CHARACTERIZATION OF TREE CANOPY IN ARLINGTON, TX FROM 1942 TO 2019

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Executive Summary

The urban forest is vital to a vibrant, healthy community; as The American Dream City, Arlington has long enjoyed a substantial urban tree canopy as the city continued to grow. Previous generations of residents, home builders, city planners, and remarkable leadership from mayors and city council members have led Arlington to where it is today with a strong and consistent tree canopy. The purpose of this study was to quantify the long-term changes in Arlington's tree canopy, and then to determine driving factors behind our current urban forest assets. This study strives to evaluate the effectiveness of Arlington's current and previous ordinances regarding tree protection, preservation, and planting. We also provide findings on drivers of change in tree canopy (both canopy loss and canopy gain) and "ownership" of the urban forest. The unique physical location of Arlington on the divide of two ecotypes is necessary to consider in regard to tree canopy and is discussed in detail. In regard to improving tree canopy throughout Arlington and by council districts we include recommendations and restrictions posed to the city government in accomplishing potential goals.

The principal finding of this study is that Arlington experienced a significant increase in tree canopy from the mid-20th century to present day with possibly the highest overall tree cover attained in the study periods from 1997 to 2011. The study looked at tree canopy over the entire city during nine distinct points in time (1942, 1984, 1997, 2001, 2005, 2007, 2011, 2015, and 2019). Analysis using NcNemar's test found the tree canopy never experienced a statistically significant decrease at the 95% confidence level. Only once during the eight time periods studied, from 2011 to 2015, did tree canopy significantly decrease at the 90% confidence level. These years coincide with a period of severe drought (see Appendix A for further detail). Although there is no way to positively determine if drought caused canopy decrease, this event could cause tree removal due to mortality and also reduce growth of existing trees or prevent new trees from establishing. In contrast, the analysis found a statistically significant increase at the 95% confidence level during two of the time periods, 1942 to 1984 and 1984 to 1997, both of which coincided with extensive development of Arlington. From 1942 to 2019 canopy gain outpaced canopy loss and tree cover increased by approximately 25%, with 22.5% tree canopy in 2019 compared to 17.9% in 1942.

We evaluated through all reasonable means to best establish the reason for tree canopy change at a sample point year over year. For example, 24 of 1,000 sample points experienced a canopy change (12 gaining canopy and 12 losing canopy) from 2015 to 2019. Tree canopy experienced no net change during this time period as canopy lost matched canopy gained; however, the changes at each individual point depict the underlying interactions in the urban forest. Canopy gain and loss are driven by activities that may not always be recognized; this study provides principal drivers of canopy change that should be the focus of policy and outreach regarding improving the urban forest.

The single largest driver of canopy increase was growth of individual trees, which emphasizes the importance of healthy, young trees that owners allow to grow. Canopy increase related to existing trees or forests make up nearly 60% of all tree canopy gain, as compared to 40% of canopy gain due to tree planting. Although 40% of canopy gain was attributed directly to tree planting, nearly 75% of this planting occurred as a result of development (which is also a driver of canopy loss). Individual tree plantings such as those undertaken by homeowners or the city (i.e. not related to development) was very low, only contributing to about 7% of all canopy increases. This is partly due to newly planted trees covering a small area, often less than 10 square feet, while a 20-year-old tree typically covers an area 30 times in size. Tree planting is necessary to maintain and expand the urban forest canopy but is not a major contribution unless trees are properly cared for and permitted to grow without unnecessary removal as discussed next.

We found canopy loss was most often caused by development (66% of the time). Owing to the difficulty of determining exact cause of tree removal, we found the next largest driver of canopy loss to be tree removal for unknown reason. Tree mortality did not appear to be a common cause for tree removal, although there is little way to determine with certainty for the entire study period. Although we found canopy loss was outpaced by canopy gain during the complete study period, loss and gain during the past two decades have remained similar ($p=0.35$). The past two decades have also seen a shift in cause of tree removals, with individual tree removal becoming a greater impact than development. Using Google StreetView and other sources we evaluated points that experienced canopy loss from 2015 to 2019. During this time 12 points lost canopy cover. We found 3 of these points were not due to removal, but tree pruning that reduced canopy width. The other 9 points lost canopy due to tree removal: 3 removed due to development or construction related conflict, 3 removed due to the tree dying or being in poor health, and 3 were removed entirely on owner preference. This further emphasizes the need to educate and encourage tree owners to keep trees on their property.

Arlington lies within two distinct ecoregions with about two-thirds of land falling in the Cross Timbers region and the remaining one-third in the Blackland Prairie region. The Cross Timbers is generally characterized by a mix of oak forest and grasslands over sandy loam and clay soils. The Blackland Prairies to the east are mainly dark, heavy, clay soils with tallgrass prairie and were characteristically devoid of trees. The Cross Timbers ecoregion consistently had higher tree canopy over the complete study period than the Blackland Prairies (Figure 15), but the Blackland Prairie region experienced significant tree canopy gains from 1942 to 1997. Most of Arlington’s city-wide tree canopy growth occurred in the Blackland Prairie, as canopy cover in the Cross Timbers remained similar from 1942 to 2019.

We evaluated the current canopy and plantable space to determine potential canopy, which in essence the maximum amount of tree cover that could currently be experienced within the City of Arlington. Potential canopy as of 2019 is approximately 41% to 45% of Arlington, including water bodies. As we discuss in the sections below, this potential may not be truly feasible due to planting limitations not visible to us. We also determined the time needed to meet a reasonable canopy goal of 35% may be as much as 100 years. For this reason we suggest a preliminary tree canopy goal of 25%. The past two decades indicate tree canopy is remaining constant or slightly decreasing, therefore any effort to increase tree canopy in Arlington will require drastic alterations to city ordinance and policy.

The aim of increasing tree canopy must then consider the ownership of plantable space that can contribute to the overall urban forest. Table 4 on page 30 provides a forthright summary on ownership of the current canopy and plantable space which would combine to create potential canopy. Residential properties contain the most significant portion of the potential tree canopy city-wide, followed by commercial properties. In contrast, city-maintained areas available for planting are limited would only allow for Arlington's tree canopy to reach 24.7%. As we discuss in this report, increasing tree canopy will be dependent on multiple stakeholders and cannot be accomplished via city tree planting alone. Residential properties would receive far greater benefit from increased tree cover and homeowners are most equipped to provide care necessary to establish new trees, such as watering and inspection. One such example is the great potential for increasing tree canopy over buildings, which we found to only be 8% currently. Initial estimates based on potential canopy width and building footprints show a potential for as much as 30% tree cover over building surface area, a 375% increase. Such an increase is conservatively projected to save homeowners $7.6 million in electricity use city-wide. Current city staff would not be able to undertake the massive increase in tree planting and maintenance needed for city-wide tree canopy goals.

In conclusion, there is potential for significantly higher tree canopy in Arlington. The tree canopy is a measurable, predictable representative of the many benefits provided by trees that we feel will generate support for efforts to improve the urban forest. This study has shown that Arlington is capable of significantly increasing the size and extent of its urban forest. Arlington's leaders have created ordinances that are working to protect trees from development. City staff plant and provide citizens with thousands of trees each year that are helping to sustain our current forest. These efforts provide a better standard of living for our residents and make Arlington a great place to live, work, and play. However, we found that the tree canopy can be increased in Arlington and we hope that our citizens would be willing to undertake efforts toward this potential canopy not only through planting trees but also by conserving our existing urban forest.

Introduction

An urban forest includes a city's planted and natural trees, sustainably managed to provide present and future residents with a range of benefits (Clark et al. 1997). Furthermore, tree canopy, or tree cover, is the blanket of leaves and branches obscuring the ground from an aerial view (Landry et al. 2018). Measuring tree canopy in a city provides an estimated status of the urban forest to inform management decisions that promote health of residents and environment. Although forests are declining in some areas, the host of benefits they provide warrant their proper management.

Urban forests face many threats. Pests and diseases cause massive damages (City of Arlington 2009) and may be exacerbated by climate change (Tubby & Webber 2010). Urbanization creates significant changes in forest status compared to presettlement conditions, including aspects such as size, age structure, density, and species diversity. Altering these factors may have negative implications for forest health (McBride & Jacobs 1986). Both natural and manmade threats impact urban trees. If threats are left unmitigated, a forest declines in health and benefits to the surrounding community.

A properly managed urban forest provides many benefits to the population. Trees provide ecosystem services. By temporarily storing runoff and allowing for permeable areas, trees retain stormwater and help manage large volumes of runoff (Landry et al. 2018). Nationwide, urban forests store 700 million and sequester 22.8 million tonnes of carbon per year (Nowak & Crane 2002), which benefits the climate by decreasing carbon dioxide. In addition, trees can lower energy costs by insulating and casting shade on structures, thereby reducing the need for air conditioning (Pandit & Laband 2010). Trees help mitigate pollution by filtering particles from the air, which improves human and environmental health (Chen et al. 2017).

In addition to delivering ecosystem services, urban forests also benefit property values and human health. A 2010 study showed that increasing tree cover near homes increases sale prices (Sander et al. 2010). Urban trees can decrease the occurrence of childhood asthma (Lovasi et al. 2008) and influence hospital patient recovery from surgery (Ulrich 1984). Views of nature can increase worker satisfaction and wellness (Kaplan 1993) and the presence of high canopy trees may reduce crime in cities (Kuo & Sullivan 2001).

A 2009 study of Arlington's urban forest used a model called i-Tree Eco to quantify the ecosystem services of air pollution removal, carbon storage, and energy savings – worth $2.94 million, $8.54 million, and $2.8 million per year, respectively. Arlington's urban forest was estimated to provide a total of $2.75 billion in structural values. Satellite imagery and field data were also employed to determine a 22.4% tree cover in the city limits (City of Arlington 2009). This study provided valuable statistics on the monetary benefit and number of trees in Arlington, but finer scale information on canopy cover over time can be used to better inform policy and management of the urban forest.

The present study seeks to produce estimates of canopy cover in Arlington over the last two decades and explore possible correlations with abiotic and biotic factors that may cause changes in tree cover. Future studies can use this established protocol and sample points to make comparisons over time as new imagery becomes available. These data will ultimately be used to improve current policies and management practices, possibly establish canopy cover targets, as well as to increase knowledge and support of urban forests through public outreach. The economic, environmental, and social values of trees warrant their protection and management for the benefit of future generations.

Policy Background

To help inform City policy, this section provides a summary of past and present ordinances regarding trees in the City of Arlington. For more complete information, please consult the online City Code of Ordinances (City of Arlington 2019).

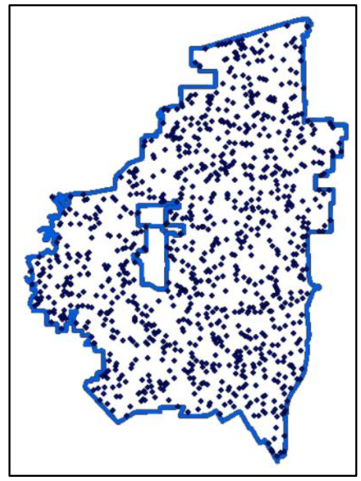
Significant changes to ordinances came about in 1994, 1997, and 2005. Prior to 1994, no ordinance was in effect. The tree replacement fund was established in 1994 to help mitigate the loss of trees. Updates in 1997 set the standards for tree loss quantification in non-residential development. In 2005, preservation standards for residential lots were added and the mitigation standard was changed from 8 to 6 caliper inches. Other minor changes have occurred, but the current City Code of Ordinances has remained largely unchanged regarding tree preservation and mitigation since 2005.

Currently, residential developments over 1.0 acre in size are required to submit a Tree Preservation Plan to protect at least 35% of the existing caliper inches for protected tree species and sizes. New trees may be planted to achieve compliance if the minimum 35% preservation requirement is not met. For non-residential, multi-family, and mixed-use lots, tree preservation is not mandatory. However, tree mitigation is required in the form of a Tree Inventory and Mitigation Plan to account for trees of a certain size, species, and location on the property. New trees may be planted or payment to the City's Reforestation Fund can achieve mitigation.

Methods

This study used point interpretation of aerial imagery to investigate tree canopy changes over time. Random points were overlaid on historical aerial imagery, and tree cover and ground cover type at the point were classified. For a complete representation of categories utilized in the study please see Appendix B. A large sample size of one thousand sample points was used to limit error.

A geographic information system (ArcGIS v. 10.6.1; ESRI, Redlands, CA, United States) was used to generate 1000 random points with the Create Random Points tool within the current 99.42 square miles of the city. These same points will be analyzed every four to five years to continue estimating changes in canopy over time. The years 1942, 1984, 1997, 2001, 2005, 2007, 2011, 2015, and 2019 were selected. We wanted to investigate possible changes in canopy cover due to significant revisions of city ordinances in 1994, 1997, and 2005. The earliest imagery available is from 1942, the most recent from 2019.



Tree classification categories included Urban Tree, Forest Tree, or Non-Tree. Urban Trees were present in developed areas, including neighborhoods and open park space. Forest Trees were in undeveloped areas like heavily wooded forests and natural park areas. A forested area was defined by being not regularly mowed and greater than 100 feet wide (assessed using the Measure tool in ArcGIS).

Ground cover types included seven categories: Grass, Landscaping, Other Pervious, Pavement, Structure, Other Impervious, and Water. The Grass category includes fields mowed regularly to occasionally, with any tree saplings present less than five feet in height. Landscaping included maintained non-grass areas with mulch, flowers, or small bushes. Other Pervious designated areas allowed water infiltration to the ground but did not fit the first two categories. Pavement was any paved surface that does not allow heavy water infiltration, such as roads, sidewalks, and parking lots. Structure included permanent structures that blocked water infiltration. Other Impervious served as a catch all for any surface that blocked water infiltration and not considered pavement or structure. The Water category included ponds, lakes, canals, large streams, or other semi-natural bodies of water and excluded swimming pools, stormwater channels, or small creeks where the water was not immediately visible.

Some pre-existing data sets were used in the analysis. GIS data from the North Central Texas Council of Governments included layers outlining water bodies, roads, sidewalks, parking lots, and buildings, as well as aerial imagery from 2001-2019. The Texas Department of Transportation provided 1984 imagery, and the U.S. Department of Agriculture provided 1942 imagery. Locations of paved storm channels, land use designations, zoning, street names, and 1997 imagery came from the City of Arlington. A data layer published by the U.S. Forest Service provided estimates of canopy cover in ten percent blocks. These data sets were used to classify tree cover and ground cover type when possible to lessen the workload on the photointerpreter. Otherwise, the photointerpreter observed each of the one thousand points for every study year and determined the appropriate tree and ground cover classifications.

<u>Data Quality</u>

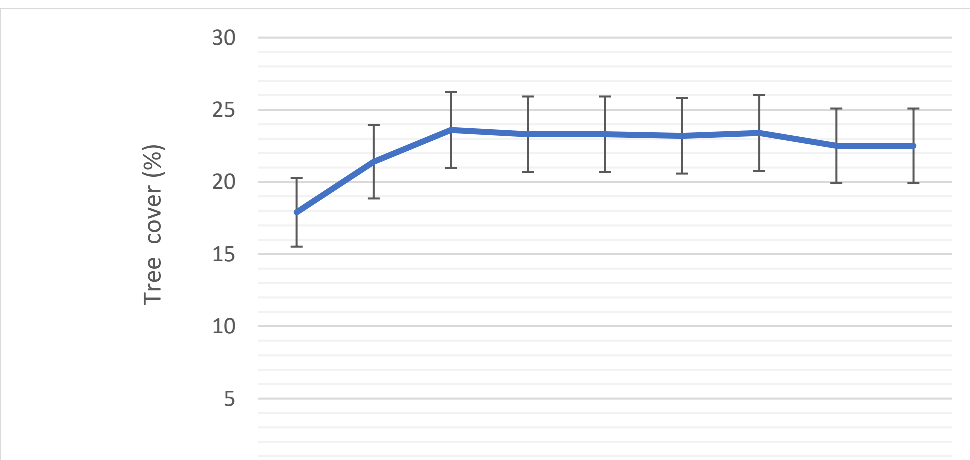
To ensure accuracy when classifying tree and ground cover types, a second interpreter reviewed 10% of the points with a goal of 95% agreement. The two interpreters only disagreed on 24 out of 900 points for a total accuracy of 97.3%. Specifically, for 2019 imagery, there was disagreement on 4 points out of 100 for an accuracy of 96%. Possible errors in point classification stem from image quality, geometric distortion, and relief displacement. The photointerpreter made note of points they were not confident in classifying due to low resolution, black and white imagery utilized for early study periods. In 1942, 0.5% of points had some uncertainty, and that level increased to 2.5% in 1984 as image quality was poor and heterogeneity in land use had increased.

Results and Discussion

<u>Tree Canopy</u>

Present day tree canopy cover in Arlington is 22.5% of all land within the municipal boundaries, including water bodies such as Lake Arlington. The land-locked cities of Pantego and Dalworthington Gardens are not included. The earliest available estimate during the study period was 17.9% cover in 1942. Canopy increased from its lowest in 1942 to its peak at 23.6% in 1997, leveled out from 1997 to 2011, and only slightly decreased from 2011 to 2015 until it stabilized present-day (Figure 1).

However, most of the change in canopy cover is not statistically significant. The only year which does statistically differ from other years based on 95% confidence intervals is 1942. All other years included in this study are statistically similar. It is important to note that confidence intervals of the lowest canopy cover (1942) do not overlap the confidence intervals of the highest canopy cover (1997), strongly indicating there was truly an increase in canopy between these time periods. This also lends to a conclusion that 1997 was the peak of tree canopy cover in Arlington, although statistically there is no difference from 1997 to 2019.



	1942	1984	1997	2001	2005	2007	2011	2015	2019
Tree cover (%)	17.9	21.4	23.6	23.3	23.3	23.2	23.4	22.5	22.5
95% CI (±)	2.38	2.54	2.63	2.62	2.62	2.62	2.62	2.59	2.59

Figure 1. Change in total tree canopy cover, 1942-2019, with error bars representing 95% confidence intervals.

McNemar's Test provides another metric to investigate significance of results (Lindren and McElrath 1969). The test is used to determine if there are significant net changes in classification over the years, since canopy cover can be both gained and lost within a time period (Nowak and Greenfield 2012). In other words, we are checking whether net change in total tree cover between years is significantly different from zero (p<0.05). Table 1 displays the results of McNemar's test with one degree of freedom. The only statistically significant net changes were from 1942-1984 and 1984-1997 (p-value 0.011 and 0.025, respectively). This result corresponds to the large increase in total canopy cover in the earlier years of the study. Changes between 2011 and 2015 were near the significance threshold with a p-value of 0.095, reflecting a slight but non-significant decrease in total canopy cover during that time. The lack of significant differences in other years shows the stabilization of percent canopy cover.

Table 1. Results of McNemar's Test on tree canopy cover change during the study time periods. Significant results shown in bold. Direction indicates increase (+), decrease (-), or no change (=).

	1942-1984	*1984-1997*	*1997-2001*	*2001-2005*	*2005-2007*	*2007-2011*	*2011-2015*	*2015-2019*
P-value	**0.011**	**0.025**	0.663	0.838	1.000	0.864	0.095	0.838
Direction	**+**	**+**	-	=	-	+	**-**	=

The earliest time periods (1942-1984 and 1984-1997) may appear to have a rapid increase in tree cover, but it is important to note that these are longer time periods than those used throughout the rest of the study. The significant increase in tree canopy during these time periods took decades to occur; conveying that tree canopy cannot be gained overnight or even during a 4-year study period. Figure 2 provides a representation of tree canopy change in actual years from 1942 to 2019. The most rapid increase in tree cover occurred from 1984 to 1997 at a rate of 1.7% of land area each decade. Any goal to increase tree canopy will need long-term commitment as even gaining canopy on 5% of land area in Arlington would realistically take at least 3 decades to occur. Outside of the first two time periods it appears Arlington's tree canopy has stagnated, experiencing some decreases over individual time periods but not significantly declining or increasing over the past two decades. We conducted McNemar's Test on tree canopy data from 1997 to 2019, as this period appears to have a slight decrease in tree canopy (23.6% and 22.5%, respectively). **The analysis, however, found this decrease is not statistically significant (p=0.35) which follows our initial conclusion that Arlington's tree canopy remains similar over the past two decades.**

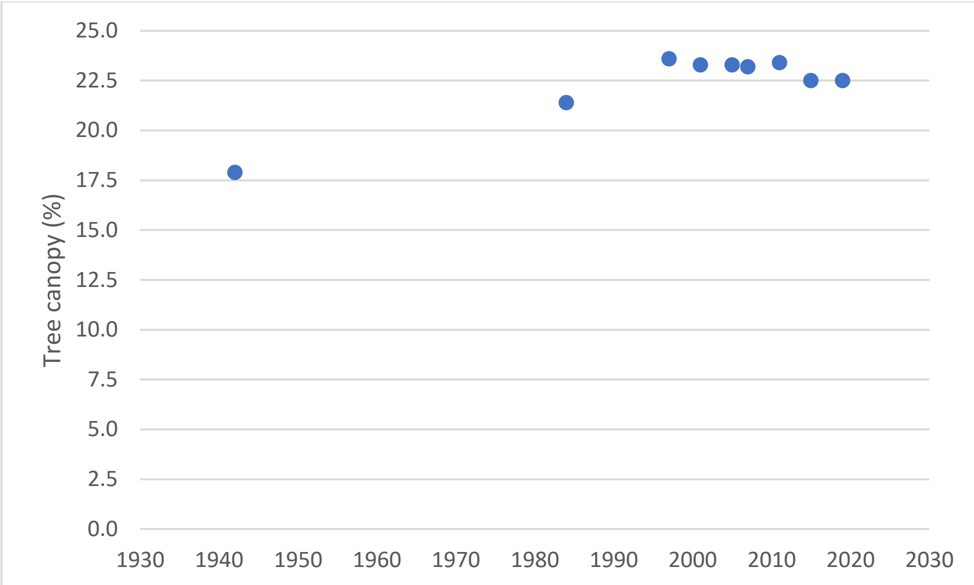


Figure 2. Tree canopy cover in Arlington represented on a yearly basis for the complete study period from 1942 to 2019. Although there is a significant increase in tree canopy from 1942 to 1997, the increase impacted only 0.1% of land area each year.

Forest and Urban Trees

Interesting patterns emerge when total canopy cover is divided into urban trees and forest trees. The distinction is based simply on the maintenance occurring in the area, with urban trees typically in mowed areas while forest area rarely experiences this type of disturbance. The stories of urban and forest canopy help explain the overall trend in total canopy cover. From 1942 to 1984, the canopy area increased by 20% (Table 2). Most of that growth was due to a 300% increase in urban canopy cover. The rest of the 1942-1984 change is explained by the accompanying decrease in forest cover of 35%. To some extent the decline in forest canopy is conversion of forest cover to urban cover as houses were constructed among existing trees. The result is a natural tree canopy that will not likely self-regenerate, therefore the trees would be considered urban trees and typically require replacement through planting. The maps shown in Figure 3 display points detected as tree canopy and a heat map of forest canopy specifically for the years 1942 and 2019. Tree canopy increased city-wide, particularly in south and east Arlington. The forest canopy became less prominent during this time due to development and changes to land management; however, forest canopy is somewhat more evenly dispersed across the city due in part to natural areas such as city parks.

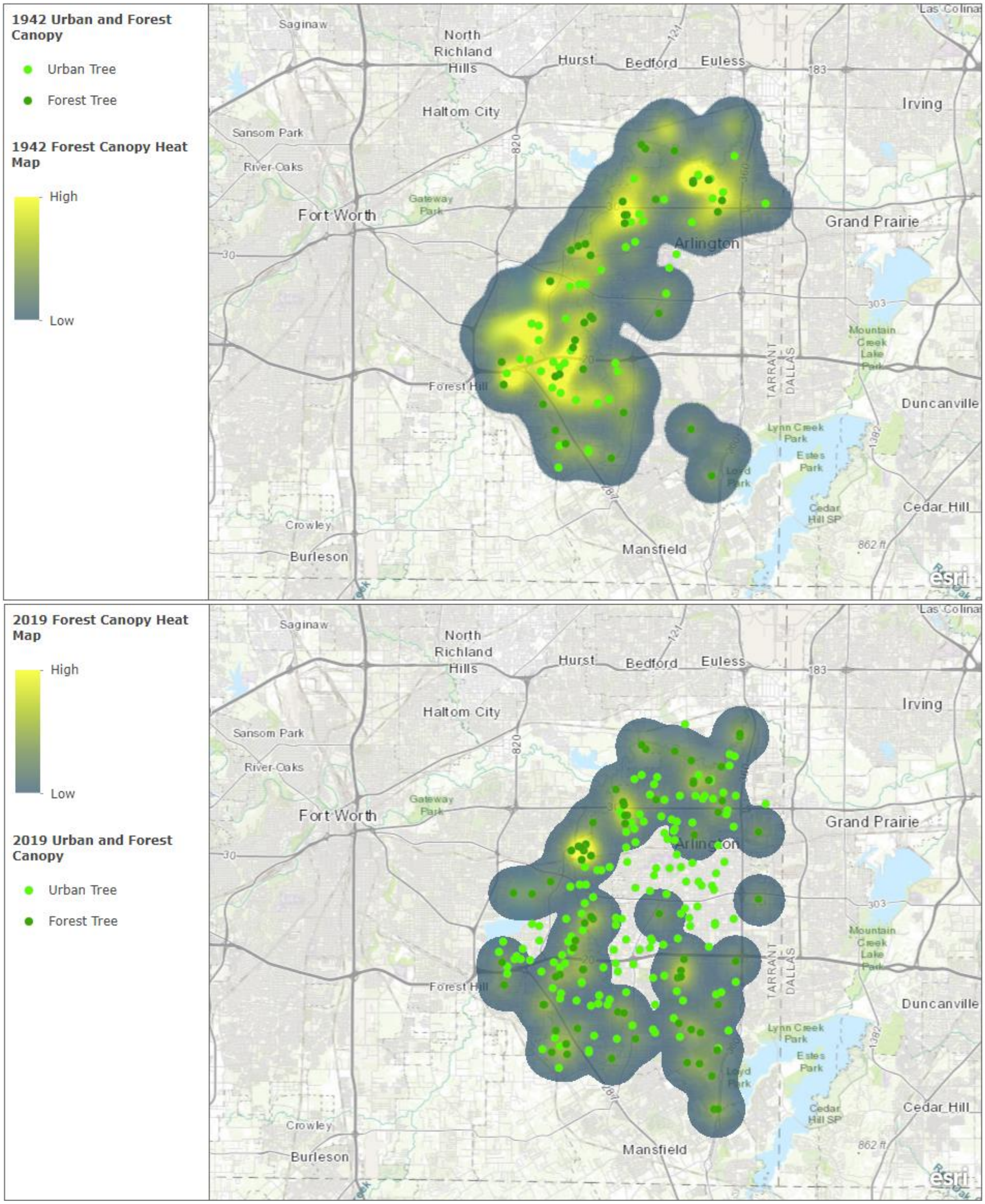


Figure 3. Maps depicting tree canopy in 1942 and 2019. Heat map shows approximate distribution of forest canopy type. Points indicate sample locations with urban or forest tree canopy.

Urban canopy cover drastically increased by 300% and forest cover fell by almost 35% from 1942 to 1984 (Table 2), reflecting the trend of less farmland and more urban sprawl. Urban trees became the dominant tree canopy in 1984, an incidence which has never reversed (Figure 4). From 1984 to 2011, urban canopy cover continued to rise, though the rate of increase slows considerably. Since 2011, urban canopy has decreased by about 6%. This supports the theory of drought as a cause of the slight decrease in tree canopy from 2011 to 2015 as urban trees appear to suffer greater losses which may be related to planting drought intolerant species in these areas. In contrast to urban canopy, forest canopy continued declining after 1984, but shows a slight growth since 2011. To summarize, forest canopy decreased and then stabilized, while urban cover increased and then slightly decreased. **Presently, the city is losing urban canopy rather than forest canopy. Although increasing all types of tree canopy is ideal, forest canopy is particularly beneficial for wildlife habitat and sustainability.**

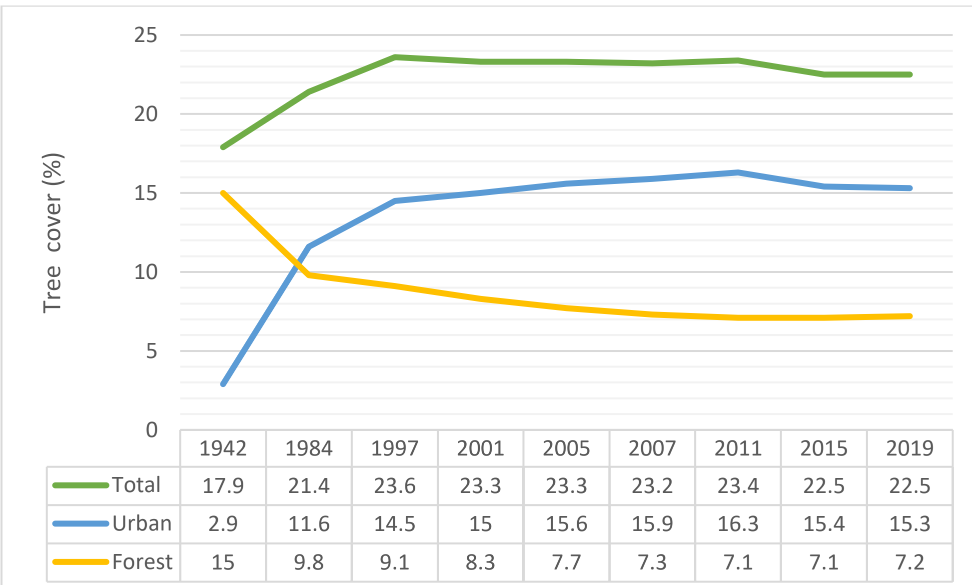


Figure 4. Change in tree canopy cover 1942-2019. Total tree canopy is divided into urban and forest tree types.

Table 2. Relative increase or decrease in tree canopy cover for each time period evaluated in the study. Rounded to the nearest percent.

	1942-1984	*1984-1997*	*1997-2001*	*2001-2005*	*2005-2007*	*2007-2011*	*2011-2015*	*2015-2019*
Total	20%	10%	-1%	0%	0%	1%	-3%	0%
Urban	300%	25%	3%	4%	2%	3%	-6%	-1%
Forest	-35%	-7%	-9%	-7%	-5%	-3%	0%	1%

Comparison to Other Cities

Studies characterizing tree canopy and ground cover are not readily available for most north Texas cities. Some national organizations, such as the US Forest Service or National Geographic, have provided estimates of tree canopy for major cities such as Dallas; unfortunately, estimates are not provided for neighboring cities. Computer modelling is commonly applied to determine tree canopy over large areas but is less reliable and is not directly comparable to point based analysis. Due to widely varying methodology, imagery sources and quality, seasonality, and the years included in different studies there is significant uncertainty as to the ability to compare tree cover across cities. One study by Nowak and Greenfield (2012) analyzed aerial imagery at sample points but may have differences in point placement or photoanalysis as results differed significantly from other studies. A study focusing on the Greater Houston Area which provided both canopy and ground level cover estimates found GHA tree canopy to be 13% in 2003 (Rose et al. 2003). A 2015 study found tree canopy within the City of Houston to be 18.4% (Nowak et al. 2017). These results greatly differ from the 27.4% tree canopy found by Nowak and Greenfield (2012).

Regardless of apparent uncertainty, we attempt comparisons based on the 95% confidence intervals of Arlington's 2019 tree cover. The following cities in the Nowak and Greenfield study had similar percent tree canopy (between 19.9 and 25.1): Detroit, Los Angeles, Miami, New Orleans, Spokane, Syracuse, and Tacoma. Of the 20 cities included in that study, only Chicago, Denver, and New York had lower tree canopy than Arlington while 10 cities had higher tree canopy. Austin, TX is reported to have 30.8% tree canopy as of 2014 (Nowak et al. 2016). The Texas Trees Foundation determined tree canopy covered 29% of Dallas utilizing computerized models (TTF). However, nearly half the canopy in Dallas was located in the Great Trinity Forest whereas all of the forest canopy in Arlington made up less than one-third of the total tree canopy. Other than Dallas, we found no formal tree canopy estimates for north Texas cities. Further research could include analysis of surrounding cities' tree canopy and tree protection ordinances. However, it is important to note that confounding factors (e.g. previous tree canopy, public opinion) likely influence development of ordinances such that comparison between cities is difficult even if long-term data is available. In conclusion, comparing tree canopy across cities provides little useful information unless the causes of canopy change are properly identified.

Ground Cover

Ground cover types were classified into three major categories (pervious, impervious, and water) for the 1997-2019 study periods. The earlier years were excluded due to image quality and time constraints. Some trends emerged in analysis (Figure 5). Grass covered areas and areas with other pervious ground cover declined from about 46% to 41% and 17% to 13%, respectively. Concurrently, paved areas and structures increased from about 22% to 26% and 11% to 15%, respectively. These changes reflect an increasingly urbanized city over the past two decades. Few changes were seen in water, landscaping, and other impervious categories.

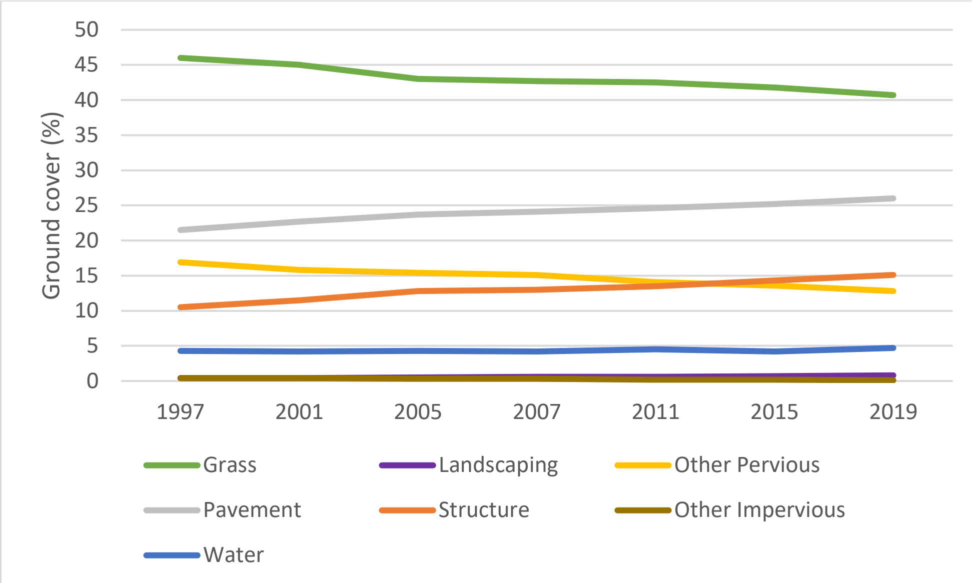


Figure 5. Changes in underlying ground cover from 1997 to 2019. In general, pervious cover types grass and other have decreased over the study period while pavement and structures have increased their footprint.

Present-day ground cover classes are shown in Figure 6. Grass makes up more than 40% of the city's ground cover, which is relatively high (Hedblom et al. 2017). Paved surfaces are the next largest category at 26%, followed by structures at 15%, and then other pervious areas at about 13%. For comparison, ground cover in the Greater Houston Area in 2003 was 35% grass, 32% paved, and 21% structures (Rose et al. 2003).

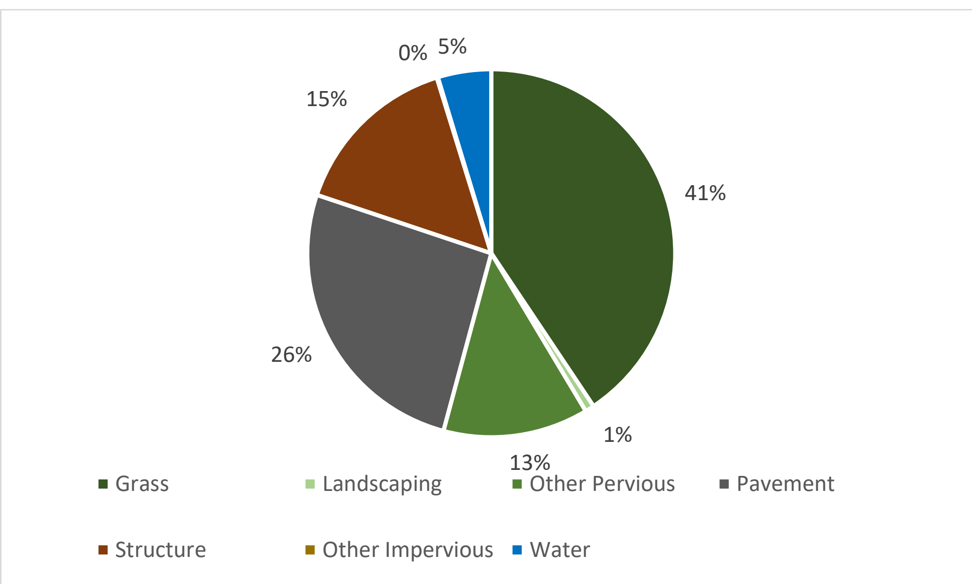


Figure 6. Arlington's ground cover in 2019. Over 40% of land in Arlington is covered with impermeable pavement or buildings.

Trees and Ground Cover

Tree canopy strictly over land (i.e. excluding water bodies) is sometimes used to define average tree canopy; by that definition, the 2019 tree canopy in Arlington is 23.2% instead of 22.5%. We chose not to exclude water bodies as these are not permanent features on the landscape, as shown by the construction of Lake Arlington in the 1950s. Pervious ground cover was overwhelmingly associated with tree cover, with 85% of 2019 tree canopy over a pervious surface and more than 50% located over a grass specifically. Surfaces classified as other impervious had the highest average tree cover, with 56% of these surfaces covered by tree canopy. Landscape beds had low tree cover, perhaps related to shade intolerant plants in these areas. This supports the idea that landscape beds, in spite of being pervious surface, should not be considered as potential planting space. Areas classified as grass or streams both had around 30% tree cover on average. As expected, larger water bodies had less tree canopy cover than streams, with ponds having 11% and lakes having only 3%. Paved surfaces and buildings had a similar level of tree cover, about 8% on average. Given the potential of tree canopy to reduce summer cooling costs this level of tree cover over buildings is disappointing and planting trees to provide shade for buildings should be encouraged. Based on potential canopy width we estimate that tree canopy over buildings could be as high as 30%, mostly from planting trees around single-family homes. **Achieving this level of tree canopy would increase cooling benefits by 375%, which would equate to a savings on energy usage city-wide of more than $7,600,000 based on current benefit levels from the 2009 UFORE study (City of Arlington 2009).**

Drivers of Canopy Change

Reasons for change in tree classification were documented, including a tree becoming non-tree and vice versa, as well as forest becoming urban tree cover and vice versa. These reasons were combined into five main categories, two related to canopy gain and three related to canopy loss: Tree planted, Existing tree growth, Development removal, Tree removed unrelated to development, and Tree trimmed (see Appendix B

Appendix B). The results of this analysis are shown in Figure 7 and discussed in detail below.

It is important to note that describing a reason for change in canopy is a subjective endeavor and may be influenced by the photointerpreter's bias and experience. For example, 181 of 1,000 sample points experienced a change (gain or loss) in tree canopy from 1942 to 1984. Each of these 181 points were evaluated to determine the cause of change as best possible given available imagery and limited data sources at the time. There were 108 points which experienced tree canopy gain due to cropland conversion, fallow field tree encroachment, natural forest encroachment or growth, growth of an existing tree's canopy, growth of an orchard, tree planting in a development, or tree planting not related to initial development. There were 73 points which had a loss of canopy due to initial development/construction, the creation of Lake Arlington, or tree removal for an unknown reason.

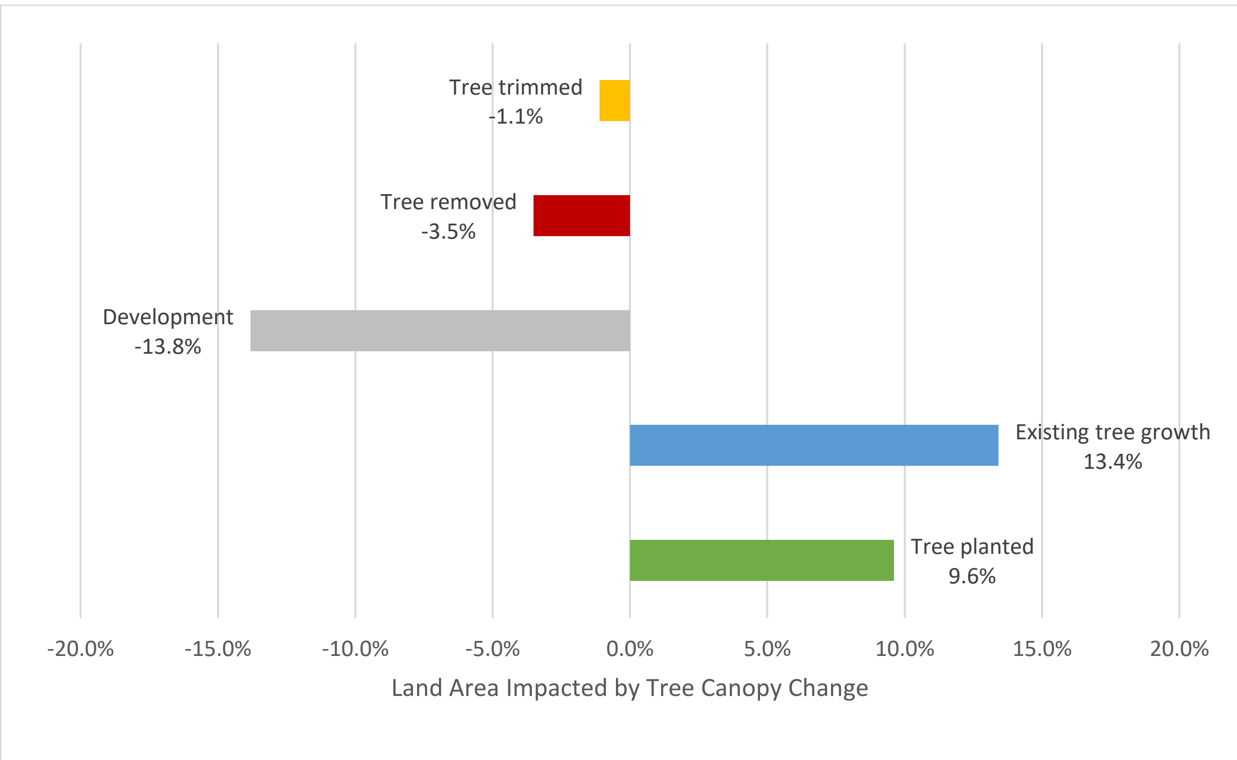


Figure 7. Summary of all activities impacting tree canopy city wide during the study period from 1942 to 2019. Although development had a large impact, this activity was found to decrease over the study period as shown in Figure 20.

Canopy Loss

Development related tree removal was the largest impact category, responsible for canopy loss on 13.8% of land area over the study period and accounted for 75% of all canopy loss (Figure 7). This category includes commercial and residential developments, as well as the effects of Lake Arlington's creation in 1957. Impact of development is discussed in greater detail in the recommendations section.

Tree trimming only accounted for 6% of the reasons for canopy loss but was kept as a distinct category because the tree retains capacity to grow and contribute to the canopy cover in Arlington.

The tree removed category may include trees that died or were removed for other reasons but does not include trees removed for development as far as we could identify. It is often difficult to ascertain the reason behind a tree removal. Available imagery may not capture the illness and death of a tree, and healthy trees may be removed for a variety of reasons. Google Maps StreetView was used to investigate reasons for a selection of tree removals where images were available. Of points in the tree removed category which were reviewed, about half were health related removals and the other half were removed for the landowner's preference (i.e. against arborist recommendations). **In sum, reasons for tree removals are difficult to understand, but tree health and individual landscaping preferences play a significant role that has an increasing impact on Arlington's tree canopy.**

Canopy Gain

Existing tree growth denotes points where a nearby tree grew new canopy over time. One instance where this occurred was when fields and orchards were abandoned and when forests could increase in size. The most common reason within this category was growth of an existing individual tree (i.e. canopy expansion allowing a single tree to cover a greater area). Overall, this was a major portion of canopy increases in Arlington over the study period, with 13.4% of land area experiencing existing tree growth (Figure 7).

The tree planted category represented an increase in tree canopy over 6.1% of Arlington's land area since 1942. This category mostly accounts for new trees planted in housing developments, but also includes a few trees planted individually for reasons not related to construction. We observed a trend of clearing agricultural land and converting it to housing developments. Once the houses were built, homeowners often planted trees in their yards. **Considering the impact of existing tree growth was double that of tree planting, we must not only add new trees to the landscape but also advocate for the ones already in place.**

Frequency of Canopy Impact

Reasons for change in tree canopy fluctuated over time (Figure 8). Tree planted and Development categories were both at their highest from 1942-1997, which is partially explained by the number of years between early study periods. However, these impacts are also related to initial construction and planting activities that took place as Arlington expanded. Following these initial time periods, the primary reasons for canopy change shifted to existing tree growth and tree removed unrelated to development. By the last time period in the study (2015-2019) there were only canopy impacts on 2.4% of land area. These impacts were growth of an existing tree (37%), removal of trees unrelated to development (29%), tree trimming (13%), tree planting (13%), and removal for development (8%).

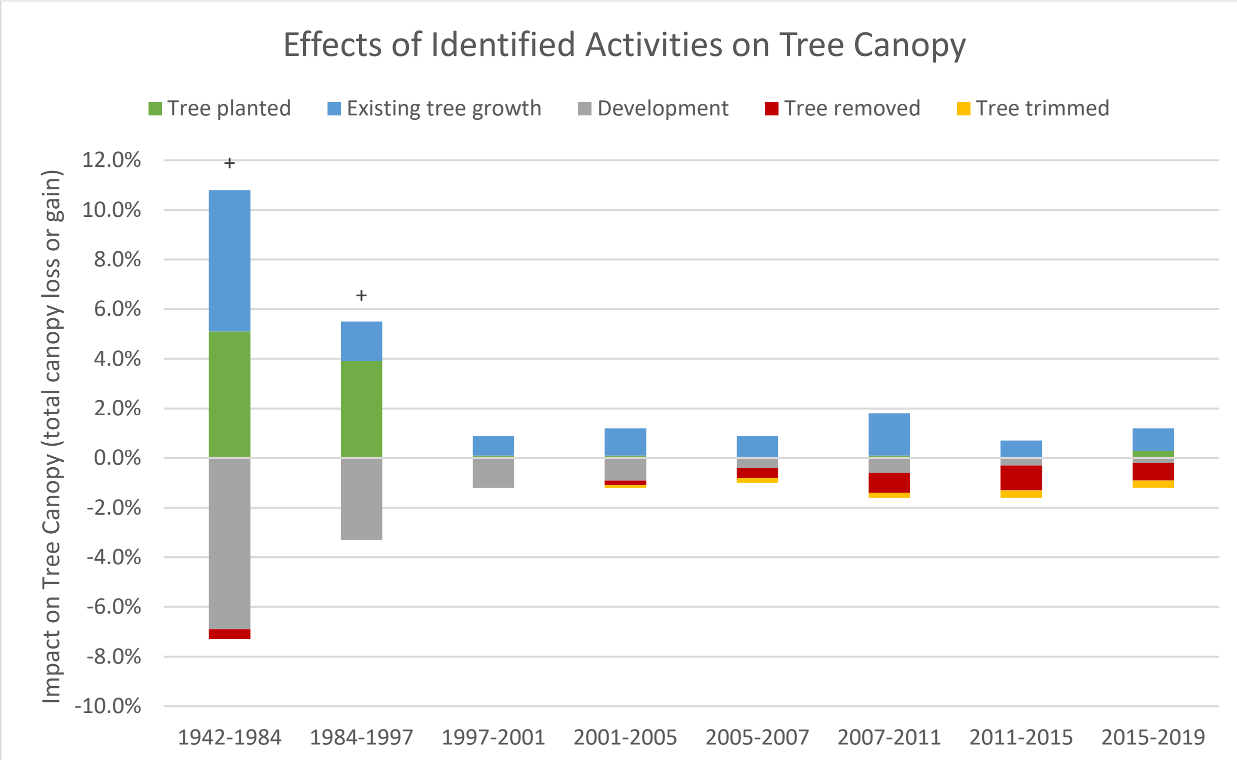


Figure 8. Canopy gain and loss incurred city-wide during study periods. The 1942-1984 and 1984-1997 time periods represent longer timeframes that account for greater change to the tree canopy, but experienced similar impacts on a per-year basis. + denotes significant increase to tree canopy ($p<0.05$).

Consistency of Tree Canopy

Sample points where tree canopy was present during every time period of this study totaled 7.2% of land area in Arlington. Although we cannot claim that this is due to tree longevity, i.e. the same tree that was present in 1942 as 2019, this is still a positive sign for consistency in our urban forest. Essentially, one-third of the current forest canopy has been persistent since 1942. Half of these points with consistent tree canopy are urban and the other half are forest trees, which indicates forested areas are slightly more likely to have persistent tree canopy. Having persistent canopy promotes a resilient urban forest, driven by long-lived tree species and the rapid replacement of dead trees.

Contributing Factors

Additional factors that may contribute to a decline in tree canopy cover are disease and drought. Studies in 2009 and 2019 conducted analyses of several pests and diseases that may cost millions of dollars in damages to trees and decreased property values. Twenty six percent of trees in Arlington parks are oaks and may be susceptible to the oak wilt or other oak specific pests. Emerald ash borer is an exotic beetle species that recently made its way to Tarrant County. Two percent of trees in Arlington parks are ash and may be affected by this pest (Priest and Najar 2019). Dutch elm disease and mistletoe also pose threats to Arlington's tree canopy (City of Arlington 2009).

Drought should also be considered when assessing Arlington's tree canopy. After the 1930s Dust Bowl ended, droughts hit Texas in 1950, 1961, 1988, 1995, 1999, 2005, 2007, and 2010

(Appendix A). The 2010-2013 drought caused large amounts of damage. 2011 was the driest year on record in Texas history, and was the year with the least rainfall since 1917. Figure 1 shows a slight decrease in tree canopy after 2011, which may be caused by varied effects of drought. Table 2 shows that all canopy loss from 2011 to 2019 occurred in urban areas whereas forest canopy stayed the same or increased. This could be related to impacts of drought for multiple reasons. Drought may influence patterns of disease. Hypoxylon canker is a weak pathogen and can only invade debilitated trees. Trees stressed from the 2011-2013 drought were susceptible to this fungus and negative impacts to tree canopy were still being seen in 2015 and beyond. Post oak in urban areas that have been damaged, even from past decades, may be more susceptible to the impacts of drought and disease. Urban areas may also have had trees that were recently planted die due to watering restrictions. Forested areas are also associated with streams and pervious surfaces which could allow for greater soil moisture and therefore protect those trees from drought.

Climate change may cause more frequent and severe droughts. Trees provide many beneficial services that could be more important with climate change, from carbon storage to reducing building energy use when planted near structures (Nowak and Crane 2002; Pandit and Laband 2010). **Property owners can prepare for droughts and take steps to increase resilience including planting appropriate tree species and following guidelines designed to improve the urban forest.**

Ownership

Ownership of land in the city was categorized as city, state, commercial, and residential. City-owned land includes parks, golf courses, municipal buildings, roads, medians, and other properties directly owned or maintained by the city. Roughly 24% of Arlington's area is categorized as city property for the purpose of this study. State property is land currently controlled and generally managed by the State of Texas (around 3% of Arlington's land area) and is located completely along Highway 287, Highway 360, Interstate 20, and some portions of Interstate 30. Although potentially influenced by city management, most of this state-controlled land could not currently be planted by the city.

Commercial lands may be businesses, offices, utility right of ways, schools, universities, or any other non-residential property not owned by the City of Arlington. Commercial property makes up about 27% of land area. The largest category of land use is residential properties, which includes single and multi-family homes as well as the grass ROW in front of residences on residential streets. Residential properties make up 46% of land in Arlington. For both the high amount of residential land and the greater pervious surface on these properties, residential properties make up a considerable portion of the current and potential urban forest. These land uses are sometimes separated into multi-family and single family for analysis to account for differences in mindsets of apartment managers versus homeowners. Single family owned land is the largest residential land use at 34%. Multi-family residential land is only 4% of the total city area.

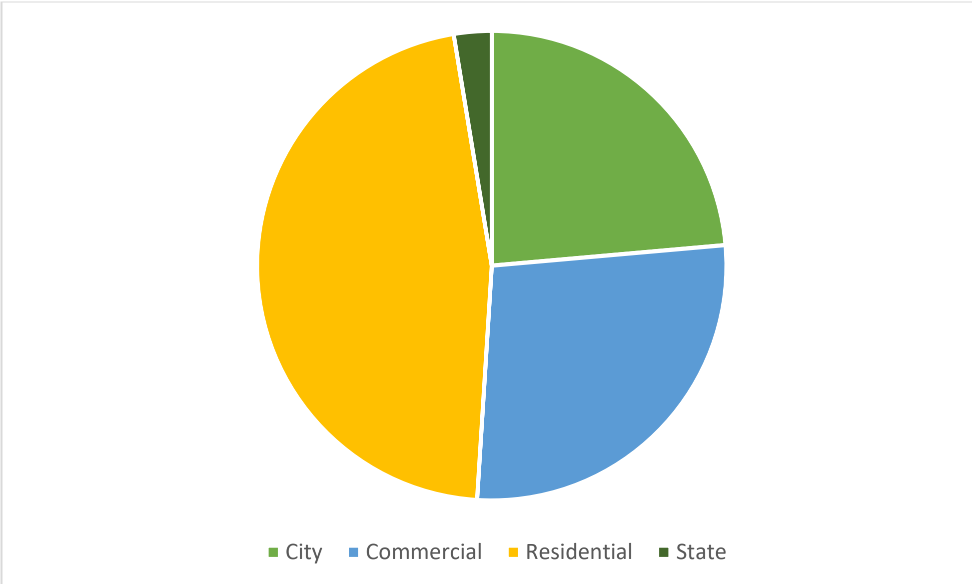


Figure 9. Land ownership in Arlington, TX. Single and multi-family residential properties make up nearly half the land area in the city.

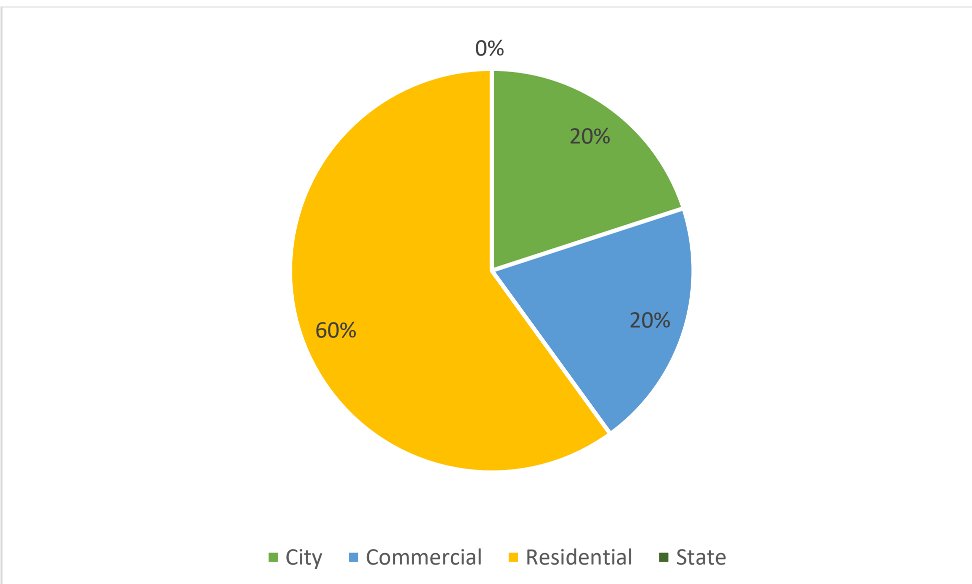


Figure 10. Tree canopy ownership in Arlington, TX. Residential properties contain more than half of the tree canopy in the city, in spite of residential properties consisting of only 46% of the land area.

Percent of total tree canopy present in each ownership category from 1997-2019 did not significantly change, so we will present information from 2019 regarding ownership. The tree canopy cover in Arlington is shown by ownership categories in Figure 10. As mentioned previously, residential properties own unproportionally more tree canopy than other property types. Residential properties contain 60% of the cities tree canopy but own only 46% of the land area (Figure 9). Single family residential lots were the most significant portion of the tree canopy, containing approximately half the tree canopy in Arlington. Multi-family residential had similar percent tree cover to single-family residential properties (Figure 11) but are a smaller land base so multi-family residential only makes up about 5% of Arlington's tree canopy.

Commercial areas contained 20% of the city's tree canopy and the City of Arlington holds the remaining 20%. Following similarly to city-wide ownership of the tree canopy, residential properties have higher tree cover on average (30%) than city and commercial properties (19% and 16%, respectively). State owned highways had 0% average tree cover. Land ownership sheds light on who has responsibility for Arlington's tree canopy as it currently stands. Although the City of Arlington can influence tree canopy, landowner participation is necessary to improve tree canopy. **As growth of existing trees was the largest positive contributor to canopy change (Figure 7), ownership data indicates the need to educate residential property owners regarding protecting their current trees.**

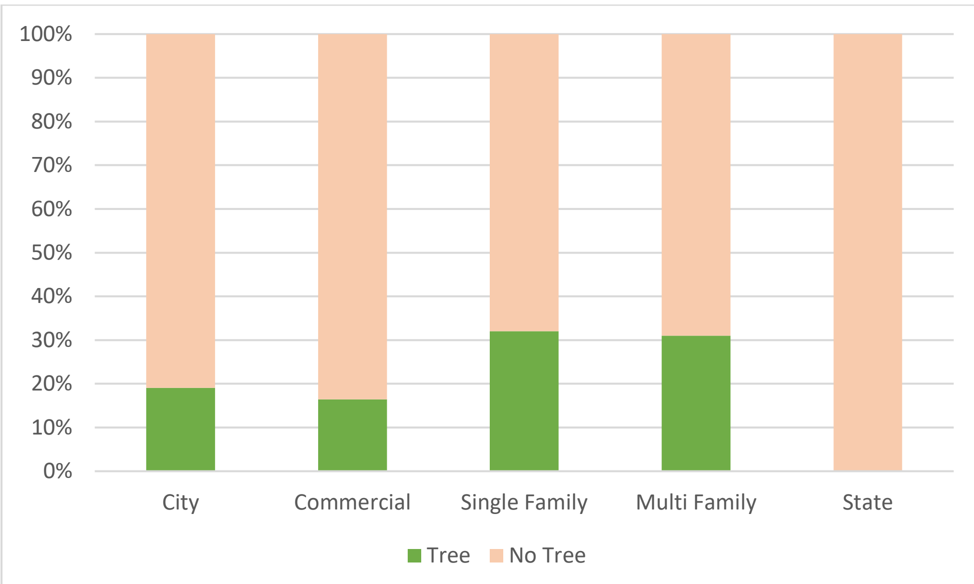


Figure 11. Average tree cover within each ownership category. Residential properties generally have higher tree cover than other properties.

Forest Canopy by Ownership

It is important to know where forested areas are located and how well protected they are in Arlington. As mentioned previously, forested areas are sustainable canopy as seeding and natural succession often occur. In 2019, forest trees were primarily found on city property, with approximately 50% of forest canopy on city owned or managed areas (Figure 12). Further review revealed most of these city-owned forested areas are within city parks and natural areas, which indicates some level of protection from canopy loss. Commercial properties followed with 28%, with residential properties only containing 22% of forest canopy, and state properties having no forested area. Forest canopy is defined by lower maintenance (particularly mowing) and must be a minimum width of 100 feet for the purposes of this study. As commercial properties are typically larger than residential properties, they are more likely to have significant portions excluded from regular maintenance and allowed to grow naturally. Protection of privately owned-forested areas may be dependent on exceptions to some city ordinance requirements such as mowing. Natural areas should be permitted and meet less stringent guidelines for upkeep and maintenance.

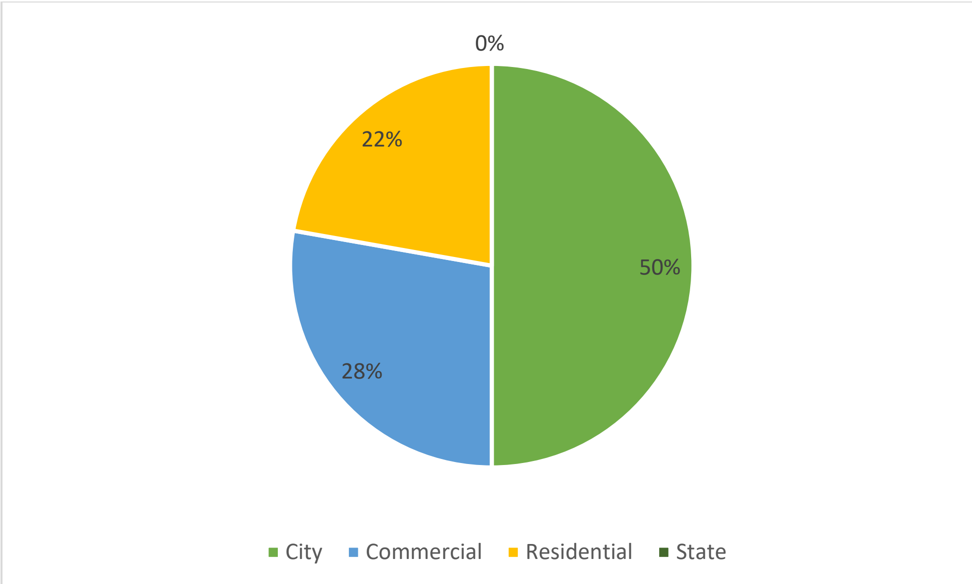


Figure 12. Ownership of current forest tree canopy. City parks account for the largest portion of forest land in Arlington.

Canopy Change by Ownership

We found tree canopy gained over the complete study period was not equal across ownership. 63% of canopy gain occurred on residential property, which is above what would be expected given residential properties are 46% of land area. In contrast, commercial and city properties accounted for only 20% and 17% of canopy gain, respectively. Considering canopy loss over the study period, a total of 16.9% of land area had a tree at one point during the study period but did not have a tree in 2019. The distribution of this canopy loss area by ownership closely matched overall land ownership for residential and state (50% and 2%, respectively); however, city property made up 28% of lost canopy, an unproportionally higher loss than other ownership categories. Commercial properties on the other hand accounted for only 20% of canopy loss, less than would be expected based on land area.

Analyzing changes within each category we found commercial properties also had 47% of tree change impacts end with a tree in 2019, whereas residential properties had 54% end with a tree. This means that residential properties experiencing some form of canopy change (tree planting, growth, removal, etc.) were slightly more likely to end up with tree canopy at the end of the study period than commercial properties. On the other hand, points with a tree in 1942 but no tree in 2019 made up 24% of residential area impacted by canopy change, whereas those areas on commercial properties made up only 21% of canopy change impacts. **Together, these results indicate that commercial properties were not more likely to remove trees, but simply had less tree canopy to begin with. This is supported by the 1942 average tree canopy being only 11.3% on properties listed as commercial in 2019.** The limited canopy gain on commercial property may be due to decreased likelihood of tree planting beyond one-time city requirements. State and city property were more likely to remove trees than other ownership categories. This was attributed to construction of new streets and highways as the city grew, and to the construction of Lake Arlington in the 1950s.

Ecoregion

Arlington intersects two ecoregions, areas of distinct geography, ecology, and species assemblages (Figure 13). The Cross Timbers and Prairies in the western two thirds of the city is generally characterized by a mix of oak forest and grasslands over sandy loam and clay soils. The Blackland Prairies to the east are mainly dark, heavy, clay soils with tallgrass prairie, but much has been cleared for agriculture and development (TPWD). The Cross Timbers covers 64.3% of the city land area and Blackland Prairies cover 34.7% (Figure 14).These separate regions should be taken into account when considering current canopy cover and new tree planting, as different species and quantities of trees are well adapted to each ecoregion. Specifically, the different soil types influence the species composition. A 2019 study found that species compositions in north and west Arlington parks versus tree species in south and east Arlington did reflect the different ecoregions (Priest and Najar 2019).

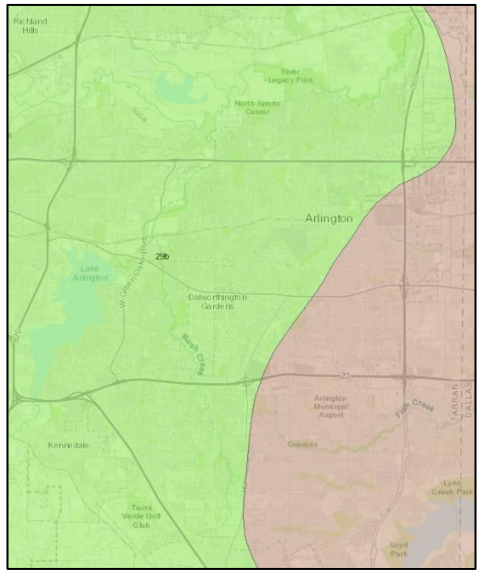


Figure 13. Cross Timbers (green) and Blackland Prairie (pink) ecoregions in Arlington, TX.

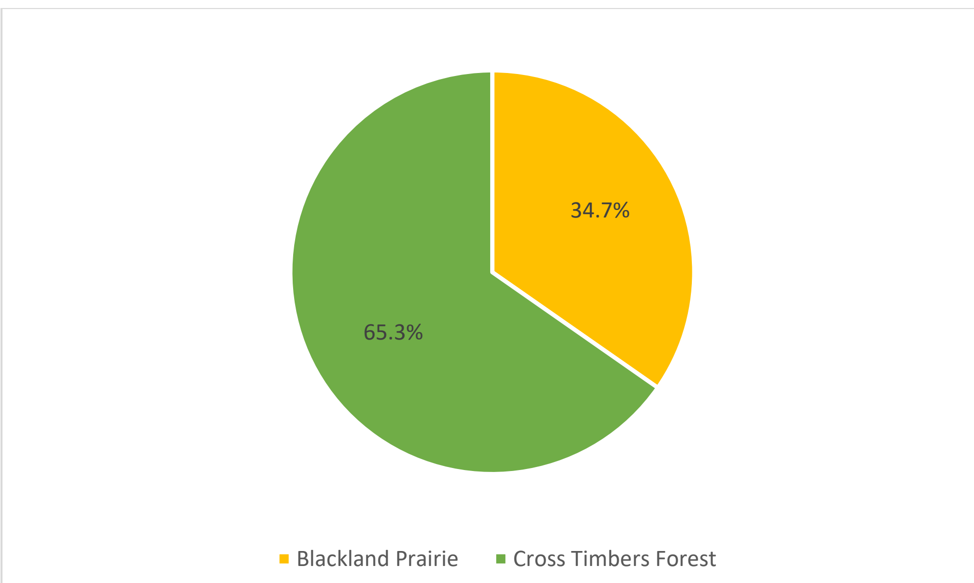


Figure 14. Distribution of land area in Arlington, TX by ecoregion. The Cross Timbers region has soils more suitable for natural forests while Blackland Prairie was typically used for agriculture purposes in the 20th century.

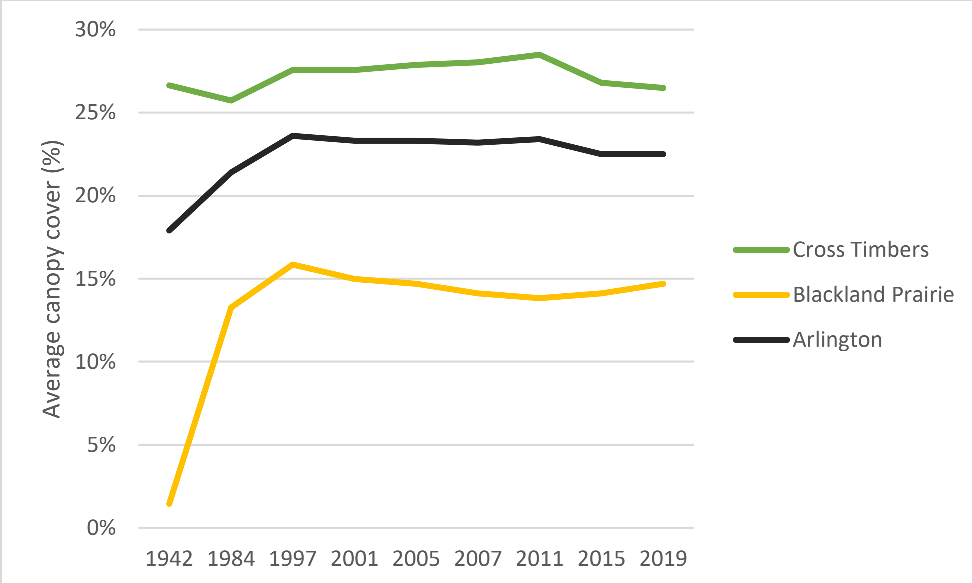


Figure 15. Average tree canopy in Arlington's two ecoregions. The dominant land use in the Blackland Prairie ecoregion in 1942 was agriculture, which led to an increase in tree cover as development occurred. Tree canopy in the Cross Timbers has been more consistent.

The Cross Timbers ecoregion consistently had higher tree canopy over the complete study period than the Blackland Prairies (Figure 15). In the Cross Timbers, canopy cover does not vary much from 1942 to 2019. The one significant change occurred 2011-2015 (p-value 0.025, McNemar's test). The decrease in canopy was likely influenced by the drought of 2011. In the Blackland Prairies, canopy cover rose significantly from 1942 to 1997 (p-values<0.05, McNemar's test), but then leveled out. The fertile soil of the prairies is ideal for agriculture, which uses large tracts of land devoid of trees. Therefore, increasing development may have contributed positively to tree canopy in this case. As houses were built over original prairie and crop fields, trees were planted in new suburban yards. Potential canopy was similar between Blackland Prairie and Cross Timbers ecoregions, which is a result of higher plantable space and lower existing canopy in the Blackland Prairie compared to the Cross Timbers. Few trees were naturally found in the Blackland Prairies which may need to be considered when determining tree canopy goals. **For example, although potential canopy is similar between the two regions, the limited selection of tree species suitable to Blackland Prairie soils and decreased survival in that region could limit the potential tree canopy. Tree canopy goals should be considered by ecoregion or city-wide targets should be adjusted for potential difficulties in heavy clay soils.**

Council Districts

Average tree cover varied by council districts and we attributed this in part to the Ecoregions found within each district. Other major features within the district may also influence tree canopy, but do not necessarily merit increased or decreased concern regarding canopy. For example, District 1 has moderate tree canopy in spite of highly disturbed canopy in newly developed areas as this is offset by the presence of River Legacy Park and the Trinity River floodplain with very high average tree canopy. District 5 has relatively low tree cover due to the ecoregions present as well as major institutional area with generally low tree canopy. Although tree canopy could be increased within District 5, there is no indication that improvements to tree canopy need to be targeted to particular areas of the city. Instead, improvements to tree canopy should be based on ownership and other factors that drive tree canopy within the districts.

Table 3. Current tree canopy and plantable space within council districts. Information provided for reference.

District	*Current Canopy*	*Plantable Space*	***Potential Canopy***
1	25%	13%	**38%**
2	23%	28%	**51%**
3	19%	32%	**51%**
4	28%	18%	**46%**
5	14%	25%	**39%**

Ground Cover by Ecoregion

Differences in ground cover between the two ecoregions would be expected given tree cover was higher in the Cross Timbers compared to the Blackland Prairie. Surprisingly they were few differences between the two ecoregions and those that existed do not provide any reason for lower tree cover in the Blackland Prairie (Figure 16 and Figure 17). Pervious surface was actually slightly higher in the Blackland Prairie than the Cross Timbers (55% and 52%). The Blackland Prairie pervious surface also consisted of a much higher percentage of grass cover and less “other pervious.” Paved surface was similar between the ecoregions but buildings covered greater surface area in the Blackland Prairie than the Cross Timbers. There was almost no surface area occupied by water bodies in the Blackland Prairie, which is mostly attributed to Lake Arlington and the Trinity River being located in the Cross Timbers.

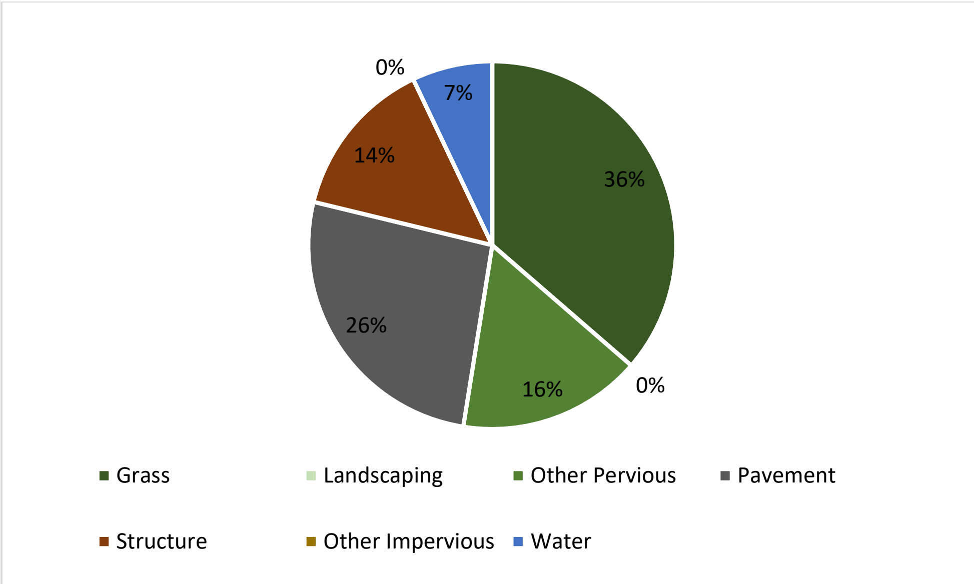


Figure 16. Ground cover within the Cross Timbers ecoregion of Arlington for the year 2019. Pervious surfaces made up 52% of land area, followed by impervious at 41% and water at 7%.

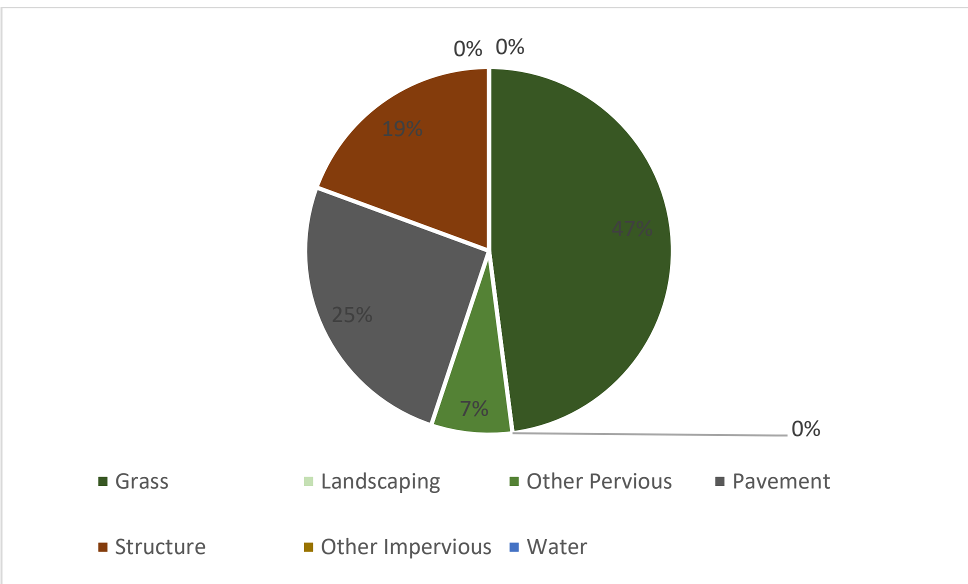


Figure 17. Ground cover within the Blackland Prairie ecoregion of Arlington for the year 2019. Pervious surfaces made up 55% of land area, followed by impervious at 44% and water at less than 1%.

<u>Potential Tree Canopy</u>

To determine hypothetical tree canopy we looked at plantable space, or locations where new trees could be added. We determined that landscaping and other land with pervious ground cover were unlikely planting locations. Logically, all impervious ground cover was excluded as currently incapable of supporting a tree. Potential canopy is equal to current canopy plus plantable space. We determined the theoretical canopy which Arlington could have based solely on grass area which could support a tree and then further analyzed to determine what is possible based on limitations we are aware of. We determined a range of potential canopy goals with a discussion on the length of time required to accomplish these goals. Given the long timeline projected to raise canopy, there is uncertainty as to what level of tree canopy may be feasible.

Conflicts with Tree Canopy

As mentioned, trees sometimes conflict with current or expected land use. These conflicts reduce the potential tree canopy and are difficult to predict or analyze at the city level. Potential conflicts include:

- Athletic fields, golf courses, and play areas
- Infrastructure, sidewalks, buildings, power lines, and underground utilities
- Shade intolerant turfgrass lawns or landscaping
- Other features such as pools, greenhouses, or solar panels

Some of these obstacles cannot be fully overcome and tree planting may not be possible to some extent. For example, planting trees in a baseball field is not acceptable, nor could trees be placed in a golf fairway. In most cases there is an opportunity to plant trees even with these limitations. With a baseball field trees are often planted along the perimeter and could be planted outside the outfield fence as long as sufficient space is allowed for tree growth. Golf courses can have trees strategically added in locations that provide shade and beauty to the course without limiting play. Other obstacles such as power lines or solar panels may necessitate planting the tree further away and using a smaller species of tree. Planting trees around buildings requires adequate space for the tree but a larger tree may have more room to grow than a smaller tree, as the canopy can expand above the building.

One of the major conflicts with trees is not infrastructure at all, but competition with other plants for light. A focus on education and introducing new ideas to homeowners regarding landscaping and lawn care may be needed to make tree planting palatable in these situations. Certain turfgrass species and many native grasses are tolerant of shade and should be encouraged so that trees are not creating issues with lawn care. We will discuss possible opportunities in the recommendations section below.

Available Planting Space

The existing tree canopy in Arlington covers 22.5% of land. Another 28.8% of the city area is grass without trees, open for planting. Added together, the hypothetical canopy potential is 51.3% tree cover. However, the 51.3% canopy is not realistically attainable or necessarily desirable as complete tree cover is not ideal in many cases. Much of the grass ground cover type is made up of sports fields, farms, and golf courses, which will not be planted over. In addition, various types of landowners will have different land use needs and constraints. To analyze this, we excluded areas within two feet of existing structure or pavement and then inspected points to determine if tree planting seemed possible with current land use. After analysis of all points regardless of current canopy, only 41% of land area is possible for tree planting based on available information. When current canopy over non-planting space (e.g. tree canopy extending over impervious surface) is included, the total land area possible for tree cover is 45%. This indicates the 40% canopy goal targeted for eastern cities (Baltimore, MD; Washington, D.C.) is possible, but would require tree planting in virtually every plantable space across the city and may create unforeseen conflicts. The non-profit organization American Forests recommends a 40% canopy goal when the city is located in forested ecosystems, but only a 20% canopy in grassland ecosystems (American Forests). **Considering the two ecoregions in Arlington, our recommended canopy goal is between these two and we infer a recommended canopy of 30-35%. Our data supports tree canopy goals up to 35% are feasible in Arlington, therefore the principal concern regarding tree canopy goals would be the projected timeline.**

Time Need to Accomplish Canopy Goals

Our complete study period covers nearly 80 years of Arlington's tree canopy history which enables a projection of time needed to accomplish canopy goals. The estimated canopy over time is projected in Figure 18 assuming growth occurs at the rates seen from 1942 to 1984 and 1984 to 1997. These time periods experienced high tree canopy growth that would be difficult today given the infrastructure and impervious surface now present, but with a high level of input in planting, education, outreach, and ordinance revisions could be accomplished. **Based on these rates of canopy growth, 25% canopy cover would take approximately 20 years to achieve. More enthusiastic tree canopy goals should be expected to take many decades or longer to achieve and therefore may not be realistic to set at this time.**

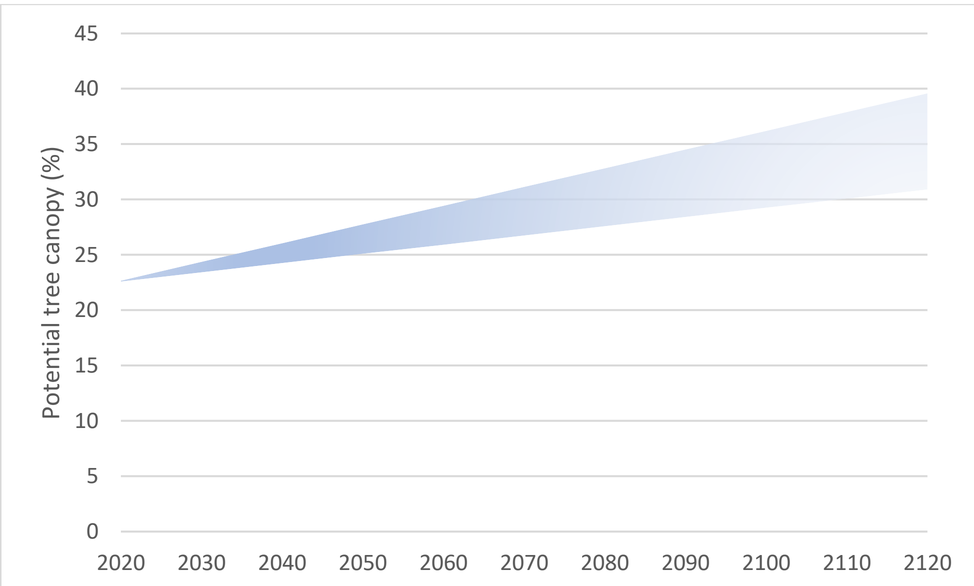


Figure 18. Potential to increase tree canopy over time based on inputs matching the 1942-1997 time period. This is not a projection of current tree canopy and is dependent on significant changes to tree canopy drivers.

The slow rate of increasing tree canopy is due in part to mature tree canopy size being reached 20-30 years after planting. A reasonable canopy goal should be expected no sooner than 30 years after the decision. A number of steps would need to be completed before improvement would commence, such as changes to ordinances or outreach programs. We recommend setting an initial tree canopy goal that is approximately 1/4th the final canopy gain desired and providing a target that could be monitored. This would allow participants the city to determine if the final goal or the strategies need to be revised. For example, a final goal of 35% tree canopy could take nearly a decade to accomplish. **Establishing an initial goal of 25% tree canopy would allow**

measurable progress toward the final goal while allowing flexibility if conditions change that limit the potential canopy (such as an increase in impervious ground cover).

Potential Canopy by Ownership

Ownership of tree canopy has been discussed, but ownership of potential tree canopy needs to be considered when determining reasonable and actionable measures to improve tree canopy. The city has frequently been charged with improving the tree canopy; however, the city is not able to accomplish this goal on city properties alone due to high levels of impervious space (particularly streets). As seen in Figure 19, city owned properties are limited on potential tree planting space. Tree canopy covers approximately 68% of plantable space on city land, whereas residential properties are 50% planted and commercial properties are only 43% planted. State owned property along highways has not been planted at all, although planting options in these areas are unknown.

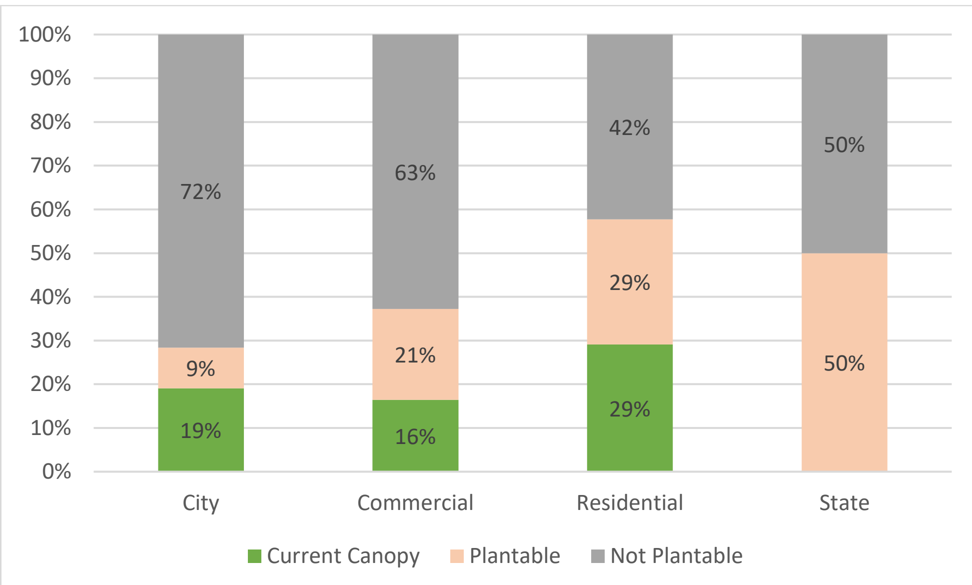


Figure 19. Average canopy and plantable space by ownership category. Each bar represents 100% of land within the ownership category.

Ownership of potential tree canopy is also important to know how much impact tree planting can have on the city-wide tree canopy. A majority of plantable space in Arlington is on residential properties (59%). In contrast, commercial properties contain 25% of plantable space, followed by city property at 10%. City properties are relatively well stocked regarding tree canopy, but more importantly, city owned plantable space only makes up 2.2% of land area in Arlington. Even if city property was at maximum possible tree cover, the total tree canopy in the city would only increase to 24.7%. **Residential properties are currently better stocked than commercial properties, yet the benefit to the city-wide tree canopy is greatest through pursuing canopy increases on residential property. If residential properties were at maximum possible tree cover and all other things constant, the city tree canopy would be increased to 35.8%. Table 4 summarizes the city-wide current and potential canopy by ownership.**

Table 4. Impact of ownership on tree canopy potential. All values shown on basis of total land area. Potential canopy is plantable space added to current canopy. As seen, city properties alone cannot greatly increase the overall tree canopy.

	Current Canopy	*Plantable Space*	*Not Plantable*	***Total Area***
City	4.5%	2.2%	16.9%	**23.6%**
Commercial	4.5%	5.7%	17.2%	**27.4%**
Residential	13.5%	13.3%	19.6%	**46.4%**
State	0.0%	1.3%	1.3%	**2.6%**
Total Area	**22.5%**	**22.5%**	**55.0%**	

Recommendations

Current tree canopy is 22.5% of all land in Arlington. Although pervious grass surface combined with current canopy makes up 51.3% of land in Arlington, we found this to be an unrealistic expectation of tree canopy. By removing spaces that are not feasible for tree planting as best possible, potential tree cover could be approximately 41-45% of land in Arlington. We also found this level of canopy could take over 100 years to realistically attain. **Due to the extensive level of tree planting that would be needed to reach even 35% tree canopy, we do not recommend a final tree canopy goal at this time. A goal that could feasibly be accomplished within 20 years would be to increase tree canopy to 25%.** The sections below discuss means to positively influence tree canopy in Arlington through ordinance, city policy, incentives, and other practices. Practices intended to improve canopy can have negative impacts, which we will discuss; however, there is little way to anticipate the long-term effects of various policy and ordinance changes. As we have discussed, tree growth provides most canopy gains, therefore tree canopy is a long-term goal that may take more than 30-50 years to see significant improvement if changes are successful.

City policy could be amended to improve urban forest canopy by focusing on the largest drivers of canopy change. The most important single factor for was expanding canopy of young, growing trees. Protecting these trees would therefore provide the greatest benefits to the community. This important factor is often overridden by popular goals of planting new trees or protecting older trees. While these are very important factors for increasing and preserving tree canopy, they often lead to neglect for the trees that provide the majority of our canopy gains. City efforts thus far have provided thousands of trees to homeowners free of charge but planting trees that do not reach maturity will not achieve canopy goals. Outreach to landowners to encourage tree planting may be necessary to alter current perceptions of tree canopy. Given Arlington's history, many residents may not realize that tree canopy has increased over the last century due to great effort. That effort includes planting and protecting existing trees, as well as caring for trees and tolerating the inconveniences that may arise at times. For example, tree owners must be influenced to not remove trees even though annual leaf fall causes additional yard work, or the limbs require pruning every few years to clear the driveway or road. Another popular effort that may provide less benefit than expected is further regulating development to protect forest canopy. This study shows that development impacts to tree canopy has dramatically decreased over the past two decades, with development now causing less than 1 in 5 tree removals. Residential development in the past century has also led to increased canopy due to planting, much of which occurred prior to modern ordinances stipulating tree planting. Instead, assisting tree owners to prevent removal appears to be of greater benefit to the urban tree canopy. Outreach through education and marketing is a powerful tool that could be used to encourage watering during periods of drought or place tree care costs into perspective (e.g. comparing tree and lawn maintenance costs). To achieve more extensive tree canopy goals, tree planting requirements for circumstances other than initial development or construction may turn out to be necessary. The simplest proposal for doing so is to suggest or require a minimum tree canopy at the property level which would be based on expected tree canopy at maturity. This proposal is discussed below (pg. 32).

Existing Tree Protection Ordinances

Existing tree protection ordinances appear to be functioning as intended to protect tree canopy, as shown by both the reduction in overall development related canopy loss and the proportion of canopy loss due to development, as shown in Figure 20. The only method we could utilize for evaluating ordinance effects in this study was to compare losses before and after implementation, although it was not possible to isolate other factors that may influence canopy changes such as total area disturbed by development. There is also delay from council authorization to actual construction under the new tree protection ordinance that could confound results. In spite of these factors, there appears to be a decrease in tree development impacts coinciding with progressively stricter ordinances. The initial effort of establishing a tree replacement fund in 1994 may have had only a limited effect on reducing tree canopy loss, as the time period from 1984 to 1997 has the highest proportion of development related canopy losses (Figure 20). The annual canopy loss from development was highest from 1997 to 2001 then began to decrease, representing an overall decrease in development related canopy loss to present (Figure 21). The 1997 ordinance update provided mitigation requirements for residential development, which may have begun the trend of decreasing development impacts. The first time period in the study with a significant drop in development related losses is from 2005 to 2007, which seems to be related to the implementation of the 2005 ordinance. This ordinance began the protection of trees during development of commercial properties. For the most recent period (2015-2019), development caused canopy loss each year made up only 0.05% of land in Arlington (approx. 30 acres). **Overall, ordinances or cultural changes have led to significantly decreased canopy losses related to development. However, as mentioned on page 22, tree canopy was low on commercial properties prior to development so merely protecting existing trees may not achieve desirable canopy results.**

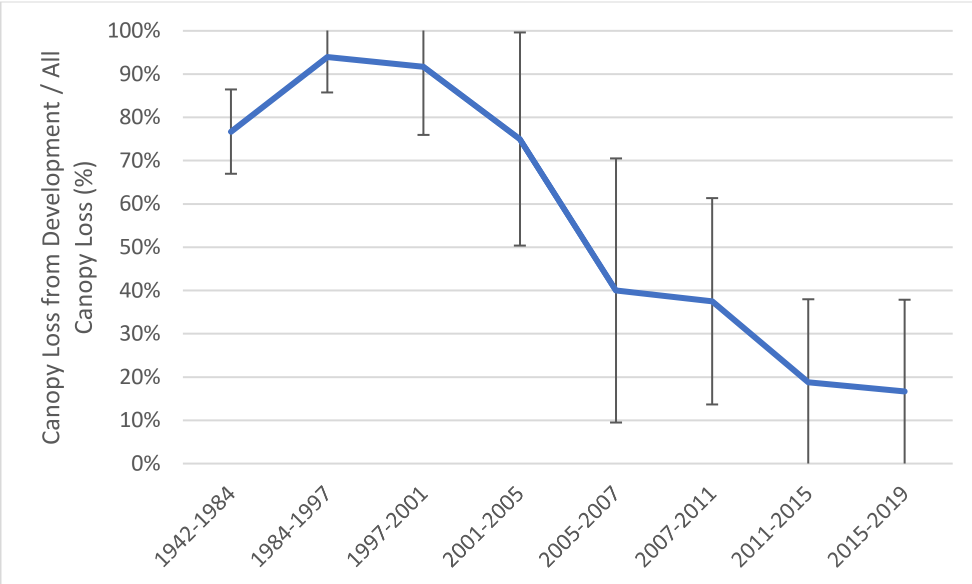


Figure 20. Proportion of total canopy loss caused by development during each time period of the study. See Figure 8 for all canopy loss drivers. Over time, development becomes less significant with individual tree removal and even tree trimming having more impact.

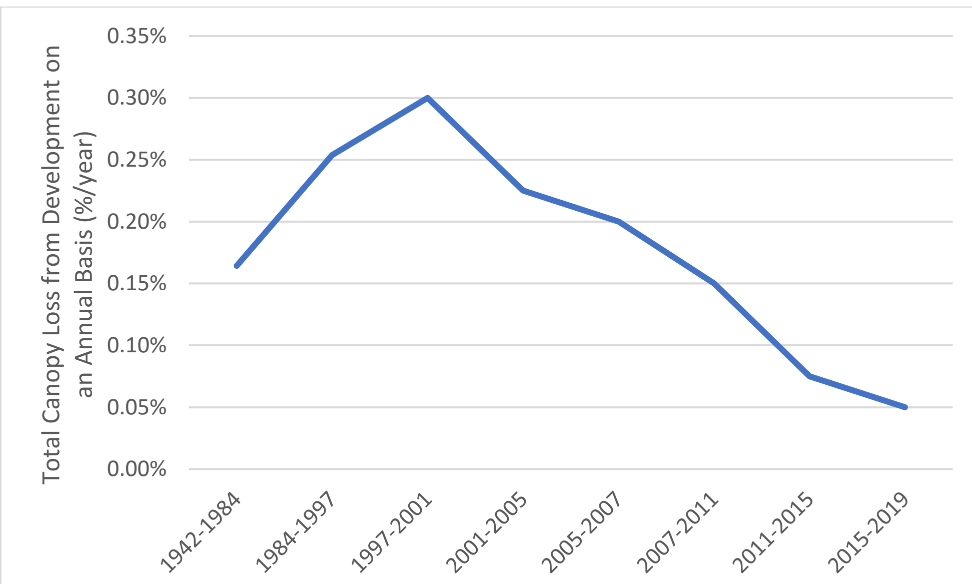


Figure 21. Land area in the City of Arlington with canopy lost due to development. Presented on an annual basis (canopy loss/length of period) to account for longer early study periods. Total canopy loss from development decreases from 2001 to present.

Potential Tree Protection Ordinance Revisions

The city’s ordinances protect trees on the basis of trunk diameter inches due to the ability to directly quantify tree protection; however, an ordinance based on maintaining a minimum tree canopy could better serve the goals of the city in protecting and maintaining a strong urban forest. Tree canopy coverage requirements have been implemented in other Texas cities such as San Antonio and Conroe, although it is unclear if canopy coverage is directly measured or based on other calculations. Tree planting requirements could be governed by anticipated canopy width at maturity when planted at proper spacing, as opposed to replacing trees on the basis of trunk caliper inches. An important consideration of these methods is that the end goal of a minimum tree canopy cannot be reasonably achieved immediately, therefore it becomes necessary to conduct long-term monitoring of sites to ensure compliance with minimum canopy requirements. This also leads to an imbalance in properties having been developed under the ordinance and those that have not, as new development must maintain a minimum tree canopy while other properties do not have this requirement.

Ideally, but perhaps unattainably, all properties of a specified land use would be required to meet a certain canopy goal or provide concessions in lieu of meeting this requirement. An approach to this requirement based on future canopy area at maturity allows for tree planting as needed without further penalization of low tree canopy properties. Since the mature size of the tree determines the canopy area it is relatively easy to calculate and apply. As mentioned regarding other policy and ordinance approaches, there would need to be extensive discussion of the methods to prevent negative outcomes such as “spite” removals or improper pruning that reduces canopy area. Minimum canopy requirements would need to be attainable for properties, accounting for realistically plantable space and suitability of the soils. As discussed, the blackland prairie ecoregion is characterized by difficult soils that restrict tree growth and may warrant lower canopy requirements for properties in that region. To some extent this would involve more intensive ordinances than seen in any other Texas city. We would recommend such an approach be implemented as a suggested or encouraged goal for property owners, at least until there is a full understanding of the probable outcomes.

Arlington currently only restricts tree removal related to development, which has limited control over the urban forest. This type of tree protection is readily enforceable as most development requires plan submission and various other forms of control. Other Texas cities, such as Austin or Fort Worth, have instituted some form of tree removal protection enforced at all times on private property, as opposed to tree protection during a singular event such as development. Tree protection ordinances not related to development require a higher level of monitoring to ensure compliance. Increased regulations would have impacts on staff and budget, especially when the permitting requirements cannot be merged with existing protocol. For example, introducing permitting requirements for all tree removals (as opposed to removals involving other permitted work) would require increased staff to accommodate the new permit applications and would require additional work to enforce ordinances when trees are removed without a permit. Few studies have ever considered the long-term effectiveness of tree protection on private property, perhaps due to the difficulty of gathering accurate data on trees removed without a permit. Consideration should be made to potential avenues stakeholders could use to bypass any new ordinance and the likelihood of those being utilized. There could be unanticipated negatives as a result of a seemingly positive ordinance. For example, Washington D.C. implemented a heritage tree ordinance which prohibits any removal of healthy trees with a trunk diameter larger than 32 inches and requires a permit for removal of trees greater than 14 inches. A property owner not wishing to be restricted in regard to their tree management decisions could conclude that it would be best to remove trees before they reach the thresholds (14 and 32 inches). As another example, implementing a permit program for tree removals could result in unsafe tree removal work if property owners attempt to avoid detection and enforcement. Further concerns arise when tree removal is only allowed following approval of permit, such as the potential for a tree to fail causing property damage or worse while the permit is being processed or after it is erroneously denied.

In contrast, requirements which involve a tree canopy goal at the parcel level, however stated and applied, do not focus on monitoring individual trees and may involve less increase to staff or budget to accommodate. For example, tree *canopy* protection focuses on the anticipated tree canopy on a property which could be evaluated on a scheduled interval. Tree removals could continue to be up to the homeowner's discretion as long as canopy is replaced by appropriate tree planting. This would ensure long-term tree canopy without ill-will from property owners, whereas tree protection ordinances limit tree removal but do not provide assurance of long-term canopy unless strict planting requirements are incorporated.

City Management of the Urban Forest

There are widely varying levels of management of the urban forest between cities in Texas and the US. Many cities choose to heavily regulate private properties as a method of controlling and providing for urban forest in the city. The justifications for these approaches are based on consideration of trees as a public good or as a nuisance if unmaintained. Other cities, particularly smaller populations, have very little city management of trees and only provide minimum tree care on city owned property. The City of Arlington is between these two extremes: tree care is well above minimum standards, directly owned parcels are managed as well as specific medians and ROWs, there is extensive tree planting, and city managed areas are well stocked with tree canopy on more than 67% of plantable space (Figure 19). Current city ordinances can require and enforce removal of hazard trees, which is beneficial to safety of the public and the homeowners. As discussed in previous sections, other cities have additional standards or policies increasing municipal control. Some of these policies are not currently undertaken by the City of Arlington: removal of trees is not prohibited or permitted except during development, residential ROWs are not maintained by the city, there are no planting requirements except during development, and there is no minimum tree canopy or number of trees required on any properties except during development permitting.

Increasing tree canopy will require changes to policies; however, there is little evidence of successful policies in regard to increasing tree canopy. Our research has shown that private properties are essential components of the current and potential tree canopy levels. There is little evidence to support increasing city driven tree planting on currently managed properties as stocking levels are high and the city's plantable space is a small portion of the potential tree canopy. Expanding city management to previously unmanaged ROWs would result in increased costs and has been reported as unsustainable by cities which manage all residential ROWs. This level of management is intrusive and results in frequent conflicts. Current citizen submitted issues related to city trees are very low, with the Forestry and Beautification Division receiving only four such requests in 2019 through the online request system. Cities maintaining residential

ROWs receive far more citizen concerns as the directives of the city rarely harmonize with all citizens needs and desires for their property. The city would need to be efficient in tree planting, which necessitates large projects that cannot take into account individual property owner concerns or desires. ROWs are also the least appropriate location for tree planting with overhead power lines, streets, sidewalks, homeowner irrigation systems, mailboxes, and landscaping frequently occupying the same narrow space. For this reason, we see continued management by the property owners as the most suitable approach to planting trees where appropriate in these areas.

Tree Care Incentives

Many cities have implemented various processes for incentivizing tree planting on private property. The city currently undertakes tree giveaways targeting a total of 3,000-4,000 new trees in Arlington each year. This practice has only been moderately successful, as there is difficulty in achieving enough public participation to give away all of the trees available. Surprisingly, the program has not been limited from a financial standpoint but by the number of people willing to take and plant a free tree. This has resulted in less extensive requirements for the program, such as forgoing any agreement to care for the tree. For such approaches to have effectiveness at a city scale there is a need for outreach or education to increase public participation.

Perhaps the most popular financial reimbursement incentive in US cities is a “tree rebate” which provides a reduction on the homeowner’s utility bill for tree planting(s). These programs typically enjoy high participation yet foresters in these cities have reported issues with these rebates: fruit, non-native, and ornamental trees are favored as opposed to shade trees, the rebate does not guarantee long-term tree care, trees are often removed later or when a new owner moves in, and the resulting environmental benefits do not justify the program cost. These issues may be overcome by stipulations such as tree size and reimbursement timelines but require additional time and effort to enforce.

An alternative to a tree rebate that ensures proper species selection is to directly supply the tree and, to reduce barriers to participation, conduct the planting of the tree. Some cities, such as Washington D.C., have implemented programs that plant trees on private property for a fee that is much lower than the cost a homeowner may pay to install a new tree. The advantage to this program is city control over species selection, reducing favor of ornamental species and ensuring appropriate site-species match. The disadvantages are similar to those involved with tree rebate programs, particularly removal of the tree later on. To some extent there are methods to reduce issues; for example, program participants could be provided a watering container with brightly colored instructions to serve as a reminder as well as an advertisement to neighbors. Tree installation incentives may be best utilized in conjunction with private tree protection as there may be greater success in improving tree canopy on private property. There does not appear to be any existing models for incentivizing ongoing tree care or to prevent urban tree removal as these would need to be continual in some way and become cost prohibitive. **Regardless of the process, it is likely that any incentive program will have some negative products and should be open to revisions as needed. Education and marketing should be considered essential components of any incentive program, and may be more valuable for increasing tree canopy than actual program participation.**

Reduced Mowing for Natural Regeneration

Canopy gain within the category of existing tree growth was analyzed from collected data to determine what specific changes were classified as existing tree growth. Single tree canopy expansion was the largest component of canopy gain from existing trees, with approximately 51% of growth in this form. Other types of "existing tree growth" include fields growing over and forests expanding into non-forest areas such as grassland. These types of expansion are not the result of a single tree growing larger but are instead a combination of multiple trees growing into new areas. This incursion into new areas by both new tree establishment and existing tree growth made up 49% of "existing tree growth". This supports allowing natural regeneration of trees as a means to provide for new forest canopy.

In our study we defined urban areas as being managed through regular disturbance, typically mowing, that inherently restricts young trees from seeding or sprouting. Priest and Najar (2019) found trees with a trunk diameter less than 4 inches made up two-thirds of all trees in Arlington parks and 95% of the time these were native species, which shows natural regeneration can result in desirable mature forests. The principle need is to reduce the frequency of mowing and protecting tree seedlings that develop during periods without disturbance. Doing so could allow hundreds of thousands of new trees to develop and grow, providing tree canopy at little or no cost. This approach is slower, similar to planting smaller specimen trees, but the natural trees will never experience transplant shock or the resulting growth delay. As a result, these trees will grow rapidly and better withstand circumstances such as drought. This multifunctional approach needs to be discussed with internal groups such as code compliance and planning and development, as well as external stakeholders. **Allowing reduced mowing, possibly in conjunction with butterfly or wildflower garden areas, will require modification to city ordinances regarding what is considered nuisance landscape. Although there may be disagreement to the level of maintenance needed in such areas, Forestry and Beautification supports the development of this approach to increasing tree canopy as there is minimal direct cost to any party involved.**

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Appendix A

Timeline of climate events in Texas' recorded history (NPR 2011).

- **1822:** The first colonists under Stephen F. Austin find Texas weather tough on farming. Their "initial food crop of corn dies from lack of moisture," according to the timeline. The first droughts are recorded in 1870, then again in 1885-1887.
- **1900:** While the early years in Texas were dry, the turn of the century was the opposite: "Heavy rains falling on the Colorado River watershed caused the river to crest 11 feet above the Austin Dam," the timeline says, "ultimately destroying it." Another flood will destroy the re-built dam fifteen years later. In 1940, it is rebuilt by the LCRA and becomes the property of Austin.
- **1908-1912:** Texas has another drought. It has a strange effect on one citizen, C.W. Post, who "spends four years and $50,000 on 23 attempts to use explosives to cause rain. He dies in 1914 believing that he could "shoot up a rain" whenever he wanted to," according to TWRI. There's another drought from 1924-1925.
- **1917-1920:** Drought relief laws are passed, which allow counties to lend funds for "citizens to purchase seed and feed." Irrigation canals are started on the High Plains.
- **1925-1929:** The first water control and improvement districts are formed, and the Brazos River Conservation and Reclamation District is created, the first of its kind. The district is "created specifically for the purpose of developing and managing water resources of an entire river basin." A drought follows in 1933-1934.
- **1934-1935:** The great dust bowl hits, with sand storms in Amarillo for three months. "Seven times, the visibility in Amarillo declines to zero," TWRI says. "One complete blackout lasts 11 hours and one storm rages for 3 ½ days." A drought happens again in 1938-1940.
- **1950-1957:** The drought of record occurs, the driest period in our state's known history. The city of Dallas restricts lawn watering, and all but ten of the state's counties are listed as "drought disaster" areas by President Eisenhower.
- **1957:** The drought ends in the spring with "heavy, general rains." The downpours result in major flooding. Several are killed and hundreds of homes are destroyed. But it isn't long before another drought arrives, from 1961-1967.
- **1962:** In the midst of the first drought since the 50s drought of record, a cold wave strikes, "comparable to the cold waves of 1899 and 1951," according to TWRI. During the second week of January, temperatures in the Panhandle drop to below fifteen degrees, and "agricultural losses are $50 million," the timeline says.
- **1965:** The worst dust storm in a decade hits Lubbock, with wind gusts up to 75 mph "and dust billowing to 31,000 feet." The timeline reports that "the rain gauge at Reese Air Force Base, Lubbock, contains 3 inches of fine sand" and visibility was reduced to 100 yards. Another sandstorm in 1977 destroys millions of dollars worth of winter wheat and injures 20 in El Paso. Yet another drought hits in 1970-1971.
- **1984-1985:** Conservation becomes the new focus for the state's water plan. "Conservation of water, which is recognized as being more economical than developing

new sources of water," the timeline states, "becomes a key factor for granting water permits by the Texas legislature." A drought arrives in 1988-1990.

- **1995-1996:** Another drought strikes, this one with more agricultural losses than any other one-year drought.
- **1999-2002:** Another drought arrives. In August of 1999, "excessive heat throughout August resulted in 16 fatalities in the Dallas/Fort Worth area. The airport reported 26 consecutive days of 100°F or greater temperatures," the timeline says. The next year, extreme heat strikes again, with a 10-day average of 103.3 degrees Fahrenheit at the Dallas/Fort Worth airport. 34 die because of heat in the state. And in 2001, the Rio Grande ceases flowing into the Gulf, and hundreds of millions of dollars worth of crops are lost in the South Plains.
- **2005-2006:** Yet another drought, this one with statewide losses of $4.1 billion. A two-year drought begins in 2007.
- **2008:** Hurricane Ike hits Texas, with winds around 110 mph. The storm kills twelve, injures another 25 and "damage amounts were near $14 billion," according to the timeline.
- **2010-2013:** The record-setting drought causes losses in agriculture and millions of tree deaths statewide. 2011 was the driest year on record in Texas history, and the least rainfall since 1917.
- **2014-2060:** The timeline shows that the state's population is projected to grow from 25.1 million in 2011 to 46.3 million in fifty years. The water demand at that point is estimated to be 22 million acre-feet a year, an increase of twenty percent over our current demand of 18 million acre-feet a year.

Appendix B

Depiction of evaluation categories and subsets for clarification.