- *Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year.*
- *Total carbon stored and net carbon annually sequestered by the urban forest.*
- *Effects of trees on building energy use and consequent effects on carbon dioxide emissions from power sources.*
- *Structural value of the forest, as well as the value for air pollution removal and carbon storage and sequestration.*
- *Potential impact of infestations by pests, such as Asian longhorned beetle, emerald ash borer, gypsy moth, and Dutch elm disease.*

Typically, all field data are collected during the leaf-on season to properly assess tree canopies. Typical data collection (actual data collection may vary depending upon the user) includes land use, ground and tree cover, individual tree attributes of species, stem diameter, height, crown width, crown canopy missing and dieback, and distance and direction to residential buildings (Nowak et al 2005; Nowak et al 2008).

During data collection, trees are identified to the most specific taxonomic classification possible. Trees that are not classified to the species level may be classified by genus (e.g., ash) or species groups (e.g., hardwood). In this report, tree species, genera, or species groups are collectively referred to as tree species.

Tree Characteristics:

Leaf area of trees was assessed using measurements of crown dimensions and percentage of crown canopy missing. In the event that these data variables were not collected, they are estimated by the model. An analysis of invasive species is not available for studies outside of the United States. For the U.S., invasive species are identified using an invasive species list (Watershed Protection Development Review) for the state in which the urban forest is located. These lists are not exhaustive and they cover invasive species of varying degrees of invasiveness and distribution. In instances where a state did not have an invasive species list, a list was created based on the lists of the adjacent states. Tree species that are identified as invasive by the state invasive species list are cross-referenced with native range data. This helps eliminate species that are on the state invasive species list, but are native to the study area.

Air Pollution Removal:

Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter less than 2.5 microns. Particulate matter less than 10 microns (PM10) is another significant air pollutant. Given that i-Tree Eco analyzes particulate matter less than 2.5 microns (PM2.5) which is a subset of PM10, PM10 has not been included in this analysis. PM2.5 is generally more relevant in discussions concerning air pollution effects on human health.

Air pollution removal estimates are derived from calculated hourly tree-canopy resistances for ozone, and sulfur and nitrogen dioxides based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi 1988; Baldocchi et al 1987). As the removal of carbon monoxide and particulate matter by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature (Bidwell and Fraser 1972; Lovett 1994) that were adjusted depending on leaf phenology and leaf area. Particulate removal incorporated a 50% resuspension rate of particles back to the atmosphere (Zinke 1967). Recent updates (2011) to air quality modeling are based on improved leaf area index simulations, weather and pollution processing and interpolation, and updated pollutant monetary values (Hirabayashi et al 2011; Hirabayashi et al 2012; Hirabayashi 2011).

Trees remove PM2.5 when particulate matter is deposited on leaf surfaces (Nowak et al 2013). This deposited PM2.5 can be resuspended to the atmosphere or removed during rain events and dissolved or transferred to the soil. This combination of events can lead to positive or negative pollution removal and value depending on various atmospheric factors. Generally, PM2.5 removal is positive, with positive benefits. However, there are some cases when net removal is negative or resuspended particles lead to increased pollution concentrations and negative values. During some months (e.g., with no rain), trees resuspend more particles than they remove. Resuspension can also lead to increased overall PM2.5 concentrations if the boundary layer conditions are lower during net resuspension periods than during net removal periods. Since the pollution removal value is based on the change in pollution concentration, it is possible to have situations when trees remove PM2.5 but increase concentrations and thus have negative values during periods of positive overall removal. These events are not common, but can happen.

For reports in the United States, default air pollution removal value is calculated based on local incidence of adverse health effects and national median externality costs. The number of adverse health effects and associated economic value is calculated for ozone, sulfur dioxide, nitrogen dioxide, and particulate matter less than 2.5 microns using data from the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP) (Nowak et al 2014). The model uses a damage-function approach that is based on the local change in pollution concentration and population.

National median externality costs were used to calculate the value of carbon monoxide removal (Murray et al 1994).

For international reports, user-defined local pollution values are used. For international reports that do not have local values, estimates are based on either European median externality values (van Essen et al 2011) or BenMAP regression equations (Nowak et al 2014) that incorporate user-defined population estimates. Values are then converted to local currency with user-defined exchange rates. For this analysis, pollution removal value is calculated based on the prices of $1,469 per ton (carbon monoxide), $682 per ton (ozone), $195 per ton (nitrogen dioxide), $79 per ton (sulfur dioxide), $24,202 per ton (particulate matter less than 2.5 microns).

Carbon Storage and Sequestration:

Carbon storage is the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. To calculate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations (Nowak 1994). To adjust for this difference, biomass results for open-grown urban trees were multiplied by 0.8. No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.

Carbon sequestration is the removal of carbon dioxide from the air by plants. To estimate the gross amount of carbon sequestered annually, average diameter growth from the appropriate genera and diameter class and tree condition was added to the existing tree diameter (Year X) to estimate tree diameter and carbon storage in Year X+1.

Carbon storage and carbon sequestration values are based on estimated or customized local carbon values. For international reports that do not have local values, estimates are based on the carbon value for the United States (U.S. Environmental Protection Agency 2015, Interagency Working Group on Social Cost of Carbon 2015) and converted to local currency with user-defined exchange rates.

For this analysis, carbon storage and carbon sequestration values are calculated based on $133 per ton.

Oxygen Production:

The amount of oxygen produced is estimated from carbon sequestration based on atomic weights: net O_2 release (kg/yr) = net C sequestration (kg/yr) × 32/12. To estimate the net carbon sequestration rate, the amount of carbon sequestered as a result of tree growth is reduced by the amount lost resulting from tree mortality. Thus, net carbon sequestration and net annual oxygen production of the urban forest account for decomposition (Nowak et al 2007). For complete inventory projects, oxygen production is estimated from gross carbon sequestration and does not account for decomposition.

Avoided Runoff:

Annual avoided surface runoff is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis.

The value of avoided runoff is based on estimated or user-defined local values. For international reports that do not have local values, the national average value for the United States is utilized and converted to local currency with user-defined exchange rates. The U.S. value of avoided runoff is based on the U.S. Forest Service's Community Tree Guide Series (McPherson et al 1999; 2000; 2001; 2002; 2003; 2004; 2006a; 2006b; 2006c; 2007; 2010; Peper et al 2009; 2010; Vargas et al 2007a; 2007b; 2008).

Building Energy Use:

If appropriate field data were collected, seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature (McPherson and Simpson 1999) using distance and direction of trees from residential structures, tree height and tree condition data. To calculate the monetary value of energy savings, local or custom prices per MWH or MBTU are utilized.

For this analysis, energy saving value is calculated based on the prices of $111.59 per MWH and $10.81 per MBTU.

Structural Values:

Structural value is the value of a tree based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree). Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information (Nowak et al 2002a; 2002b). Structural value may not be included for international projects if there is insufficient local data to complete the valuation procedures.

Potential Pest Impacts:

The complete potential pest risk analysis is not available for studies outside of the United States. The number of trees at risk to the pests analyzed is reported, though the list of pests is based on known insects and disease in the United States.

For the U.S., potential pest risk is based on pest range maps and the known pest host species that are likely to experience mortality. Pest range maps for 2012 from the Forest Health Technology Enterprise Team (FHTET) (Forest Health Technology Enterprise Team 2014) were used to determine the proximity of each pest to the county in which the urban forest is located. For the county, it was established whether the insect/disease occurs within the county, is within 250 miles of the county edge, is between 250 and 750 miles away, or is greater than 750 miles away. FHTET did not have pest range maps for Dutch elm disease and chestnut blight. The range of these pests was based on known occurrence and the host range, respectively (Eastern Forest Environmental Threat Assessment Center; Worrall 2007).

Relative Tree Effects:

The relative value of tree benefits reported in Appendix II is calculated to show what carbon storage, sequestration, and air pollutant removal equate to in amounts of municipal carbon emissions, passenger automobile emissions, and house emissions.

Municipal carbon emissions are based on 2010 U.S. per capita carbon emissions (Carbon Dioxide Information Analysis Center 2010). Per capita emissions were multiplied by city population to estimate total city carbon emissions.

Light duty vehicle emission rates (g/mi) for CO, NO_x, VOCs, PM10, SO_2 for 2010 (Bureau of Transportation Statistics 2010; Heirigs et al 2004), PM2.5 for 2011-2015 (California Air Resources Board 2013), and CO_2 for 2011 (U.S. Environmental Protection Agency 2010) were multiplied by average miles driven per vehicle in 2011 (Federal Highway Administration 2013) to determine average emissions per vehicle.

Household emissions are based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household in 2009 (Energy Information Administration 2013; Energy Information Administration 2014)

- *CO_2, SO_2, and NO_x power plant emission per KWh are from Leonardo Academy 2011. CO emission per kWh assumes one-third of one percent of C emissions is CO based on Energy Information Administration 1994. PM10 emission per kWh from Layton 2004.*
- *CO_2, NO_x, SO_2, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) from Leonardo Academy 2011.*
- *CO_2 emissions per Btu of wood from Energy Information Administration 2014.*
- *CO, NO_x and SO_x emission per Btu based on total emissions and wood burning (tons) from (British Columbia Ministry 2005; Georgia Forestry Commission 2009).*

Appendix II. Complete UTC Results

Assessment Results & Key Findings

This section presents the key findings of this study, including the land cover base map as well as the canopy analysis results, which were analyzed across various geographic assessment boundaries. These results, or metrics, help provide a benchmark and inform a strategic approach to identifying future planting areas. Complete assessment results for target geographies and additional maps can be found in the Appendix.

Citywide Land Cover

In 2014, 30% of Denton was covered by tree canopy, 45% was non-canopy vegetation, and 14% was impervious. Further dividing the impervious surface areas into more detailed classifications shows that 3% of the city is covered by buildings, 3% is covered by roads, 2% is covered by parking lots, and 0.2% is covered by sidewalks, leaving 5% classified as "Other Impervious." Parking lots and sidewalks may offer opportunities for new tree plantings and additional canopy cover. Table 1 shows the five-class land cover results, while Figure 8 shows the more detailed map and distribution.

Table 1: Five-Class Land Cover Classification Results for Denton, TX

Total Acres	Tree Canopy (acres)	Tree Canopy %	Non-Canopy Vegetation (acres)	Non-Canopy Vegetation %	Impervious (acres)	Impervious %	Water (acres)	Water %	Soil/Dry Vegetation (acres)	Soil/Dry Vegetation %
74,492	22,540	30%	33,321	45%	10,506	14%	730	1%	7,394	17%

Citywide Urban Tree Canopy

Results show that within the City of Denton, TX, 22,540 acres was covered by urban tree canopy, making up 30% of the 73,761 land acres, and 32,609 acres of land has been identified as non-canopy vegetation that provides the possibility for addition tree canopy. This possible planting area (PPA Vegetation) makes up 44% of the city. Non-building and non-road impervious areas cover 5,418 acres that may also offer additional planting opportunity (PPA Impervious), while 19% of the city's land has been identified as unsuitable for planting. This includes sport fields, golf course fairways, buildings and roads, and soil/dry vegetation.

Table 2: Urban Tree Canopy Assessment Results
**Note: Percentages are based on Land Area*

*Land Area (acres)	UTC (acres)	UTC %	PPA Vegetation (acres)	PPA Veg-etation %	PPA Impervious (acres)	PPA Impervious	Total Possible Planting (acres)	Total Possible Planting %	Unsuitable UTC* (acres)	Unsuitable UTC* %
73,761	22,540	30%	32,609	44%	%	7%	38,028	52%	13,923	19%

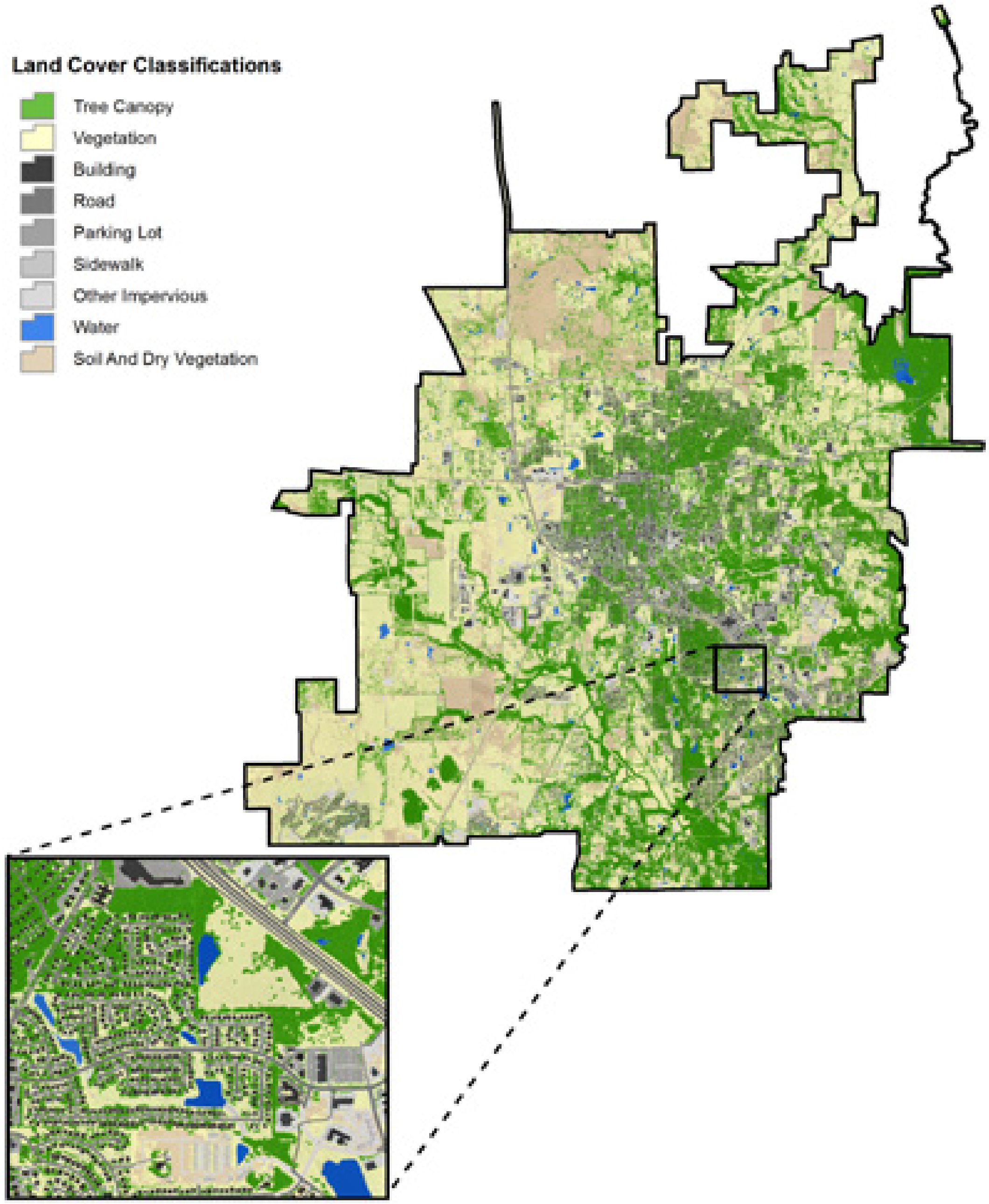


Figure 1: Detailed Land Cover Classifications and Distribution

Land Use

Many of the policies, regulations, ordinances, and actions influencing tree canopy in Denton are dependent on land use classes. To provide data that advances UTC policy and management, 12 land use classes were assessed (Figure 9).

The Single-Family Residential and Undeveloped land use classes have the highest canopy cover at 45% and 38%, respectively. These two classes combined constitute 74% of the UTC in the city, while Industrial, Agricultural, Multi-Family Residential, and Parks/Open Space land use classes account for 22%. The six other classes, including Commercial and Government property, make up the remaining 5% of UTC coverage.

Aside from the Agricultural land use classification, the greatest opportunity to expand the urban tree canopy is within the Industrial class which contains 60% PPA Vegetation. The Parks and Open Space (43%) and Government (19%) classes also present significant opportunity for canopy growth, most of which is city-owned and managed.

Undeveloped land use contributes 46% of total citywide urban tree canopy. This classification, it should be noted, will diminish in size with future development as land use within the classification changes. Opportunities to preserve existing UTC within this classification should be considered as this land is absorbed into other land use categories as a result of future development.

Percent UTC and PPA (Veg.) by Land Use Class

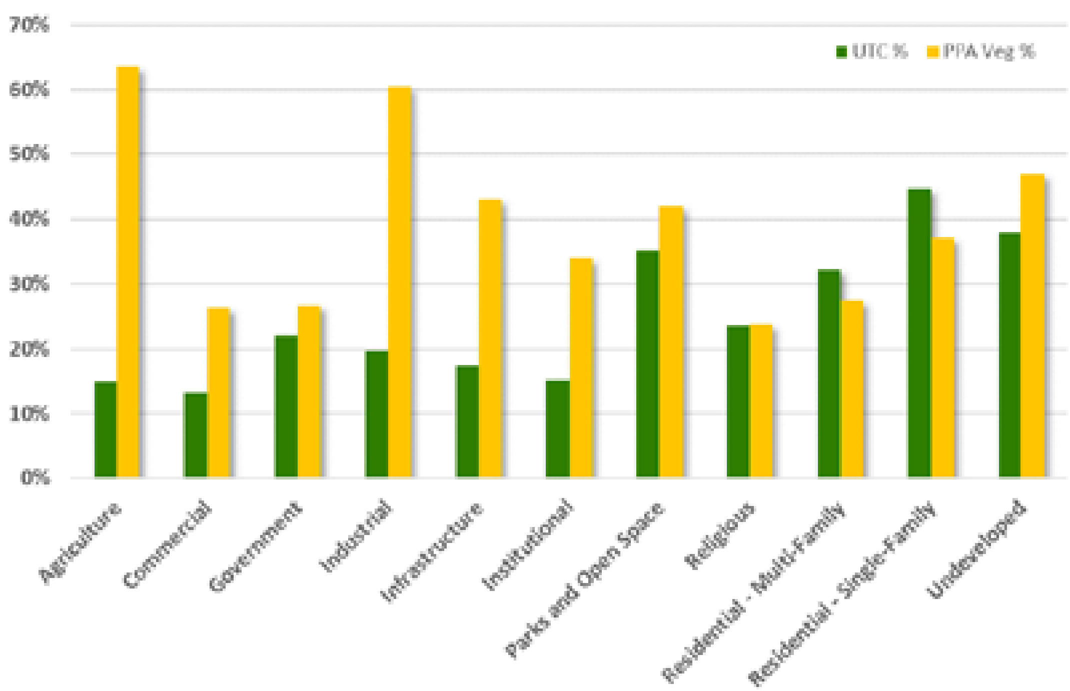


Figure 2: Percent UTC and PPA by Land Use

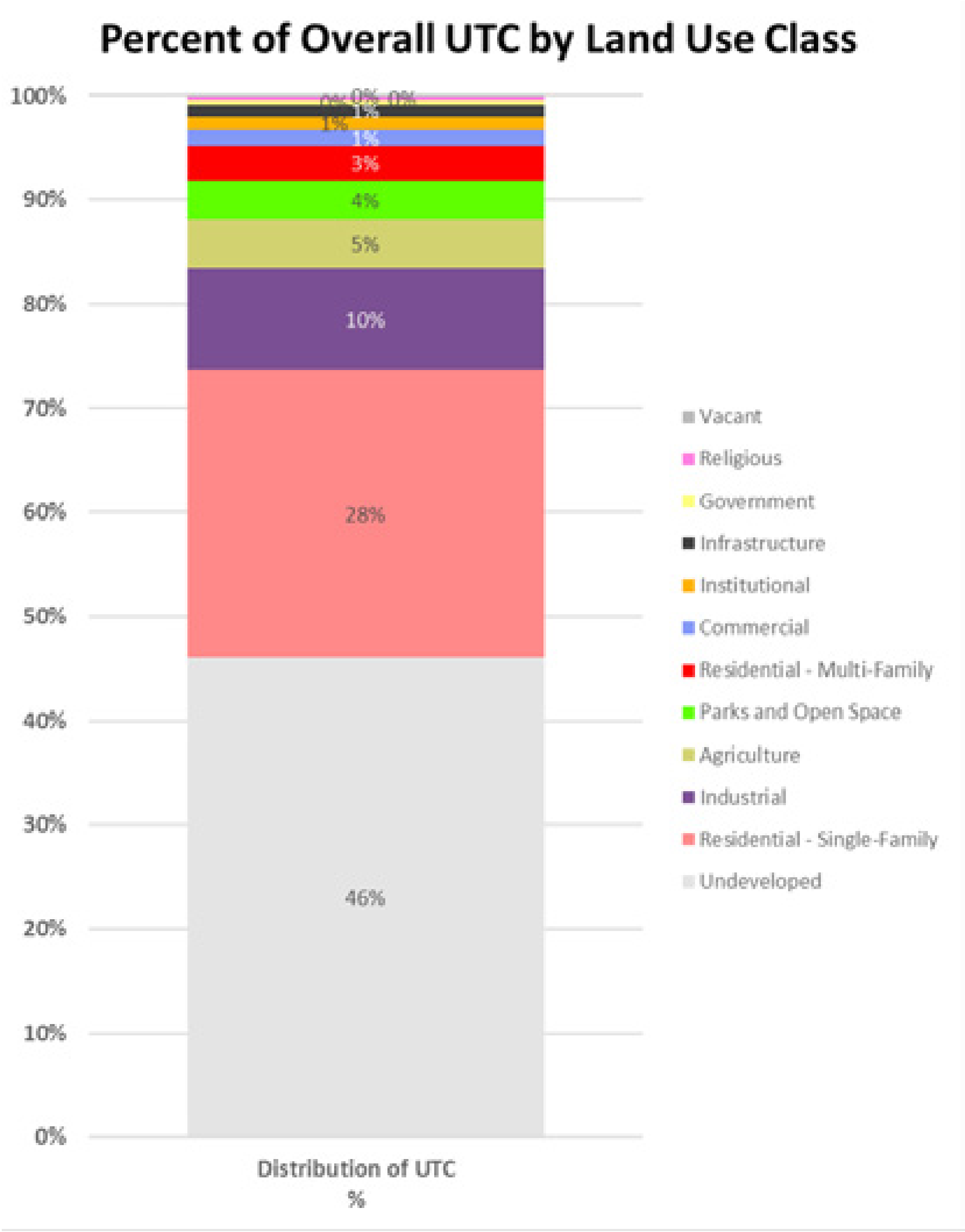


Figure 3: Percent of Overall UTC by Land Use

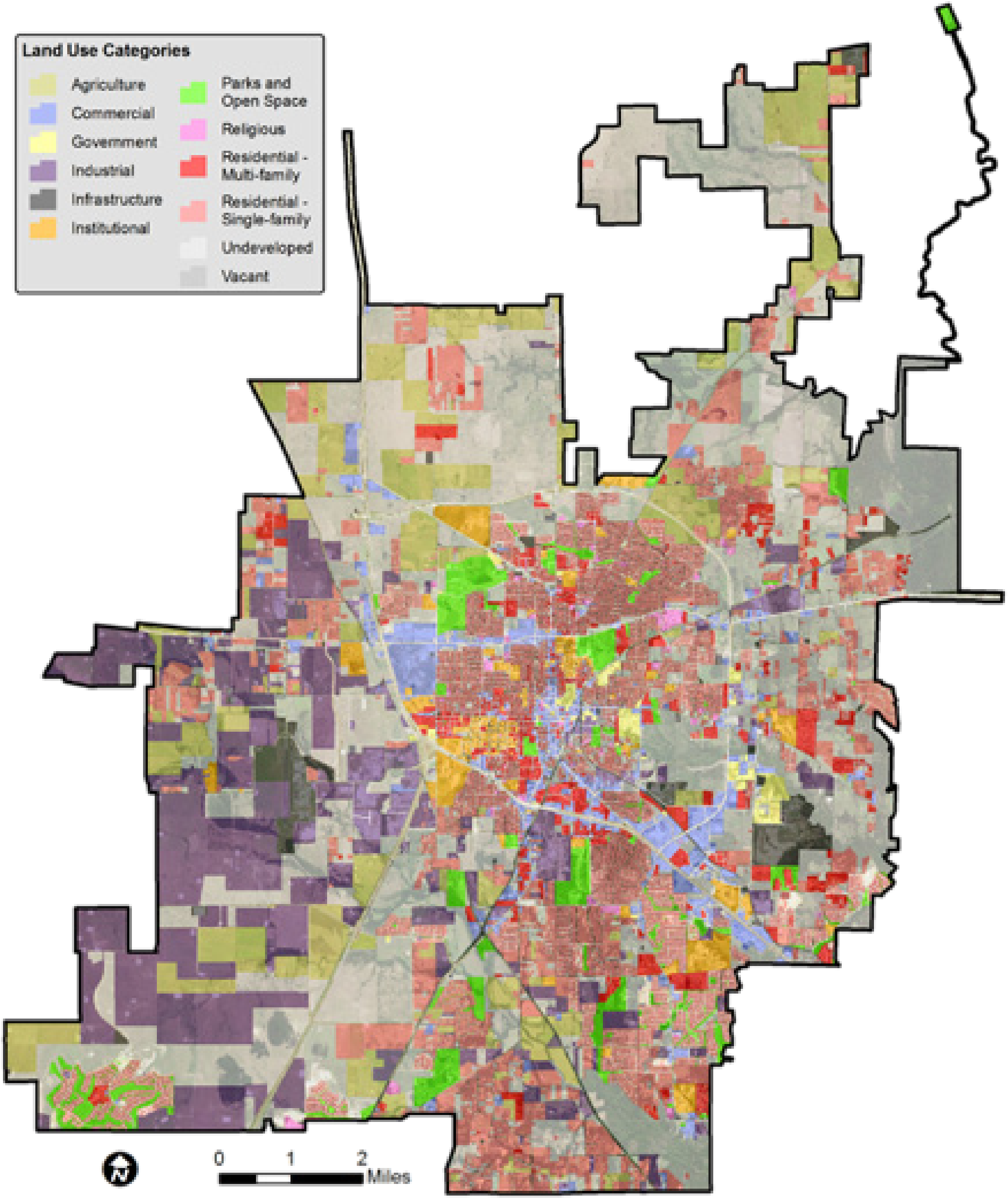


Figure 4: Land Use Categories

Census Block Groups

This study processed UTC totals and Possible Planting Areas (Vegetation, Impervious, and Total PPA) data for 86 census block groups. Canopy cover is most prevalent in the eastern half of Denton where the majority of urban development has occurred, while the western half of the city is composed of more farmland and open space which decreases UTC potential.

When looking at possible planting areas in vegetation, this trend is reversed. The western half of the city provides the most significant opportunity to increase UTC, with the entire region being more than 45% PPA Vegetation. However, it may be difficult to make substantial increases in UTC in these areas of privately-owned agricultural land. The city center has the least potential with less than 20% PPA Vegetation.

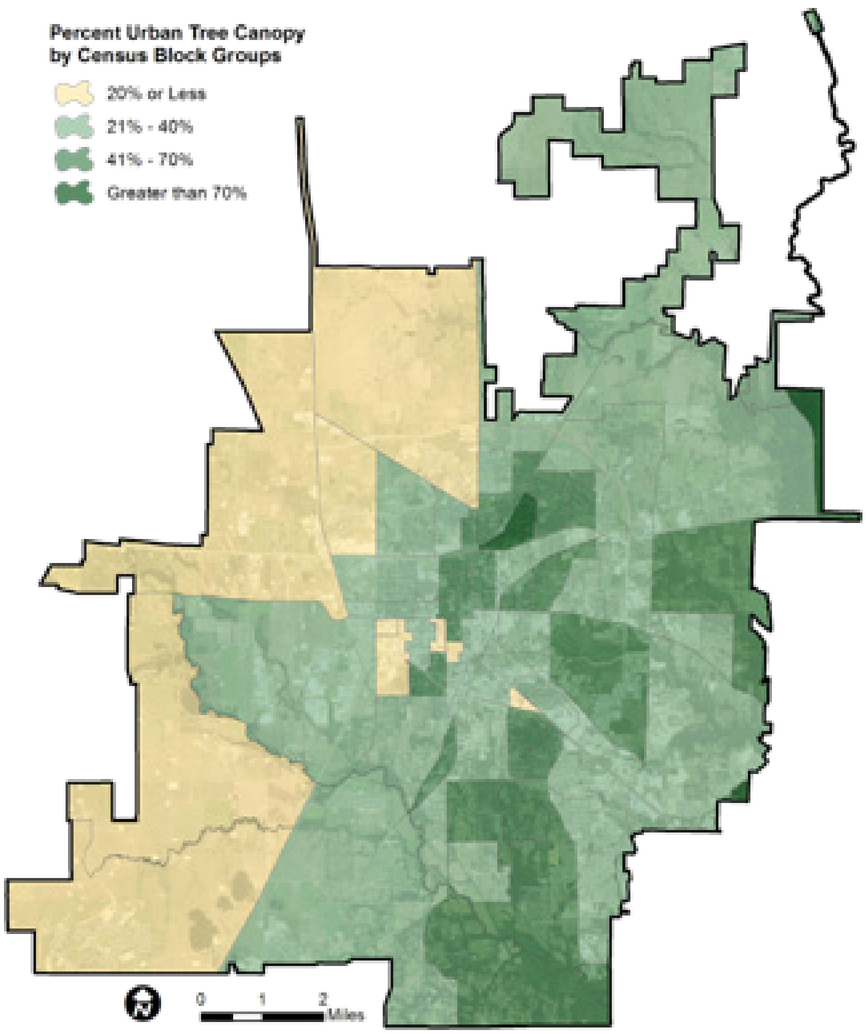


Figure 5: UTC by Census Block Groups

Parcels

The most detailed assessment geography analyzed for this study was the parcel layer. This study calculated UTC totals and Possible Planting Areas (Vegetation, Impervious, and Total PPA) for each individual property with over 38,000 records. Due to the size of the dataset, comprehensive data have been provided to the city in GIS format, and are not included in tabular format in this report. The parcel dataset can be queried to find specific areas in the city that have low UTC, high PPA, particular land use types, or a certain amount of impervious area.

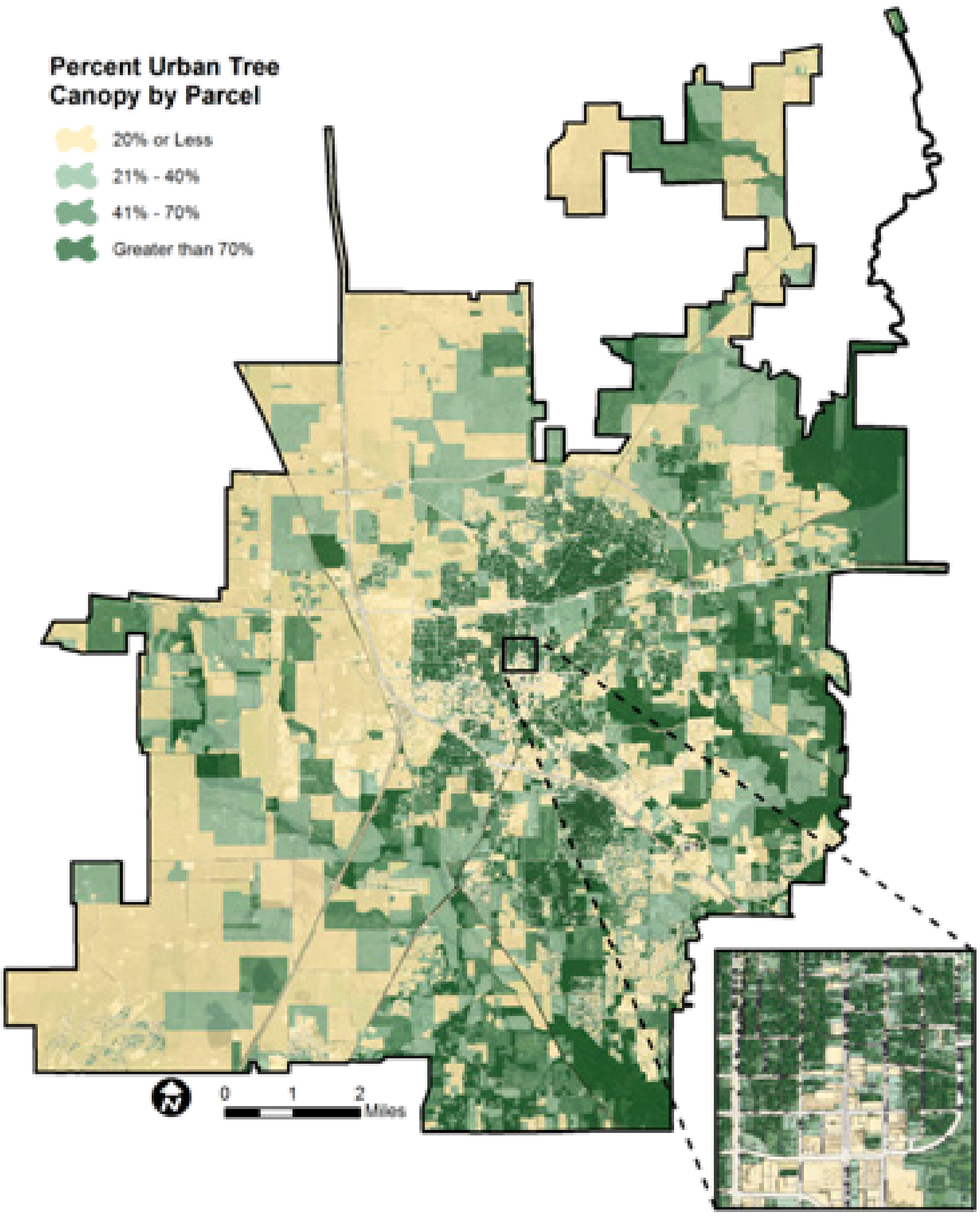


Figure 5: UTC by Census Block Groups

Zip Codes

Urban Tree Canopy (UTC) totals and Possible Planting Areas (Vegetation, Impervious, and Total PPA) were evaluated for the 13 zip codes located within the City of Denton. One Denton zip code, 76209, has the highest percent canopy cover at 47%. However, it only makes up 9% of the canopy cover citywide because it is a smaller area. East Denton and South Denton zip code 76205 both contain 41% canopy cover and make up 35% of the canopy cover citywide.

Possible planting areas in vegetation are abundant throughout the city. One zip code with high potential to increase UTC coverage is North Denton with 53% PPA Vegetation, accounting for one third of the total PPA Vegetation in the city. Krum, Ponder, and Aubrey provide additional opportunities for tree planting with 63%, 59%, and 52%, respectively. Within the Denton zip codes, there are an additional 4,700 acres of PPA Impervious. Possible planting areas located along city-owned impervious infrastructure are easy targets for increasing tree canopy cover.

Figure 7: Urban Development and Agricultural Lands contribute to areas of Low Urban Tree Canopy

Canopy Change

This urban tree canopy assessment processed UTC data for Denton's ETJ as well as within the city limits, totaling 170,938 acres. Two different years were mapped in order to perform a change assessment: 2008 and 2014. Similar methods were used for 2008 and 2014. However, data from 2014 were produced using high resolution LiDAR data collected in 2015. Using LiDAR data in conjunction with aerial imagery can help to increase overall mapping accuracy. Canopy cover in 2008 equaled 34,810 acres, comprising 20.4% of the city and ETJ. Canopy cover in 2014, totaled 38,561 acres, comprising 22.6% of the city and ETJ. This means that the UTC in the city and ETJ increased by 3,751 acres or 2.2% in the six years between 2008 and 2014.

Table 3: Urban Tree Canopy Assessment Change Results: Years 2008 – 2014

Total Acres	UTC Area 2008 (acres)	UTC 2008 %	UTC Area 2014 (acres)	UTC 2014 %	Percent Change 2008-2014
170,938	34,810	20.4%	38,561	22.6%	2.2%

Despite the overall gain in canopy cover, there were many areas within the city and ETJ that experienced loss in canopy cover. Many of these areas appear drought-stricken or are the result of clear-cutting for new development (Figures 15 and 16)

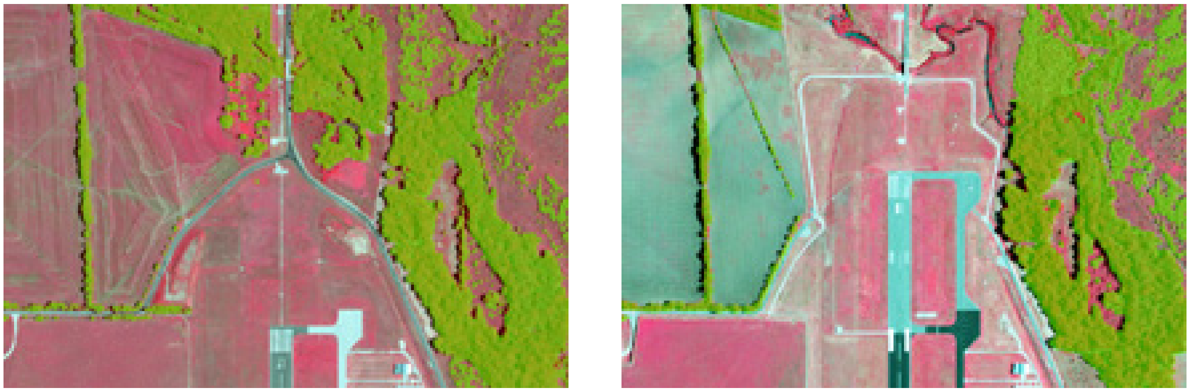


Figure 8: Extension of the runway on the north side of the Denton Enterprise Airport led to major tree loss and reduced canopy cover from 2008 (left) to 2014 (right)

Figure 9: A prolonged drought period in much of Texas during the early 2010's caused the water level at Lake Ray Roberts to drop in 2014 (right). As a result, many trees experienced natural thinning and a decrease in canopy cover

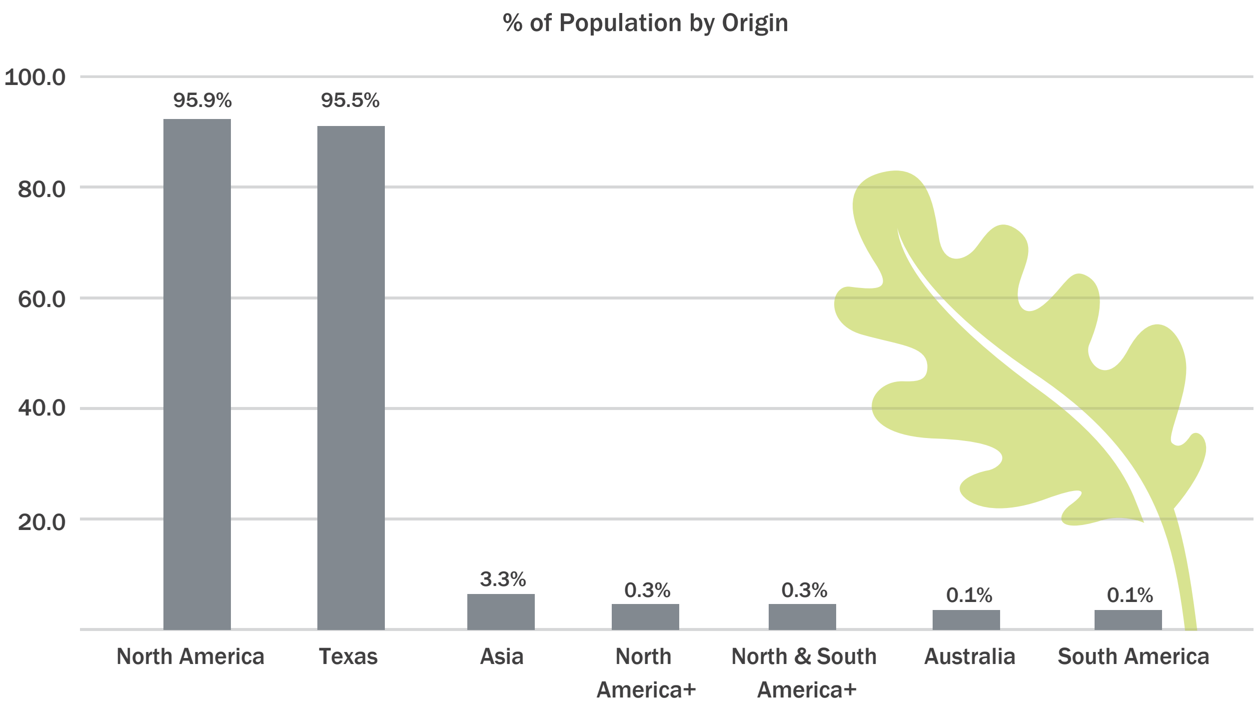
In other areas of the city, recent growth and development of previously agricultural land led to increased canopy cover. The area around the CH Collins Athletic Complex was first developed in 2004. Figure 14 shows the growth of recently planted trees in the past six years as well as the addition of new trees at the educational facilities to the west.

Figure 10: Growth and development of undeveloped lands led to increased canopy cover from 2008 (left) and 2014 (right)

It is important to note that there were slight inaccuracies and differentiations in data quality between the 2008 and the 2014 canopy mapping. While accuracy assessments for both years of mapping revealed over 97% accuracy for canopy cover, it is difficult to accurately compare data produced with differing data sources. The 2008 canopy mapping lacked the extra detail provided by the LiDAR elevation data. Canopy mapping in 2014 showed a slight overestimation due to subtle shifts between the 2014 NAIP aerial imagery and the 2015 LiDAR data. In future studies, it is recommended that data be derived from sources collected concurrently.

Figure 11: Maturation of newly planted trees leads to increased canopy cover in between 2008 (left) and 2014 (right)

Appendix III. Percentage of Live Trees in Denton by Species Origin



The plus sign (+) indicates the plant is native to another continent other than the ones listed in the grouping

Appendix IV. Invasive Species of the Denton Urban Forest

The following inventoried tree species were listed as invasive on the Texas invasive species list (Watershed Protection Development Review):

Species Name	Number of trees	% Tree Number	Leaf Area (mi^2)	% Leaf Area
Chinaberry	10,766	0.31	0.35	0.36
Chinese pistache	8,858	0.26	0.33	0.34
Tallow tree	3,589	0.10	0.04	0.04
Total	23,212	0.67	0.72	0.73

[a]Species are determined to be invasive if they are listed on the state's invasive species list

Appendix V. Relative Tree Effects

The urban forest in Denton provides benefits that include carbon storage and sequestration, and air pollutant removal. To estimate the relative value of these benefits, tree benefits were compared to estimates of average municipal carbon emissions, average passenger automobile emissions, and average household emissions. See Appendix I for methodology.

Carbon storage is equivalent to:
- Amount of carbon emitted in Denton in 279 days
- Annual carbon (C) emissions from 324,000 automobiles
- Annual C emissions from 133,000 single-family houses

Carbon monoxide removal is equivalent to:
- Annual carbon monoxide emissions from 52 automobiles
- Annual carbon monoxide emissions from 142 single-family houses

Nitrogen dioxide removal is equivalent to:
- Annual nitrogen dioxide emissions from 4,180 automobiles
- Annual nitrogen dioxide emissions from 1,880 single-family houses

Sulfur dioxide removal is equivalent to:
- Annual sulfur dioxide emissions from 17,900 automobiles
- Annual sulfur dioxide emissions from 47 single-family houses

Annual carbon sequestration is equivalent to:
- Amount of carbon emitted in Denton in 14 days
- Annual C emissions from 16,300 automobiles
- Annual C emissions from 6,700 single-family houses

Appendix VI. General Recommendations for Air Quality Improvement

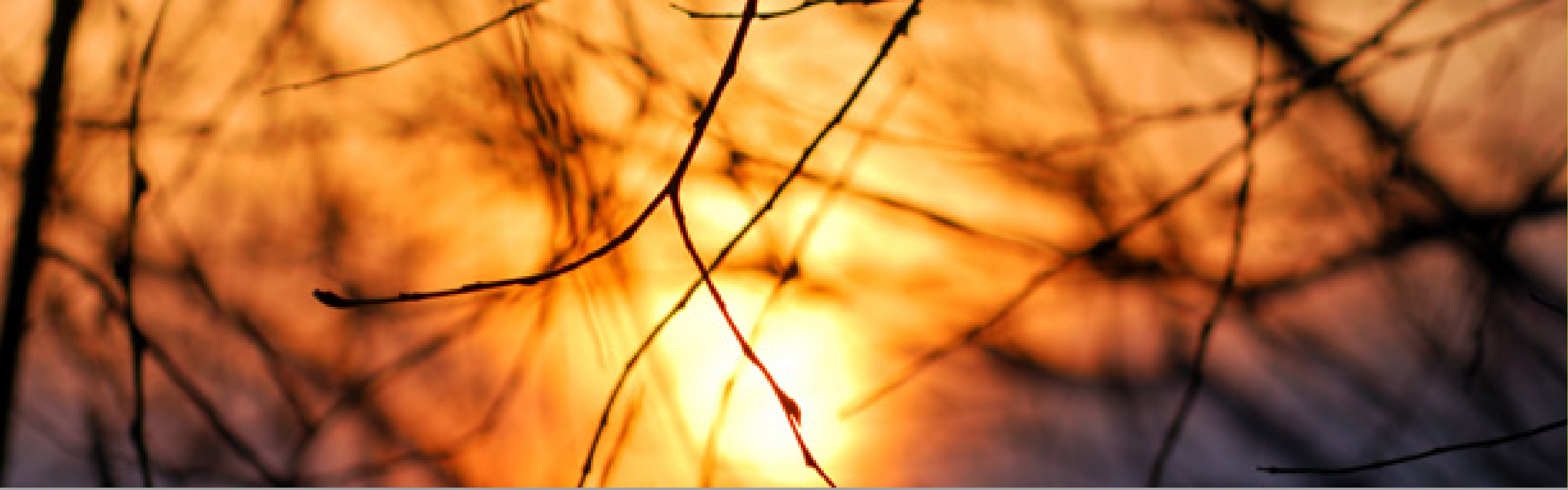
Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmosphere environment. Four main ways that urban trees affect air quality are (Nowak 1995):

- Temperature reduction and other microclimate effects
- Removal of air pollutants
- Emission of volatile organic compounds (VOC) and tree maintenance emissions
- Energy effects on buildings

The cumulative and interactive effects of trees on climate, pollution removal, and VOC and power plant emissions determine the impact of trees on air pollution. Cumulative studies involving urban tree impacts on ozone have revealed that increased urban canopy cover, particularly with low VOC emitting species, leads to reduced ozone concentrations in cities (Nowak 2000). Local urban management decisions also can help improve air quality.

Urban forest management strategies to help improve air quality include (Nowak 2000):

Strategy	Result
Increase the number of healthy trees	Increase pollution removal
Sustain existing tree cover	Maintain pollution removal levels
Maximize use of low VOC-emitting trees	Reduces ozone and carbon monoxide formation
Sustain large, healthy trees	Large trees have greatest per-tree effects
Use long-lived trees	Reduce long-term pollutant emissions from planting and removal
Use low maintenance trees	Reduce pollutants emissions from maintenance activities
Reduce fossil fuel use in maintaining vegetation	Reduce pollutant emissions
Plant trees in energy conserving locations	Reduce pollutant emissions from power plants
Plant trees to shade parked cars	Reduce vehicular VOC emissions
Supply ample water to vegetation	Enhance pollution removal and temperature reduction
Plant trees in polluted or heavily populated areas	Maximizes tree air quality benefits
Avoid pollutant-sensitive species	Improve tree health
Utilize evergreen trees for particulate matter	Year-round removal of particles



Appendix VII. Trees and Oxygen Production

Oxygen production is one of the most commonly cited benefits of urban trees. The net annual oxygen production of a tree is directly related to the amount of carbon sequestered by the tree, which is tied to the accumulation of tree biomass.

Trees in the City of Denton are estimated to produce 52,700 tons of oxygen per year. However, this tree benefit is relatively insignificant because of the large and relatively stable amount of oxygen in the atmosphere and extensive production by aquatic systems. Our atmosphere has an enormous reserve of oxygen. If all fossil fuel reserves, all trees, and all organic matter in soils were burned, atmospheric oxygen would only drop a few percent.

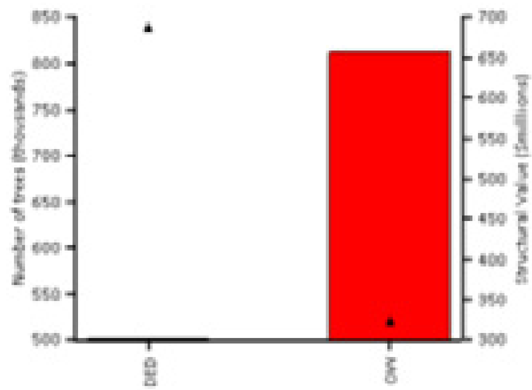
Species	Oxygen (tons)	Net Carbon Sequestration (tons/yr)	Number of Trees	Leaf Area (mi^2)
Post oak	10,309.84	3,866.19	301,937	10.17
Sugarberry	10,200.17	3,825.06	735,436	22.39
Cedar elm	6158.70	2309.51	633855	14.03
Pecan	4156.28	1558.61	34571	3.37
Shumard oak	3222.04	1208.26	113952	3.66
American elm	3055.41	1145.78	203675	8.99
Honey locust	2368.63	888.24	279314	2.07
Honey mesquite	2071.23	776.71	258242	3.68
Green ash	1996.79	748.8	151966	7.38
Boxelder	1513.83	567.69	50425	3.62
Live oak	1142.38	428.39	23665	1.21
Eastern cottonwood	1134.43	425.41	11865	2.82
Eastern red cedar	818.78	307.04	157027	4.31
Blackjack oak	631.59	236.85	45262	0.45
Loblolly pine	568.83	213.31	22200	1.87
Callery pear	495.51	185.82	28291	0.68
Red mulberry	432.05	162.02	19479	0.60
Black willow	429.28	160.98	11865	0.40
Crepe myrtle	363.54	136.33	41854	0.35
Black oak	349.92	131.22	3589	0.02

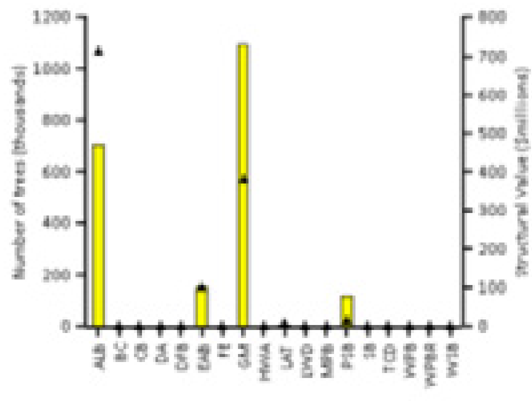
Appendix VIII. Potential Risk of Pests

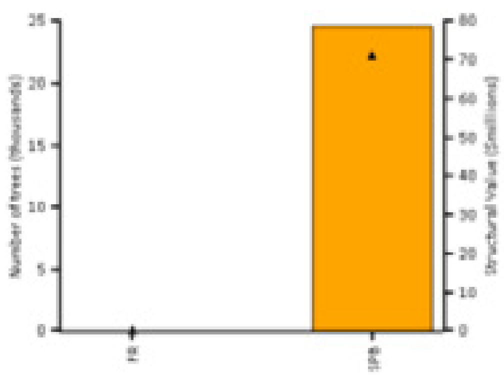
Thirty-six insects and diseases were analyzed to quantify their potential impact on the urban forest. As each insect/disease is likely to attack different host tree species, the implications for Denton will vary. The number of trees at risk reflects only the known host species that are likely to experience mortality.

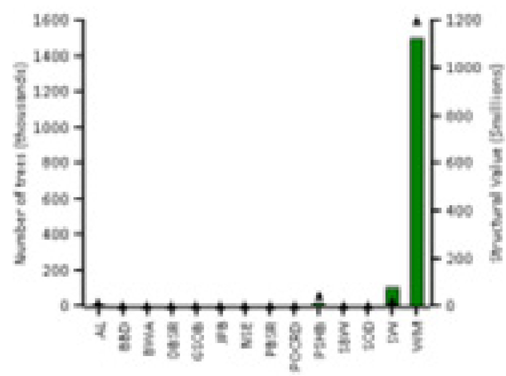
Code	Scientific Name	Common Name	Trees at Risk (#)	Value ($ millions)
AL	*Phyllocnistis populiella*	Aspen Leafminer	11,865	$4
ALB	*Anoplophora glabripennis*	Asian Longhorned Beetle	1,069,281	$469
DED	*Ophiostoma novo-ulmi*	Dutch Elm Disease	837,530	$301
EAB	*Agrilus planipennis*	Emerald Ash Borer	151,966	$103
GM	*Lymantria dispar*	Gypsy Moth	571,477	$728
LAT	*Choristoneura conflictana*	Large Aspen Tortrix	11,865	$4
OW	*Ceratocystis fagacearum*	Oak Wilt	519,817	$657
PSB	*Tomicus piniperda*	Pine Shoot Beetle	22,200	$79
PSHB	*Euwallacea* sp.	Polyphagous Shot Hole Borer	50,425	$12
SPB	*Dendroctonus frontalis*	Southern Pine Beetle	22,200	$79
SW	*Sirex noctilio*	Sirex Wood Wasp	22,200	$79
WM	*Operophtera brumata*	Winter Moth	1,591,139	$1,126

In the following graph, the pests are color coded according to the county's proximity to the pest occurrence in the United States. Red indicates that the pest is within the county; orange indicates that the pest is within 250 miles of the county; yellow indicates that the pest is within 750 miles of the county; and green indicates that the pest is outside of these ranges.









Note: points --- Number of trees, bars --- Structural value

Based on the host tree species for each pest and the current range of the pest (Forest Health Technology Enterprise Team 2014), it is possible to determine what the risk is that each tree species in the urban forest could be attacked by an insect or disease.

Spp. Risk	Risk Weight	Species Name	AL	ALB	BBD	BC	BWA	CB	DA	DBSR	DED	DFB	EAB	FE	FR	GM	GSOB	HWA	JPB	LAT	LWD	MPB	NSE	OW	PBSR	POCRD	PSB	PSHB	SB	SBW	SOD	SPB	SW	TCD	WM	WPB	WPBR	WSB
Yellow	8	Black willow	Green	Yellow												Yellow				Yellow															Green			
Red	7	Cedar elm		Yellow							Red																								Green			
Red	7	Post oak														Yellow								Red											Green			
Red	7	American elm		Yellow							Red																								Green			
Red	7	Shumard oak														Yellow								Red											Green			
Red	7	Blackjack oak														Yellow								Red											Green			
Red	7	Bur oak														Yellow								Red											Green			
Red	7	Live oak														Yellow								Red											Green			
Red	7	White oak														Yellow								Red											Green			
Red	7	Black oak														Yellow								Red											Green			
Orange	6	Loblolly pine																									Yellow					Orange	Green					
Yellow	5	Green ash		Yellow									Yellow																						Green			
Yellow	4	Boxelder		Yellow																								Green							Green			
Yellow	3	Eastern cottonwood		Yellow																															Green			
Yellow	3	Silver maple		Yellow																															Green			
Yellow	2	Callery pear														Yellow																						
Yellow	2	Sweetgum														Yellow																						
Yellow	2	apple spp														Yellow																						
Green	1	Peach																																	Green			

Note: Species that are not listed in the matrix are not known to be hosts to any of the pests analyzed.

Species Risk:

- Red indicates that tree species is at risk to at least one pest within county
- Orange indicates that tree species has no risk to pests in county, but has a risk to at least one pest within 250 miles from the county
- Yellow indicates that tree species has no risk to pests within 250 miles of county, but has a risk to at least one pest that is 250 to 750 miles from the county
- Green indicates that tree species has no risk to pests within 750 miles of county, but has a risk to at least one pest that is greater than 750 miles from the county

Risk Weight:

Numerical scoring system based on sum of points assigned to pest risks for species. Each pest that could attack tree species is scored as 4 points if red, 3 points if orange, 2 points if yellow and 1 point if green.

Pest Color Codes:

- Red indicates pest is within county
- Orange indicates pest is within 250 miles of county
- Yellow indicates pest is within 750 miles of county
- Green indicates pest is outside of these ranges

Appendix IX. Top Ten Most Important Species by Percent Population & Leaf Area

Species Name	Percent Population	Percent Leaf Area	IV
Sugarberry	21.2	22.8	44.0
Cedar elm	17.5	14.0	31.5
Post oak	8.7	10.4	19.1
American elm	5.9	9.1	15.0
Green ash	4.4	7.5	11.9
Honey mesquite	7.5	3.7	11.2
Honey locust	8.1	2.1	10.2
Eastern red cedar	4.5	4.4	8.9
Shumard oak	3.3	3.7	7.0
Boxelder	1.5	3.7	5.1

(Importance values (IV) are calculated as the sum of relative leaf area and relative composition)

Appendix X. Comparison of Urban Forests

A common question asked is, "How does this city compare to other cities?" Although comparison among cities should be made with caution as there are many attributes of a city that affect urban forest structure and functions, summary data are provided from other cities analyzed using the i-Tree Eco model.

I. City totals for trees

City	%Tree Cover	Number of trees	CarbonStorage (tons)	Carbon Sequestration (tons/yr)	Pollution removal (tons/yr)
Atlanta, GA	36.8	9,415,000	1,344,818	46,407	1,662
Morgantown, WV	35.9	661,000	93,696	2,976	66
Freehold, NJ	34.4	48,000	19,842	551	21
Denton, TX	30.0	3,463,000	458,000	23,000	405
Woodbridge, NJ	29.5	986,000	159,835	5,512	211
Washington, DC	28.6	1,928,000	522,495	16,094	418
Moorestown, NJ	28.0	583,000	116,845	3,748	118
Minneapolis, MN	26.5	979,000	250,224	8,929	305
Syracuse, NY	23.1	876,000	173,063	5,401	109
Boston, MA	22.3	1,183,000	318,568	10,472	284
New York, NY	21.0	5,212,000	1,351,432	42,329	1,677
Baltimore, MD	21.0	2,627,000	596,350	16,094	430
Toronto, Canada	20.5	7,542,000	992,079	40,345	1,213
Philadelphia, PA	15.7	2,113,000	530,211	16,094	577
Jersey City, NJ	11.5	136,000	20,944	882	41
Calgary, Canada	7.2	11,889,000	445,333	21,385	326

Appendix X. Comparison of Urban Forests

II. Per acre values of tree effects

City	No. of Trees/acre	Carbon Storage (tons/acre)	Carbon Sequestration (tons/yr/acre)	Pollution Removal (tons/yr/acre)
Morgantown, WV	119.7	17.0	0.27	11.9
Atlanta, GA	111.6	15.9	0.28	19.7
Calgary, Canada	66.7	2.5	0.06	1.8
Woodbridge, NJ	66.5	10.8	0.19	14.2
Moorestown, NJ	62.0	12.5	0.2	12.6
Syracuse, NY	54.5	10.8	0.17	6.8
Baltimore, MD	50.8	10.43	0.14	7.5
Washington, DC	49.0	13.3	0.21	10.6
Toronto, Canada	48.3	6.4	0.13	7.8
Denton, TX	46.5	6.1	0.31	0.01
Freehold, NJ	38.5	16.0	0.22	16.8
Boston, MA	33.5	9.0	0.15	8.0
New York, NY	26.4	6.8	0.11	8.5
Minneapolis, MN	26.2	6.7	0.12	8.2
Philadelphia, PA	25.0	6.3	0.09	6.8


Preservation
Tree