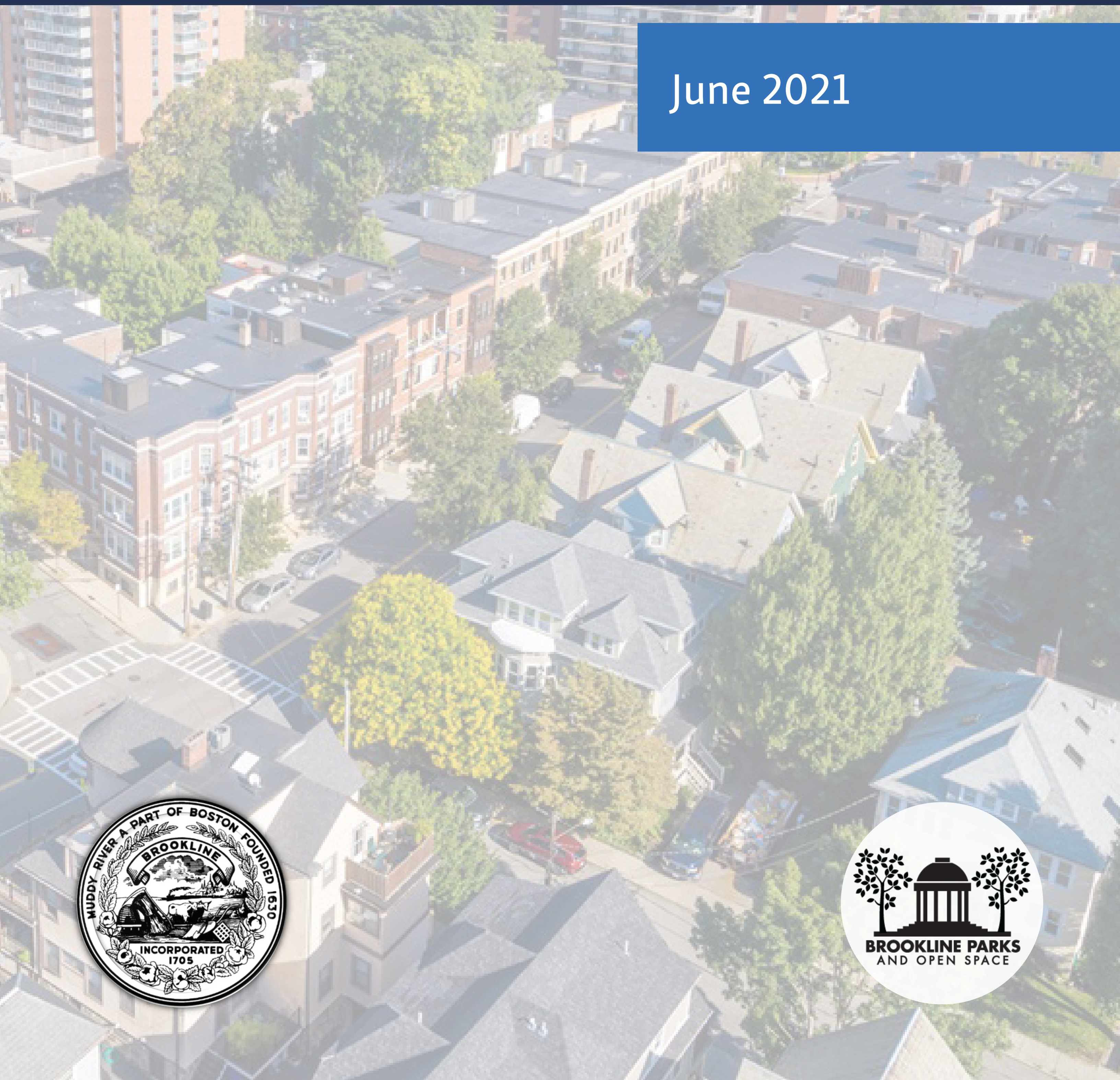
BROOKLINE URBAN FOREST CLIMATE RESILIENCY MASTER PLAN

June 2021



MUDDY RIVER A PART OF BOSTON FOUNDED 1630
BROOKLINE
INCORPORATED 1705

BROOKLINE PARKS AND OPEN SPACE

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TOWN of BROOKLINE
Massachusetts
DEPARTMENT OF PUBLIC WORKS
PARKS AND OPEN SPACE DIVISION

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Alexandra Vecchio
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Dear Reader,

The Brookline Department of Public Works, Parks and Open Space Division, is pleased to present the 2021 Brookline Urban Forest Climate Resiliency Master Plan. Over the past 20 years, the Town of Brookline has taken great strides towards climate resiliency and adaptation, and has widely incorporated climate considerations into projects, plans, and policies across departments. The development of this Plan was underpinned by these previous efforts and spurred by the recommendations of previous planning processes. Most notably, an urban forest master plan was identified as a priority in the Town's Climate Vulnerability Assessment and Action Plan (2017), and was recognized as a necessary planning tool following Brookline's first Sustainability and Climate Action Summit (2019).

The Plan was developed during a particularly difficult year, in which the United States tackled the devastating effects of Covid-19, while also grappling with the pain and trauma of violence against Black Americans. Public health and climate justice/equity were chief considerations throughout the development of this Plan. As part of the inventory process, the project team identified areas/communities that are particularly under-served in terms of tree planting and/or are more vulnerable to the impacts of climate change. Recommendations were specifically developed to address tree canopy distribution inequities, as well as issues related to heat, safety and accessibility.

We owe a debt of gratitude to the Select Board's Committee on Tree Protection, which led the public planning process. Comprehensive community outreach was critical to this project, and included four public forums, two final presentations, a community survey, site visits to Brookline Housing Authority properties, a social media campaign with a local environmental advocacy group, yard signs, and more. We truly believe that Brookline is strongest when everyone is heard and able to contribute, and hope that these engagement efforts have not only been informative, but encourage stewardship of the urban canopy amongst Brookline residents.

It is important to note that climate scientists are discovering new information on the impacts of climate change daily. As we move forward to implement this Plan, we must be mindful of new scientific findings regarding forestry and climate, as well as new green infrastructure technologies. Equally as important, we must commit to extensive collaboration across municipal departments, and ongoing communication with neighboring municipalities with whom we are facing these climate crises.

Very truly yours,

Erin Chute Gallentine
Commissioner of Public Works

Alexandra Vecchio
Director of Parks and Open Spaces

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EXECUTIVE SUMMARY 1

Current projections indicate that, over the coming decades, climate change will bring warming temperatures, a decrease in air quality, changing precipitation patterns, more frequent extreme weather, and an increase in threats from pests and diseases. These significant environmental impacts will put Brookline's urban forest at risk, including its ability to filter groundwater, mitigate intense storms, control erosion, moderate extremes in temperature, sequester carbon, provide wildlife habitat and food, bolster the economy and frame cultural and natural landscapes. To combat climate-related challenges, the Town must act now to ensure the urban forest is resilient, robust, and equitably distributed.

Among their many benefits, trees capture and store large amounts of carbon from greenhouse gas emissions and provide valuable shading. Unlike some other strategies for mitigating rising temperatures, trees don't require costly and complicated technology. Since the 1700s, Brookline has fostered the development of its urban forest; consequently the canopy is a well-established asset that plays a large role in offsetting the impacts of climate change. The Town has very good overall tree canopy coverage (44.7% in 2020) comprised of approximately 204,000 trees. However, the tree canopy coverage is not distributed equally across the Town, with North Brookline's dense population exhibiting the lowest canopy cover.

North Brookline also has a high percentage of heat-retaining impervious surfaces in addition to its relatively low canopy coverage. These conditions place it under threat from higher temperatures and localized areas of poor air quality as a result of climate change which is further exacerbated by the urban heat island (UHI) effect. The environmental impacts of these challenges are expected to be significant and may directly affect resident health and well-being. In addition, these impacts disproportionately affect Brookline's most vulnerable or at-risk populations. Rising temperatures will also affect the composition of the urban forest itself, with climate change altering environmental niches and shifting habitat ranges. However, through policy, management, and implementation changes, Brookline can protect and grow its urban forest to its full potential.

Substantially increasing tree canopy coverage in Brookline will require detailed planning, comprehensive interdepartmental coordination, and enhanced community education and outreach. This Master Plan recommends that Brookline strive to achieve a Town-wide canopy goal of 49.1% coverage over the coming decade which will require the planting of 900 trees on public and private land each year for the next 10 years. This goal aims to dramatically improve the environmental and health benefits associated with additional canopy coverage in North Brookline. Every 10% increase in tree

canopy coverage can decrease the ambient air temperature by one degree Fahrenheit, which can lead to one less heat related ambulance visit per month. To facilitate new tree plantings in this urbanized area with large swathes of pavement, roads will need to be redesigned to accommodate street trees and paved areas on private land will need to be converted to planting areas.

Even with trees providing environmental and health benefits, adding other 'green' improvements to the Town's suite of climate change mitigation and adaptation tools can do even more, e.g. converting roofs to green roofs or using light colored roofing materials, reflective pavement and permeable pavement.

Planting large quantities of new trees each year is a good way to increase the tree canopy coverage for future generations, to replace species that are susceptible to pests and disease brought on by climate change, to increase biodiversity, and to replace trees that will be lost naturally due to age. It is even more important for both the short and long-term health of the urban forest to protect and care for existing trees.

The tree canopy analysis conducted as part of this planning process revealed that the Town's coverage decreased from 46.3% in 2014 to 44.7% in 2020, which amounted to a net loss of 71 acres of tree canopy. Most of this loss occurred on one to three family residential properties in South Brookline. More protection for existing trees is critical to prevent further private tree loss as a result of development and redevelopment. Greater protection can be provided by establishing an effective tree protection bylaw and developing canopy-specific guidelines to be considered under Design Review (Zoning Bylaw, Section 5.09), as well as conducting more outreach and education with private landowners. Absent any tree removal or loss, the tree canopy in Brookline would naturally grow 25 acres per year.

The Town manages an urban forest with a great legacy; consequently it has large, mature trees that provide significant benefits. However, these same trees can be time-consuming and expensive to care for. More resources are needed to fund the forestry and landscape sector to care for the approximately 60,000 public trees under their jurisdiction, particularly if the tree canopy is to grow. The cost of privately contracted tree pruning has risen almost 300% since 2008 and will severely impact the ability to proactively prune trees on a regular basis, respond to storm damage and residents' requests, and ultimately achieve the tree canopy coverage goals needed to mitigate the effects of climate change.

In order to administer, manage, and protect the urban forest, a full-time Tree Warden is needed. Additionally, a good strategy to control the costs of tree pruning and planting, while also increasing the standard of care, would be to hire two arborists and purchase a bucket truck, chipper and log truck for Town use.

This Climate Resiliency Urban Forest Master Plan establishes challenging, but achievable, goals for tree canopy expansion, tree care and protection. The urban forest is a character-defining feature of Brookline and greatly effects the well-being and health of its residents. The Town has a long history of forward-thinking tree planting and planning, and that legacy will live on with implementation of this plan.

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CLIMATE CHANGE IMPACTS

Climate Change Overview

Introduction

There is considerable scientific, data-based research and text, from public and private sources, on the topic of climate change. Our understanding of this phenomenon is informed by a worldwide network of weather records and modeling derived from historical data, advanced scientific tools, emission predictions and climate trends. While the Earth's climate has always fluctuated, the rapid pace of change that we see today cannot be explained by natural causes alone. Evidence overwhelmingly suggests that an increase in greenhouse gases, such as carbon dioxide, are causing the climactic trends we are seeing today. (DeGaetano et al, 2011; Wuebbles et al, 2017)

When discussing climate change, it is imperative to recognize the differences between the terms "climate" and "weather." While the Earth is experiencing an overall warming trend, any individual year, season, or day may be colder or warmer than the climactic trend might indicate due to factors such as volcanic eruptions, El Niño/La Niña weather patterns, or changes to the jet stream (fast-flowing air currents in the atmosphere). While weather is the daily, seasonal and annual variability we experience, climate change refers to shifts in conditions that occur over decades, or even longer. (DeGaetano et al, 2011)

The magnitude and speed of future climate change will depend primarily on the amount of greenhouse gases, especially carbon dioxide, emitted across the globe. If global emissions continue at their current rate, it is predicted that by the year 2100, the global average annual temperature will have risen 9°F above that of the preindustrial era (prior to 1750). However, with significant reductions in emissions, that increase could be limited to 3.6°F or less by 2100. Emissions reductions would need to be at least as aggressive as those in the Paris Agreement to meet this target. (Wuebbles et al, 2017)

While climate change is a global issue, its impacts are variable and depend heavily on factors such as geography and an area's unique societal and demographic characteristics. Still, due to the intricacies of globalization and interwoven global economies, the fates of international communities are intimately linked. Even within Massachusetts, urbanized areas, such as Brookline, depend on rural communities for agriculture and recreation. Meanwhile, the rural areas of Massachusetts depend on the economic capacity of the urban cities. Analyses of regional and local impacts can help communities prepare for, and respond to, climate change using the most relevant tools and resources to develop climate resilience. (Dupigny-Giroux et al, 2018)

Regional and Local Climate Change Impacts

The Northeast region of the United States has a four-season climate and a diversity of ecological communities that improve quality of life, support local and regional economies, and contribute to cultural identity. Beaches and forests provide recreation for residents and the many tourists that contribute heavily to the regional economy. The region's seasonal climate, ecosystems, recreational opportunities and economies are threatened by a decline in snow and ice, rising coastal sea levels, and increasing temperatures.

The coastal areas of the Northeast are rich in history and in ecological and economic services. However, the region's productive fisheries, marshes and infrastructure are sensitive to the changing environmental conditions that accompany climate change. Shifting air and water temperatures, ocean acidification, storm surges, sea level rise, flooding and erosion are already affecting our coastal communities. As the most densely-populated region in the country, the ecosystems of the Northeast have the added pressure of withstanding intense development and human impacts. (Dupigny-Giroux et al, 2018)

Residents of urbanized areas, such as Brookline, are being challenged by a number of physical climate changes - extreme temperatures, poor air quality, intense weather events and more frequent flooding. These environmental changes are expected to lead to more adverse health impacts, including additional deaths and emergency room visits, a higher risk of infectious diseases, lower quality of life, and the increased costs that come with an increased use of healthcare services. Some people - the elderly, disabled, marginalized, those with low incomes, recent immigrants and language-isolated individuals - are particularly vulnerable because of their limited ability to prepare for and cope with climate challenges and its associated heath risks. Climate hazards can also lead to emergency evacuations and the short or long-term displacement of residents. Impacts on communities will include the need to provide emergency services, a plan for rebuilding, and support for displaced populations. (Dupigny-Giroux et al, 2018)

The Northeast's long history of development means that the region has an older housing stock and an aged critical infrastructure system that is at particular risk to climate shifts. Extreme weather damage to critical infrastructure, such as water, sewer, energy, transportation, and telecommunications systems, would increase the risk of system disruption, creating a decrease in quality of life, a drop in economic productivity and increasing social inequality. The interconnectedness of these infrastructure systems exacerbates the risks of climate-related disruptions.(Dupigny-Giroux et al, 2018)

Temperature

Since 1901, temperatures in Massachusetts have risen approximately 3°F. (Runkle et al, 2017) By 2035, under a range of greenhouse gas emission models, the Northeast region of the United States is expected to be approximately 3.6°F warmer than it was at the start of the 20th century (Figure 2-1). That is the largest expected temperature increase in the contiguous United States. The Northeast will experience this temperature increase up to 20 years before the global average reaches that same threshold. By 2050, as the warming continues, the average annual temperature in the Northeast is expected to be between four and five degrees higher than it was in 1900. (Dupigny-Giroux et al, 2018)

Observed and Projected Temperature Change

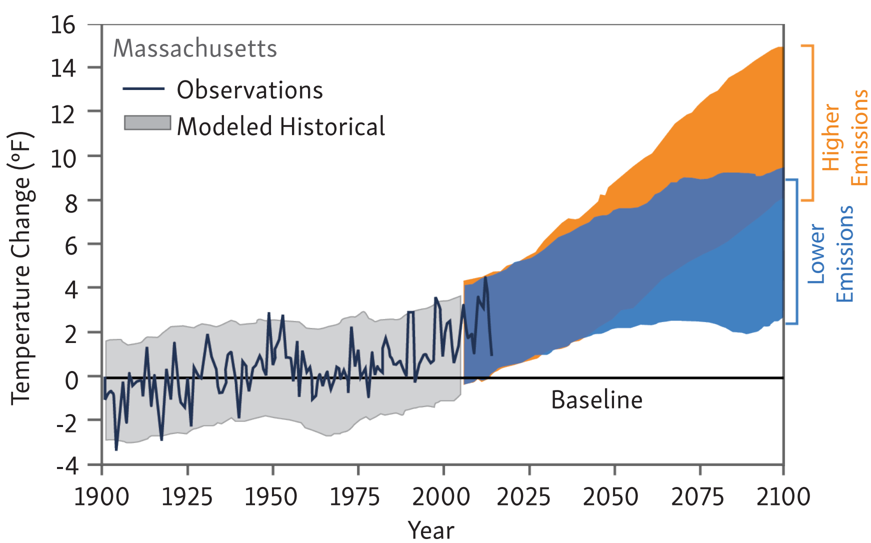


Figure 2-1: Air Temperature Change for Massachusetts

Historical and projected temperature change in Massachusetts shows a trend of rising air temperature over time.

Figure source: Dupigny-Giroux et al, 2018

Boston Area Average Annual Temperature Is Increasing

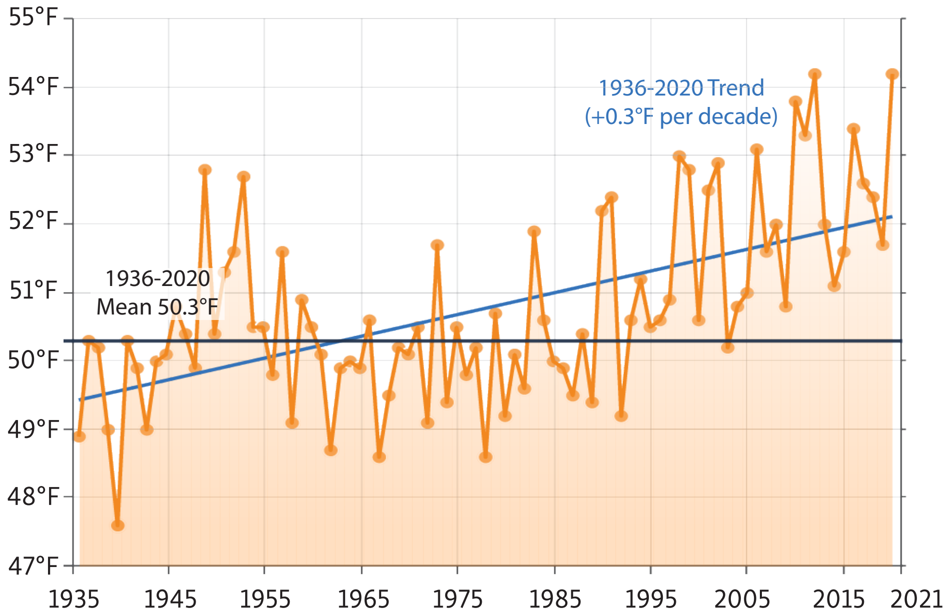


Figure 2-2: Average Annual Temperature 1936-2020, Boston, MA

Average annual recorded temperature (January-December) at the Boston weather station (USW00014739) located at Logan Airport. Period record 1-1-1936 to present.

Data source: https://www.ncdc.noaa.gov/cag/

In the Boston area, temperatures have been rising an average of 0.3°F each decade since the mid-1930s (Figure 2-2). These increased temperatures combined with high humidity create dangerous conditions where the human body struggles to cool itself. The National Weather Service tracks heat indexes that combine temperature and humidity to determine what a given combination feels like. By 2065, the number of "feels like 100°F" days will double compared to the year 2000. By 2100, the number of "feels like 100°F" days will quadruple relative to the year 2000. (UCS, 2019)

The National Oceanic and Atmospheric Administration's National Centers for Environmental Information found that by 2100, a Massachusetts summer will feel like a present-day summer in Maryland (under a low carbon emission projection) or a present-day summer in South Carolina (under a high carbon emission projection). From 1971-2000, the Northeast experienced, on average, nine days over 90°F each year. By the middle of this century, modeling suggests that the region will experience 19 to 44 days over 90°F, depending on the carbon emission projection used. (Melillo, Richmond and Yohe, 2014) When considering 5-year averages from 15 long-term reporting stations in Massachusetts from 1950-2014, the number of hot days (over 90°F) in the state has been above average since the 1990s. In addition, using the same data set, the frequency of warm summer nights (low temperatures over 70°F) has also been increasing since the mid 1990s. (Runkle et al, 2017)

Summer is not the only season showing a trend in increasing temperatures. In Massachusetts, and across the continental U.S., the number of very cold nights with minimum temperatures below 0°F has been below average since the 1990s. (Runkle et al, 2017)

In fact, the temperature differences between seasons in the Northeast have narrowed as average winter temperatures have increased three times faster than average summer temperatures. As this trend toward milder winters continues, it is anticipated that by 2050, the Northeast will experience a shorter cold season with fewer frost days and a longer transition period between winter and summer. (Dupigny-Giroux et al, 2018)

There is a wide range of temperature increases predicted, depending on which models are considered. In general, however, heat waves are expected to increase in their intensity and frequency while cold spells are expected to decrease. Densely populated urban areas, such as North Brookline, are particularly vulnerable to the impacts of extreme heat, including heat-related illnesses and fatalities. (Runkle et al, 2017)

Heat Island Effects

Increasing daily average temperatures and prolonged heat waves are exacerbated in urban areas due to the urban heat island effect. The urban heat island effect is the tendency for higher air temperatures to persist in urban areas, making cities warmer than surrounding areas, both during the day and at night (Figure 2-3). During daylight hours, urban areas tend to be warmer because they generally have less vegetation than rural or suburban areas. (EPA, 2020; UCAR, 2020) Trees and other vegetation not only help to lower surface and air temperatures by providing shade, but also cool the environment through the process of evapotranspiration, in which plants release water to the surrounding air, thereby dissipating heat. (EPA, 2020)

Urban areas also contain a greater proportion of heat-retaining materials (such as asphalt roadways, concrete sidewalks, and infrastructure) and heat-emitting sources (such as vehicles, industrial facilities, and air-conditioning units). (EPA, 2020; UCAR, 2020) At night, the extra heat that has been absorbed by these materials during the day is radiated back into the air, in some cases increasing local air temperatures up to 22°F. (CalEPA, 2020) Calm and clear weather tends to create the most severe effects because there is maximum heating during

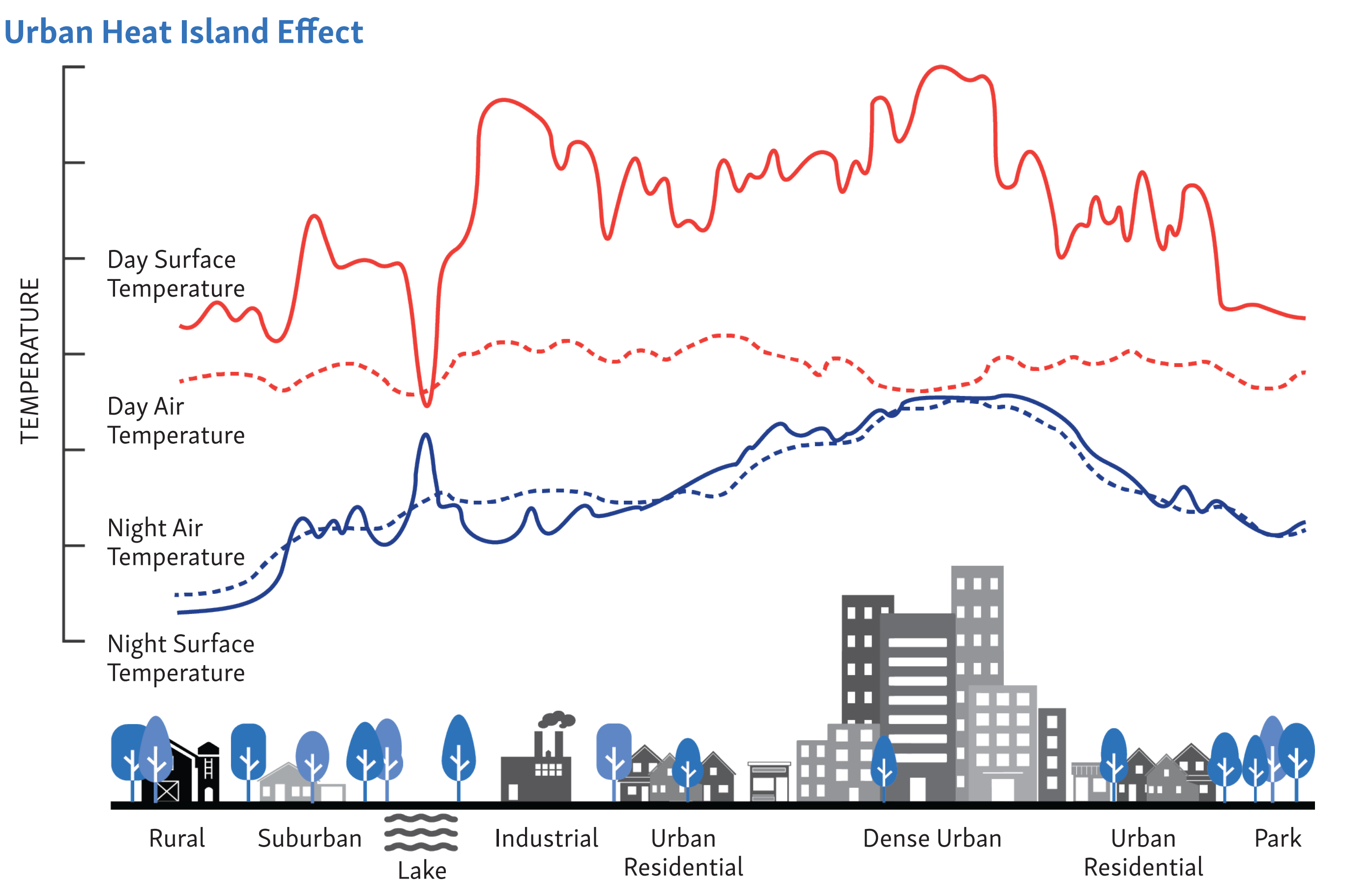


Figure 2-3: Example of the Urban Heat Island Effect

Surface and air temperatures vary based on land use, groundcover and tree canopy shading. During the day, surface temperatures fluctuate more than air temperatures. At night, surface and air temperatures are fairly similar, but urban areas still remain warmer at night than more rural areas.

Figure derived from: EPA, 2020

Observed Ambient Temperatures at 6 a.m.

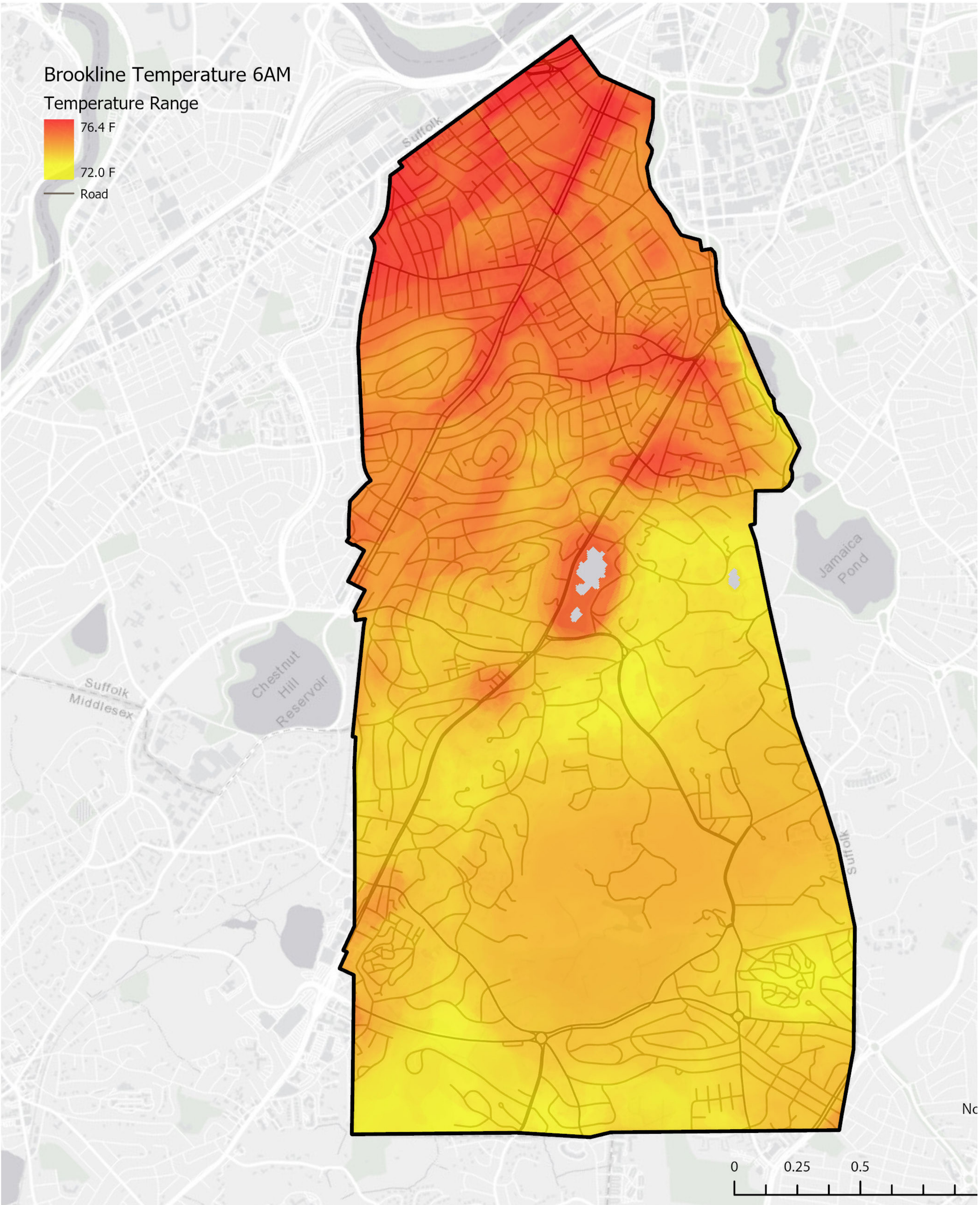


Figure 2-4: Observed Ambient Air Temperatures on July 29, 2019, 6 a.m.

Even in the early morning hours, higher temperatures are concentrated in more urbanized areas where pavements hold heat, through the night. The area surrounding the Brookline Reservoir, which acts as a moderator of temperature change, is also considerably warm, because the water has been increasing in temperature slowly throughout the summer.

Figure source: Data collected through Museum of Science's heat mapping campaign, named "Wicked Hot Boston" (Museum of Science)

Observed Ambient Temperatures at 3 p.m.

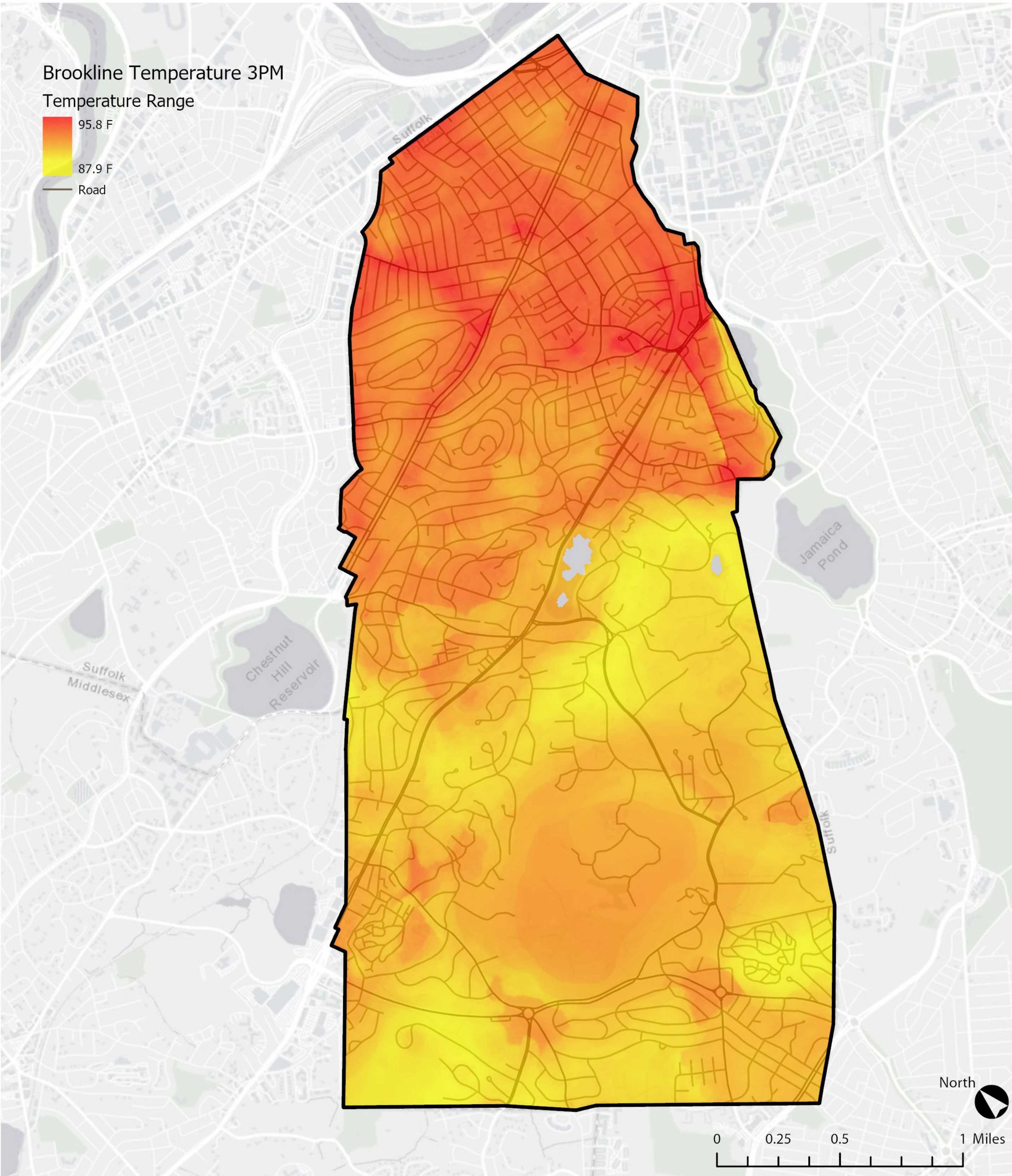


Figure 2-5: Observed Ambient Air Temperatures on July 29, 2019, 3 p.m.

By mid-afternoon, all of Brookline has warmed, but areas with more canopy cover (South Brookline) are cooler than areas that have more pavement and impervious surfaces (North Brookline). The moderating effect of the Brookline Reservoir now makes the surrounding area cooler than it would be if the reservoir were not present.

Figure source: Data collected through Museum of Science's heat mapping campaign, named "Wicked Hot Boston" (Museum of Science) the day and little wind to carry heat away. (EPA, 2020) The urban heat island effect is primarily influenced by local land cover. As a result, ambient air temperatures and their heat-related health effects can vary significantly over even small geographic areas (Figures 2-4 and 2-5). (Dupigny-Giroux et al, 2018)

Urban heat islands experience higher daytime temperatures and less cooling at night. Residents of areas experiencing the urban heat island effect are at greater risk of heat-related illnesses and deaths, as well as diminished air quality that has its own negative health impacts. (EPA, 2020)

Efforts to cool interior spaces also play a role in the urban heat island effect. Preliminary studies have shown the effect to be most pronounced in the evenings when residential and commercial facilities are using air conditioning systems, releasing waste heat into the environment. An emerging area of research is investigating the role of waste heat in urban heat island formation. Increased usage of air-conditioning units increases the demand for electricity that relies heavily on fossil fuel power plants, exacerbating climate change by causing an increase in greenhouse gas emissions. (EPA, 2020)

Power plant emissions also impact human health and contribute to air quality problems, including fine particulate matter, acid rain, and the formation of ground-level ozone, also called smog. Elevated temperatures in urban areas also increase the rate of ground-level ozone formation that requires sunlight and hot weather to form. (EPA, 2020)

Precipitation

The past 20 years have been the wettest years on record for Massachusetts. Annual precipitation amounted to an average of 51 inches, compared to the long-term average of 45 inches (Figure 2-6). (Runkle et al, 2017) In

Average Annual Precipitation

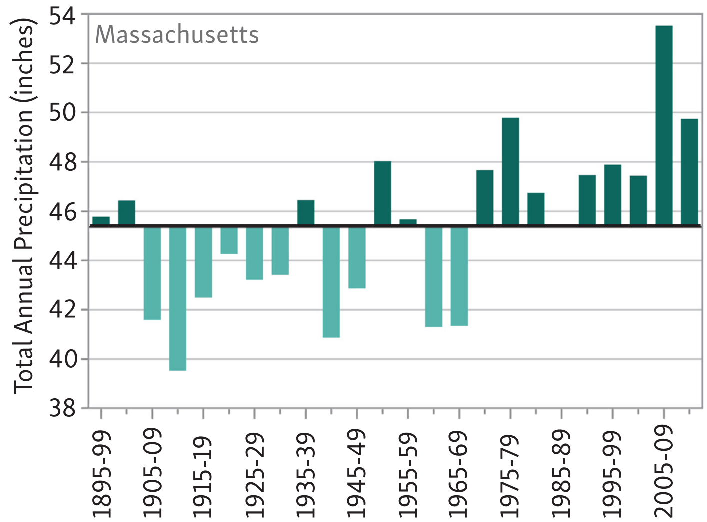


Figure 2-6: Observed Annual Precipitation

Massachusetts' annual precipitation averaged over five-year periods. The dark horizontal line represents the long-term average. Annual precipitation has been highest in the most recent decade.

Figure source: Runkle, 2017

Frequency of Extreme Precipitation Events

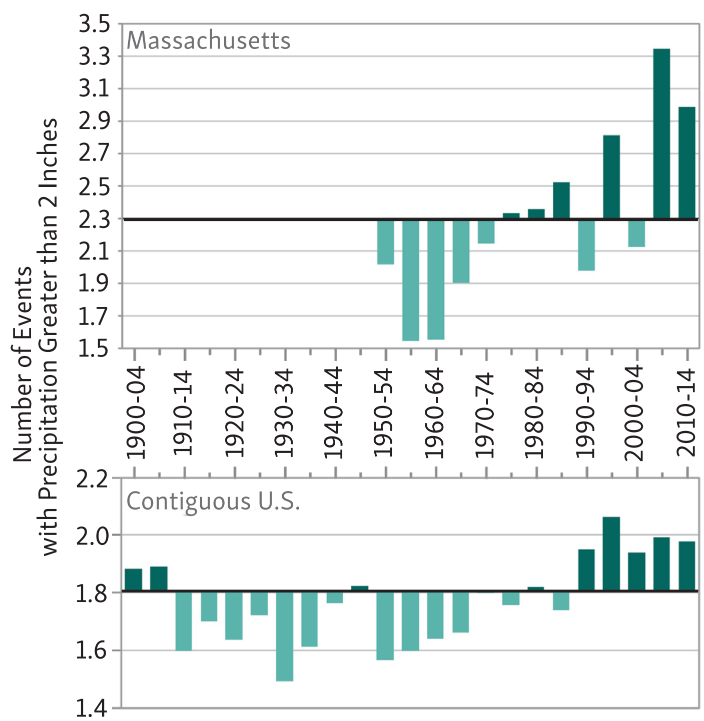


Figure 2-7: Observed Number of Extreme Precipitation Events (>2 Inches) Averaged over Five Year Periods

The dark horizontal line represents the long-term average. Values for the contiguous United States are shown for context because long-term station data is not available for Massachusetts.

Figure source: Runkle, 2017

the Northeast, increases in total precipitation volumes are expected primarily during the winter and spring, with little change in total precipitation predicted for the summer months. Under some high emission projections, it is anticipated that by 2070, December to April's monthly precipitation will be about 1 inch greater than it has been historically. (Dupigny-Giroux et al, 2018) Due to the projected increase in winter temperatures, approximately 12-30% of winter precipitation is expected to fall as rain, rather than snow. In fact, snow events in Massachusetts winters are expected to fall from a historical average of five events per month to anywhere between one and three events per month. (Runkle et al, 2017)

Precipitation events have also been growing in intensity over the past 50 years. From 1958-2012, the Northeast region of the United States experienced a 71% increase in the amount of rain falling during very heavy storm events. (Melillo, Richmond and Yohe, 2014) Since 2005, Massachusetts has experienced about 30% more days than average where more than 2 inches fell over a 24-hour period (Figure 2-7). The frequency of extreme precipitation events is projected to more than double by the end of the 21st century and storm intensity in the Northeast is expected to exceed that of other parts of the country. (Runkle et al, 2017)

With rain falling in fewer, more intense storms, the volume of water falling per storm will increase. Storms with more intense precipitation are likely to result in flooding which causes erosion, damage to property, injury, and even death. (Melillo, Richmond and Yohe, 2014) Changes in precipitation patterns will also affect agriculture and natural ecosystems. Within the Northeast, with more precipitation expected in the winter and spring (Figure 2-8), planting may need to be delayed, while summer could bring drought conditions as warmer temperatures increase evaporation. (Melillo, Richmond and Yohe, 2014)

In addition, more intense storms may impact infrastructure, particularly transportation. Heavy storms can cause roadway washouts, scouring, and roadway rutting. Temperature shifts and precipitation shifts could cause more frequent freeze-thaw periods, increasing the possibility of pavement cracking and the formation of potholes. Because of the population density of the Northeast, extreme storms at the region's airports can cascade, having effects on passenger and cargo movements across the United States. Researchers expect that climate change will strain the nation's infrastructure networks and raise the costs of maintaining, repairing, and replacing our power, transportation and telecommunications infrastructure. (Dupigny-Giroux et al, 2018)

Projected Percent Change in Spring Precipitation

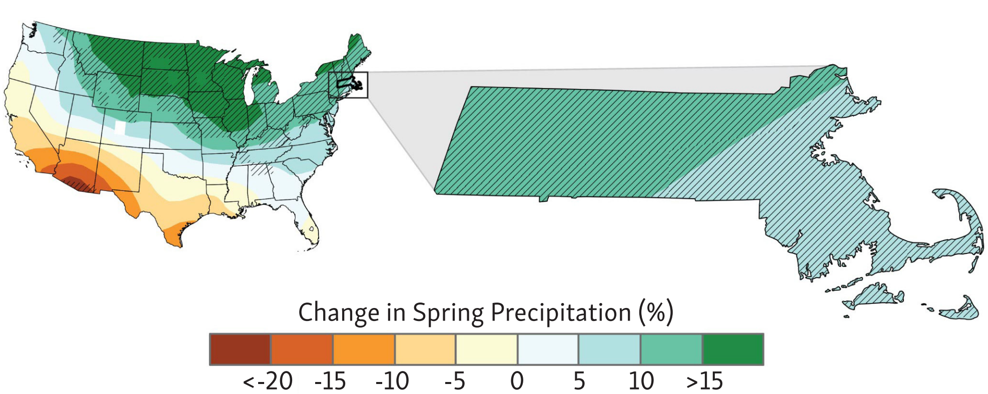


Figure 2-8: Projected Change in Spring Precipitation in Massachusetts

The potential percent change in spring precipitation for 2050, compared to the late 20th century, under a high emissions scenario. Hatching shows areas where the models indicate that the projected change is statistically significant.

Figure source: Runkle, 2017

Drought

From 1981-2010, Massachusetts received, on average, 3.2 to 4.3 inches of rain each month. However, droughts are not uncommon in the region. For example, according to the National Oceanic and Atmospheric Administration's U.S. Drought Monitor, over half of the state was affected by a D3 drought (Extreme Drought) in September of 2016, with widespread water restrictions and reports of crop losses. Since 2000, Massachusetts' longest duration of drought was almost one year long, from mid-2016 to mid-2017. (Massachusetts Wildlife Climate Action Tool, 2017c; NIDIS, 2020)

More recently, in October 2020 after several months of below average summer rainfall, the Commonwealth of Massachusetts issued a Level 3 Drought Status (Critical Drought)for the Charles River Watershed, including Brookline, in October 2020. Brookline's streams were in low-flow conditions, groundwater reserves were diminishing, and there was an increased risk for drought-induced fires. A few months of heavy winter precipitation returned Brookline to normal levels. However, as of mid-April 2021, with precipitation, streamflow, and groundwater below normal levels, the Town is under a Level 1 Drought Status (Mild Drought). (MA EEA, 2021)

Historical records indicate that recent droughts (over the last 60 years) in the Northeast have been more frequent and more severe than those in the very distant past (those found using paleoclimate records). Climate change may bring increased evaporation and lower snowmelt as a result of warmer temperatures. Therefore, the increase in extreme precipitation events could intensify the effects of any naturally occurring drought. (Massachusetts Wildlife Climate Action Tool, 2017c; Runkle et al, 2017)

In general, the Northeast currently experiences relatively short-term droughts of six months or less. This category of drought is expected to increase in frequency, with the greatest risk in the summer and early fall due to higher temperatures that result in greater evaporation. Snow melting earlier in winter and spring could mean that the late spring and summer growing seasons will start with lower water levels, thereby stressing crops, ornamental plants and trees. Hot summer days with reduced soil moisture would also worsen any drought's effects, further intensifying those stressors. (Massachusetts Wildlife Climate Action Tool, 2017)

Ecological drought is relatively recent term developed to describe the interconnected effects of drought on fish, wildlife, their habitats and human communities. Ecosystems that have been altered by human development, such as towns and cities, are more vulnerable to drought due to competition for limited water resources. In particular, droughts weaken trees, making them more vulnerable to pests, including the emerald ash borer and southern pine beetle, and stunting their growth over an entire season, or permanently. This diminishes the ecological benefits the trees could be providing. (USGS CASC)

Young trees in particular are susceptible to drought stress. Recently planted trees have a limited root mass which reduces the tree's ability to absorb sufficient water. In times of extreme heat or drought, trees need to receive supplementary watering. Without additional watering, young trees are likely to experience a high rate of mortality due to droughts.

Flooding

Increased precipitation and more intense storms also challenge the local infrastructure, including the stormwater network. Extreme precipitation events can bring flooding, overwhelm the storm sewer system, and result in power outages. (MAPC, 2017) Across the Northeast, much of the existing infrastructure, including drainage systems, flood protection measures, transportation systems, and aspects of the power grid are past or nearing the end of their life expectancy. New stressors related to climate change will deepen the existing issues related to an aging infrastructure network. (Dupigny-Giroux et al, 2018)

Infrastructure failures are a particular threat to dense, urban areas, such as North Brookline, as any single event would affect a significant number of people. The extent of the damage could require intensive emergency response efforts, potentially stretching local governments beyond their existing resources. (Dupigny-Giroux et al, 2018)

In Brookline, many stormwater outfalls discharge directly into the Muddy River. When river levels rise in heavy storms, the outfalls can be submerged, creating backups in the system. (Brookline Conservation Commission, 2019) The U.S. Army Corps of Engineers is currently leading the Muddy River Restoration Project to improve flood control and minimize risk to vulnerable properties and infrastructure. (MMOC, 2021)

Sea Level Rise

While Brookline is not expected to experience a widespread impact from sea level rise, localized impacts from Brookline's primary floodplain are anticipated. A floodplain is a low-lying area, bordering a stream or lake, that is vulnerable to flooding during and after storms. Brookline's major floodplain is located along the Muddy River, from Wards Pond to the intersection of Park Drive and Brookline Avenue. As sea level rise causes flooding along the Charles River, flood waters could impact Brookline's floodplain (particularly in storm surge conditions). (Brookline Conservation Commission, 2019; MAPC, 2017)

From 1921 to 2006, relative sea level in Massachusetts increased 0.1 inch per year. This translates to about 10 inches gained over the past century - an increase substantially greater than the global average. This can, in part, be attributed to natural land subsidence along the eastern coast. The result has been an increase in tidal nuisance floods that generally have minor impacts but can still affect infrastructure, result in road closures, and overwhelm the storm sewer system. Projections indicate that Massachusetts could experience a sea level rise of between one foot and six feet by 2100 (Figure 2-9). (Runkle et al, 2017)

Changes in Global Sea Level

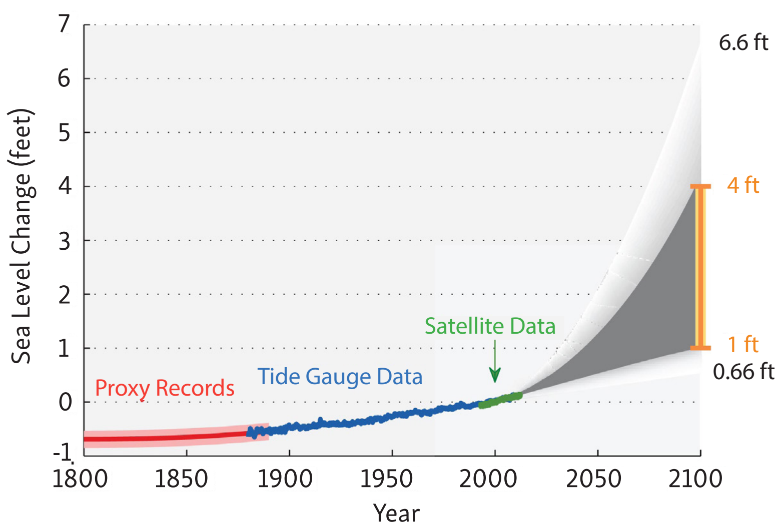


Figure 2-9: Past and Projected Changes in Global Sea Level
Estimated, observed, and possible future amounts of global sea level rise from 1800 to 2100, relative to the year 2000. The orange bar at the right shows the most likely range of sea level rise at 1 to 4 feet by 2100, based on current scientific studies. The full possible range is 0.66 feet to 6.6 feet.
Figure source: Runkle, 2017

Effects on People

Climate change impacts, along with other stressors in the environment, influence health and disease prevalence in a population. Some climate-related challenges, such as ground-level ozone, allergies, and heat-related deaths, are present already and will likely intensify with climate change. Other threats will be new, such as pressures on food and water safety from rising air and water temperatures. (CDC, 2020)

Some examples of health impacts that may result from the environmental shifts accompanying climate change include:

- Extreme heat, which can lead to cardiovascular failure, heat-related illnesses, and death (Figure 2-10)
- Severe weather, including winter storms, flooding and droughts, which can cause falls, injuries, fatalities, and mental health pressures such as anxiety and post-traumatic stress disorders
- Air pollution, which can cause asthma and cardiovascular disease, and affect individuals already suffering from those conditions
- Changes in pest ecology, creating changes in the patterns of diseases such as hantavirus, Lyme disease, and West Nile virus
- Increased allergens, which can cause respiratory allergies and asthma
- Water quality degradation, leading to waterborne illnesses and harmful algal blooms
- Water and food supply impacts, which can cause malnutrition and diarrheal disease
- Environmental degradation, which has mental health impacts (e.g. fear of displacement or loss of income) and can lead to forced migration from areas that frequently flood or can no longer support farming or fishing

Days with a Heat Index of 90°+

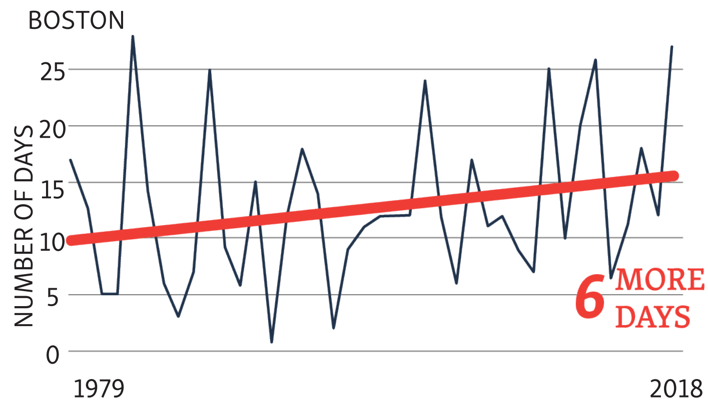


Figure 2-10: Annual Number of Days with an Extreme Heat Index Level

An Extreme Heat Index level 'feels like' 90°F or above. The Boston areas now averages 6 more days with an Extreme Heat Index level per year. At this combination of heat and humidity, there is a heightened health risk for outdoor activities.

Figure source: www.climatecentral.org, 2019

- 'Eco-anxiety', or a chronic fear of environmental doom that is accompanied by thoughts of anger, powerlessness or exhaustion (Clayton et al, 2017; CDC, 2020; Dodgen et al, 2016)

Extreme Heat

Locally, high temperatures are more prevalent in North Brookline largely because it is more urbanized, with more heat-absorbing materials, and lower tree canopy cover (Figures 2-4 and 2-5). As a result, the residents of North Brookline are more vulnerable to heat-related injuries and are at a higher risk of death from extreme heat. Census data from the 2019 American Community Survey 5-Year Estimates shows that North Brookline census tracks are also the areas with a greater percentage of individuals and families that are renters. In general, five to six out of every 10 households in North Brookline rent, while only three to four out of every 10 households in South Brookline are renters. (U.S. Census Bureau, 2019) In general, renters typically have fewer economic resources with which to combat heat stress, and are often constrained in their ability to modify their residences for relief from high temperatures.

Heat waves can result in an increase in fatalities, primarily from heat-related illnesses such as heat stroke and dehydration. However, extreme temperatures and heat waves have also been associated with increased hospital admissions for people with respiratory disorders, kidney problems, and cardiovascular issues. Higher air temperatures have the greatest effect on people experiencing homelessness, people who work outdoors, individuals who live in older homes with less efficient systems or homes without air conditioning, and those who are socially isolated. (CDC, 2020) An aging population and an increase in urbanization nationwide means that the number of people vulnerable to heat-related impacts is likely to rise. According to the U.S. Census Bureau's 2019 American Community Survey 5-Year Estimates, seniors make up 16% of Brookline's total population, and nearly 30% of those over 65 live alone, placing them at increased risk. (CDC, 2020; U.S. Census Bureau, 2019)

Extreme heat is responsible for more weather-related fatalities than any other hazard, including hurricanes, tornadoes, and flooding. From 2006 to 2015, 1,130 heat-related fatalities were recorded in the United States. The number is likely even higher because many heat-induced deaths are recorded as deaths due to respiratory or cardiovascular causes, without mention of the heat event that triggered the health emergency. This leads to an undercounting of heat-related deaths. (EPA & CDC, 2016)

In areas such as the Northeast, where climate change will bring milder winters, injuries and deaths associated with cold temperatures and snowfall are expected to decrease. However, the decline in winter injuries and deaths is unlikely to offset the increase in heat-related injuries and deaths. (CDC, 2020; National Center for Environmental Health, 2020c)

Some heat-related risks have gone down over the past few decades, possibly due to an increase in air conditioning, better weather forecasting, or more extensive warning systems. However, the CDC considers all heat-related deaths to be preventable. (CDC, 2020; National Center for Environmental Health, 2020c)

Air Quality

In the Northeast, the dangers of extreme heat are exacerbated by the association between hot temperatures and higher levels of air pollutants, including particulate matter and ground-level ozone. Ozone is not emitted directly, but is formed in the air through chemical reactions that require heat. Rising temperatures lead to increased levels of ozone. Ozone concentrations across the region were reduced 22% from 1990 to 2016, largely due to efforts to control emissions. However, there is evidence that climate change will offset some of those gains. Climate change is expected to directly cause ozone air pollution to increase as a result of higher temperatures and natural increases in emissions that are precursors for ozone formation. (Nolte et al, 2018)

Ground-level ozone, one of the key components of smog, has been tied to a range of health issues, such as decreases in lung function, an increase in emergency room visits for people with asthma, and an increase in premature deaths. (CDC, 2020) Even with decades of emissions controls, almost a third of Americans were still exposed to ozone values above the EPA's national standard in 2015. Ozone levels tend to be highest in Southern California, the Northeast urban corridor, and other large cities. (Nolte et al, 2018)

The American Lung Association's "State of the Air" report for 2020 found the Boston metro area ranked the 38th most polluted area for ozone, with 6.8 high ozone days on average for the period of 2016-2018. The previous 3-year weighed average (for 2105-2017)was 5.7 days.

Norfolk county received a D grade for ozone in the same report. The report card found that the state showed some improvement in short- and long-term particulate pollution. Interestingly, the three years covered by the 2020 report were among the hottest recorded in global history. (American Lung Association, 2020)

Air pollution, including ozone and particle pollution, increase the risk of asthma attacks, dementia, lung cancer, cardiovascular damage, developmental effects, and can increase the risk of premature death and shortened life expectancy. Emerging research is showing a link between the long-term exposure to fine particle pollution and an increased death rate in COVID-19 patients. Unhealthy air pollution levels mean that some people are facing multiple threats to their lung health. Because air pollutants cause respiratory stress, this likely increases people's vulnerability to illness, including COVID-19. (American Lung Association, 2020)

Example of an Air Quality Forecast

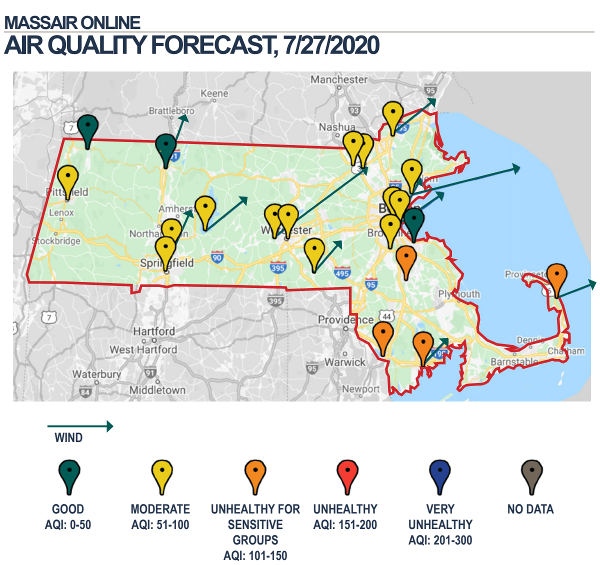


Figure 2-11: Air Quality Index (AQI) Values - 7/27/20 Forecast

An AQI value of 100 corresponds to the national air quality standard for a specific pollutant, which is the level US EPA has set to protect public health. Values below 100 are generally thought of as satisfactory. When AQI values are above 100, air quality is considered to be unhealthy, at first for certain sensitive groups of people, then for everyone as AQI values rise.

Figure source: MassAir Online, 2020

The combination of heat stress and poor air quality can create a significant public health threat for certain population groups - particularly young children, the elderly, people experiencing homelessness, outdoor workers, and those with chronic illnesses or preexisting conditions such as asthma. (CDC, 2020; National Center for Environmental Health, 2020a) Unfortunately, high temperatures also put increased demand on our power supply infrastructure, which is more likely to fail when demand exceeds supply (as when air conditioning usage increases in response to high temperatures). (Dupigny-Giroux et al, 2018)

Flooding can also bring air quality threats that remain after flood waters have receded. Water that enters buildings can cause mold contamination that isn't immediately evident, leading to indoor air quality issues. People who live in damp indoor environments have an increased incidence of upper respiratory tract issues, such as asthma and wheezing, as well as lower respiratory tract conditions, such as pneumonia. (National Center for Environmental Health, 2020b)

Pests and Allergic Reactions

Climate change will also alter the distribution of insects and other pests, possibly increasing the range of certain species of mosquitoes and ticks along with their transmitted diseases and viruses, including Lyme disease, West Nile Virus, Eastern Equine Encephalitis (EEE), and Zika Virus. A longer frost-free season also extends the season during which the pests are active (Figure 2-12 and Figure 2-13). The combination of heat and flooding can lead to explosive growth of these pest populations. (CDC, 2020)

Length of Mosquito Season

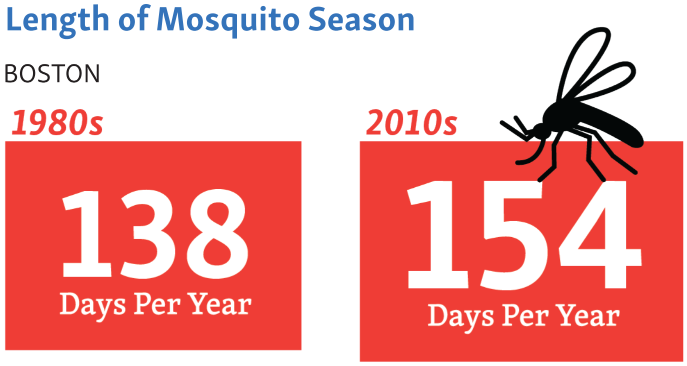


Figure 2-12: Increase in Mosquito Days
The National Institutes of Health reports that mosquitoes survive best at temperatures between 50-95°F and a relative humidity of 42% or more. These Mosquito Day conditions are increasing in metro Boston and in almost 2/3 of the contiguous U.S. A longer mosquito season means an increased risk for mosquito-borne diseases such as West Nile virus.
Figure derived from: www.climatecentral.org, 2020

Lyme Disease Uptick

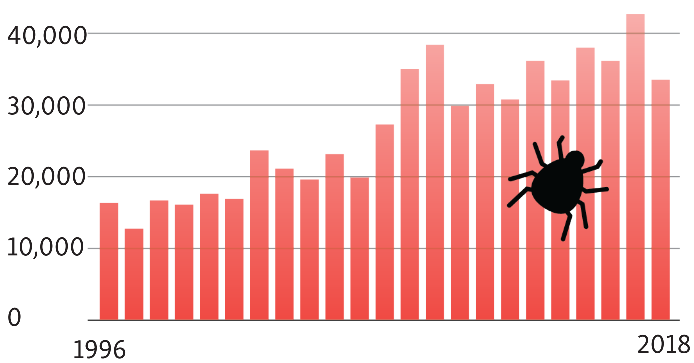


Figure 2-13: Incidence of Lyme Disease Cases in the U.S.
Total number of U.S. cases of lyme disease are on the rise. Rising temperatures are associated with faster tick development and population growth. Ticks are active earlier in the year, and spreading into areas that were once too cold for their development.
Figure derived from: www.climatecentral.org, 2020

The higher temperatures and increased levels of atmospheric CO2 associated with climate change are predicted to accelerate the start of "allergy season," and increase both the duration of the pollen season and the amount of pollen that plants produce. This significant influx of allergens is anticipated to increase the occurrence and severity of allergic reactions, including allergy-induced asthma and hay fever. (Nolte et al, 2018)

Water and Food Safety and Security

As climate change brings more extreme storms, one consequence will be increased soil erosion and agricultural runoff, which contains manure, fertilizer, and pesticides. The contaminated runoff causes excess nutrient loading to water bodies, as well as possible food safety or public health issues from food and waterborne infections. More generally, power outages related to extreme storms also pose a risk of foodborne illness, as people unknowingly consume spoiled food, or cannot easily access fresh food. (Dupigny-Giroux et al, 2018)

While Brookline is an urbanized community, its access to food and drinking water depend on a relationship with more rural or coastal areas. Climate change is already bringing warmer late winter and early spring temperatures, causing trees to leaf out and blossom earlier than in the past. Climatically early budbreak that is followed by a climatically normal hard freeze has led to widespread losses in fruit trees, such as apples. An increase in late winter and spring rains may cause many farmers to delay their planting. Warmer winters also mean farms can expect increased pressure from weeds and crop pests, increasing demand for pesticides and heightening the risks to human health from chemical exposure. Once summer arrives, warmer nighttime temperatures may reduce agricultural crop yields because many agricultural crops flower based on temperature signals. (Dupigny-Giroux et al, 2018)

Fisheries are also being affected by climate change. Ocean and coastal warming has already shifted the timing of fish reproduction and fish migration. A number of fish and invertebrate species have moved northward or to deeper waters. Species that are near the southern extent of their habitat range are diminishing in productivity as waters warm, while other species are becoming more prevalent. For the Northeast, ocean acidification is also a concern, and acidification is expected to increase with climate change. Shelled organisms (e.g. lobsters, scallops, oysters and mussels) can suffer detrimental effects in acidic conditions. Due to ocean warming or acidification, declines are expected in the region's populations of Atlantic cod, American lobster and Atlantic sea scallops. Climate change is also increasing the prevalence of marine toxins, pathogens, and algal blooms, all of which threaten human health through contaminated seafood consumption. (Dupigny-Giroux et al, 2018)

Threats to drinking water are also a concern. Brookline's drinking water comes from the Quabbin Reservoir, about 60 miles west, and the Wachusett Reservoir, about 30 miles west. The land uses in the reservoirs' watersheds are primarily forest and wetlands, providing some natural protection and a buffer against drought. However, while the water resource has been carefully managed and has seen a successful reduction in water usage over the past decades, the reservoirs are still dependent on the snow and rainfall the region receives. The extreme heat and potential for droughts due to climate change will likely make managing this resource more challenging.

Violence and Aggression

The American Psychological Association reports that warmer weather is tied to increased aggression and violence. Numerous real-world and controlled studies provide similar results - violence and assault increase when it is hotter. A study by Anderson and DeLisi in 2011 compared almost 60 years of data from FBI Uniform Crime Reports for both violent crimes (e.g. homicide and assault) and nonviolent crimes (e.g. burglary and vehicle theft) with temperature data. Average annual temperatures were significantly correlated with violent crime rates, but not with nonviolent crime rates. Based on their findings, the researchers expect that if climate change brings even a conservative warming of 2°F, there would be a 6% increase in violent crime rates. (APA, 2017)

Researchers hypothesize that this interpersonal aggression may be due to an increase in arousal levels and a resulting decrease in self-regulation. Studies have also shown that heat lowers individuals' cognitive function, limiting their ability to resolve conflicts through reasoning. Hotter weather also has links to intergroup aggression. A 2016 study found that respondents reacted more negatively to policies supporting migrants and minorities when room temperatures were raised. Another experiment found that people who were asked to think about climate change became more hostile to people outside their social group (people unlike themselves), and more likely to support maintaining existing social inequities. This could create a feedback loop where distrust and a lack of social empathy prevent community members from working together to solve the very problem contributing to the hostile behavior. (APA, 2017)

A study by the National Bureau of Economic Research examined the link between daily temperatures and incidents of violent crime over a 7-year period in Los Angeles. Statistically, criminologists have shown that over decades, violent crimes are more frequent in hot summer months. However, they suspected that some of this relationship was attributable to younger people being out of school during summer months, and the fact that people spend more time outdoors in warmer weather, increasing the chances of a hostile encounter. The Los Angeles study controlled for whether schools were in session, and for the overall level of social activity in the city, and still found that overall crime rose by 2.2% and violent crime rose by 5.7% when the daily high temperature exceeded 85. (Heilmann & Kahn, 2019)

As warmer temperatures become more common, there is the potential for a rise in conflict among individuals and groups. However, the precise causal relationships between climate change and conflict are still being studied as an emerging issue. (Dodgen, et al, 2016)

Health and Equity

Just as climate change impacts are not evenly distributed over the globe, the health effects of climate change are not distributed equally across a given community. The vulnerability of any individual or group depends on three primary factors: their exposure to the risks that climate change brings, their susceptibility to health risks associated with climate change, and their ability to adapt and respond to climate change and climate variability (Figure 2-14). (Gamble, 2016)

The ultimate health impacts of climate change depend on how these various factors interact and combine. Vulnerable groups include older adults, children and pregnant women, persons with disabilities, those with low income, individuals with preexisting medical or mental health conditions, immigrant groups, people in certain occupations, and members of some communities of color. These individuals and groups not only suffer disproportionate impacts from climate change, but due to existing disparities and challenges in accessing resources, may also be less able to adapt to its health impacts. (Gamble, 2016; CDC, 2020)

Framework For Vulnerability

EXPOSURE
Contact between a person and one or more biological, psychosocial, physical or chemical stresses

Examples of factors:
- Outdoor Occupations
- Occupational Risk (e.g Utility Repair, Emergency Responders)
- Housing Insecurity
- Compromised Mobility
- Infrastructure Condition/ Access
- Poverty
- Discrimination
- At-Risk Communities

SUSCEPTIBILITY
Degree to which people or communities are affected by climate variability or change

Examples of factors:
- Underlying Community Health Disparities
- Chronic Medical Conditions
- Chronic Psychological Conditions
- Allergies
- Low Levels of Physical Activity
- Poor Access to Healthcare
- Age
- Life Stage

CAPACITY TO ADAPT
Ability of people or communities to adjust to potential hazards, prepare for adverse events and respond to consequences

Examples of factors:
- Socioeconomic Status
- Education Level
- Social or Linguistic Isolation
- Solitary Living
- Social Norms
- Economic Policies
- Social Cohesion
- Governance

VULNERABILITY TO CLIMATE CHANGE IMPACTS AND ITS ASSOCIATED HEALTH EFFECTS

Figure 2-14: Understanding the Multiple Factors that Impact Vulnerability to Climate Change and Its Health Impacts

Vulnerability to the health impacts of climate change depends on a combination of an individual or community's exposure to the risks of climate change, their susceptibility to the risks, and their capacity to adapt to climate variability and change. The cumulative effect of each category of factors can make some individuals or groups relatively more vulnerable than others. Some groups face a number of stressors related to both climate and non-climate factors, such as social or economic stressors.

Figure Source: Derived from Gamble et al, 2016

The more stressors an individual or group faces, the more severe their health risk from climate change. For example, people of low socioeconomic status who live in a dense urban area that is prone to flooding are more vulnerable to extreme weather and the long-term effects of climate change. The stressors people experience may occur simultaneously or over time, and may be linked directly to climate or be a result of other social and economic pressures. The stresses interact and can build up and reinforce each other, creating disproportionate, and complex risks to people's health and well-being. (Gamble, 2016)

Ultimately, vulnerability varies across time, across communities and between individuals within a community. People differ in their levels of exposure, their inherent susceptibility and their ability to adapt, or even take advantage of, climate change impacts. Vulnerability is also closely tied to place. Any individual's risk factors overlap with the geographic environment in which they live. Recognizing and exploring this relationship can facilitate the development of appropriate assistance, government policies, and community interventions. (Gamble, 2016)

Figure 2-15: Sugar Maple Tapping
Tapping sugar maple trees for maple syrup production.

Effects on Ecosystems

If you think that spring comes earlier than it used to, or that summers are hotter than they used to be, you are likely seeing the effects of climate change. These shifts in New England's seasons have a significant impact on ecosystems, the services they provide, and the flora and fauna that occupy them.

Range and Distribution

The distribution of native tree species in the Northeast is changing. A defining characteristic of New England is its fall foliage - the sugar maple tree is one particularly admired species, cherished for its exceptional fall color that ranges from brilliant yellow to burnt orange. While originally native to much of the Northeast, however, while originally native to much of the Northeast, this maple species' potential range has shifted further north. Predictions suggest that the amount of habitat suitable for sugar maple growth in New England will diminish even further by 2100. (Iverson et al, 2008; Prasad et al, 2014)

The sugar maple isn’t just a key species in the fall foliage experience - it is also an important part of the regional ecology and economy. Like many trees, sugar maples support a number of plant and animal communities, provide leaf litter rich in organic matter to help restore soils, promote the cycling of nutrients, and keep pollutants out of the groundwater. These trees are also paramount to the maple syrup industry, a key component of the region’s tourism, and a popular hardwood species used in furniture production and flooring. (Bishop et al, 2015)

The sugar maple tree raises an interesting aspect of the impact of climate change on ecosystems. The trees are slow-growing but long-lived. It can take up to 40 years before they can be tapped for maple syrup, but they can live for well over 100 years. The precipitation and temperature changes we see with climate change are more accelerated than many trees can adjust to. Given that trees can't pick up and move, the future of the maple tree and maple syrup industry in New England is uncertain. (Coin, 2019)

As with the sugar maple, forests in the Northeast are changing in response to the warmer climate, notably altering "leaf-out" dates and bloom times. Regionally, tree species that are already on the edge of their range and high-elevation tree species, including spruce and fir, are among the most vulnerable to climate change. Consequently, birds dependent on spruce-fir forests are already in decline and vulnerable to further population losses due to climate change. (Dupigny-Giroux et al, 2018)

The geographic range of plants that have historically been found in more southern states may be shifted northward as a result of climate change. (Massachusetts Wildlife Climate Action Tool, 2017b) However, a shifting range for a tree species does not necessarily indicate that the species will move into that area and successfully establish its population. The successful establishment of a species in a given area depends on a number of factors including the efficacy of seed dispersal, fragmentation of the landscape, competition with other species, and human intervention. (Prasad et al, 2014)

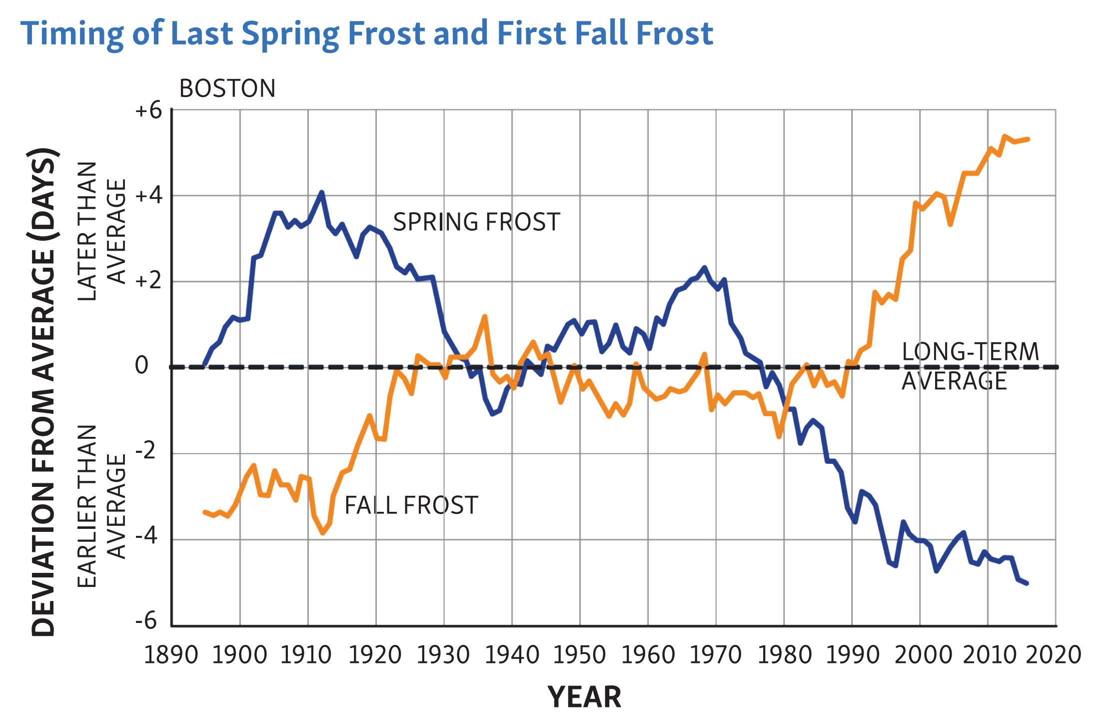


Figure 2-16: Spring and Fall Frost Dates are Shifting

In the Boston area and across the U.S., the frost-free season (the time between the last temperature reading below 32°F in the spring and the first reading in the fall) has grown longer. Locally, the season is extending on both ends. In fall, warmer nighttime temperatures can reduce productivity of grains and fruits, which could increase supermarket costs. The shift in season could also prevent necessary plant-pollinator interactions. Pests may also survive longer, damaging or destroying crops.

Figure Source: Derived from www.climatecentral.org

Shifting Seasons

Climate change, and its predicted impact on seasons, is expected to alter the life cycles of plant, fish, and wildlife species. Historically, certain species that overlap in time and place at key points during their life cycles have grown to be dependent on one another. For example, butterflies may emerge just as flower nectar is most abundant. Climate change is expected to disturb these relationships and alter the availability of species' food and habitat resources. This can impact individuals of a species, but can also affect entire populations and ecological structures, particularly if the species are highly specialized and cannot change their behavior to adapt to other available resources. (Massachusetts Wildlife Climate Action Tool, 2017b)

Compared to 50 years ago, spring now arrives in New England over a week earlier than it used to (Figure 2-16). However, there is also more variability in temperatures. So, while plants are emerging from their winter dormancy sooner, that may leave them vulnerable to cold spells. (Massachusetts Wildlife Climate Action Tool, 2017b) In recent years, early warm periods followed by a hard freeze have resulted in fruit crop losses and reduced growth in native tree species. Pests that depend on trees and wildlife are also affected by climate change. Just as trees are responding to warmer winters with earlier bud-break, warmer winters may contribute to insects emerging earlier or expanding their range and population size with longer breeding periods. In particular, these pests pose a distinct threat to trees that are already experiencing stress as a result of drought or damage. (Massachusetts Wildlife Climate Action Tool, 2017d) Tree pests of concern in Brookline include the hemlock woolly adelgid, emerald ash borer, and the Asian longhorned beetle (Figure 2-17).

Shifts in springtime bird migrations have also been documented across the United States (Figure 2-18). Some migratory bird species now arrive too late to access the peak of springtime food resources. Temperatures at the sites where they overwinter are changing more slowly than at the spring breeding grounds, so birds are not receiving the temperature cues they need to start their northward migration in time. Other birds rely on the number of daylight hours, which remains unaffected by climate change, to start their migrations, creating a mismatch between their arrival and the emergence of their food sources. (Melillo, Richmond and Yohe, 2014)

Tree Pests of Concern

Asian Longhorned Beetle and Its Egg-laying Site

Emerald Ash Borer and Its D-shaped Exit Hole

Wooly Adelgid Insects and Their White Protective Coating

Figure 2-17: Current Tree Pests of Concern in Brookline

Figure 2-18: Migrating Birds
Migrating birds across the United States have been showing evidence of a shift in migration timing.

While the effects of increasing winter and spring temperatures on ecosystems (and their associated flora and fauna) are relatively well understood, the effects of increasing summer and fall temperatures are less clear. For many summer-producing fruits and vegetables, flowering is determined partly by a narrow range of nighttime temperatures. As a result, temperatures that are too high could decrease overall crop yields, though a longer growing season could offset those losses. Temperature also plays a role in fruit ripening, leaf color change, and insect, bird, and animal hibernation and migration patterns. Exactly how climate change will impact these natural processes is unclear. (Dupigny-Giroux et al, 2018)

Hydrology

The warmer winters and earlier springs associated with climate change are anticipated to bring earlier snowmelt, affecting the volume and the timing of peak spring stream flows. In Massachusetts, winter-spring flow rates now peak around six days earlier than they did 50-90 years ago. This impacts fish spawning and affects the breeding and migration of other aquatic and wetland species. (Massachusetts Wildlife Climate Action Tool, 2017a; 2017b)

Increased runoff from more extreme storms means more pollutants will be moved downstream, and ultimately to coastal areas, during times of intense rainfall. Warmer temperatures and erratic precipitation events could impact water levels. Low water levels leads to the warming of lakes and ponds and an increase in algal blooms, particularly if the waterbodies have excess nutrients. Low water levels also alter stream connectivity which would severely impact ecosystems and the aquatic and wildlife species that rely on them. (Massachusetts Wildlife Climate Action Tool, 2017a; 2017b)

Urban Forests

While urban forests only make up a small percentage of the trees in the United States, more than eight of out every ten Americans live in an urban area; therefore these trees are critically important to the everyday lives of millions of Americans.

An increase in carbon dioxide and warmer temperatures may actually enhance urban tree growth, at least for a time. However, warmer temperatures without sufficient nutrients and water will eventually stress trees and restrict future growth. Warmer winter temperatures also increase the possibility of winter kill - a phenomenon in which tree cells, responding to warmer temperatures, come out of their winter dormancy and become active (Figure 2-19). If a rapid cooling occurs after one of these warm periods, the tree tissues will freeze, causing injury or tree death. (Safford et al, 2013)

Erratic temperature changes will not only directly affect urban tree mortality, but will also affect the pests and pathogens that impact tree survivability rates. Cold winter temperatures usually help to reduce the prevalence of tree

Figure 2-19: Winter Kill Damage on Tree
Tree injury from winter kill, when extreme fluctuations in temperature damaged this tree's tissues.

pests and pathogens. Warmer temperatures, on the other hand, may result in the survival of larger pest populations through the winter season. While the life cycle of a tree is considerably long, many pests and pathogens have shorter life cycles and are able to evolve more rapidly to adapt to changing conditions. What's more, the type of hot and dry summer weather that is anticipated as a result of climate change tends to concentrate carbohydrates in tree leaves, making the trees an even more attractive target to pests. (Safford et al, 2013)

Climate change's influence on the water cycle also poses risks to the urban forest. Higher temperatures and increasing periods of drought may cause accelerated evaporation and transpiration. This can result in soil water shortages, which can be compounded by the percent of impervious surfaces in urban areas and the tendency for urban soils to exhibit high levels of soil compaction. Flooding from more intense storms can uproot trees, or cause tree injury or even death if the roots remain inundated for a long period. Winter storms also pose a physical risk to trees from the extra weight of ice and snow loading. Urban forests are subject to the same pressures on their range and reproductive rates as trees in natural forests, perhaps more so given factors such as the urban heat island effect. (Safford, et al 2013)

Summary

Climate change is threatening many of the ecosystem services that we have come to rely on for general health, well-being, and recreation. At risk are the ecosystem's ability to filter groundwater, mitigate storms, control erosion, moderate temperature extremes, provide food, sequester carbon, provide habitat, and preserve cultural heritage and natural landscapes. (Dupigny-Giroux et al, 2018) Communities rely on the benefits and services that natural ecosystems provide. These ecosystem services are the tangible connection between society and the natural environment. The ability of Brookline, and all human communities, to mitigate and adapt to climate change will determine everyone's well-being.

BENEFITS OF TREES

Benefits of the Urban Forest

The urban forest of Brookline can be described as the collection of trees and other vegetation found along the Town's streets and in its built environment. In this plan, the term urban forest focuses on trees (Figure 3-1). An urban forest is significant for its unique setting in a population center. Rather than a woodland where trees form the primary organizing element, an urban forest occurs within a network of paved surfaces, buildings, parks, and a concentration of people.

In general, the urban forest is created by people – the result of both purposeful tree planting along streets, in parks, and in private yards, and from vegetation that grew because it was ignored or intentionally allowed to remain. It is different from a forest ecosystem, although the trees still do much of the same work. In part because of its proximity to humans and built infrastructure, the urban forest requires regular maintenance to keep the trees healthy and to keep sidewalks, roads, parks, and other busy areas clear and safe. Thinking of the urban forest as a collection of trees, rather than individual specimens, highlights the cumulative benefits of the forest and encourages a holistic approach in its management as a resource of the Town and its inhabitants.

Every day, Brookline's trees improve residents' quality of life and the environment where they live, work and play. Early studies on tree benefits focused primarily on environmental services, but tree quality and quantity have much broader implications that impact community wellness. Trees not only purify the air and reduce stormwater runoff, but also beautify streets, increase property values, make neighborhoods more resilient, enhance community livability, and improve health and general well-being. From the historic beech trees lining Longwood Mall to the diverse trees dotted throughout the commercial district of Coolidge Corner, the urban forest helps to make Brookline a desirable place to live, work, and visit. This chapter will explore some of the specific economic, social, and environmental services that urban forest trees provide (Figure 3-2).

The Urban Forest

Figure 3-1: Brookline's Urban Forest

Brookline's urban forest is comprised of public street trees, trees on private or institutional property, and trees on Town-owned grounds and public spaces.

BENEFITS OF TREES

ENVIRONMENTAL BENEFITS

- Improve Water Quality and Quantity
- Mitigate Urban Heat Island Effect
- Decrease Energy Use
- Improve Air Quality
- Store and Sequester Carbon
- Provide Habitat & Support Biodiversity

SOCIAL BENEFITS

- Improve Physical Health
- Reduce Air Pollutants
- Moderate Excessive Heat
- Protect from Ultraviolet Rays
- Support Mental Health
- Reduce Noise and Improve Privacy
- Promote an Active Lifestyle
- Enhance Community Livability & Resilience

ECONOMIC BENEFITS

- Increase Property Values
- Support Retail Spending
- Reduce Community Maintenance Costs

Figure 3-2: Trees Benefit Communities in Many Ways

Research has linked the presence of urban trees to a variety of environmental, social and economic benefits for individuals and communities. These benefits may not always be obvious, but they are part of what make trees such an important part of people's lives.

Urban Forests and Climate Change

The ability of trees to absorb and store carbon dioxide, regulate local temperatures, and intercept and absorb stormwater becomes even more important as we face the challenges of climate change, including higher temperatures, more extreme precipitation events, and rising carbon dioxide levels. Urban trees can support efforts in both carbon mitigation and climate adaptation. Not only do trees remove carbon dioxide from the atmosphere and reduce greenhouse gas emissions, they can also help both human and natural communities to adapt to changing conditions, such as warmer temperatures. (Vibrant Cities Lab) These benefits and many others are described in more detail below.

Environmental Benefits

There is a wealth of information available regarding the environmental benefits of trees. Multiple studies across the U.S. have shown that a healthy, high-quality urban forest contributes to better air quality and improved stormwater management for cities and towns. Strategically-placed trees reduce building energy use and mitigate the urban heat island effect, decreasing the number of heat-related deaths and improving local air quality. In some parts of the United States, tree planting and maintenance programs are used to meet regulatory requirements of clean air and water statutes. (USDA, 2016)

Trees and Water Quality

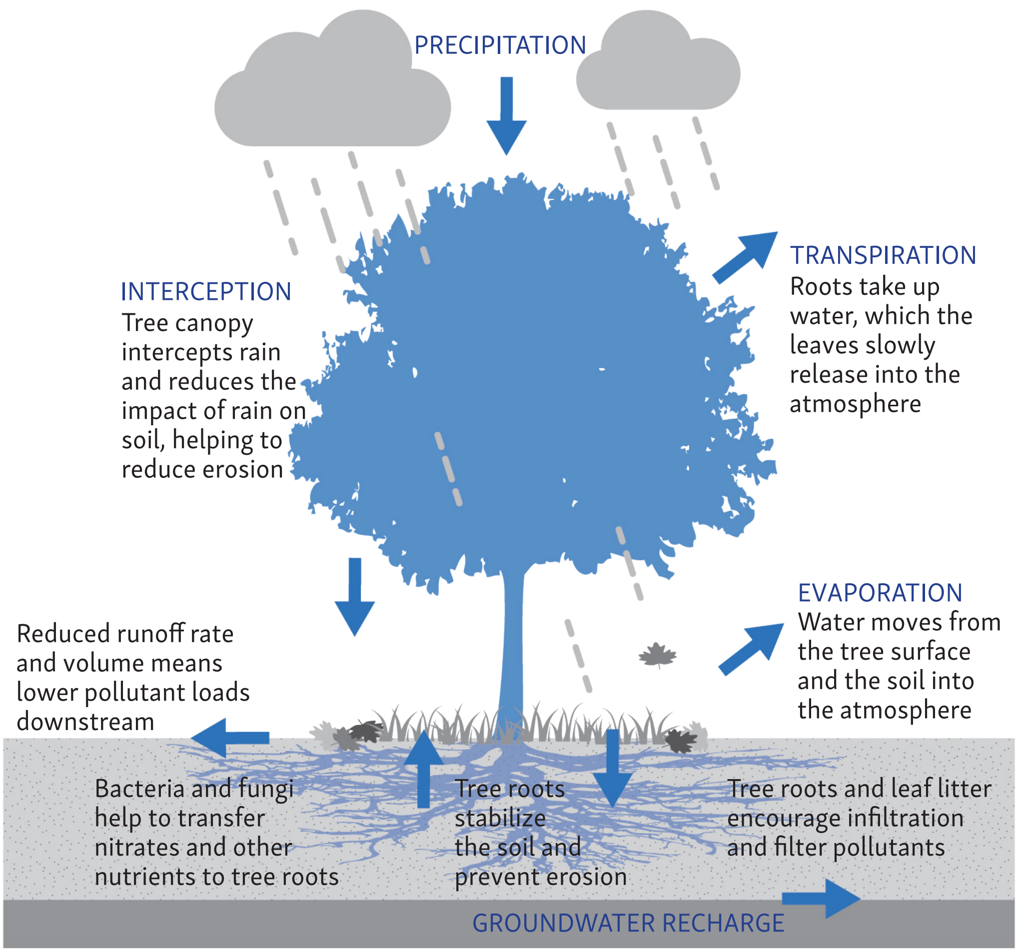


Figure 3-3: Impact on Water Quality

Through infiltration, transpiration and evaporation, trees improve water quality, reduce erosion, and help limit flooding.

Water Quality and Quantity

Trees can have a significant impact on both water quality and quantity, especially in developed areas. Much of the benefit comes from the way trees interact with stormwater (Figure 3-3). Stormwater runoff is precipitation (rain or snowmelt)that flows over the ground's surface, and is considered a primary cause of degraded waterways in urban or semi-urban areas, where much of the runoff flows over impervious surfaces like roads, rooftops, and parking lots. As the water flows along the ground, it picks up pollutants including trash, oil and grease from vehicles, pesticides, excess fertilizer, pet waste, sediment, and bacteria. This runoff makes its way through gutters, storm drains and ditches, and will eventually flow into a surface waterbody or wetland, ultimately compromising the health of that resource. (CWP, 2017)

Trees are most effective at reducing runoff from smaller storms, which account for the majority of precipitation events. Trees intercept rainfall, holding some of the rain on their leaves and bark, and take up water through their roots, reducing the volume of runoff. One study in California found that in summer, trees intercepted more than 35% of the rainfall that hit them. (USEPA, 2008) By slowing and temporarily storing water, trees decrease the possibility for flooding, minimize runoff, and limit erosion. Water intercepted by trees is slowly released back to the atmosphere through evapotranspiration.

In addition, trees improve water quality by infiltrating polluted water into the soil, where it can be taken up by the tree's roots. To a certain extent, common waterbody pollutants like nitrogen and phosphorus are beneficial to tree health, and are used as nutrients for tree growth. Tree leaf litter improves soil health, increases the soil's ability to store and filter water, and improves groundwater recharge and groundwater quality. (CNT 2010; CWP, 2017)

Urban Heat Island Effect

The urban heat island effect describes the phenomenon where urban areas generally experience warmer ambient air temperatures than surrounding rural areas, both during the day and at night. As areas become more developed, open land, soil, and vegetation are replaced with buildings, roads, and other hard materials that absorb and retain heat more readily. (CNT 2010; USEPA 2008)

Trees help to lower surface and air temperatures by providing shade and releasing moisture into the atmosphere through a process called evapotranspiration. In the summer, only 10-30% of the sun's energy may get through a tree's canopy. The remaining sunlight is absorbed by the leaves for photosynthesis or reflected back into the atmosphere. Shaded surfaces, such as buildings, can be 20-45 degrees Fahrenheit cooler than the peak temperatures of unshaded materials. This not only makes for a more comfortable bench to sit on, but also helps diminish urban heat island effects by reducing the heat absorbed by materials during the day. (USEPA, 2008)

Annual runoff avoided through interception and infiltration by Brookline's street trees

3.9 million gallons

Transpiration is the process in which plants absorb water through their roots and release it through their leaves into the surrounding air. Evaporation, which is the transformation of water from a liquid to a gas, occurs in the soil surrounding trees and from the tree itself following rainfall. Together, evaporation and transpiration, called evapotranspiration, reduce ambient air temperatures by taking heat from the air to release water. Evapotranspiration on its own, or combined with the shading effects of trees, can reduce ambient air temperatures by 2-9 degrees Fahrenheit. (USEPA, 2008)

Shade provided by tree canopy also plays an important role in water quality. Without shade, surface water bodies are more susceptible to degradation by thermal pollution. One study showed that when pavement temperatures were 20-35 degrees warmer than ambient air temperatures, the runoff from a summer afternoon storm was as much as 20-30 degrees Fahrenheit warmer in urban areas than in rural areas. The stormwater runs into storm sewers where it is routed into local streams and ponds, raising surface water temperatures. Rapid temperature changes in surface water systems can stress or even shock aquatic life. (USEPA, 2008)

Health impacts of the urban heat island effect are discussed later in this chapter.

Energy Use

By providing shade and acting as windbreaks, trees can help to reduce energy consumption. This, in turn, results in burning less fossil fuels to generate electricity for cooling and heating, resulting in improved air quality and reduced contributions to climate change. Trees are most effective in reducing energy consumption when they are planted strategically around buildings (Figure 3-4). For summer weather, trees are most effective when they shade rooftops, streets or paved parking lots. Trees that directly shade buildings reduce the demand for air conditioning, especially if the trees shade windows and portions of the building's roof. Energy savings of up to 47% over the summer months were observed when trees were planted to the west and southwest of buildings. (USEPA, 2008)

Trees not only help with cooling, but can also influence winter heating needs. Strategically-placed conifer trees can be used as windbreaks in winter to reduce cold northern wind speeds, providing energy benefits in reduced heating pressure. Wind speed, especially in areas with cold winters, can have a significant impact on the energy needed for heating homes and businesses. (CNT 2010; ICLEI, 2006)

Trees and Energy Use

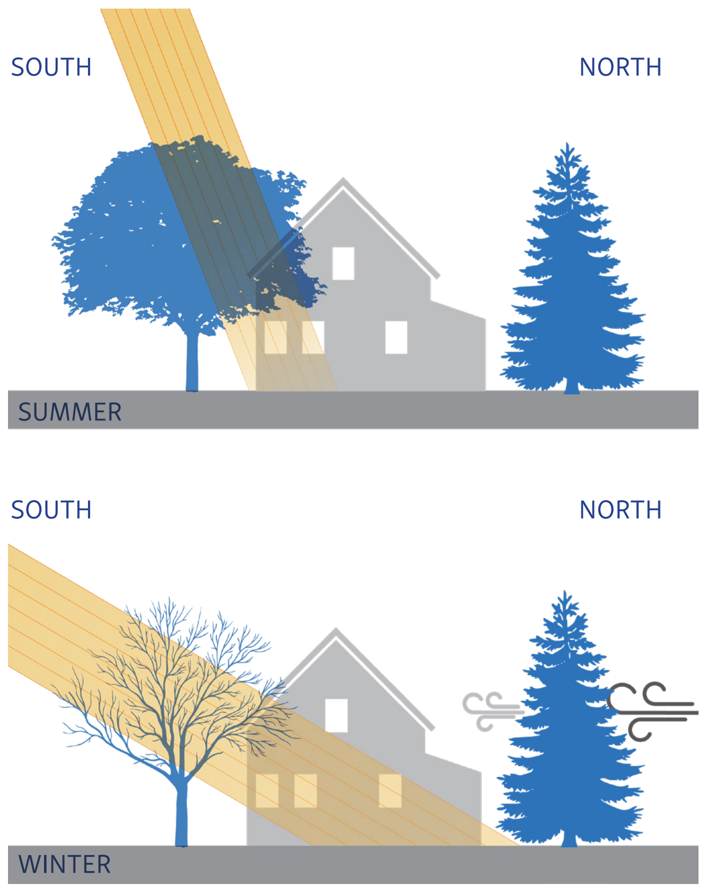


Figure 3-4: Impact on Energy Use
Deciduous trees on a building's western and southern sides shade and cool the building in the summer, while allowing the sunlight to warm the building in winter. Evergreen trees on a building's northern exposure help to block cold northern winds in winter.

Air Quality

Trees also offer air quality improvements and greenhouse gas benefits. Trees take up air pollutants through pores in their leaf surfaces, and can also intercept particulate matter as winds hit plant surfaces such as tree bark and foliage. These simple mechanisms can reduce a number of common air pollutants including nitrogen oxides, sulfur dioxide, carbon monoxide, ground-level ozone, and particulate matter. The existing air quality, pollutant levels, tree size, and tree species all contribute to the effectiveness of a given tree at taking up or intercepting pollutants. (CNT; USEPA, 2008) As with many tree benefits, larger, more mature trees remove a greater amount of air pollution than smaller trees. (ICLEI, 2006)

As described above, when trees reduce energy demand, they also contribute to better air quality by reducing the production of the air pollution and greenhouse gas emissions associated with energy production. A modeling study found that the energy savings from strategic shading by trees and other vegetation could reduce carbon emissions from 1.5 to 5 percent. Tree shade can also keep parked cars cooler, including car gas tanks. Volatile organic compounds (VOCs) are typically released by the gasoline in gas tanks, particularly in hot weather. VOCs are a precursor in the formation of ground-level ozone. Tree shading programs can be part of a strategy to reduce these emissions. (USEPA, 2008)

Health impacts of improved air quality are discussed later in this chapter.

Carbon Storage and Sequestration

As trees grow, they absorb carbon from the atmosphere, storing it and sequestering it, reducing the levels of carbon dioxide in the atmosphere. The process by which carbon dioxide is removed from the atmosphere (through photosynthesis) and stored in the tree's structure is called carbon sequestration. Stored carbon, on the other hand, refers to the amount of carbon held in the tree's tissues - in its roots, trunk and branches, for example. (ICLEI, 2006; USEPA, 2008)

When trees die or deposit litter on the ground, the previously stored carbon is released to the atmosphere or shifted to the soil. A significant amount of carbon is stored in trees and soils. Based on tree cover and urban land data, researchers estimate that urban trees in the United States sequester 36.7 million tons of carbon per year, and the total carbon stored in the country’s urban tree mass is 919 million tons. (USEPA, 2008; Nowak and Greenfield, 2018)

Amount of carbon sequestered each year by the growth of Brookline's trees	***2,180 Tons***
Carbon stored in Brookline's trees long-term	***65,890 Tons***

Tree Maturity and Environmental Benefits

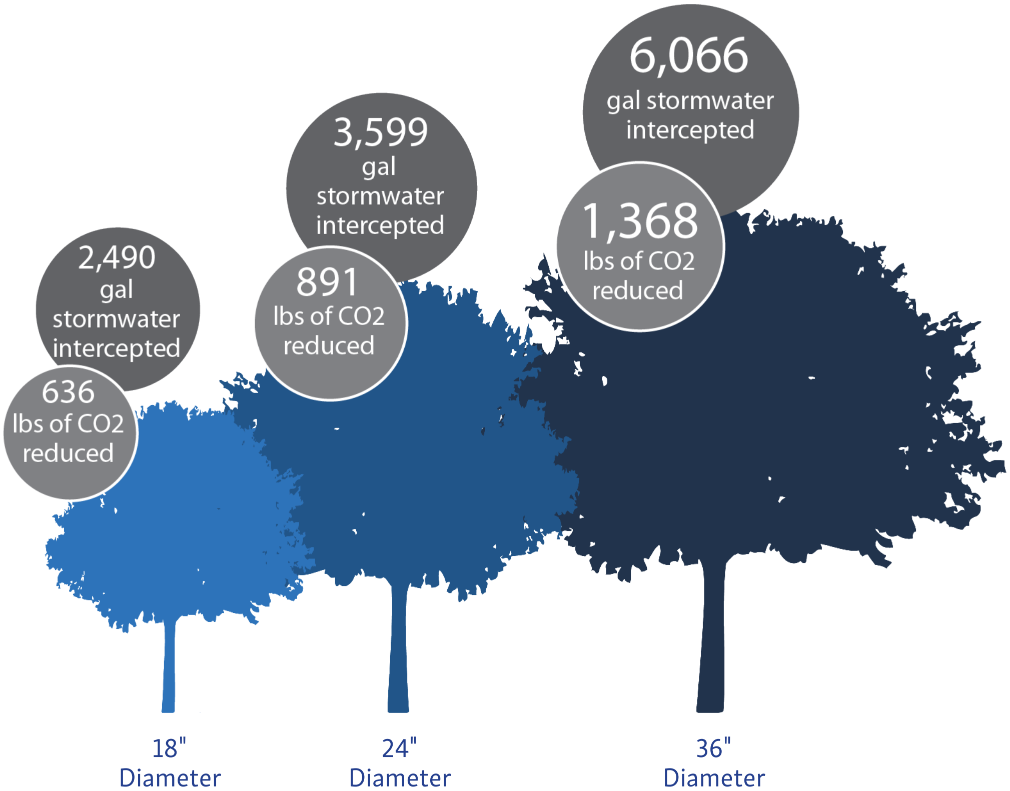


Figure 3-5: Environmental Benefits Grow as Each Tree Matures

Larger trees have larger canopies, providing more surface areas to intercept rainfall. Trees' natural growth also removes and stores carbon dioxide that is pulled from the atmosphere.

Figure date source: National Tree Benefit Calculator at http://www.treebenefits.com/calculator/

While urban trees make up only a small percentage of the trees in the U.S., their effect is tremendous. Urban trees have a potential for larger canopies, given the less intense competition from neighboring trees. Larger canopies often indicate a greater capacity to shade structures and other heat-absorbing infrastructure (Figure 3-5). What's more, large, mature trees (>30" dbh) can sequester 90 times more carbon every year when compared to small immature trees (<4" dbh). Large trees also store about 100 times more carbon than small trees. A single mature tree can absorb as much as 48 lbs of CO_2 per year and release enough oxygen to support two people. Choosing large trees with long life spans, where appropriate, helps to maximize these gains. (ICLEI, 2006)

Habitat and Biodiversity

Adding trees to urban parks, streets, yards or parking lots can provide habitat for birds, insects, and other living creatures. (USEPA, 2008) Planting trees increases the availability and diversity of wildlife habitat, especially when native tree species are used and tree plantings are part of a connected network of green spaces. Trees provide habitat, food and shelter for both resident species and migratory species. Some trees even provide a sort of nursery for species that live their adult lives elsewhere. (CNT, 2010) Expanding and enhancing our urban forests increases biodiversity and habitat connectivity, helping to advance climate adaptation and resiliency efforts, as well. (Vibrant Cities Lab)

Social Benefits

Healthy urban forests support healthy communities. Only within the last few decades have researchers started to investigate the value of the urban forest for human health, social connections, and quality of life. Recent studies highlight the value of natural resources, including trees, for human health and mental well-being. Being able to see trees has been linked to reduced stress levels, better performance from children in school, and an increased attention to work tasks for adults. (USDA, 2018)

Much of the evidence is observational, and it can be difficult to establish a definitive causal relationship between nature and health, in part because of the difficulty in controlling for the variability in health factors and quantifying people's experiences. Still, existing studies provide a compelling case for maintaining and expanding the tree canopy in communities. Research in this area continues to expand, and the recent COVID-19 pandemic and the subsequent reliance on outdoor spaces for safe recreation will likely accelerate the pace of research exploring the connections between nature and health. (USDA, 2018)

Beyond direct health benefits, trees also play a significant role in improving our general quality of life and the strength of our communities. Tree-lined, shaded streets are generally more walkable, promoting more active and healthy lifestyles and more opportunities for neighbors to interact. When people exercise outdoors, they tend to exercise at a greater intensity and for a longer period of time. Research also shows that a well-maintained, mature tree canopy had a negative association with crime rates of robbery, burglary, theft, assault, vandalism, arson, and shootings. This held true even when controlling for income, population density and housing type. (USDA, 2018)

Physical Health Benefits

Trees provide a range of physical health benefits, many of which derive from improved environmental conditions. For example, trees can improve air quality, temper the urban heat island effect, and help us avoid exposure to harmful UV rays. (USDA, 2018) With the high cost of treatment, health providers are exploring relationships between nature, including trees, and positive health outcomes. An often-cited study by Ulrich (1984) found that hospital stays were reduced by 1 day, on average, for patients with views of trees from their hospital room window. Patients also required less pain medication and had fewer post-surgical complications.

Harmful ozone that Brookline's trees remove from the atmosphere each year	**56 Tons**
Estimated particulate matter that Brookline's trees remove from the air each year	**8.25 Tons**

Air Pollution

Common air pollutants include particulate matter, sulfur dioxide, ground-level ozone, nitrogen dioxide, and carbon monoxide. This pollution can exacerbate existing health conditions such as asthma, pulmonary disease, and cardiovascular disease. Even in otherwise healthy people, air pollution can cause inflammation of the airways and reduced lung function. (USEPA, 2008; USDA, 2018) Some communities of color and low-income groups have a higher rate of respiratory illnesses such as asthma and COPD, increasing their sensitivity to air pollution. (Gamble, 2016) A 2014 study (Nowak et al) found that in 2010, trees removed 17.4 million tons of air pollution across the United States. This pollutant reduction prevented 850 deaths and 670,000 cases of acute respiratory symptoms.

As mentioned above, trees remove pollutants including carbon dioxide and particulate matter directly from the atmosphere, and reduce air temperatures through shade and evapotranspiration, ultimately limiting the formation of smog. Trees also contribute to better air quality indirectly by helping to reduce energy consumption, resulting in the burning of fewer fossil fuels. Trees have the greatest impact when sited close to a pollutant's source, where the pollution is most concentrated. For example, studies show that vegetation should be close to roadways to reduce the sediment and dust created by street traffic. At an even finer level, vegetation with large, hairy leaves are most effective at trapping particulates. (USDA, 2018)

A study by the Massachusetts Institute of Technology in 2013 found that air pollution causes approximately 200,000 premature deaths each year (Caiazzo et al). For the Boston metropolitan area, researchers estimated that 106 out of every 100,000 residents die prematurely in any given year due to long-term exposure to air pollution, especially particulate matter. By examining weather and air quality models to relate emissions to pollutant concentrations, researchers were able to determine that, for the metro area, the leading cause of these premature deaths was the cumulative result of commercial and residential activities. These activities include meeting energy demands for lighting, heating, cooling, and operating appliances, along with natural gas for heating and cooking. Secondary contributing causes were industrial activities and transportation, largely from personal vehicles.

Excessive Heat

The urban heat island effect (described above) impacts health by causing breathing difficulties, exhaustion, heat stroke and even heat-related mortality. The phenomenon also contributes to elevated emission levels of air pollutants and greenhouse gases through the increased energy demand (for air conditioning) that occurs when temperatures are high. Shading and evapotranspiration by trees help to temper the impacts of the urban heat island effect and can prevent avoidable heat-related illnesses and deaths. (CNT, 2010; USEPA, 2008)

Trees provide cooling through two mechanisms: evapotranspiration through micro-cooling and relief from heat stress through shade. Cooling by trees can provide benefits at a number of scales. Connected green spaces provide the most benefit, as this structure can improve the flow of cool air through an urban area. Every 10% increase in overall tree canopy creates a 2°F reduction in the ambient temperature. (USDA, 2018)

People with preexisting health conditions, children, and the elderly are particularly vulnerable to the effects of heat. In addition, because lower socio-economic and ethnic minority neighborhoods often have few trees, these groups are disproportionately exposed to heat stress. (USEPA, 2008; USDA, 2018) These groups are less likely to have access to air conditioning, so trees can be an especially useful intervention to fight the effects of summer heat. Trees can shade buildings, reducing their daily heat gain, lowering indoor air temperatures and minimizing the health impacts from high temperatures. (USEPA, 2008)

Ultraviolet Rays

Trees reduce our exposure to harmful ultraviolet radiation, which can have negative effects on skin and eyes. Long-term exposure to UV rays is linked to skin cancer, but the shade provided by tree canopies can lower our UV exposure. Shading can have an especially large impact at playgrounds and schoolyards, encouraging children to be more active while reducing heat-related illness and minimizing exposure to harmful UV rays. Other locations where trees can be effectively used in this regard are places where people tend to congregate or rest for longer period of time, such as bus stops, sport team seating, and picnic tables. (USEPA, 2008)

Mental Health Benefits

As discussed above, trees help to promote physical health and activity. There is also a growing recognition that urban forests and nature can be restorative to psychological health, including improvements to concentration and reduction in stress and anxiety levels. Individual and community effects can also facilitate social cohesion, a factor in our well-being. (Vibrant Cities Lab)

Could trees be used as a mental health improvement strategy? A study in Wisconsin (Beyer et al, 2014) compared mental health outcomes with the percentage of tree canopy coverage. After controlling for a number of socioeconomic factors in both rural and urban areas, the researchers found a strong association between better mental health and the percentage of tree canopy coverage. High levels of green space were associated with lower levels of symptoms of depression, stress and anxiety. [Note that when the term 'green space' is used in this section, it includes areas with trees that may also have other green amenities, such as shrubs or lawns. Particularly when analyzing real-world situations, it can be difficult to separate the benefits of trees from the benefits of other green spaces, since they often co-exist.]

Tree coverage may also play a role in children's academic success. Using remote sensing technology, researchers investigated the relationship between the vegetative cover surrounding over 900 elementary schools and the schools' standardized test scores. Even after adjusting their analysis to account for income, the researchers found that higher test scores were correlated with increased canopy cover. A Michigan study found that views from classroom and cafeteria windows that included more trees and shrubs were associated with better test scores and higher graduation rates. These results held even when controlling for the students' socioeconomic status and racial/ethnic makeup, the age of the school buildings and the size of the school's enrollment. (USDA, 2018)

Views of nature have also been shown to decrease stress levels and help a person to more effectively cope with the stress they do experience. Study participants who experienced a stressful event viewed one of ten 6-minute videos showing a tree canopy density that varied from 2% to 62%. Those who watched the video with 62% tree cover had a 60% increase in their stress recovery over those who watched the video showing 2% tree canopy cover. (USDA, 2016) To the extent that trees encourage people to spend more time outdoors, where they are more likely to encounter friends and neighbors, the resulting social contact has also been shown to relieve stress. (USDA, 2018)

Noise Reduction and Privacy

Well placed trees and other woody vegetation can reduce sound transmission, decreasing urban noise levels by 3 to 5 decibels. Denser stands of mature trees can reduce noise levels by up to 10 decibels, comparable to the sound reduction achieved with effective highway barriers, and certainly a more attractive solution. (USEPA, 2008) Trees can also increase privacy and block undesirable views, minimizing their negative effects (Figure 3-6). In general, people are more troubled by negative effects that they can see and hear, such as a noisy road - trees can help to block both negative views and intrusive sounds. (USDA, 2018)

Trees and Noise Reduction

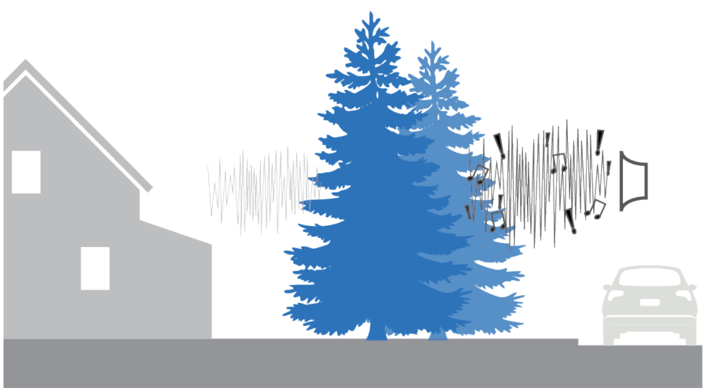


Figure 3-6: Impact on Noise and Undesirable Views
Trees can provide both a visual screen and a noise buffer to help control sounds from unwanted intrusions, such as traffic noise.

Active Lifestyles

Over the past several decades, Americans have been decreasing their levels of physical activity. Fewer people walk or bike to school and work, and many jobs are now more sedentary. Jobs requiring a moderate level of physical activity accounted for 50% of all jobs in the 1960s, but now make up around 20%. Kids are playing outdoors less and fewer play on organized sports teams than in the past. Screentime has increased, and both adults and children are spending more time in front of televisions, computers, and mobile devices such as smart phones. In general, people are burning fewer calories in exercise, work, or play than they did 30 or 40 years ago. Between 1988 and 2010, the percentage of women who reported not engaging in regular physical activity rose from 19 percent to 52 percent. For men, the percentage increased from 11 percent to 43 percent. (USDA, 2018)

The Centers for Disease Control and Prevention reports that being physically active is one of the most important factors in Americans' health. People who are physically active generally live longer and have a lower risk for heart disease, stroke, type 2 diabetes, depression, some cancers, and obesity. (CDC, 2014) Trees can have a positive impact in this regard. In a study among low-income families in urban environments, a higher local tree density was found to be associated with a decreased risk of childhood obesity, depression, and type 2 diabetes. (USDA, 2018)

People who exercise outdoors tend to do so for longer periods and more energetically than people who only exercise indoors. However, the mere availability of green spaces hasn't been conclusively linked to higher levels of physical activity. Likely, other factors such as infrastructure, attractiveness, programming, and safety play a role. Still, the presence of trees and the shade they provide certainly make being outdoors more pleasant, and this, in turn, may encourage an active lifestyle. (USDA, 2018)

The CDC recommends that communities increase access to quality parks and sidewalks, and support urban design efforts that encourage physical activity and walkability, such as tree planting and maintenance. (CDC, 2014) An Atlanta study found that 37% of adults living in neighborhoods with high walkability (including the presence of sidewalks and tree canopy cover) were meeting physical activity guidelines. However, only 18% of people living in low walkability neighborhoods were meeting those same benchmarks. (USDA, 2018)

Community Livability and Resilience

Trees can also improve neighborhood quality of life. Fundamentally, trees provide beauty, improving community aesthetics. Researchers often use visual preference studies to obtain information on design alternatives. In general, these types of studies find that people express a preference for scenes that include vegetation over scenes that show only built features. This response is due to perceptions and mental processes that ultimately drive people's behavior. Our innate responses to community aesthetics have real-world consequences. Business decision-makers and workers are attracted to places that have high quality natural environments and strong urban forests. (Wolf, 2010)

Planting trees also increases recreational opportunities for communities by improving sidewalks and pathways, creating places to gather and providing shade during warm weather. Trees provide a sense of place and well-being, which can strengthen community cohesion. (CNT, 2010) Americans are more socially-isolated than they were 20 years ago, and this was true even before the COVID-19 pandemic. As with physical activity, social relationships are an important part of our health. Without social connections, studies have shown that people are more prone to cardiovascular disease, more likely to engage in risky behavior such as drug use and smoking, and more susceptible to depression, anxiety and mental distress. Particularly for the elderly, greater social interaction is correlated with lower rates of mortality, depression, and cognitive impairment. (APA, 2016; USDA, 2018)

Research generally shows a positive relationship between social cohesion and green space. However – the type of green space matters. Quality green space that is well-maintained, litter-free, and thoughtfully laid out is key for building social cohesion by encouraging gathering and an increased amount of time spent outdoors. (USDA, 2018)

Tree planting and other nature-based volunteer efforts not only help to build a community's physical resilience, but can also build the local leadership necessary to respond to future natural disasters when they occur. The United States Forest Service's New York Field Station investigated the relationship between environmental stewardship and community resilience following natural disasters. The researchers found that as community members became stewards of their local natural resources, the communities showed greater ecological literacy and an increase in civic engagement. Working together on natural resource protection or improvement can also build the social connections we all inherently seek. (USDA, 2018)

Structural value of Brookline's street trees (replacement value)	***$46.2 Million***
Value of stored carbon in Brookline's street trees	***$1.8 Million***

Economic Benefits

In Brookline, there are an estimated 204,000 trees total and a canopy coverage of 44.7%. The Town's trees produce more than $2.5 million in functional value annually, due to air pollution removal ($207,000), avoided runoff ($1,950,000), and carbon sequestration ($370,000). Reduced building energy, improved water quality, wildlife support, and avoided pollutant emissions are additional savings that are certainly present, but are unable to be precisely calculated with the data and research available at this time. Numerous other benefits (for example, improved physical and psychological health, higher real estate values, noise reduction, et cetera) are more difficult to quantify, but research is ongoing.

For urban forests, the highest economic values come from healthy, thriving trees. Valuation studies show the great potential for return-on-investment through cultivation of trees into maturity. Trees help communities save on costs for cooling, air quality, and gray infrastructure (such as pipes and water treatment plants) for water quality. The health benefits described above also come with monetary savings across our lifetimes. While trees are silently working to improve air and water quality and reduce stress, they're also increasing property values and improving the performance of local businesses. These economic benefits can be converted into additional local government revenue to fund programs supporting tree planting and maintenance. (USDA, 2016)

Without healthy, mature trees, a community would not experience the full extent of benefits that an urban canopy can provide. When a mature tree has reached the end of its life, there are also opportunities for the sustainable recovery and reuse of the tree as a variety of wood products. (USDA, 2016; Vibrant Cities Lab)

Tree Maturity and Benefits

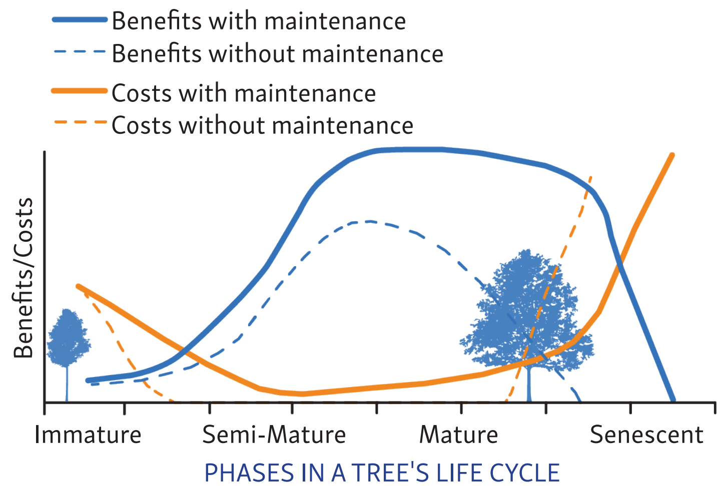


Figure 3-7: Benefits of Tree Maintenance

Theoretical benefits and costs for trees over their lifetime, both with and without maintenance. Trees provide the greatest benefits when they are healthy and maintained into maturity.

Figure derived from: Vogt, 2015 and USDA, 2016

Property Values

A number of studies show that trees increase property values. Studies attribute general increases of 3 to 10 percent in residential property resale value when those properties have existing trees and vegetation as compared to properties without those features. (USEPA, 2008) The presence of larger, mature trees in yards and lining the street can add anywhere from 3% to 15% to home values throughout neighborhoods. Street trees can also add value to adjacent properties, even those up to 100 feet away. (Wolf, 2010) The specific effects on residential property values are impacted by the buyer's socioeconomic status and the quality of the vegetation. However, STRATUM, a USDA Forest Service tool that evaluates the benefits of street trees, includes an increase in residential property value from tree planting measures. (USEPA, 2008)

Regarding new development, the same relationship holds if existing trees are preserved. Development costs in suburban areas can be about 5% greater for lots where existing trees were conserved, but many developers find that the extra upfront cost is more than recovered with faster sales and higher sale prices. (Wolf, 2010)

Tree Retention and Home Sale Prices

Figure 3-8: Tree Retention in Development
Building lots that retained mature tree cover had an 18% higher sales price than comparable homes on lots where tree cover was not maintained.

Commercial rental rates are less well-studied, but an increase in revenue for retail tenants indicates that those building owners should be able to earn higher rental rates for providing amenities like trees and other green infrastructure. Furthermore, at least one study has shown that a well-designed landscape and the provision of shade can both increase rents for office buildings by about 7%. (Clements et al 2013)

Retail Spending

Trees can also increase value in retail areas. Shopping centers with well-maintained landscaping can be more prosperous than those without, largely because shoppers linger for longer, and in doing so, purchase more goods. (USEPA, 2008) A similar relationship exists for business districts and main streets. A healthy urban forest helps to attract more shoppers. (USDA, 2018) Using contingent valuation studies, researchers have found that shoppers indicate they will pay a 9-12% premium to buy goods and services in a central business district with a high-quality tree canopy. Shoppers also claim they will travel greater distances to visit a shopping district with high quality trees and spend more time there once they arrive. This can translate into significantly greater sales revenue, particularly in urban areas, where an expanded radius could add thousands of potential shoppers. This is seen in spending data, with businesses showing an increase in sales and customer satisfaction with a rise in tree canopy cover. (Wolf, 2010)

As discussed above, in visual preference studies, people respond more positively to scenes that contain trees, with their scores increasing as the proportion of trees increased. Even business districts with well-designed buildings and well-kept sidewalks were rated quite low if they did not contain any trees. Scenes with large, mature trees forming a canopy over the sidewalk and street received the highest scores. Consider that many shoppers, particularly in higher socioeconomic classes, do not purchase items simply to meet a need. These shoppers are looking for their overall shopping experience to be pleasant, and a streetscape with high canopy cover is, for many people, an important component of a welcoming shopping district. (Wolf, 2010)

Community Maintenance Costs

Trees have been shown to reduce a community's pavement maintenance costs. Tree shade reduces or slows the deterioration of asphalt street pavements. One study found resurfacing savings of up to 60%, depending on the type of trees used. Specific costs and benefits depend on local conditions, climate, and paving practices, but when considering trees as infrastructure, their contribution to the longevity of street and sidewalk conditions cannot be ignored. (ICLEI, 2006; USEPA, 2008)

Of course, as any public works commissioner can tell you, trees are also a source of maintenance costs. Much of these costs are due to ignoring the advice of 'Right Tree, Right Place". Placing a large tree with a shallow root system in a small tree pit will inevitably result in heaved sidewalks and roadway damage. However, placing trees strategically and appropriately can reduce overall maintenance costs of paved surfaces.

Strategic tree placement is also important for solar photovoltaic (PV) panel systems. Trees and organic soils store carbon, but solar panels reduce the amount of carbon dioxide emitted into the environment and can reduce your carbon footprint. Looking exclusively at pounds of carbon kept out of the atmosphere on an annual basis, solar panels do more to decrease carbon dioxide impacts than a tree. However, a tree is more than just a way to sequester carbon. It also cools the air, filters water, cleans the air, and provides health and aesthetic benefits that are hard to monetize. Mature trees also contain a large amount of stored carbon. Ultimately, the choice between solar and trees isn't clear cut, and depends a great deal on the particularities of the site. Sometimes even tall trees are far enough away so that they do not substantially impact solar access. Homeowners may be able to get enough sunlight on another rooftop exposure to make up the deficit created by tree shade. In addition, newer technology is now in use that can help boost productivity in shady conditions. Research into boosting the efficiency of solar panels in partial shade is likely to continue, as the industry realizes that people interested in 'going green' want both solar power and trees, not one or the other.

A few things are clear. Solar panels should be encouraged first on already-developed or degraded land, as well as on buildings and parking lot canopy systems, rather than placement on ground-mounted arrays over greenspace that diminish habitat and the other benefits of natural land. (Mass Audubon, 2020) Second, pruning and properly maintaining trees that are already planted will maximize tree benefits while also increasing solar output. Third, the adage 'right tree, right place' applies to solar PV panel systems. Arborists and solar experts can examine sunlight angles and provide recommendations on tree species and placement so that people can enjoy both solar energy benefits and the benefits of a healthy urban forest.

Droughts, floods, ice storms and heat stress from the more extreme weather caused by climate change may reduce tree performance and survival rates. Experts say that all trees have the potential to fail from extreme weather. Trees may be uprooted, drop large limbs, or snap. It depends on where the weak or decaying areas are in a particular tree. Healthy trees with good branching structure and a healthy root system are less likely to experience storm damage. Unfortunately, urban conditions put pressure on tree health because tree pits and development generally limit the natural extent of roots. This makes urban trees more vulnerable to being uprooted. Compaction can also impact root health. Proper pruning when trees are young can improve a tree's ability to withstand extreme weather. Early and proactive pruning can eliminate weak points in the tree's structure, such as branches, included bark and sites of decay. While more frequent pruning is an added cost in tree care, it can eliminate more costly storm or ice damage that occurs when the tree is larger.

Equity

While equity is discussed throughout the master plan, some historic practices have contributed to an inequitable distribution of tree benefits within communities nationwide. Redlining was a racially discriminatory practice developed in the 1930s that prevented immigrants and people of color, particularly Black Americans, from obtaining mortgage financing in certain neighborhoods or receiving loans to renovate their houses. The federal government's Home

Owners' Loan Corporation graded neighborhoods A through D. Neighborhoods receiving the highest grade of "A" - colored green on the maps (greenlined) - were deemed minimal risks for banks and other mortgage lenders when they considered who should received loans and which areas in the city were safe investments. "B" areas were considered "Still Desirable" while "C" areas were classified as "Definitely Declining." Areas receiving the lowest grade of "D," shown in red on the maps, were considered "hazardous" investments. "D" areas were often marked in red (redlined) by loan officers and lending institutions, indicating they were areas where loans should be denied.

The grades were based on sales data, but also on the racial and ethnic makeup of residents. The Home Owners' Loan Corporation assumed that the residency of African Americans and immigrants, as well as working-class whites, compromised the values of homes and the security of mortgages. The maps they developed helped to set the pattern for almost a century of real estate and lending practices.

Essentially, redlining directed both public and private capital to native-born white families and away from African American and immigrant families. Since homeownership was, and still is, perhaps the most significant means of building intergenerational wealth, redlining practices created long-term wealth inequalities that still exist today. (Nelson et al, 2021)

Historical Redlining Map

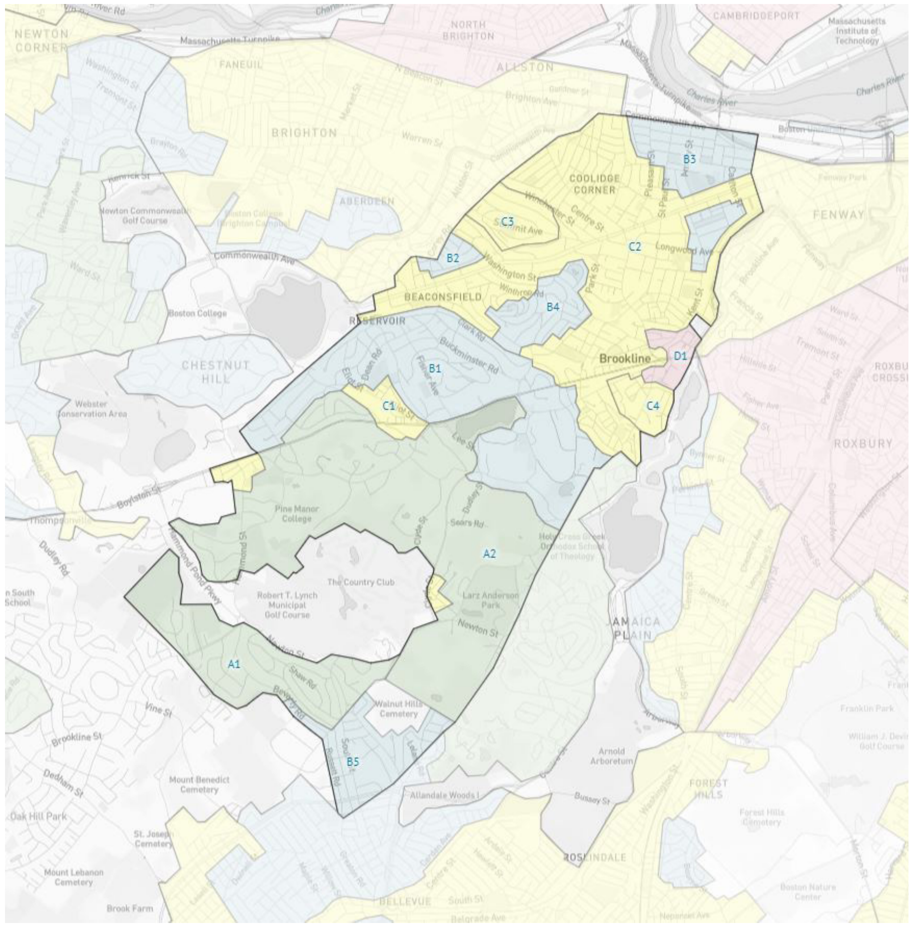


Figure 3-9: Historical Redlining Map of Brookline

In the 1930s the federal government's Home Owners' Loan Corporation assigned grades to neighborhoods for mortgages and lending purposes. Grades ranged from "A-Best" to "D-Hazardous." The grades were based, in part, on the ethnic and racial makeup of the neighborhood. These grades were often a tool for redlining: making it difficult or impossible for people in certain areas to access mortgage financing and become homeowners. The effects of redlining practices from over eight decades ago continue to be seen in neighborhood inequalities today.

Figure Source: Nelson et al, 2021

Although the practice of redlining legally ended in the 1970s, the effects of the practice are still visible. Formerly redlined neighborhoods across the U.S. have a canopy coverage averaging 23%, whereas greenlined neighborhoods have an average canopy cover of 43%. (Locke et al, 2020)

Brookline's grading map (Figure 3-9) shows that North Brookline was mostly graded "C - Definitely Declining" and "D - Hazardous", while South Brookline was generally graded "A-Best" and "B - Still desirable".

While Brookline's overall tree canopy coverage is good at nearly 45%, the coverage is not equally distributed; some areas have nearly 95% coverage and some are as low as 10%. North Brookline only has a 35% average tree canopy coverage and has the largest concentration of minority, non-English speaking, and low income populations. Considering that every 10% change in tree canopy coverage can raise or lower the ambient air temperature 1°F, it is essential that the Town target these low-canopy areas for existing tree protection efforts and additional planting opportunities.

Tree equity can actually promote improved social equity by equalizing access to nature and reducing some of the health disparities between low- and high-income neighborhoods. Due to high housing costs, historical discrimination, and redlining, minority and low-income communities are typically located in more dense, urban areas. These communities are then exposed to higher concentrations of pollutants and heat because there is greater traffic, more hardscape and less green open space. Increasing canopy coverage in these dense, urban neighborhoods, in particular, is a necessary step towards addressing the environmental injustices throughout Brookline.

While the Town works to increase canopy coverage in North Brookline, they must also be mindful and wary of gentrification, and actively work to ensure that at-risk populations are not displaced as a result of the Town's canopy expansion efforts. The Parks and Open Space Division should work closely with the Planning and Community Development Department to monitor this possible consequence and determine appropriate programs or policies to maintain neighborhood economic diversity.

Summary

Trees offer an array of services: environmental, social and economic. Some benefits are directly identifiable and can be counted or monetized. Other benefits are experienced and contribute immensely to Brookline residents' quality of life. These benefits are services that trees provide every day, similar to other community infrastructure such as water mains, power lines, and streets. However, unlike other types of infrastructure, trees generally appreciate in value over time, with more mature trees providing more benefits than younger, less-developed trees.

There are an estimated 5.5 billion urban forest trees in U.S. towns and cities, with an environmental asset value of $18.3 billion. (Nowak and Greenfield, 2018) On average, every $1 invested in a street tree returns $1.37 to $3.09 in benefits. (McPherson et al, 2005) Because tree care and maintenance provides a return on investment, trees can actually be categorized as an asset in city budgets, not just an expense. Like any community asset, a community’s forest requires ongoing care and stewardship. (USDA, 2016)

Why Soils Matter

Soil is a large determining factor in the success and health of a tree, and therefore soils across Brookline were assessed as part of this review process. The soils were tested for a multitude of properties to assess their health, quality, and productivity as a growing medium (Table 4-1).

While soil may appear simple, it is a complex system made up of living and decomposing matter that interacts with the physical and chemical properties of the non-living components. In general, the ideal soil is comprised of about 45% minerals such as clay, silt and sand, 5% organic matter (living and dead organisms) and 50% water and air, by volume (Figure 4-1). (NRCS, 2019)

Soil Components

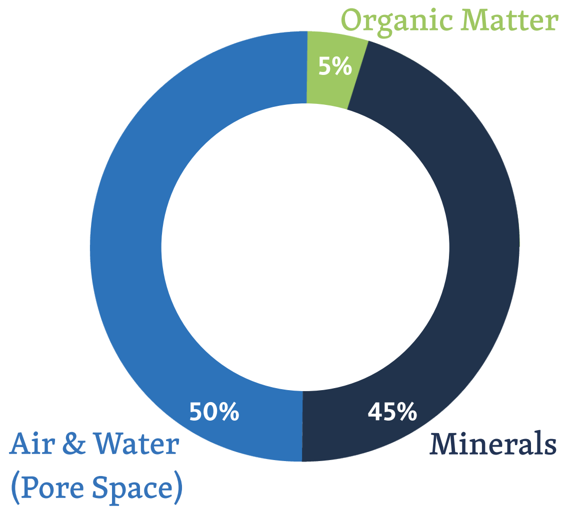


Figure 4-1: Components of a Typical Soil
Soil is not completely solid. The ideal soil has 45% mineral particles, 5% organic matter, and 50% pore space, divided between air and water.

Soil minerals typically come from local weathered rock, but in urban areas, the minerals are often transported to the site from elsewhere. (NRCS, 2005) Organic matter is made up of dead plant and animal material and all the living organisms in the soil. The living organisms, including fungi and bacteria, move nutrients between the soil and the tree roots, creating a food web under our feet. Water and air occupy the spaces between the mineral particles in tiny pockets called pore spaces. These pore spaces provide a way for the water and air to be used by plants and the organisms living in the soil. When everything is in balance, and the soil is healthy and high-quality, it is able to support tree growth and productivity. (NRCS, Soil Health; NRCS, 2019)

A healthy soil supports five functions that are essential to plant growth, including the growth of urban trees:

- Regulate water flow and water storage infiltration and runoff
- Sustain life, from microorganisms to 100-year old trees
- Filter, immobilize, and degrade pollutants through minerals and microbes
- Store, transform, and cycle nutrients such as carbon, nitrogen, and phosphorous
- Provide physical support and a growing medium for plant roots (NRCS, Soil Health)

Understanding soils in urban and semi-urban areas, such as Brookline, is particularly important because the soil is used intensively. Soils support man-made structures and infrastructure, such as homes, roads and sidewalks, and provide many of our ecosystem services, including tree growth and water infiltration. In more urbanized areas, such as North Brookline, the natural layers of soil found in an undisturbed forest, for example, are rarely seen. In the process of constructing an urban environment, as hills are flattened, debris is buried, and low areas are filled, natural soils are mixed and moved. Understanding soil conditions across Brookline will not only inform the Town's urban forest management practices, but also Brookline's actions on climate change and watershed planning. (NRCS, 2005) As a carbon sink, healthy soils sequester carbon. They also help control temperature and provide the growing conditions for trees and other vegetation that can help mitigate climate change impacts.

Within this report, the analysis of local soil conditions sampled across Town will be discussed.

Climate Change and Soil

Soils are the second-largest carbon sink on earth, after the oceans. It is thought that over half of the carbon held in soils is stored more than one foot below the surface. Soils hold more carbon than the world's forests and other vegetation, and even more than the atmosphere. Climate change and its impacts - increased temperature, irregular and changing precipitation patterns, flooding and droughts - may affect a soil's ability to support plant growth, regulate water flow, and store carbon. As a major carbon sink, soils are both a potential casualty of climate change and a potential component of our response to climate change. (European Environment Agency, 2019)

By sequestering carbon, healthy soils can decrease greenhouse gas levels. However, poor soil management can lead to CO_2 being released into the atmosphere, accelerating climate change and its impacts. While this is a major concern for the agricultural industry, urban soils also require strategic management to ensure carbon dioxide is sequestered and soils are not needlessly disturbed. (Food and Agriculture Organization of the United Nations, 2015)

Increased temperatures from climate change may affect soil moisture and result in a need for increased irrigation. (European Environment Agency, 2019) On a more micro level, climate change-related disturbances such as flooding and droughts result in stressful conditions for the microorganisms that reside in the soil. These microorganisms are necessary for cycling nutrients for tree growth and development. In general, the organisms in a high quality, healthy soil will recover quickly from a short term disturbance. However, a chronic stress condition will cause the organism population to shift to a new equilibrium, one that may or may not benefit tree growth. (NRCS, 2015a)

Particularly in urbanized areas, healthy soils are an essential tool in mitigating the impacts of climate change. Not only does a high-quality soil sustain plant and tree growth, but it also absorbs and stores water to minimize flooding and provides a buffer in times of drought. Soils contribute to cooling through both water storage and tree growth and shading. (European Environment Agency, 2019)

Assessing Soil Health with Sampling

Soil health depends on the physical, chemical and biological attributes of the soil. The categories are not always clearly divided since a single soil property can affect multiple soil attributes. There are a large number of soil properties and a correspondingly large number of indicators that can be tested to assess soil health. (NRCS, January 2015)

When sampling and assessing Brookline soils, the goal was to obtain a set of representative samples that would provide a broad look at overall soil conditions in Town. For that reason, testing focused on soil indicators that are sensitive to changes and soil properties that can be modified through effective management practices. The indicators can be used as a snapshot of conditions at a point in time, or can be re-assessed regularly to establish trends and act as a confirmation that management techniques are improving a soil's properties.

Sampling can also be used to compare areas with different management practices, such as an area where leaf litter is left on the ground in autumn versus an area where it is removed. Over time, changes can be tracked in soil quality, providing feedback on what management techniques are working or where additional or different practices might be needed. (NRCS, 2001)

Finally, targeted soil assessment can identify specific problems and their location occur. Prior to planting, soil sampling is critical to assess soil fertility and the ability of a particular soil to support a tree or other vegetation.

Soil Properties

Physical Properties and Soil Composition

A soil's physical properties provide the basis for how well that soil can support plant life. Physical properties relate to the mineral components of the soil, how the soil particles are arranged or aggregated, and the pore space in a given soil. Examples include soil compaction levels, texture, and aggregate stability. Generally, physical properties control root growth and tree stability. (University of Massachusetts Extension, 2017)

The mineral portion of a soil is made up of particles of sand, silt, and clay. Soil texture is determined by the relative proportion of those soil particles. Sand particles are the largest, silt particles are medium in size, and clay particles are the smallest (Figure 4-2). The texture of the soil controls how much water and air a soil can hold (porosity) and how fast water can move though that soil (permeability). A soil with a high percentage of clay will hold more water than a sandy soil, but it will also hold less oxygen,

Soil Particle Sizes

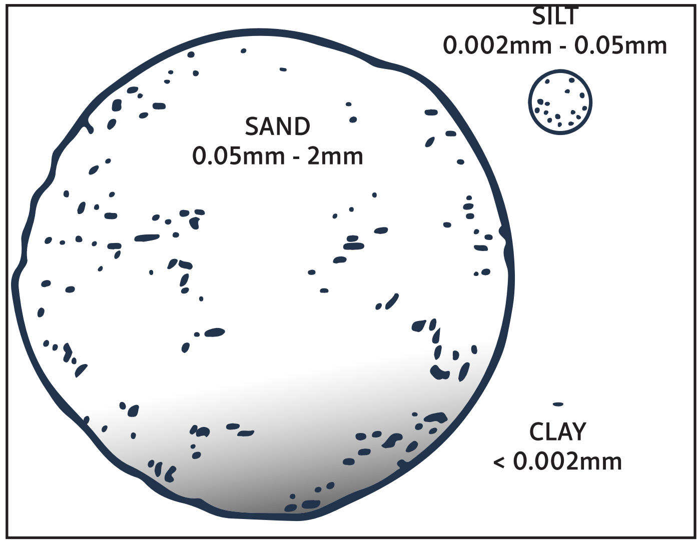


Figure 4-2: Relative Sizes of the Different Types of Soil Particles

which tree roots also need. A coarse soil with lots of sand will drain quickly, preventing root rot, but it will leave the plant without much water. Medium-textured soils, generally called loams, are suitable for the widest range of plants. (University of Massachusetts Extension, 2017)

It is difficult to change the texture of a soil. Natural weathering can change the size of the particles, but this happens over thousands of years. (University of Massachusetts Extension, 2017; Trowbridge and Bassuk, 2004) In urbanized areas, such as Brookline, much of the soil is not the original, native soil, and the soil texture of imported soil can vary even within a few feet. For that reason, soil texture was not tested in this round of sampling where the goal was a broad snapshot of current conditions. Soil texture can be useful, however, for investigating problems with specific trees or small areas.

Soil structure refers to the way individual mineral particles of a soil are aggregated and how much surface area is available in the soil. This structure affects the ability of air and water to move through the soil, a feature that is necessary for sustaining plant growth and the health of soil-dwelling organisms. Depending on

Reference Table of Soil Properties Tested in Brookline

Soil Property Tested	What It Measures	How It Was Tested
Bulk Density	Soil compaction	Weight of soil was examined for a given volume (Lab test)
Water Infiltration	How quickly water enters and passes through the soil	Single ring infiltration method (Field test)
Aggregate Stability	Stability of large soil particles in water	Slake test (Lab test)
pH	The acidity or alkalinity of a soil	pH test (Lab test)
Cation Exchange Capacity	Soil fertility	Electrical conductivity test (Lab test)
Organic Matter	Living and decomposing components in that soil; biological activity	Soil respiration test/Solvita CO_2 test (Field test)
Nutrients	Availability of nutrients that are necessary for tree growth, such as phosphorus, potassium, magnesium, calcium	Chemical evaluation (Lab test)
Heavy Metals	Levels of arsenic, barium, chromium, nickel, copper, zinc, cadmium, and lead	Chemical evaluation (Lab test)

Table 4-1: Overview of Brookline Soil Testing Procedures

Soil properties evaluated through soil sampling completed as part of this Master Plan. Not all samples received each test. See Appendix A - Soil Test Results for full soil sampling results.

the soil texture, different factors play a greater role in soil structure. For example, physical and chemical factors influence the structure of clay soils, but biological factors, like burrowing earthworms, largely determine the structure of sand-based soils. In developed areas, the biggest impact on a soil's structure is usually from the way people manage and interact with soils. For example, digging in wet soils or using heavy machinery can destroy good soil structure, while adding organic matter can improve soil structure. (NRCS, 2008d)

Soil structure in urban and developed areas, such as Brookline, are often negatively affected by everyday activities, creating poor conditions for street plantings. For example, commercial areas and locations where the sidewalks are too narrow for the pedestrian traffic they accommodate often suffer from compaction. You can see evidence of this in the tree pits in Coolidge Corner, where repeated foot traffic tamps down the soils into a material that is closer to concrete in appearance than a healthy soil.

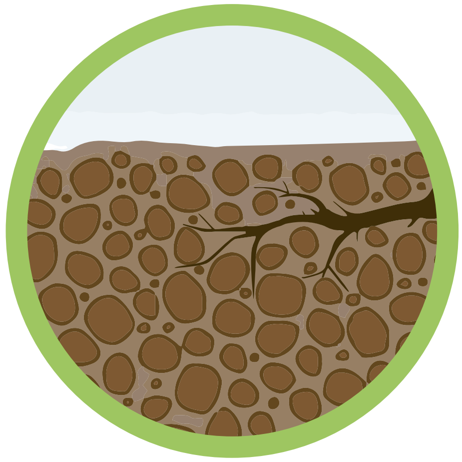
In general, foot traffic, vehicle traffic, and construction activities are common factors that increase soil compaction. Removing the leaf litter that helps to replenish the soil also contributes to high compaction levels. Compacted soil is dense, making it more difficult for tree roots to grow and penetrate into the soil and limiting the amount of water and air available. The lack of pore space between particles also means that more rainfall runs off the soil's surface, rather than infiltrating into the soil, which can lead to flooding and erosion. For trees, compacted soils can lead to restricted root growth and subsequently, poor overall growth (Figure 4-3). (Cornell, 2017; NRCS, 2005; NRCS, 2008a)

Bulk Density

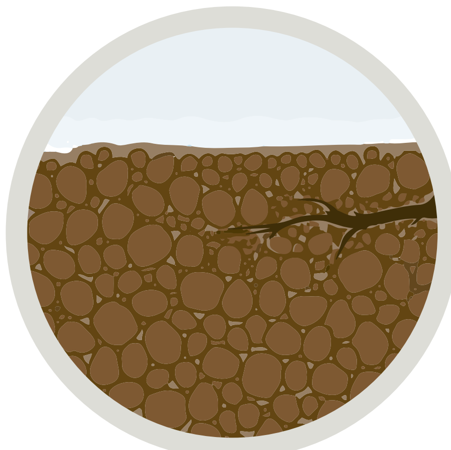
Bulk density is an indicator used to measure soil compaction. It is defined as the weight of soil for a given volume. Bulk density is a good way to gauge a soil's ability to sustain life and promote growth, to regulate water flow, and to provide stability for plants. In general, a high bulk density indicates a compacted soil with less pore space available for air and water movement, root growth and root penetration. (NRCS, January 2015)

Given the developed nature of Brookline, we would expect Brookline's soils to show some evidence of high bulk density, which would indicate high compaction. The expectation is that South Brookline sampling locations would have lower bulk density values than North Brookline. Typically, the more urbanized or well-traveled an area is, the higher the compaction level.

Impact of Soil Compaction on Tree Roots



Tree Roots in Ideal Soil



Tree Roots in Compacted Soil

Figure 4-3: Comparison of Root Growth in Ideal and Compacted Soils
Image adapted from www.russelltreeexperts.com/

Water Infiltration

Infiltration is the movement of water downward into the soil. The infiltration rate is a measure of how quickly water enters the soil, and is used as another indicator of soil compaction and overall soil health. Infiltration is a particularly important factor in soil health because it impacts water availability for tree roots and supports habitat for soil-dwelling organisms. Generally, a relatively high infiltration rate is desirable for tree growth. If the infiltration rate of a soil is too low, it can lead to "ponding" in which water accumulates on the soil's surface, or lead to runoff and erosion if the ground is sloped. When ponding occurs, pore spaces in the soil are taken up by water, leaving no room for air. This effectively drowns the tree's roots, limits growth, and reduces the amount of available nutrients. Runoff carries nutrients, chemicals and soil particles away from a tree, decreasing the productivity of that soil, and often causing flooding downhill. (NRCS, 2008b)

The infiltration rate is influenced by the soil texture (water moves more quickly into large pore spaces), soil structure, and the existing water content of the soil. Infiltration is also affected by soil compaction and the amount of organic matter present, which helps in the development of soil pore space and increases infiltration. Soils with a sufficient amount of organic matter also provide a suitable habitat for soil dwellers, such as earthworms, that increase pore space and further improve soil structure through burrowing. (NRCS, 2008b)

Vegetated soils tend to have better infiltration rates and lower erosion than bare patches of soil. Falling rain will dislodge small soil particles on bare soil, clogging the soil pores and limiting infiltration. Trees act as protection from erosion and help to break up soil crusts that form on bare earth. Tree roots also create conduits for water flow into the soil. (NRCS, 2008b)

Largely due to the foot traffic that Brookline's tree lawns experience, we would expect Brookline's soils to be low in their ability to infiltrate water, especially in the most urbanized areas where tree pits often lack vegetation.

Aggregate Stability (Slaking)

Slaking is the process by which large soil aggregates break down into smaller pieces, called microaggregates, when exposed to water. A slake test measures how stable a soil is when it is suddenly exposed to water. It also measures how well a soil resists internal stresses when wetted, such as the swelling of clay soil particles, or the release of trapped air. The results of a slake test indicate how well a soil can withstand erosion and maintain its pore structure. A poor test result means that a soil is likely to suffer from loose soil particles that block available pore space, leading to reduced infiltration, reduced water availability for tree growth, and increased erosion and runoff potential. Slaking, however, is reduced in soils with a higher percentage of organic matter. The organic matter helps bind the soil particles together, promotes good aggregate formation, and makes the aggregates more stable. (NRCS, 2008c)

Urbanization and low organic matter, due to the annual cleanup of autumn leaf debris along Brookline's streets, could lead to poor results in the slaking test.

Chemical Properties

Several major chemical properties affect soils including soil pH, cation exchange capacity (CEC), organic matter, and the levels of various nutrients and minerals needed for tree growth, such as potassium, phosphorus and magnesium. Chemical properties generally affect water and nutrient availability, water quality, and the manner in which soil and trees interact. (NRCS, 1996) These properties are discussed for Brookline's soils below.

pH

pH measures the acidity or alkalinity of a soil. Soil pH is one of the best indicators of the general chemical status of soil and determines how well a tree can take up nutrients from the soil. Some nutrients are not available to tree roots unless the pH of the soil is within a given range. pH also affects the abundance of soil microorganisms, which perform essential nutrient cycling services. Generally, bacteria are more prevalent in alkaline soils and fungi dominate in acidic soils. The most diverse and numerous populations of microorganisms are found in soils that have a pH close to neutral. (NRCS, 2014b; Soil Quality Institute, 2001)

New England soils tend to be low in pH, and without active and regular efforts to raise the pH, we would expect Brookline's street tree soils to have low pH levels.

Cation-Exchange Capacity & Nutrients

Cation-exchange capacity (CEC) is a measure of soil fertility, and is another factor analyzed for Brookline's soils. It measures the degree to which a soil can take in and exchange cations, which are positively charged ions. Many of the nutrients trees need are taken up as cations, such as magnesium, calcium, and potassium. Clay particles and organic matter particles are negatively charged, and hold onto the positively charged cations, preventing them from leaching out of the soil when it rains. This ensures that nutrients are available for use by the plant when they are needed. Sandy soils, soils low in organic matter, and soils with a low pH (acidic) tend to have low CEC. (NRCS, 2014a; Trowbridge & Bassuk, 2004: 41)

A deficiency of an essential nutrient in the soil can inhibit tree growth and render it susceptible to disease. On the other hand, high levels of a particular nutrient can negatively impact the ability of the tree to uptake other nutrients. For example, soils that are too high in calcium have trouble taking up potassium. Trees that are deficient in potassium are unable to utilize nitrogen and absorb water efficiently, and may be more susceptible to disease.

An electrical conductivity test measures how well soil water transmits an electrical current, and indicates the soil's cation-exchange capacity. Measuring conductivity is an excellent indicator of the availability or loss of nutrients and the available water holding capacity of a soil. It also indicates the level of activity of microorganisms, which in turn influences the emission of greenhouse gases. (NRCS, 2014a; January 2015) Microbes mediate the exchange of carbon between the land and the air, and can be greenhouse gas consumers or producers, depending on soil conditions.

All soils contain some ions, which are necessary for plant growth. A higher electrical conductivity value generally means the soil has a significant amount of nutrients available for a tree. However, a conductivity/salinity level that is too high will limit plant growth by impacting the soil-water balance and increasing surface compaction. (Soil Quality Institute, 2001)

Since we expect the soils in Brookline's tree lawns (the strip of land between the street and sidewalk) and tree pits to have low pH and low organic matter (see next section), we expect the tested soils to also have a low CEC.

Biological Properties

Biological properties include measurements related to organisms and their activities, and can include decomposing plant residue in the soil as well as populations of microbes, fungi, and larger organisms such as earthworms. Biological indicators help us to understand nutrient cycling in the soil and the ability of soil to filter contaminants. (NRCS, 1996)

Organic Matter

The organic matter in a soil is a measure of the living and decomposing components in that soil. Even though organic matter is present as a small percentage of total soil volume, it has a big effect on physical and chemical properties. Organic matter increases porosity, lowers bulk density, increases water infiltration and available water holding capacity, and reduces excessive cohesion of soil particles. (Soil Quality Institute, 2001)

Soil microorganisms such as bacteria and fungi break down dead plant and animal tissues, helping to transfer nutrients from the atmosphere or the soil to the tree roots. The microbes act as recyclers, making nutrients available for plants to use. Generally, microorganisms can release more nutrients when the soil is warm and moist, and are less active when the soil is cold and dry. In addition to the bacteria, fungi, and algae present in the soil, larger organisms (such as worms, insects, slugs) and small animals (such as mice) increase aeration, improve soil structure, degrade pollutants, and break down organic matter to help cycle nutrients. (NRCS, 2015a)

Since all of these organisms depend on the soil to live and respond quickly to changes in soil management, they can be good indicators of soil quality. It can be difficult to measure their presence directly, so respiration is used as a surrogate for their prevalence. (NRCS, 2015a) Soil respiration measures the amount of carbon dioxide being released from the soil and is a way to evaluate the biological activity and level of decomposition occurring in that soil. Essentially, soil respiration is a measure of soil life. (NRCS, 2014d; NRCS, January 2015).

Soil respiration can be tested in the lab or in the field. Brookline's soil analyses used a respiration test that could be performed at the soil sampling location, providing information on the natural level of soil respiration, while avoiding any unwanted effects of lab processing. The field test, called a Solvita field CO_2 soil test, is a good general indicator of soil biological activity.

Very low soil respiration readings indicate very low microbial activity in the soil and means that nutrients are not being released to feed the tree roots. Causes could include compaction, drought, flooding, or low organic content. Soil respiration readings that are too high could indicate an unstable soil system or excessive fertilization. (NRCS, 2014d; NRCS, January 2015)

Images from the Soil Sampling Process

Bulk Density Testing

Timing the Infiltration Rate

Slake Test

Electrical Conductivity Testing

Respiration/Organic Matter Testing

Sampling Soils for Laboratory Tests

Figure 4-4: Selected Images from Brookline Soil Sampling and Testing Procedures

Given Brookline's population density and the regular cleanup of potential organic matter (e.g. leaf debris), we would expect Brookline's soils to show low organic matter. Tree pits and unvegetated tree lawns would likely have lower organic matter levels than vegetated tree lawns, which experience some turnover of organic materials.

Sampling Brookline's Soils

Soil sampling was confined to public tree lawns or tree pits in Town. The soil sampling and analysis was confined to the upper four to five inches of the soil profile. This portion of the soil profile is where the vast majority of absorptive tree roots reside. Anchoring and stabilizing tree roots do extend deeper, but the primary interest in this analysis was the potential constraints on water and nutrient uptake by the absorptive roots.

Indicators Analyzed for Brookline Soil Samples

ALL 16 SITES	ALL 16 SITES	ONLY 8 SITES
SOIL CHEMISTRY Indicators analyzed: • pH • Organic Matter • Cation Exchange Capacity (CEC) • Phosphorus • Potassium • Magnesium • Calcium	**HEAVY METALS** Indicators analyzed: • Arsenic • Barium • Chromium • Nickel • Copper • Zinc • Cadmium • Lead	**URBAN SOIL HEALTH ASSESSMENT (USHA)** Indicators analyzed: • Bulk Density • Water Infiltration • Aggregate Stability (Slaking) • Solvita • Electric Conductivity

Figure 4-5: Breakdown of the Types of Indicators Chosen to Analyze Brookline's Soils

Sampling Locations and Selection Process

Sixteen locations across Town were selected for soil sampling to represent the diversity of planting locations for public trees within Brookline (e.g. tree pits in the commercial Coolidge Corner area, and tree lawns along Shaw Road, a residential street in South Brookline). These locations were also selected to represent a selection of soil types present in Town (see the Soil Map and the Soil Sampling Locations Map on page 54 and page 55).

Two types of analyses were used to sample the soils. Sixteen sites were sampled in total and were analyzed using a standard soil chemistry approach to evaluate soil fertility and a set of additional tests to detect and measure the occurrence of eight heavy metals. Eight sites were more extensively analyzed using an Urban Soil Health Assessment (USHA) approach that was designed to measure soil health using selected soil quality indicators of soil biology, chemistry, and physics to determine existing and potential soil constraints. The USHA approach provided more in-depth biological and physical soil information, with a focus on tree health (see following section on soil properties and indicators). These parameters were also able to be tested quickly, easily and cost-effectively, allowing the Town to continue a testing protocol in the future.

Sampling and Testing Protocols

Soil sampling took place on May 27, 2020 and was conducted by Chuck Sherzi, Jr., of Sherzi & Co. LLC. All samples were taken from the tree lawn or tree pits between the sidewalk and the street. Some tests, such as the water infiltration test, were completed in the field. All soil samples from each location were transported to a laboratory for further testing and chemical analysis, which was completed by Spectrum Analytic, LLC.

Soil Sampling Results

The full data from each of the 16 sampling sites is included in Appendix A - Soil Test Results.

All sixteen sites received analysis for a standard soil chemistry approach to evaluate soil fertility and additional testing for heavy metals to test for health concerns. Eight sites were more extensively analyzed using an Urban Soil Health Assessment (USHA) approach that was comprised of five indicators: bulk density, water infiltration, slake, Solvita (a testing protocol measuring respiration), and electric conductivity. While the five indicators were tested separately, the results were analyzed as a whole and can provide a cross-check to confirm results and to identify inconsistencies. For example, we would expect that a soil with a low level of compaction (low bulk density) would have a good level of water infiltration. If water

Soil Sampling Locations

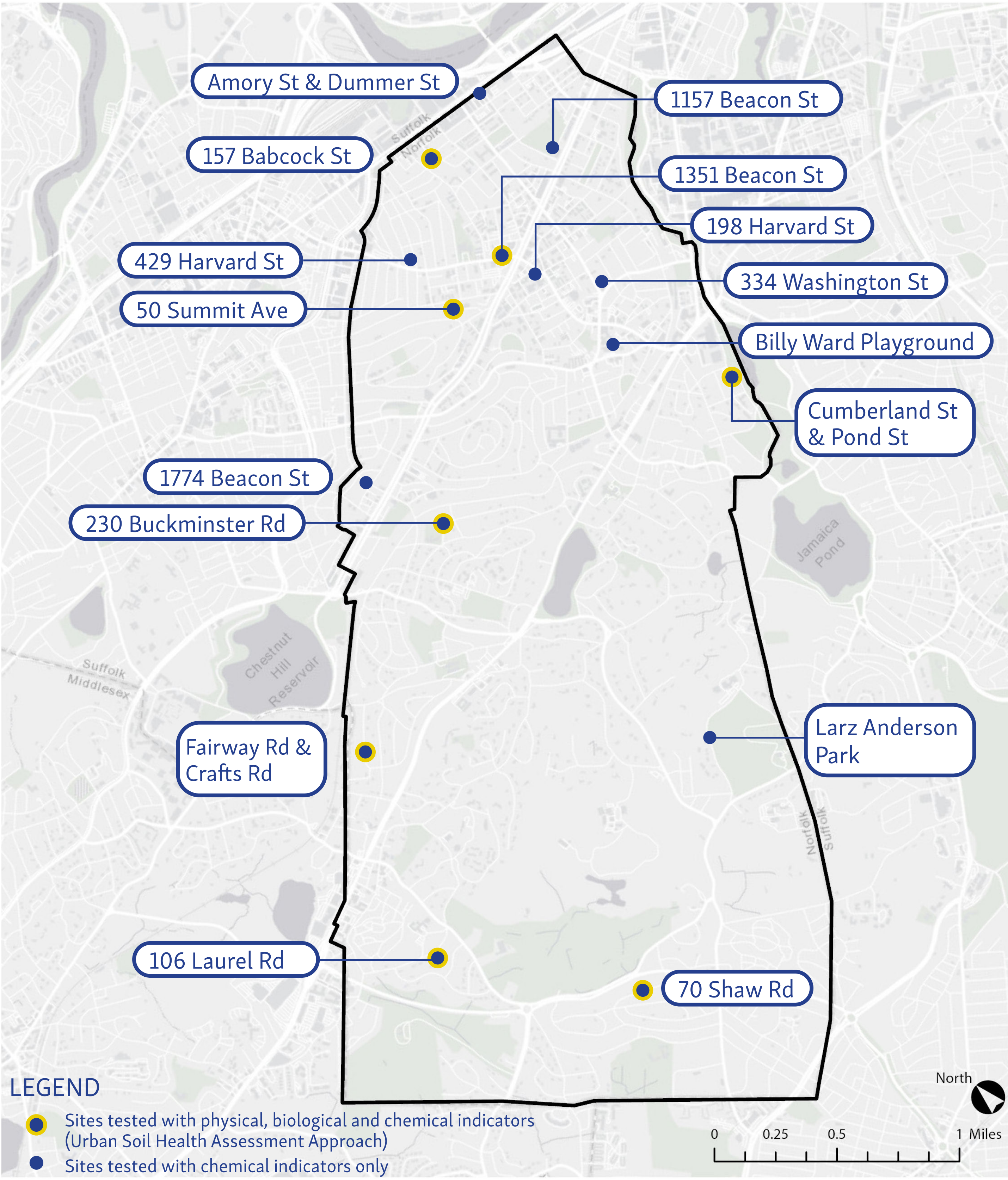


Figure 4-6: Soil Sampling Locations in Brookline

Locations where soil in a tree lawn or tree pit was sampled and tested for its physical, biological and chemical properties. Not all sampling location received each test. See Appendix A - Soil Test Results for full soil sampling results.

Brookline Soil Types

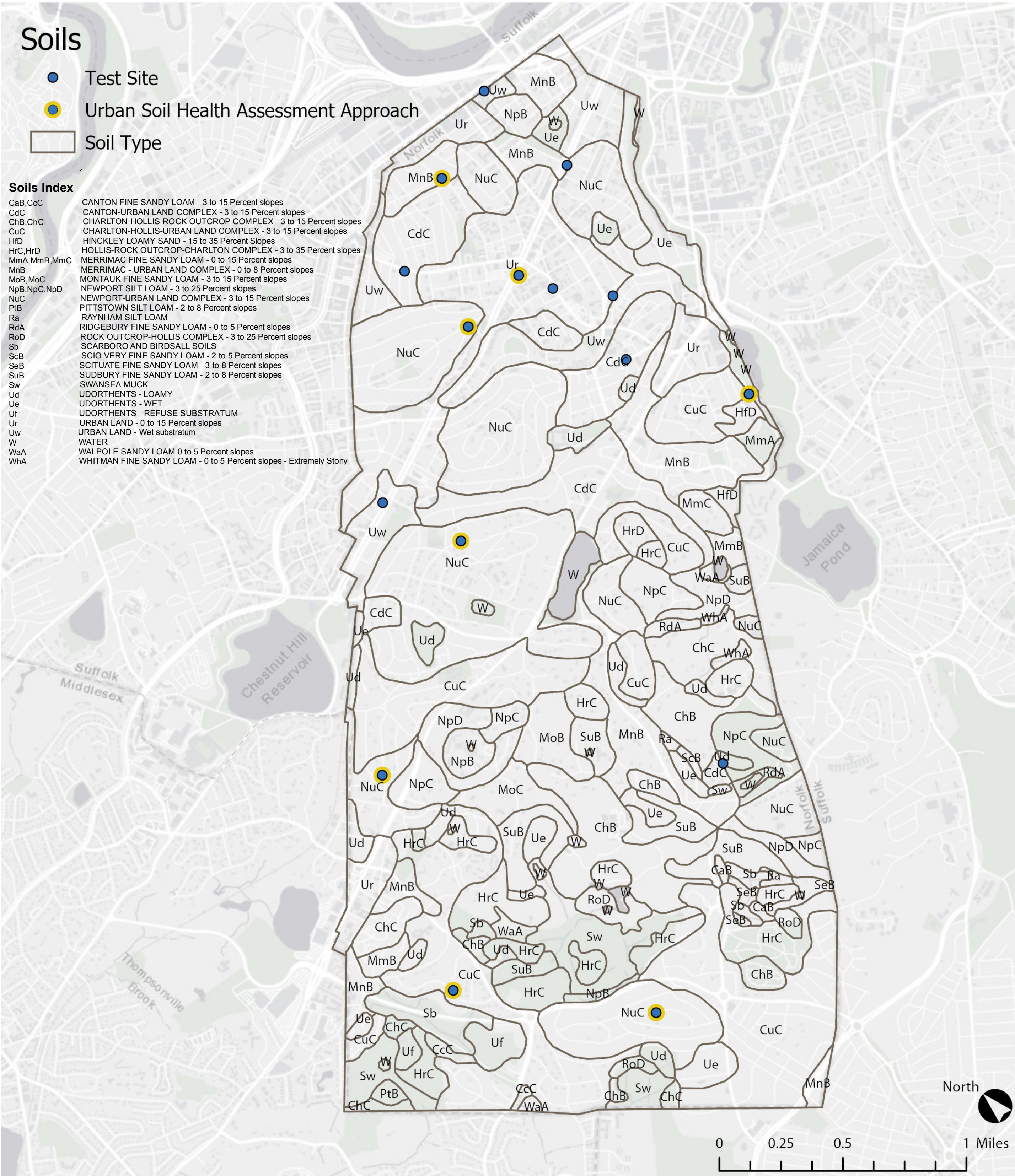


Figure 4-7: Soil Types in Brookline Shown with Soil Sampling Locations

Soil types in Brookline as described in the USDA Natural Resources Conservation Service Soil Survey. The soil survey maps soil boundaries and provides descriptions of soil properties and features.

infiltration was low in a soil with a favorable bulk density, that could indicate that another factor is at work, or that the test should be repeated.

Compaction

Of the eight sites tested using the USHA approach, six sites had 50% or better soil porosity. This is higher than is usually expected in urban soils, where pedestrian and vehicular exposure often have a negative effect on soil porosity. In addition, all eight sites scored optimally for water infiltration, slaking, and electrical conductivity. Generally, the data were in agreement regarding the soil health at the sampled locations. However, a few anomalies were noted. It is unusual that the two sites that scored low on porosity would score well on the other indicators (see the discussion on bulk density above). Another noted anomaly is that three of the sites that scored 50% or greater in porosity displayed low microbial activity. Good porosity usually promotes strong microbial activity. In the case of these two noted anomalies, a retest is recommended to determine if the results were due to a test kit defect or if other constraints are present.

While the physical and biological tests indicated soils in good condition, the chemical analysis resulted in values that showed a greater range of soil conditions from optimal to low levels. In general, medium and low values indicate deficiencies that result in constraints on soil function, and potentially on tree growth. Many of the identified soil deficiencies are related to the low levels of organic matter.

Organic Matter

A majority of the samples (11/16) had a below-optimal level of organic matter. Organic matter in cultivated or developed areas of New England, such as Brookline, tend to be relatively low, in the 2-4% range. Low levels of organic matter usually correlate with low cation exchange capacity, which is the way that soils retain fertility. Generally, the samples bore out this correlation, with nine of the eleven samples with low organic matter also testing below optimal on cation exchange capacity. Low cation exchange capacity also signals a depletion of positively-charged nutrients in the soil and the tendency for a drop in pH. However, the documented low levels of organic matter can be amended at the time of initial tree planting, or through regular maintenance practices.

pH

Optimal pH for tree growth and microbial soil activity is around 5.8 to 6.6. Most New England soils are naturally acidic because frequent rains wash away the more alkaline components of the soil and the granite parent material of the soil doesn't provide any buffering. Nine samples out of 16 fell within the optimal pH range. However, seven out of the 16 samples had pH values below 5.8. It is important to note that pH is measured on a logarithmic scale, meaning that a pH of 5.0 is 10 times more acidic than a pH of 6.0, and 100 times more acidic than a pH of 7.0, which is considered neutral.

Nutrients

Trees need a variety of nutrients to grow and remain healthy. The chemistry assessment included tests for the following macronutrients: phosphorus, potassium, magnesium and calcium. These nutrients are needed in greater quantities than micronutrients, such as iron, copper, and zinc, which are only needed in minuscule amounts. Nutrient deficiencies can cause slow or stunted growth, poor root development, or limited ability to photosynthesize effectively.

All samples scored at or above the optimal range for phosphorous. An above-optimal score is not highlighted in the results (Appendix A - Soil Test Results) because there is no specific amendment recommendation that can be applied. Over time, the nutrient will be used by the tree or leached from the soil profile during rain events. All but two soil samples tested low in potassium. 75% of the samples tested low in magnesium and five samples tested low in calcium.

Heavy Metals

Heavy metals are elements such as lead or arsenic that can be toxic to people or plants if they are present in high quantities. Heavy metal contamination is usually more of a problem in urban soils where construction, fossil fuel combustion and prior land uses, such as manufacturing, are more common. Current regulations prohibit dumping heavy metals into the environment and many products are no longer made with heavy metals. However, heavy metals break down very slowly, so even without additional toxins, any affected soils typically require removal or remediation. The most common contaminant in urban soil is lead, which can remain in the soil profile for thousands of years. (Saunders, Olivia and Thomas Buob, 2017)

Of the 16 samples tested using the heavy metals panel (which assessed the presence of arsenic, barium, chromium, nickel, copper, zinc, cadmium, and lead), all samples scored below the maximum level recommended by the Massachusetts Department of Environmental Protection or U.S. Environmental Protection Agency guidelines. Some of these metals are needed as micronutrients for tree growth, such as copper and zinc, however high concentrations of these nutrients indicate contaminated soil and require further evaluation. Elevated levels of copper, nickel and zinc can cause plant toxicity and elevated levels of arsenic or cadmium are a concern for human health. (Saunders, Olivia and Thomas Buob, 2017)

Soil Volume and Tree Growth

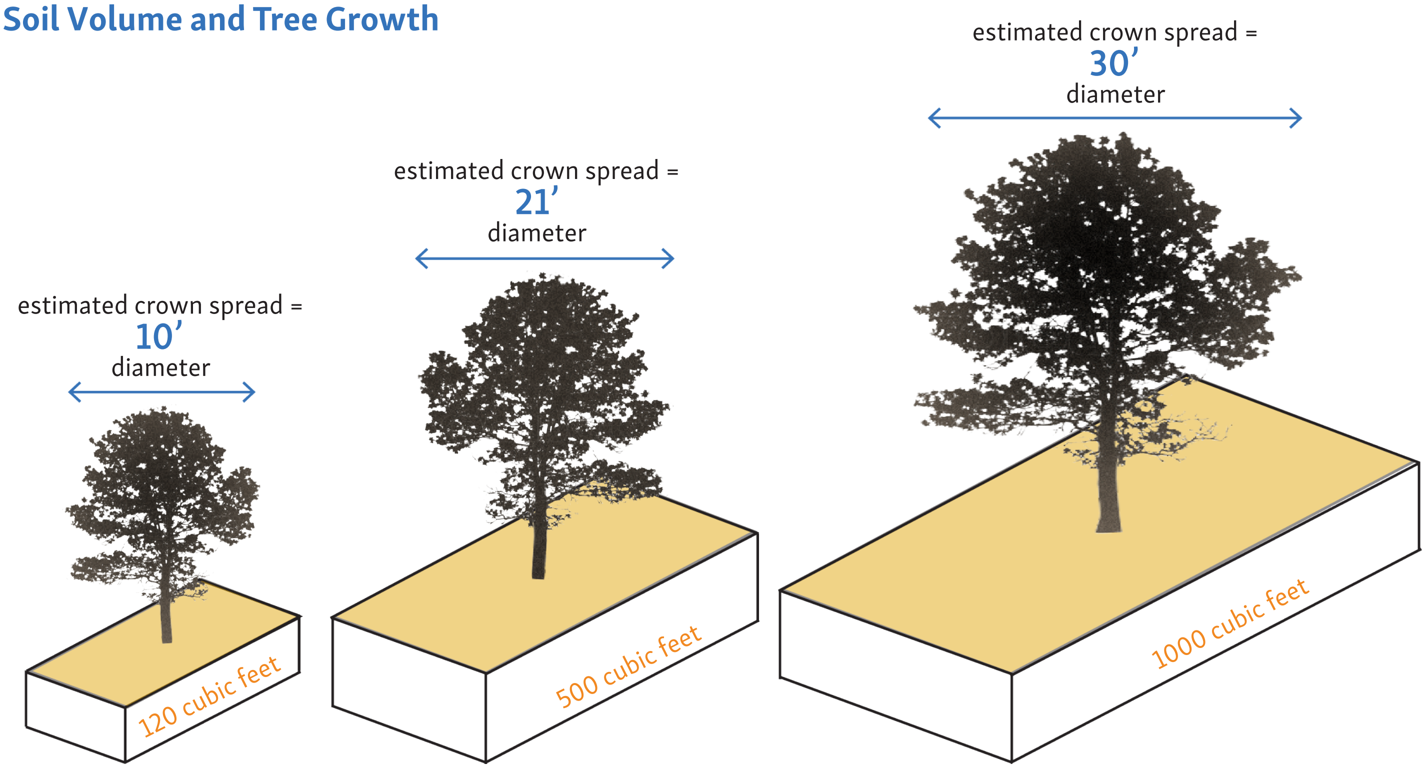


Figure 4-8: Relationship between Soil Volume and Tree Growth
There is a strong correlation between the soil volume available to a tree and its canopy spread.

Summary and Conclusions

The soil sampling described above has provided a snapshot of the quality of Brookline's tree lawn and tree pit soils and how well those soils are supporting the growth of street trees. Soil testing and assessment work is important to establish a baseline for future evaluation as Brookline looks to improve the health and longevity of its urban forest. Fortunately, the sampling conducted in Brookline revealed primarily correctable chemical deficiencies.

Trees in a forested environment germinate and successfully grow if conditions are suitable for the tree. They also benefit from a large, shared soil volume. In general, urban trees are exposed to more foot traffic, higher pollution levels, and more construction activities than their counterparts in a natural setting. Urban street trees are placed in a very artificial, man-made environment and asked to grow and perform a multitude of ecosystem services. This places trees in environments that may not be optimal for their growth. Street trees are planted in turf or mulch, constrained in a limited volume of soil between sidewalks, curbs and roadways. Soil sampling can tell us about soil quality, but another important element is the soil volume available for an urban tree to grow.

Another characteristic of the urban environment is that the street and sidewalks surrounding our street trees are largely impermeable surfaces. Incorporating permeable surfaces into streetscape design could better support the life and growth of the street trees in the community. Permeable surfaces can decrease temperatures and increase water availability in the soil, which in turns supports greater microbial activity and soil health.

Regarding management, streetscape cleanliness unfortunately has a detrimental effect on Brookline's street trees. In a forest, leaf litter would accumulate over the years, renewing the soil. Along Brookline's streets, leaf litter is removed every autumn. While streetscape cleanliness is important for maintaining accessibility and safety, removing the leaf litter contributes to low organic matter levels. Although soils are supplemented with fertilizer, fertilizers cannot replace natural soil building processes. Returning composted leaf material to the soil in Brookline's tree pits and tree lawns would go a long way toward improving street tree health. For example, the Natural Resources Conservation Service (NRCS) notes that just a 1% increase in soil organic matter enables soils to hold an additional 25,000 gallons of water per acre per year.

Finally, changes in soil quality are not necessarily quick fixes. It is important to continue a landscape soil assessment program so that, as different management or planting techniques are implemented, their results can be tracked and evaluated. A landscape soil assessment program for the Town could be a regular soil testing program that is part of Forestry Services operations to inform tree care and management as well as tree planting decisions. This program would build on the soil testing performed as part of this project, but it should expand the testing to include more areas in the Town and continue to test for physical and biotic characteristics. In the future, it could be valuable to conduct further sampling in the 4-8" depth range to see if there are additional constraints that could be limiting street tree growth and health.

Commitment to this type of experimentation and evaluation will help to track data over time and provide a more accurate accounting of the Town's efforts and results.

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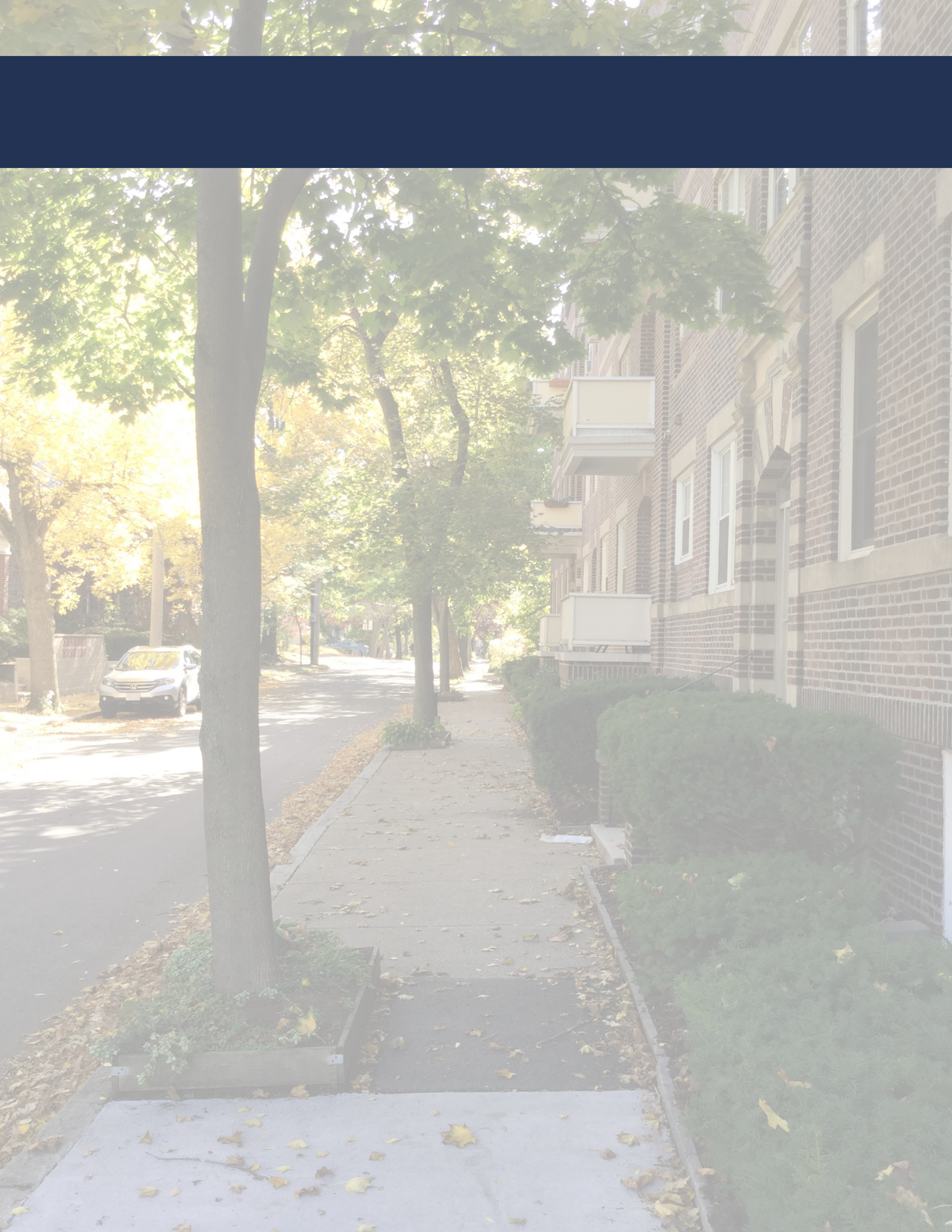


EXISTING CONDITIONS OF THE URBAN FOREST

5

Two methods were used to inventory and evaluate Brookline's urban forest: 1) a stem-by-stem inventory of Town trees overhanging the public way, and 2) an urban tree canopy analysis of public and private trees. Together, these methods provided a comprehensive overview of the Town's urban forest and informed the identification of needs across Brookline, particularly areas that are underserved in terms of tree planting and/or are more vulnerable to the impacts of the climate change.

Stem-by-Stem Inventory

Brookline's first street tree inventory occurred in 1994 with the help of approximately 100 volunteers. The Town's Parks and Open Space Division performed a complete update of the street inventory in 2009, assessing 12,041 trees along 104 miles of road. Since that time, the data has been maintained by the Town in a GIS-based database, and used to track tree health, maintenance history (such as pruning work) and emergency response actions. As part of this master plan, there has been a complete update of the public street tree inventory.

Process

For the purposes of the stem-by-stem inventory, trees located within the public way and Town trees overhanging the public way were inventoried as a group because they are managed very similarly by the Town's Forestry Sector. Within the master plan, they are collectively referred to as "street trees."

From April to August 2020, arborists from Bartlett Tree Experts inventoried every Town tree with a trunk diameter greater than 3" that was within the public right-of-way or overhanging the public way. Town staff inventoried the trees with trunk diameters smaller than 3". In total, 12,041 public street trees were inventoried and evaluated. In general, the inventory team worked from North to South Brookline, evaluating every street tree and documenting a number of tree characteristics.

Figure 5-1: Stem-by-Stem Inventory in the Field
An arborist logs a tree's location, genus, species, size, and condition during the stem-by-stem inventory in Brookline.

PeopleGIS Software

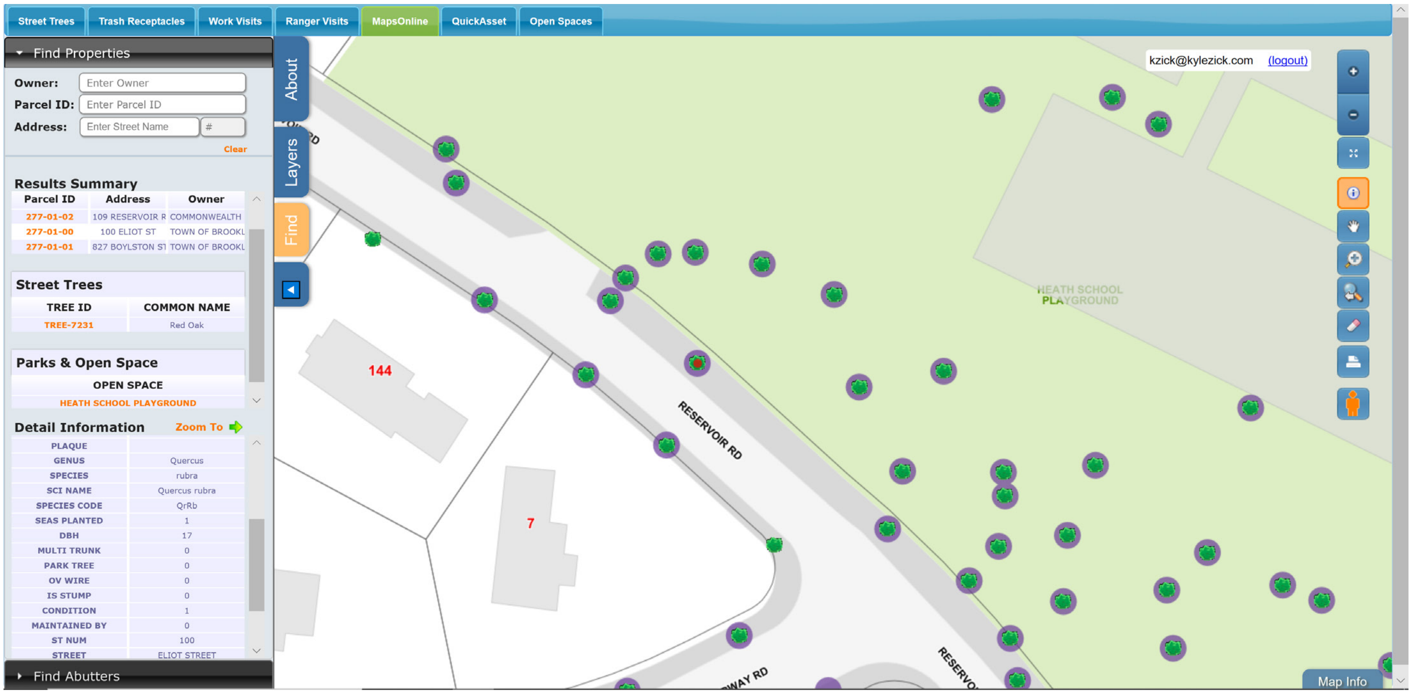


Figure 5-2: Screenshot from PeopleGIS, the Town's Maintenance Management System for the Stem-by-Stem Tree Inventory

Data collected for the stem-by-stem street tree inventory included:

- Tree Location, Longitude, Latitude
- Tree Genus, Species, and Common Name
- Tree Size, measured as the trunk diameter at breast height
- Tree Condition on a scale from 1 to 5

Each tree was logged into PeopleGIS. PeopleGIS is a proprietary web-based software that is used to manage the public trees in Brookline. Using a computer, tablet or mobile phone, users can access public tree data. The Town uses the platform to update tree inventory information and record new tree plantings, pruning work, or tree removals. The stem-by stem tree inventory completed as part of this master plan was recorded in the field by Bartlett Tree Experts in PeopleGIS. More information on how the Town uses PeopleGIS in its day-to-day forestry operations can be found in Chapter 7.

Tree Location

Each tree's location was logged using a global positioning system (GPS) device and a geographic information system (GIS). The GPS device utilizes satellites to identify the location of an individual tree using geographic coordinates, such as latitude and longitude. This is the same technology used on smart phones to relay a car's location and indicate the distance to your next turn. With GPS data, a tree's location is accurate to within approximately 10'. However, accuracy is reduced when satellite signals are blocked or reflected by obstacles, such as buildings or bridges. The GIS is a framework for gathering, managing, and analyzing data that organizes layers of information spatially, using the geographic coordinates collected with the GPS device.

Tree Genus, Species, and Common Name

A two-word naming system is used in the scientific community to identify living organisms, including trees - a genus and a species. A species is the most specific

Town of Brookline Stem-by-Stem Inventory Along Public Roads

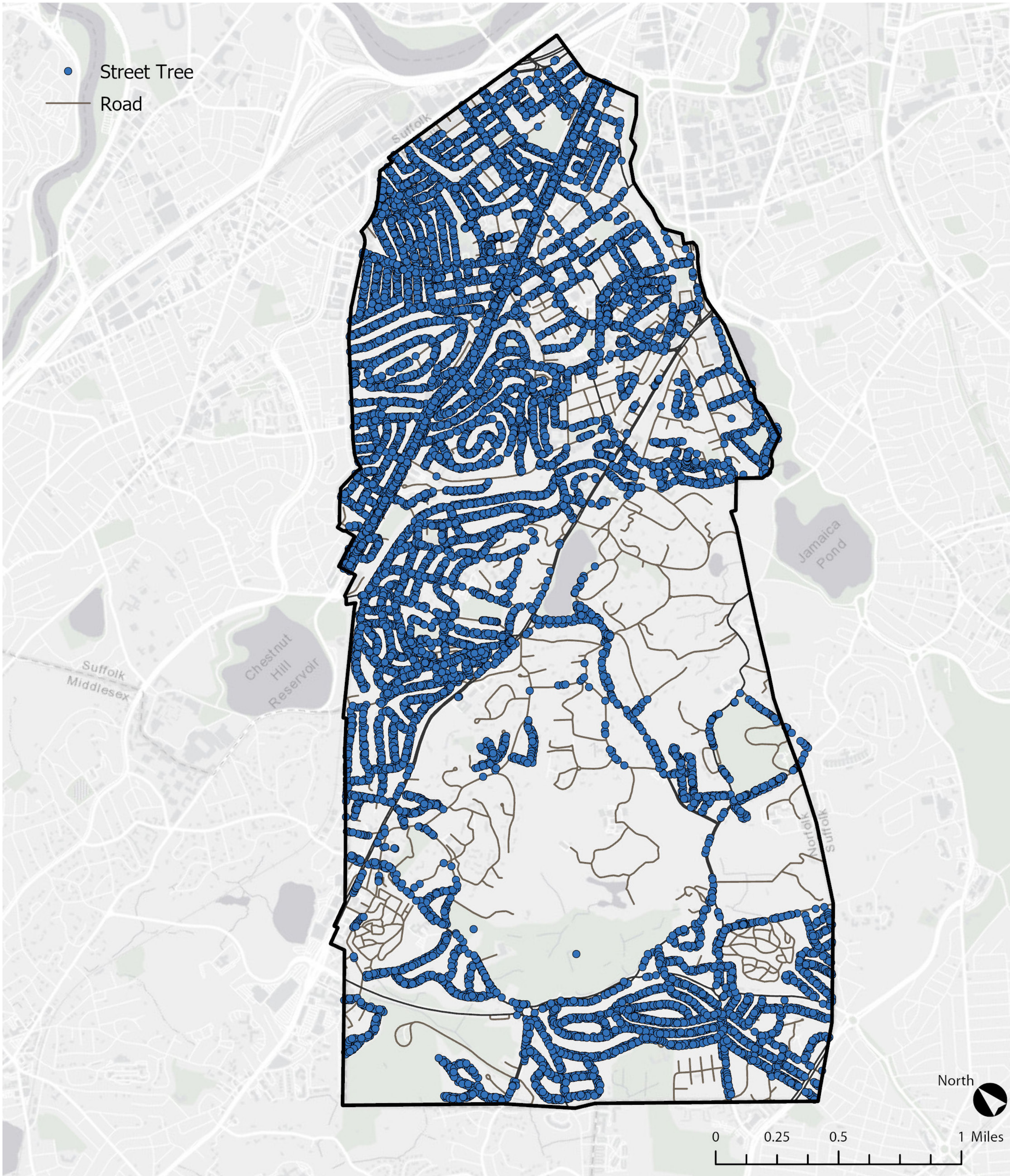


Figure 5-3: Stem-by-Stem Inventory Results

Data points show the locations and distribution of public street trees within the Town. Note that the map shows both public and private roads.

classification level. A genus is a group of closely related species. The genus and species naming system helps to avoid confusion and was used in the inventory to provide a more accurate tally.

As an example, the familiar group of trees known as oak trees are all under a single genus: *Quercus*. But there are over 60 different kinds of oak trees under the genus name *Quercus*. When the species name (for example - *rubra*) is added, a very specific type of tree can be logged. *Quercus rubra,* Northern red oak, is native to eastern North America and common in Massachusetts. In this document, common names, in popular usage in New England may be referenced alongside the formal scientific name.

Tree Size

Diameter at breast height, or DBH/dbh, is the nationally recognized standard for measuring tree size. DBH refers to the tree diameter measured at 4'-6" above the ground.

DBH can be measured quickly with a specially calibrated diameter measuring tape that displays the diameter measurement when wrapped around the circumference of a tree. The diameter can also be found by determining the circumference of the tree and dividing this number by pi (3.14).

DBH not only communicates a tree's size, but can also be used to estimate a tree's age if some consideration is given to a tree species' average growth rate. Within a single species growing in similar conditions, one can generally expect that a tree with a DBH of 8 inches is younger than a tree with a DBH of 20 inches.

Diameter at Breast Height

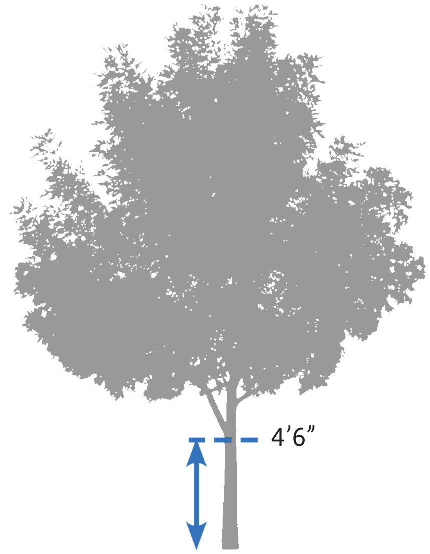


Figure 5-4: Measuring Tree Size

Tree size is measured using by evaluating DBH (Diameter of the tree trunk at Breast Height), approximately 4'6" from the ground.

Street Tree Condition

The condition of a street tree describes the health and overall quality of a tree given its site-specific conditions. A tree condition rating can also indicate the general health of a tree population.

The rating system utilized in this inventory and the criteria influencing these different ratings were developed in coordination with the Town's Tree Warden. Each tree condition rating considers the quality of the tree, given its urban condition (Table 5-1).

Street Tree Condition Rating Descriptions

Rating	Rating Description
1 - Excellent	Trees in this category are judged to be exceptional trees and possess the best qualities of the species. All have excellent form and very minor maintenance problems and are growing in a location which will enable them to achieve a full, mature shape.
2 - Good	Trees in this category are judged to be good trees which with proper maintenance can be brought into very good condition for the future. They may be growing in close proximity to utility lines or may have moderate insect problems or nutritional deficiencies.
3 - Fair	Most trees in this category have one or more of the following problems: large dead limbs with as much as one-half of the tree already dead; large cavities; drastic deformities; girdling roots; severe insect or pathological problems.
4 - Poor	Trees in this category are in very poor condition with irreversible problems and will have to be removed in the near future.
5 - Dead	Trees in this category are standing but are no longer alive.

Table 5-1: Description of street tree condition ratings used for the stem-by-stem inventory

Street Tree Results

Condition

Of the 12,041 inventoried trees, 75% were classified as being in Excellent condition and 18% were classified as being in Good condition. Only 5% were classified as Fair and less than 3% were classified as either Poor or Dead.

Street Tree Conditions

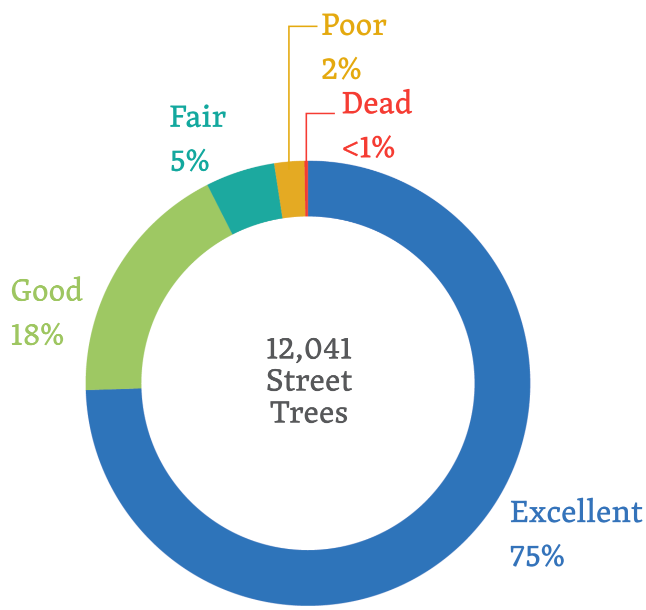


Figure 5-5: Street Tree Condition Ratings Results
The ratings show a healthy street tree population, given their urban environment.

Species

The variety of species present within an area, called species diversity, impacts the availability of specific habitats and food sources for local fauna, the range of ecosystem services a forest provides, and overall resiliency to climate change.

Species diversity also affects the ability of the urban forest to withstand threats from invasive pests and diseases. Low species diversity can destroy a community's tree cover if a species-specific disease or pest attacks the most prevalent trees. For example, the American elm (*Ulmus americana*) was once a popular street tree across the country. However, when Dutch

Street Tree Condition

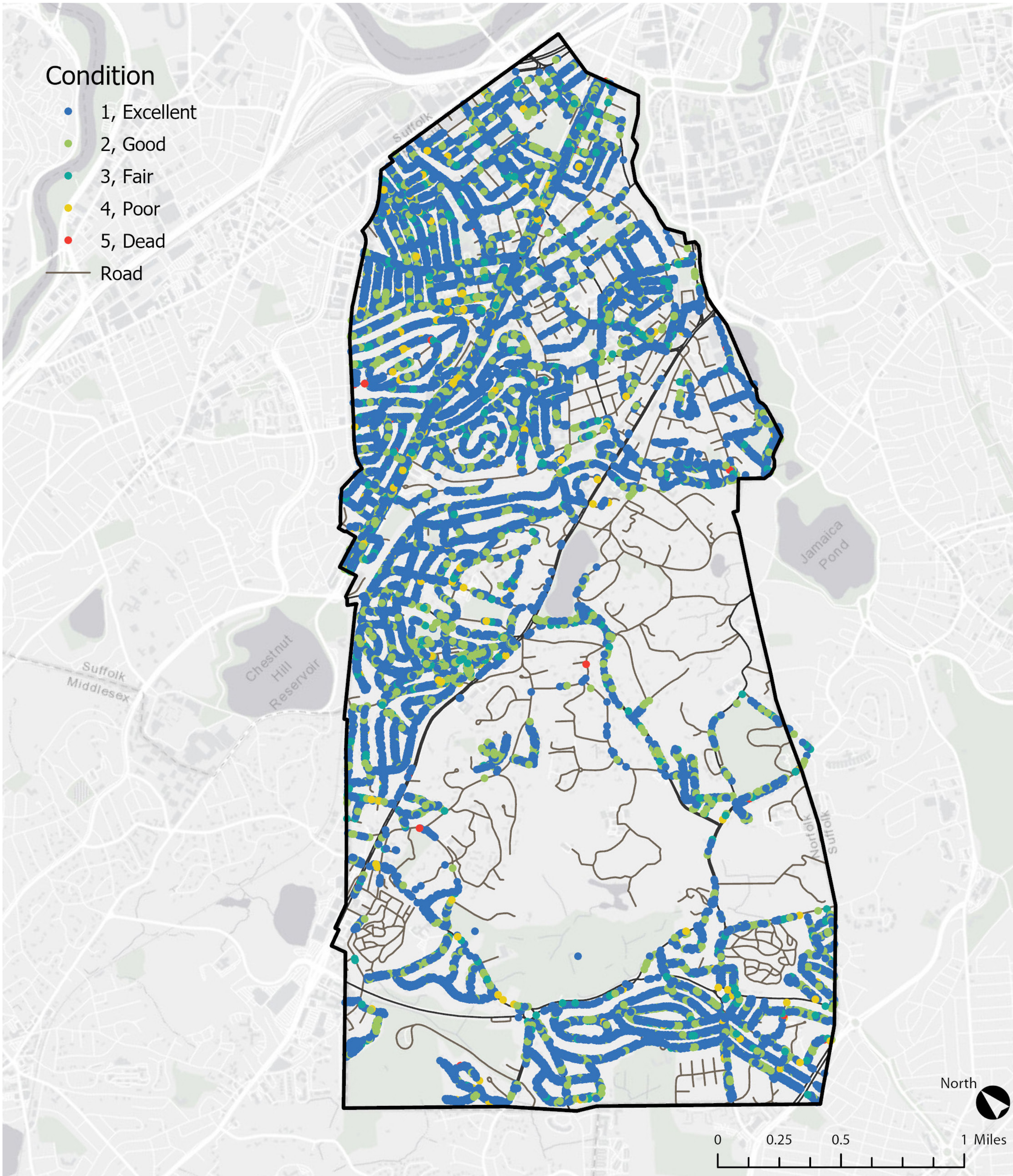


Figure 5-6: Distribution of Public Street Trees by Condition Rating Across Brookline.

elm disease, a lethal tree disease that hinders a tree's ability to move nutrients and water to its branches, arrived in the United States in the 1930s, the nation witnessed first-hand the importance of species diversity. Over several decades, the disease devastated American elm populations across the Midwest and Northeast. In towns where American elms had been extensively planted, Dutch elm disease spread quickly and devastated many of these communities' shade tree populations.

It has become common practice for arborists to recommend that the ideal composition of an urban tree population should follow the 10-20-30 rule for species diversity. First referenced in print by Dr. Frank Santamour (Santamour, 1990), the 10-20-30 rule suggests that:

- A single species should represent no more than 10% of the total trees in an urban forest
- A single genus should represent no more than 20% of the total trees, and
- A single family should represent no more than 30% of the total trees

For example, according to the 10-20-30 rule, northern red oak (*Quercus rubra*) would be less than 10% of the total number of trees in an urban forest. All types of oaks would make up less than 20%, and oaks and beeches (which are in the same family) would make up less than 30% of a community's tree population. However, some debate exists regarding whether this rule ensures sufficient species diversity. As a result, some localities have adopted a more aggressive guideline. For example, Portland, Oregon adopted a 5-10-20 standard for its urban forest.

In Brookline, 103 different species are represented along its streets. The single most common street tree is the Norway maple, with almost 1800 individual trees. Other common street trees in Brookline include the northern red oak, red maple, and honeylocust, each composing 8-11% of the total street tree population. Pin oaks, littleleaf lindens and London plane trees are close behind, each composing 6-7% of the total population.

Brookline's Top 10 Street Tree Species

Common Name	Number of Trees	Percent of Total
Norway maple	1790	14.9%
Northern red oak	1280	10.6%
Red maple	1034	8.5%
Honeylocust	997	8.2%
Pin oak	877	7.3%
Littleleaf linden	831	6.9%
London plane	780	6.4%
American elm	606	5.0%
Green ash	399	3.3%
Sweetgum	352	2.9%

Table 5-2: Breakdown of the 10 Most Common Tree Species Along Brookline's Streets.
Each species includes all cultivars of that species.

At nearly 15% of the total street tree population, Norway maples exceed the recommended 10% maximum for a single tree species. This species was planted widely across the region in past decades due to its tolerance to pollution, quick growth rate and impressive shade. However, it is now listed as an invasive species in Massachusetts and is no longer sold commercially. Beyond its invasive tendencies, the Norway maple has proven to be particularly susceptible to storm damage, requires a great deal of pruning and maintenance, and has a propensity for girdling tree roots.

The high percentage of Norway maples, along with the prevalence of red maples, means that maples in the tree population also exceed the 20% guideline for a single genus.

Size

Analyzing tree trunk diameter through size classes enables us to evaluate the relative age of a tree population. Since tree-related benefits increase with increasing tree size, the overall economic and environmental value of the Town's trees are determined based on DBH. Understanding the distribution of tree sizes also helps to anticipate and plan for maintenance needs and related costs.

Studies on tree size have resulted in the idea of an "ideal" distribution for street tree size classes. Common examples include Richards' Ideal Distribution and McPherson's Ideal Distribution. (Richards, 1983; Soares et al, 2011) While these two theories utilize different size classes, the overall conclusion is the same: the Town's ideal distribution of street trees would have the greatest number of trees in the smallest/ youngest size class, and a much lower number of street trees that are established, mature trees.

Mature trees provide the most benefits and efforts should be made to maintain the health of the existing mature trees. However, continued planting of new, young trees is necessary to ensure that in 50 years, there will be a continued presence of mature trees. To become mature trees, younger trees must manage to survive foot traffic, construction, pests, storm damage and other causes of mortality. As a result, the ideal distribution is one that has the largest percentage of trees in the smallest DBH category.

In terms of size, over a third of Brookline's street trees are 1"-10" in diameter. Nearly another 40% are 11"-20" in diameter. Traditional thinking on ideal distributions would have an even greater proportion of trees in the smallest size category. The data suggests that there should be an increase in planting efforts to better plan for succession and the next generation of canopy coverage.

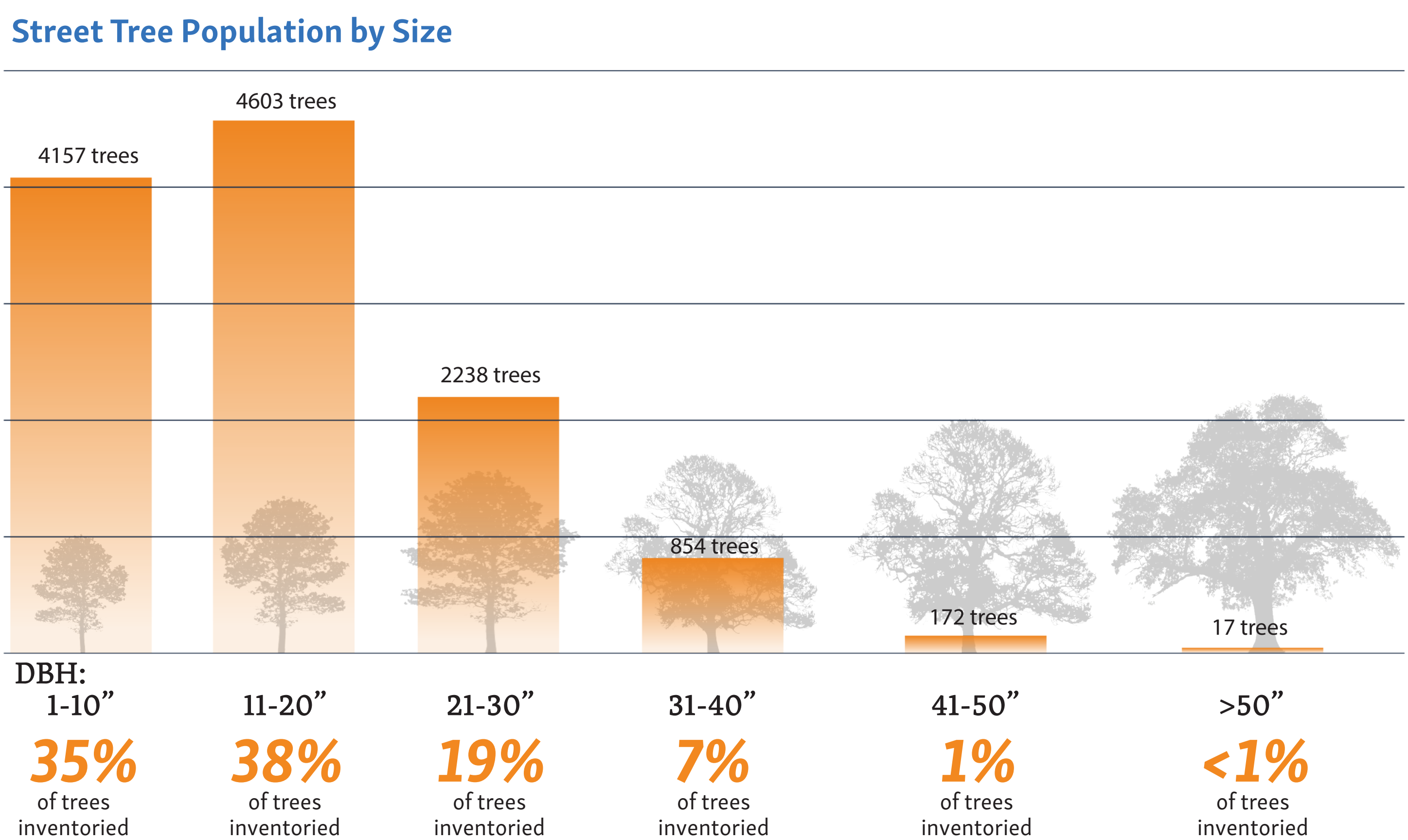


Figure 5-7: Distribution of the Street Tree Population by Size, as Measured by DBH (Diameter of the tree trunk at Breast Height)

Street Trees of Concern - Invasive Species

Examining the street tree population of Brookline, a number of invasive tree species are present. As discussed above, Brookline's 1,790 Norway maple trees have been classified as an invasive species by the Massachusetts Invasive Plant Advisory Group. In addition, Norway maples are a fast growing species which lends itself to being a weak-wooded tree. As a result, Norway maples are prone to storm damage, especially in the winter months when the tree is dormant. Additional pruning and removal efforts will be needed to compensate for these issues.

The Norway maple is no longer planted by the Town and efforts are underway to replace these trees. The Town is using the strategy of actively removing older, declining Norway maples. However, younger Norway maples without structural defects are being monitored and allowed to remain, as they are still providing important benefits including shade and habitat. Arborists also logged 5 other invasive tree species in Brookline's street tree inventory. Due to the large number of Norway maples, 15.5% of Brookline's total street tree population is comprised of invasive species.

Invasive vs Non-Invasive Species

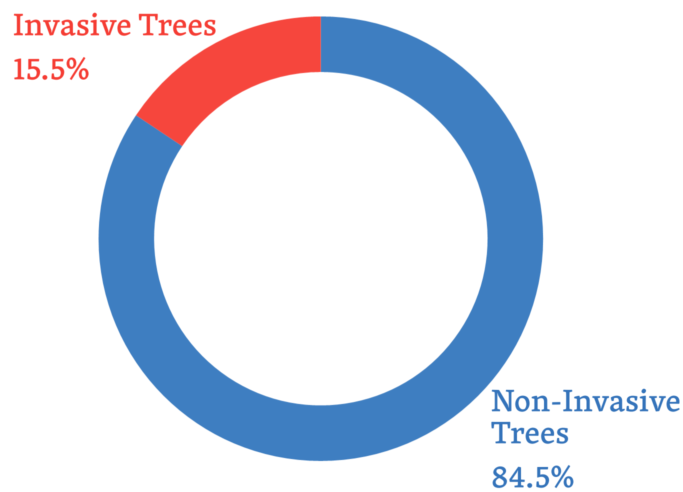


Figure 5-8: Inventory Results of Invasive and Non-Invasive Tree Species in Brookline's Street Tree Population
Invasive street tree species include those species that are on the Massachusetts Invasive Species List maintained by the Massachusetts Invasive Plant Advisory Group.

Brookline's Invasive Street Tree Species

Common Name	Number of Trees	Percent of Total
Norway maple	1790	14.9%
Tree of heaven	28	0.23%
Black locust	21	0.17%
Sycamore maple	19	0.16%
Amur corktree	5	0.04%
Buckthorn	1	<0.01%
Total	**1864**	**15.5%**

Table 5-3: Breakdown of Invasive Tree Species in Brookline's Street Tree Population
Invasive street tree species include those species that are on the Massachusetts Invasive Species List maintained by the Massachusetts Invasive Plant Advisory Group.

Invasive Species Present in Brookline's Street Tree Canopy

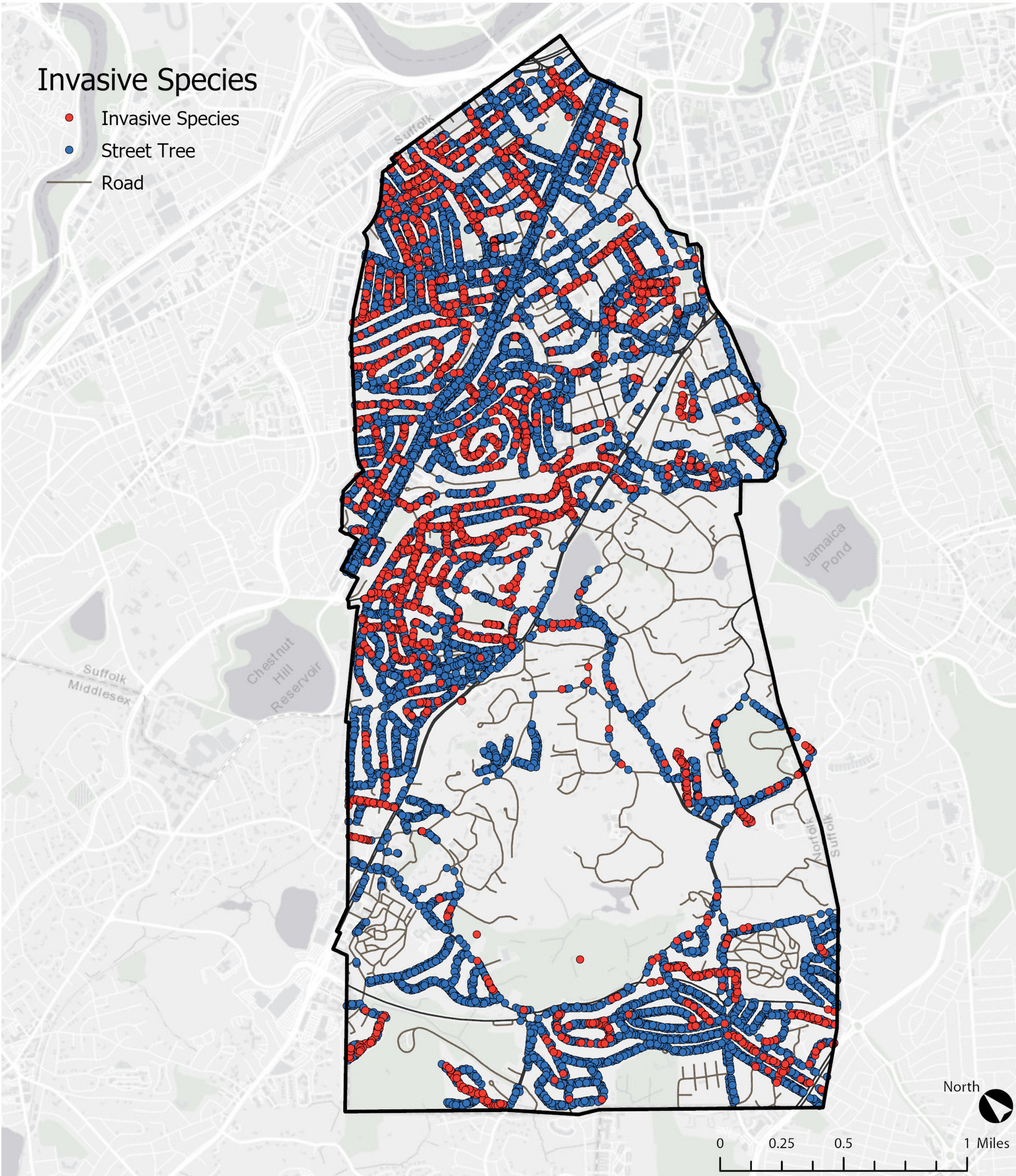


Figure 5-9: The Location of Invasive Tree Species within Brookline's Street Tree Population.

Street Trees of Concern - Pests and Disease

Brookline has a number of street trees that are susceptible to pests and diseases that are already present locally or are emerging as serious threats to tree health. Some pests target a single species, while others may target an entire genus. Pests may also use some species only as hosts, while inflicting the most damage on a group of other species.

Green ash and white ash are species of concern due to the emerging threat of emerald ash borer. Ash trees, in general, are relatively short-lived; but with the added stress of emerald ash borer, these species of trees can be entirely eradicated due to the pest and the subsequent diseases that infect this species. The emerald ash borer will tunnel its trademarked 'D' shaped holes in tree trunks and will lay eggs within the stem of a tree. The larvae then feed within these cavities, disrupting the tree's vascular tissues, leading the tree to have difficulty transporting water and nutrients. While there are remedies to this pest, such as a systemic insecticide that is typically injected at the base of the trunk, this method of protection is only feasible if there is a monetary commitment to treat the trees every two years. Still, proactive pest detection efforts can improve the odds of controlling pests while invasions are still manageable, reduce the possibility of unchecked spread across the region, and reduce the costs of long-term tree management, removal and replacement.

While green ash and white ash require immediate attention, additional species may also be at risk due to the impacts of climate change and the alteration of the distribution and population structures of certain tree pests and pathogens. A number of trees from the stem-by-stem inventory, including oaks, aspens and dogwoods, are at risk from a variety of pests and diseases either present in New England, or at risk of moving into New England as a result of climate change (Table 5-4).

Trees at Risk from Insects or Disease

Insect or Disease	# of Trees at Risk	Tree Species at Risk (in rough order of overall risk)
Dogwood Anthracnose	36	Dogwoods
Dutch Elm Disease	727	Elms
Emerald Ash Borer	457	Green and white ash Douglas fir
Gypsy Moth	4,028	Most birches Most oaks Lindens Washington hawthorn Chinese elm Sweetgum Crabapple Callery pear
Large Aspen Tortrix	100	Birches
Winter Moth	6,188	Birches Oaks Most elms Maples Green and white ash Washington hawthorn Some fruit trees
Asian Longhorned Beetle	5,178	Birches Elms Green ash Maples Apples and plums Horse chestnut London plane Katsura tree Yellow buckeye
Oak Wilt	2,287	Oaks
Southern Pine Beetle	49	Pines Spruces
Sudden Oak Death	1,886	Northern red oak Pin oak Douglas fir

Table 5-4: Trees at Risk from Insects or Disease

Within each insect/disease, the individual tree species are shown in rough order of overall risk from greatest to smallest risk. The number of trees at risk includes only species likely to experience mortality. The red bar indicates the insect/disease is present in Norfolk County. An orange bar indicates the insect/disease is present within 250 miles. The green bar indicates the disease is present only beyond 750 miles.

Data Source: i-tree

For example, oak trees in the red oak family are succumbing to oak wilt, a disease that has been present in areas of Long Island and recently, in small areas of western Massachusetts. Although the disease isn't present in the Boston Metropolitan area at this time, a longer frost-free season is increasing the odds that the beetle that spreads this disease will be able to overwinter in this area. Oak wilt can completely kill a mature tree within 1-2 growing seasons. This disease can also affect species found in the white oak family, but the tree's decline is typically drawn out over 5 or more growing seasons. This disease could dramatically affect urban trees and the native hardwood forest, which are all predominately oak. To limit the spread of the disease, oak trees should generally not be pruned during the growing season, as the sap will bleed out of the fresh cuts and attract the beetle that carries the oak wilt disease. Winter pruning for all oaks, if possible, would be an effective way to control oak wilt if it becomes established in this area and is a good practice to proactively institute as a pest/disease prevention technique.

Street Tree Benefits by Voting Precinct

Name	Number of Street Trees	CO Removed Annually (lbs)	NO_2 Removed Annually (lbs)	O_3 Removed Annually (lbs)	SO_2 Removed Annually (lbs)	Particulate Matter 2.5-10 Microns Removed (lbs)	Air Quality Total (lbs)	Carbon Stored in Trees (tons)	Carbon Sequestered (tons)	Avoided Runoff Annually (gal)
Precinct 1	784	5	25	396	17	58	501	231	8	170,905
Precinct 2	280	2	9	138	6	20	175	81	3	59,665
Precinct 3	316	2	10	164	7	24	207	96	3	70,738
Precinct 4	345	2	10	167	7	24	211	98	3	72,204
Precinct 5	518	4	18	287	12	42	364	168	6	124,112
Precinct 6	566	4	18	289	12	42	366	169	6	124,798
Precinct 7	240	1	7	112	5	16	141	65	2	48,282
Precinct 8	768	5	24	374	16	55	473	218	7	161,312
Precinct 9	797	5	24	379	16	55	479	221	7	163,533
Precinct 10	428	3	13	204	9	30	258	119	4	87,944
Precinct 11	728	5	23	360	16	53	455	210	7	155,359
Precinct 12	845	6	30	468	20	68	592	273	9	202,249
Precinct 13	1557	12	56	882	38	129	1116	515	17	381,008
Precinct 14	1224	9	44	701	30	102	887	409	14	302,653
Precinct 15	1434	11	52	823	35	120	1042	480	16	355,611
Precinct 16	1211	9	43	685	30	100	866	399	13	295,651

Table 5-5: Environmental Benefits of Brookline's Street Trees by Voting Precinct

Benefits are calculated by taking the total benefits for all street trees and apportioning benefits according to the percentage of total street trees in each precinct

Data Source: i-tree and CanopyKeeper

Benefits of Street Trees

The environmental benefits of Brookline's street trees were calculated (Table 5-5) and can be used to communicate the value of street tree care and maintenance. Report cards are one way that Brookline can communicate the current status of street tree conditions, benefits and planting efforts at a scale that residents can easily understand. It also provides an effective way to examine progress over time and to compare tree coverage between different geographic or political boundaries, such as voting precinct (Figure 5-10).

Street Tree Report Card Example

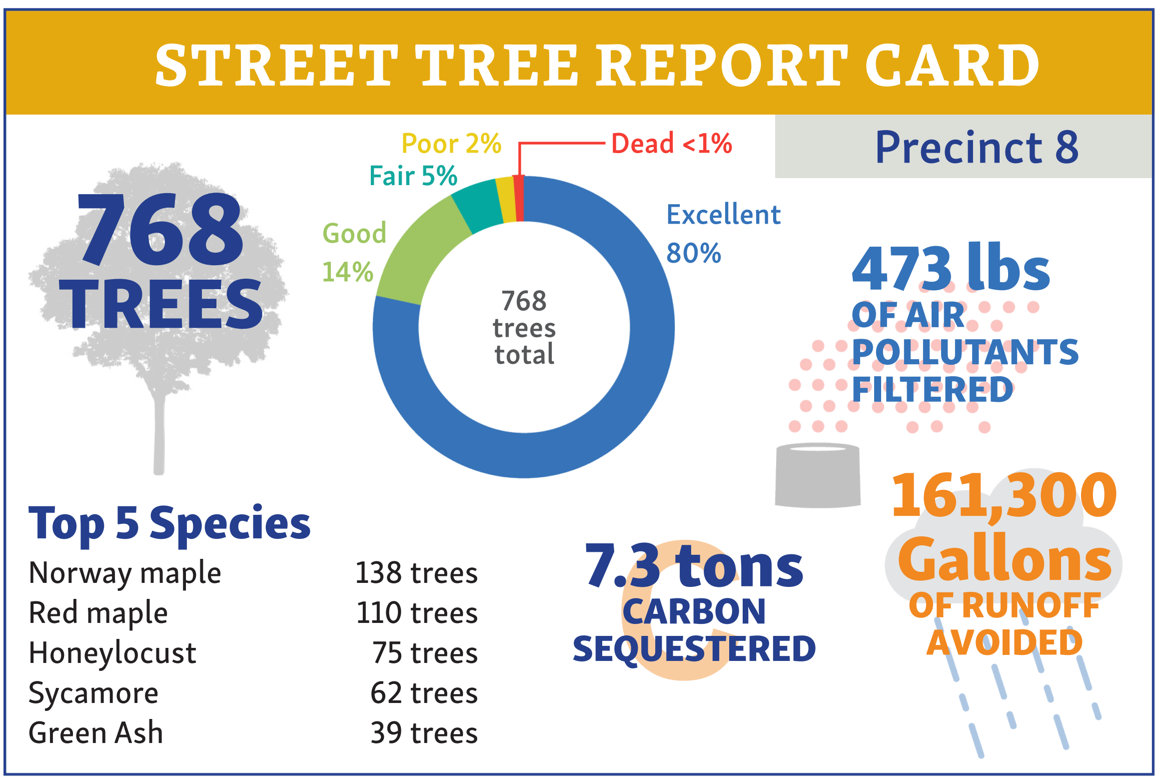


Figure 5-10: Mock-up of a Street Tree Report Card, Shown Here for Voting Precinct 8.

Urban Tree LiDAR Canopy Analysis

High-resolution aerial imagery and Light Detection and Ranging (LiDAR) data were obtained in 2014 and 2020 for the purposes of analyzing the urban tree canopy. LiDAR, a method for measuring distances using a pulsed laser of light, is combined with aerial photography because it provides three-dimensional information that can help distinguish trees from shrubs. Using an airborne LiDAR system can also enable analysis of canopy heights, canopy health, crown diameter, biomass, and leaf area. The technology can even be used to estimate the biodiversity of trees across large areas.

Process

The aerial imagery and LiDAR data were provided to the University of Vermont Spatial Analysis Lab who prepared an Urban Tree Canopy (UTC) assessment available in Appendix F - Tree Canopy Assessment, 2014-2020. The UTC assessment protocols used were developed by the USDA Forest Service to help communities develop a better understanding of their green infrastructure through tree canopy mapping and analytics. Tree canopy is defined as the layer of leaves, branches, and stems that provide tree coverage of the ground when viewed from above. When integrated with other data, such as land use or demographic variables, a UTC analysis can provide vital information to help governments and residents plan a greener future.

Tree canopy mapping is performed using a scientifically rigorous process that integrates cutting-edge automated feature extraction technologies with detailed manual reviews and editing. This combination of sensor and mapping technologies enabled the Town's tree canopy to be mapped in greater detail and with better accuracy than ever before. From a shade tree in the Larz Anderson Park to a forest patch at Lost Pond Conservation Area, every tree canopy in the town was documented.

The tree canopy analysis is overlaid on land cover features (grass/shrub, bare soil, water, buildings, roads and other impervious features) and then the tree canopy coverage can be summarized by different land use categories and different geographic units (i.e. parcels, census tract, precincts).

Results

Brookline, like many other municipalities, has an uneven tree canopy distribution. There are some areas with less than 10% tree canopy and others with more than 95% tree canopy. This variety is attributed to natural features, land use history, and historical policies and practices such as redlining. The canopy coverage also has an impact on the residents living and working in these areas. Residents with more tree canopy

2014 and 2020 LiDAR data

2014: 46.3% tree canopy coverage

2020: 44.7% tree canopy coverage

Canopy gains and losses

153 acres of gain

224 acres of loss

3.5% relative decrease in tree canopy

Tree Canopy Coverage in U.S. Cities

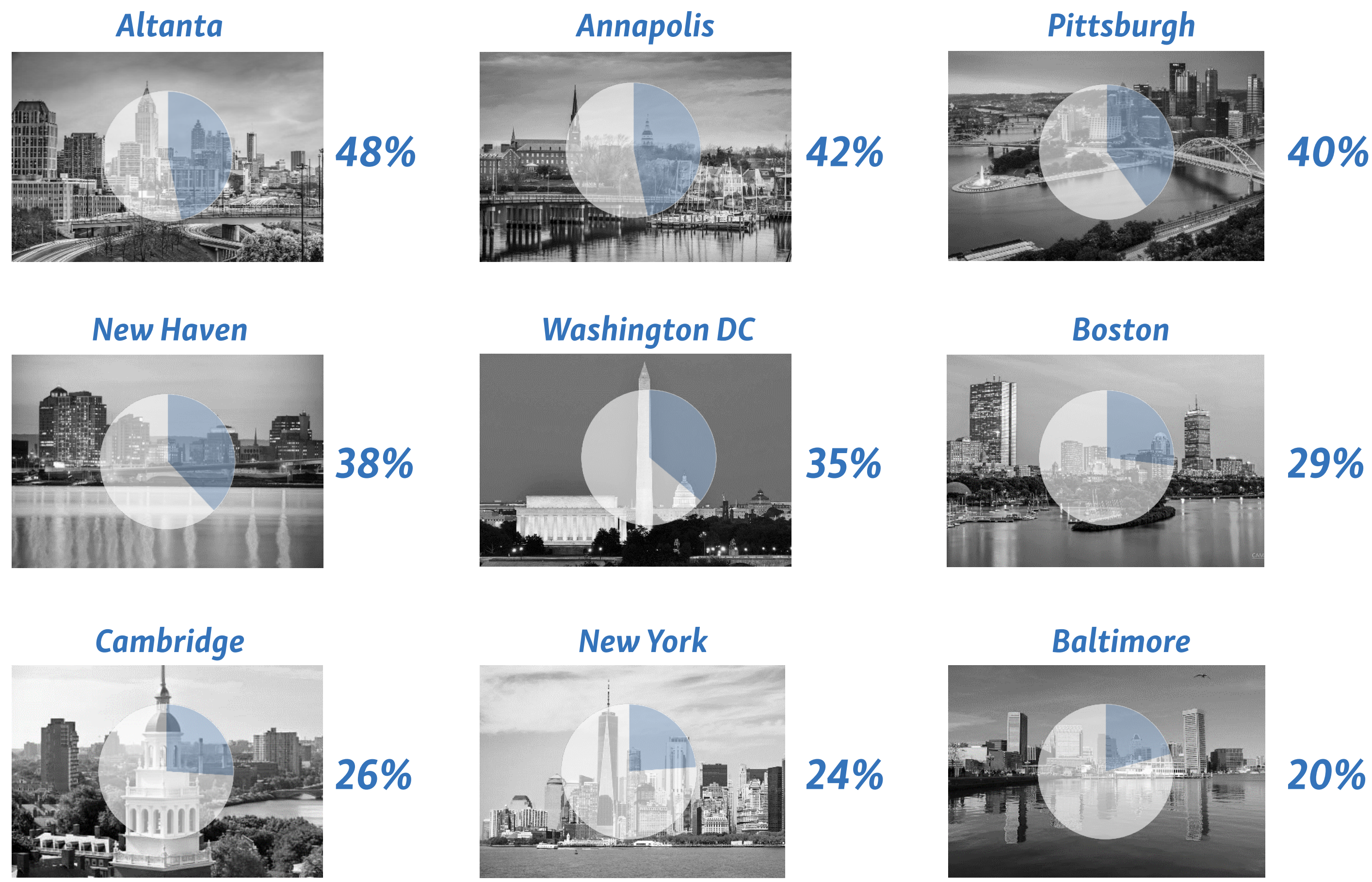


Figure 5-11: Tree Canopy Coverage Comparison

Tree canopy coverage percentages for urban areas along the East Coast.

Data Source: Cambridge data from City of Cambridge's 2020 Urban Forest Report: Healthy Forest, Healthy City. Data for remaining cities from Leff, 2016

Gains and Losses by Land Use

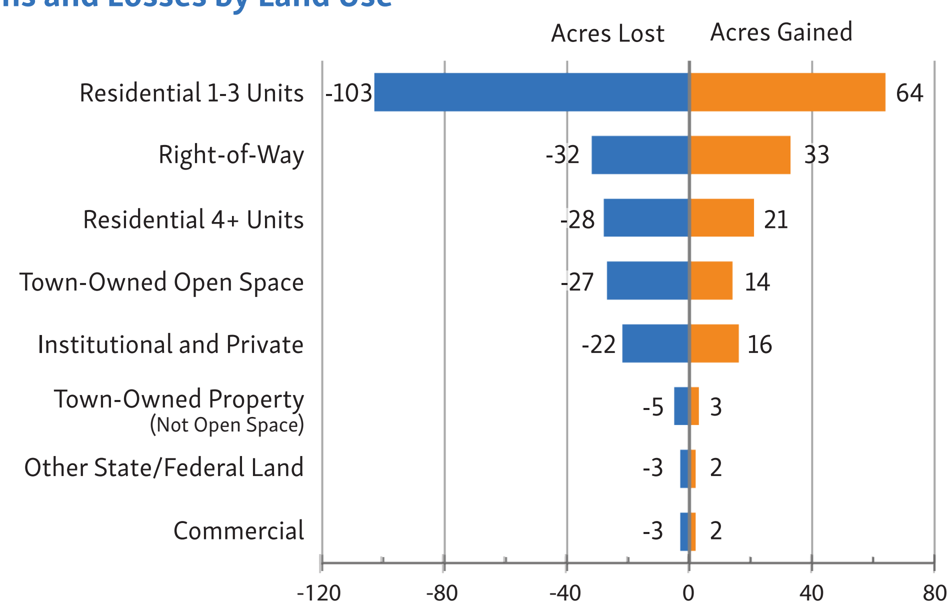


Figure 5-12: Summary of Tree Canopy Gains and Losses between 2014 and 2020, Organized by Land Use

Data Source: University of Vermont Spatial Analysis Lab, 2021

2020 Tree Canopy Coverage

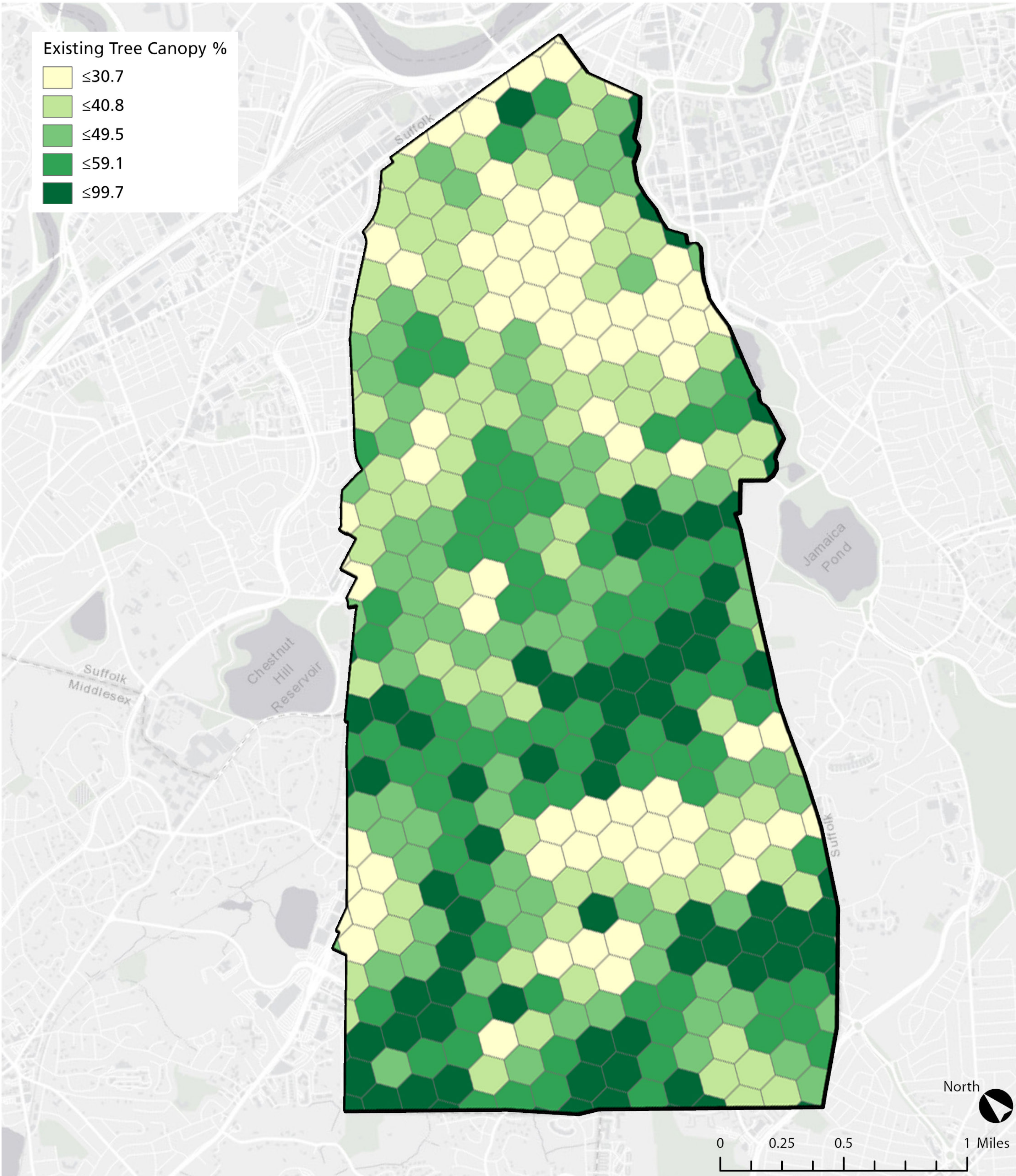


Figure 5-13: Existing Tree Canopy Coverage Percentage for 2020 Conditions Summarized with 25-Acre Hexagons

Tree canopy coverage is an average for each 25-acre hexagonal area (excluding water bodies). The analysis has no relation to geographic or political boundaries.

Figure Source: University of Vermont Spatial Analysis Lab, 2021

2020 Tree Canopy Coverage by Voting Precinct

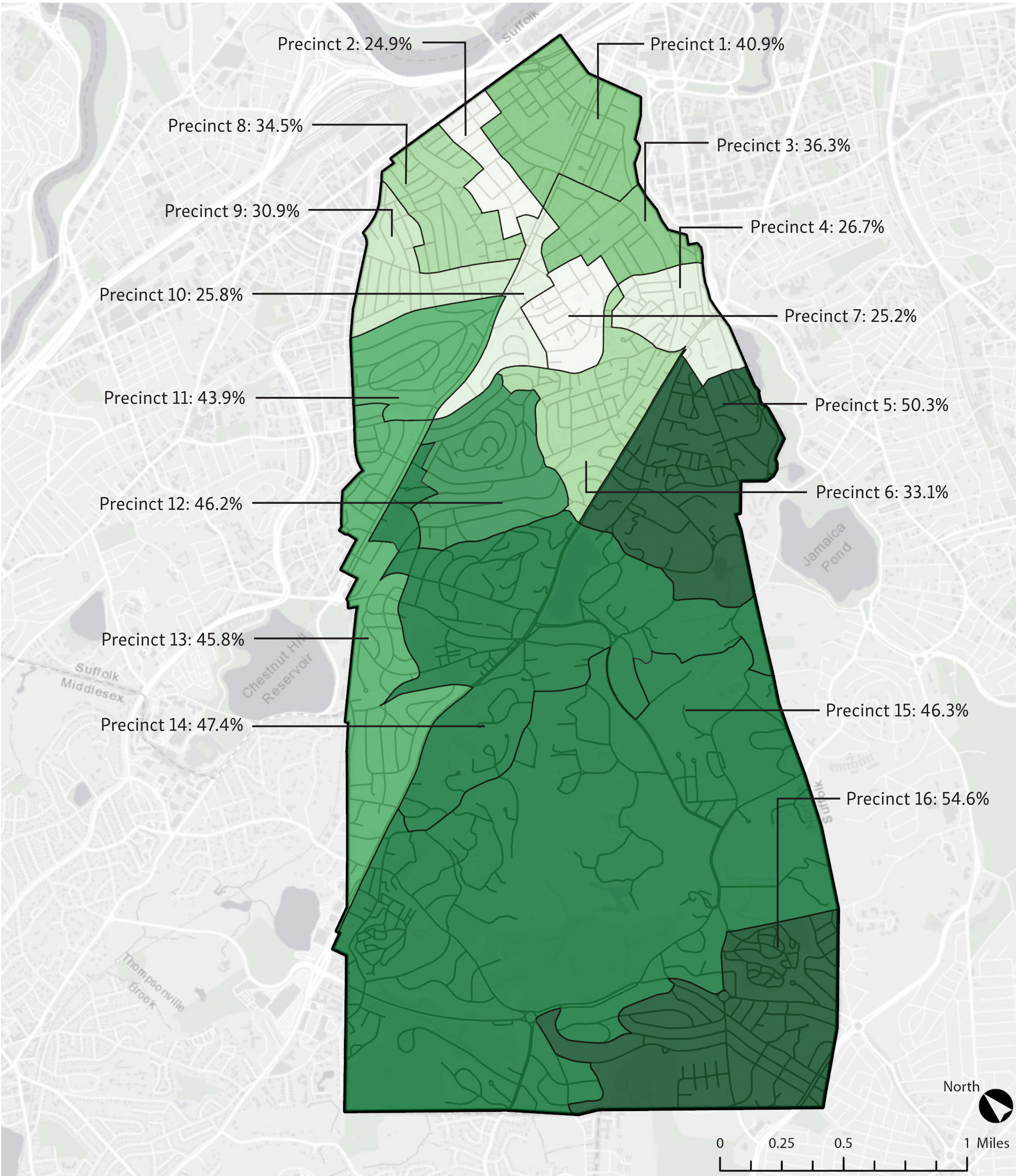


Figure 5-14: Existing Tree Canopy Coverage Percentage for 2020 Conditions, Summarized by Voting Precinct

Tree canopy coverage is an average for each voting precinct (excluding water bodies).

Data Source: University of Vermont Spatial Analysis Lab, 2021 benefit from the services the trees provide, while others who live or work in areas lacking in canopy coverage receive fewer ecosystem services.

Areas of loss and gain can be identified and can show trends or one-time impacts (i.e. capital projects or storm damage). The relative change percentage is calculated by taking the tree canopy in 2020, subtracting the tree canopy area in 2014, then dividing that by the area of tree canopy in 2014.

Loss is attributed to tree removal, either by construction, storm events, or other natural causes. Gain is either related to growth of existing trees or the recent planting of trees. However it is important to note that newly planted trees can take 4 to 6 years to be large enough to register on LiDAR imaging. When reviewing the areas of canopy change, the losses are predominantly on single family residential properties (from renovation or new construction) with some other losses on government land (largely from capital projects, storm damage, or standard removal of declining or hazardous trees).

Several Town properties did show loss of canopy from 2014 to 2020 including the following (with notes about the cause of the tree loss):

- Putterham Meadows Golf Course
    - Tree clearing for driving range construction
- Brookline Reservoir Park
    - Tree clearing for reservoir structural repairs
- East Gateway
    - Street tree removal for roadway reconstruction

Significant re-planting was undertaken following these capital projects that will be reflected in next LiDAR analysis:

- Fisher Hill Reservoir Park (1,550 Trees, 6,869 Shrubs/Herbaceous)
- Brookline Reservoir Park (56 Trees, 188 Shrubs)
- Skyline Park (368 Trees, 139 Shrubs)
- Back Landfill (309 Trees, 1,035 Shrubs)

LiDAR analysis classified land cover as: existing tree canopy, possible tree canopy - vegetated (lawns, shrub areas), possible tree canopy - impervious (bare soil, walkways, driveways) and not suitable (buildings, roads) (Figure 5-17). This information shows the potential for canopy growth since lawn and shrubs are immediately ready for tree planting, and impervious areas that aren't roads or buildings could be modified to introduce more tree planting. It is important to note that not all land deemed as "possible tree canopy" is actually appropriate for planting. The site-specific conditions and existing land use of each location must be considered as the Town determines where planting opportunities exist. For example, athletic fields in Brookline's parks and open spaces may be considered "possible tree canopy" as part of this UTC analysis, however these facilities are already in use for public recreation and are not appropriate sites for planting, except perhaps on their periphery. Similarly, some areas may not be conducive to tree planting due to the size constraints of a particular site, adjacent buildings, et cetera.

Average tree canopy in North Brookline	**35%**

Below Average Tree Canopy Coverage

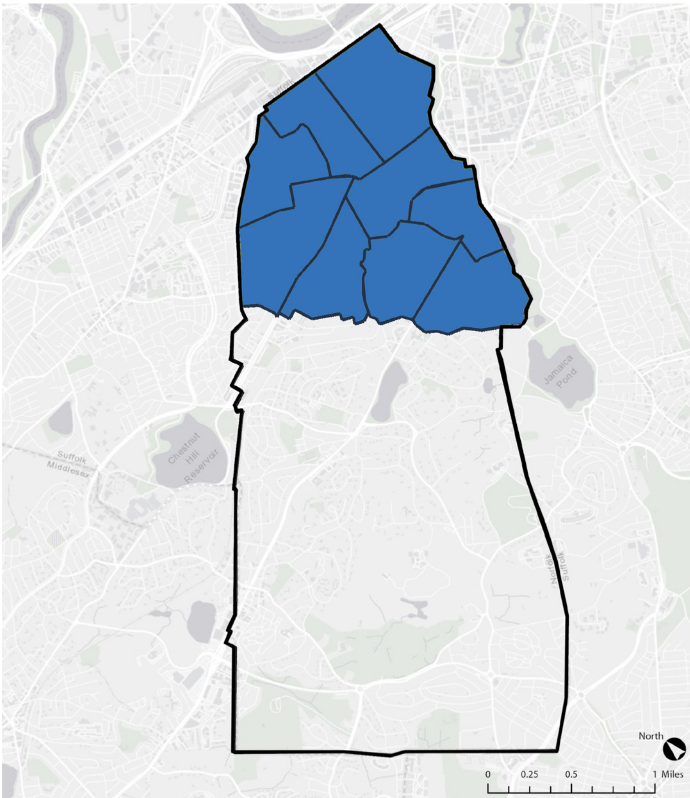


Figure 5-15: Census Tracts with Below Average Tree Canopy Coverage

The highlighted census tracts have tree canopy cover that is lower than the Town-wide average of 44.7%.

Data Source: University of Vermont Spatial Analysis Lab 2021

Relative Change in Tree Canopy Coverage 2014-2020

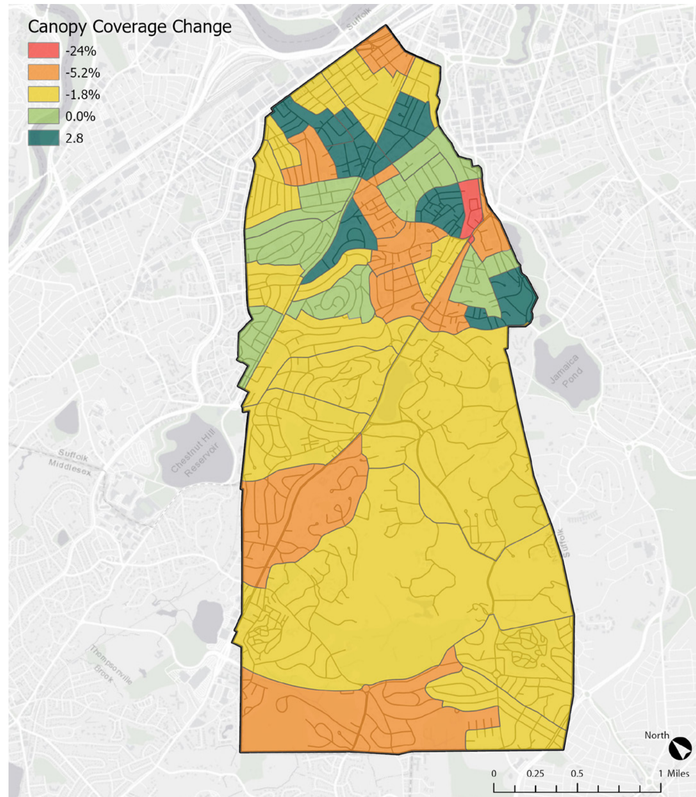


Figure 5-16: Relative Change in Tree Canopy Coverage by Census Blocks

Tree canopy coverage relative change from 2014 to 2020, for each census block.

Figure Source: University of Vermont Spatial Analysis Lab 2021

Land Cover by Land Use

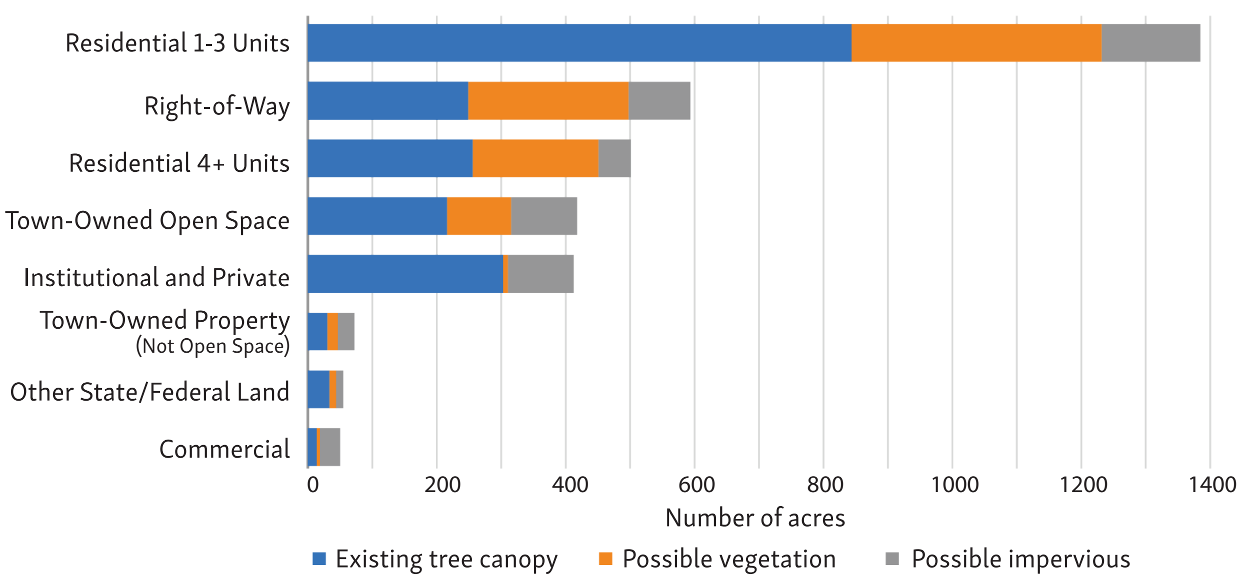


Figure 5-17: Summary of Land Cover in Acres, Organized by Land Use

Data Source: University of Vermont Spatial Analysis Lab 2021

LiDAR Analysis of Individual Trees

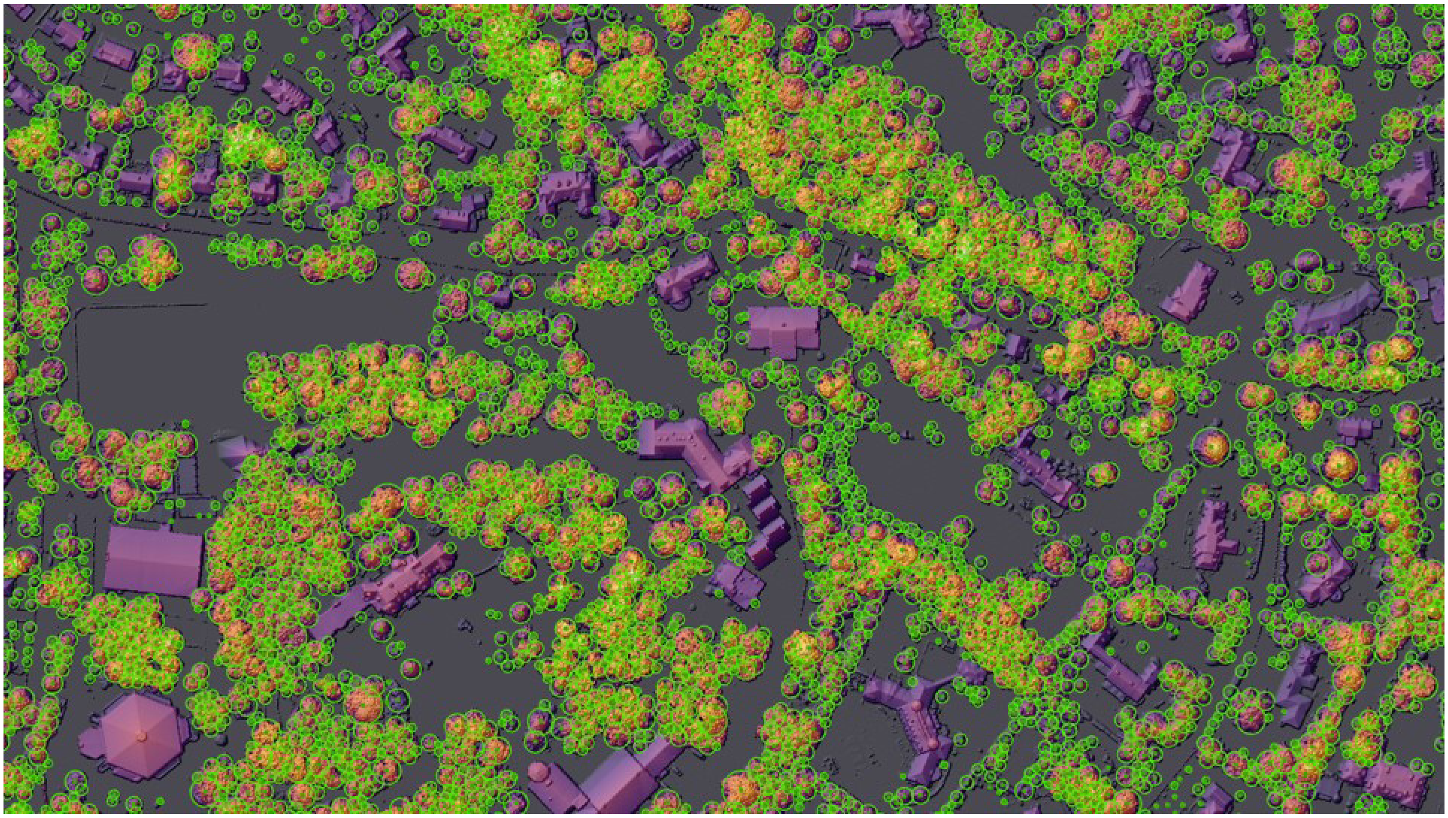


Figure 5-18: LiDAR Analysis Identifying Individual Trees.
Figure Source: University of Vermont Spatial Analysis Lab, 2021

While the Town's overall tree canopy coverage of approximately 45% is very good, the land cover analysis shows that there is even more potential to expand tree plantings. Grass and shrubs cover 22% of the Town and paved areas (excluding roads) cover another 13%. This means that 35% of the Town's land cover should be assessed for suitability as potential sites for expanded tree planting. Only 20% of the land cover in Brookline are buildings or roads that are not available for tree canopy expansion (Figure 5-17).

This analysis also allows detailed views of tree canopy coverage at the parcel level or for specific land uses (i.e affordable housing or environmental justice areas). For example, canopy coverage in most environmental justice areas is near or above the Town average. In Massachusetts, a neighborhood is defined as an environmental justice population if any of the following are true:

- annual median household income is not more than 65% of the statewide annual median household income;
- minorities comprise 40% or more of the population;
- 25% or more of households lack English language proficiency; or
- minorities comprise 25 percent or more of the population and the annual median household income of the municipality in which the neighborhood is located does not exceed 150 per cent of the statewide annual median household income.

A detailed examination shows that even among environmental justice neighborhoods, there is a disparity between North Brookline and South Brookline. While overall, the canopy coverage across all environmental justice neighborhoods is higher than the Town average, if the three southernmost environmental justice areas are removed from the equation, the remainder have an average canopy coverage of only 33.6%. There is one site that has particularly low canopy coverage - the East Gateway area's tree canopy coverage is only 17.2%, largely due to a recent street redesign project.

The UTC assessment estimates that there are 204,000 trees in the Town (on both public and private land) with a margin of error of plus or minus 10,000 trees. 32%, or approximately 65,150 trees, are on public land and 68% or 138,850 trees are on private land. Nearly 110,000 trees, 44% of Brookline's total tree canopy, are on single-family and multi-family residential properties. In total, the Town's trees provide a substantial contribution to Brookline each year through environmental benefits such as carbon sequestration, stormwater management and air quality improvements (Figure 5-20).

Estimating tree age by LiDAR is not possible, but LiDAR can measure tree height which can be an indicator of age. It is therefore valuable to study the distribution of height and likely the age of the urban forest. Brookline has a good diversity in tree height, ranging from newly planted

Tree Canopy Change by Height Class

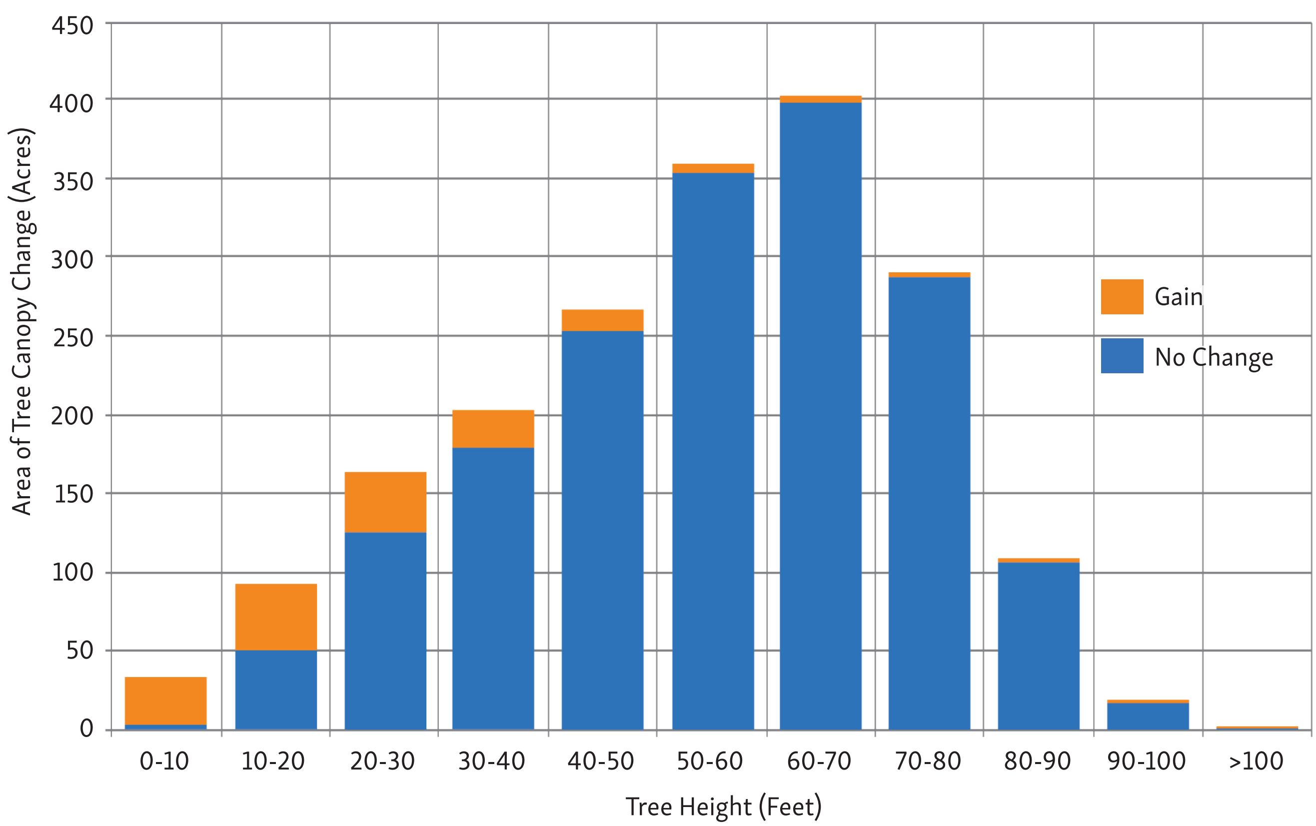


Figure 5-19: Tree Canopy Change from 2014 to 2020, Organized by Tree Height Class
Area of tree canopy that was unchanged or increased from 2014-2020 broken down by 10ft height classes.
Data Source: University of Vermont Spatial Analysis Lab 2021

Environmental Benefits of Brookline's Urban Forest Annually

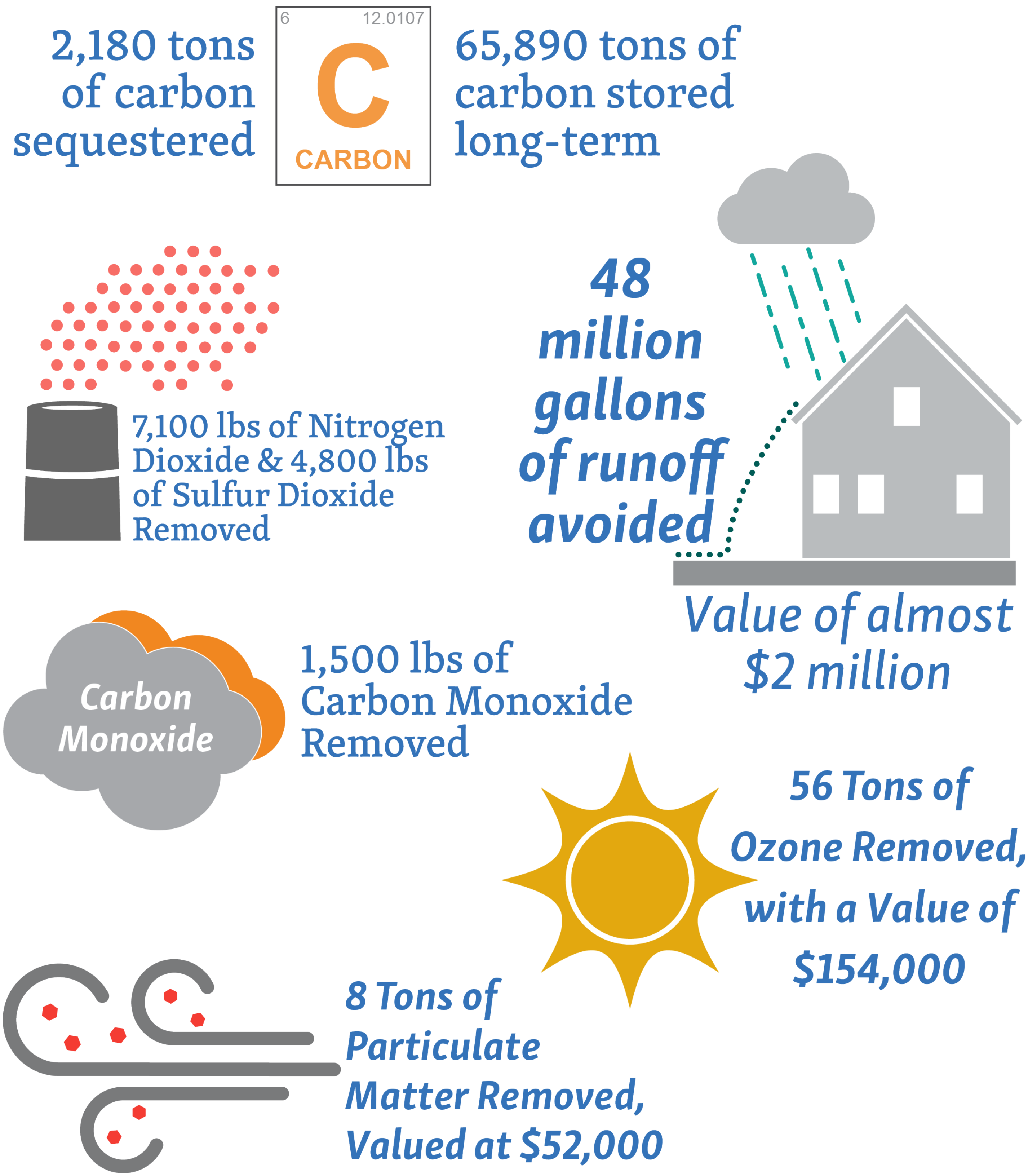


Figure 5-20: Summary of Environmental Benefits for All Trees in Brookline, Based on LiDAR Analysis
Benefits are shown per year, with the exception of carbon stored long-term, which is cumulative.
Data Source: Davey TreeKeeper

saplings to trees that are one-hundred feet tall. Caring for Brookline's largest trees is critical because, as discussed in Chapter 3, the larger the surface area of canopy, the more environmental benefits a tree contributes. From 2014 to 2020, trees 50' in height or less saw the greatest gain in canopy growth. Trees 60' to 100' tall contribute the most environmental benefits, but have a slowed growth rate and are not gaining tree canopy as quickly as smaller trees (Figure 5-19).

Summary

The trend of decreasing canopy coverage observed from 2014 to 2020 in Brookline must be addressed. To effectively mitigate the effects of climate change, the Town's tree canopy should reflect a net increase. With most canopy loss found on single family residential properties, educating residents on the importance of tree preservation, tree care, and planting of new trees is of critical importance. The losses on government properties reflected in the 2020 UTC analysis do not take into account the large-scale re-planting efforts undertaken as part of capital projects (due to the small size of the newly planted trees), but will be reflected in future LiDAR canopy analyses.

The UTC assessment also indicated that there is good potential for tree canopy growth to meet coverage goals. 35% of Brookline's land can be assessed for suitability as a potential planting site - some of which is immediately ready for planting.

Brookline also has good canopy coverage compared to adjacent communities and national peers, but the canopy distribution is unequal, under-serving North Brookline, where there is the greatest population density and the greatest proportion of at-risk populations.

REGULATIONS, POLICIES AND PRACTICES

6

Assessing Brookline's urban forest policies, procedures, and budget can provide insight into how best to achieve the Town's goal of a coordinated and standard level of tree care. This chapter is a starting point for a continuing dialogue on how to support the development and maintenance of Brookline's urban forest.

Assessment Methods

Information about Brookline's policies and procedures was obtained through interviews with staff, budget documents, and records from PeopleGIS, the Department of Public Works' maintenance management system. Information about nearby municipalities was obtained through a survey completed by Tree Wardens from the cities of Cambridge and Newton and a review of publicly available information.

Overview of Urban Forest Management

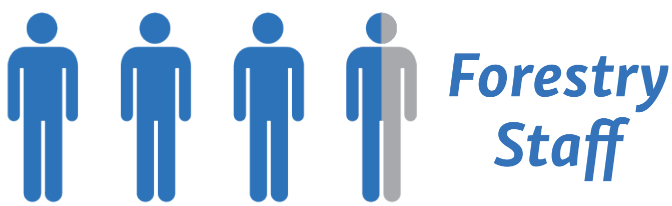
Brookline's urban forest is comprised of approximately 204,000 trees (based on estimates from the Town-wide LiDAR analysis). The Town's forestry program falls under the Parks and Open Space Division within the Department of Public Works. The Forestry Services sector preserves and maintains more than 50,000 trees along public roads, parks, school grounds, cemeteries, and other public grounds. Forestry Services cares for trees in the public right-of-way covering over 500 acres of public open space, and over 120 sites including 38 parks and playgrounds, 3 sanctuaries, 10 public school grounds, land around 15 public buildings, 5 public parking areas, 2 cemeteries, and over 60 traffic circles and islands.

Forestry Staff

Brookline has three and a half full-time employees in the Forestry Landscape Services Section. The Town Arborist/Tree Warden is a half-time position with time split as the Conservation Administrator. Additional staff positions are the Forestry Supervisor, Forestry Zone Manager, and Groundsperson. All staff, excluding the Groundsperson, are Certified Arborists, each with a Massachusetts Pesticide License. They attend trainings and seminars on an ongoing basis to maintain licensure and ensure proficiency in best practices.

Town Arborist/Tree Warden Responsibilities:

- Administration including:
  - Issuing tree work permits
  - Records management
  - Responding to the public
  - Creating and maintaining partnerships
  - Assisting the Town attorney in addressing tree-related claims and providing value assessments for damaged public shade trees
- Sourcing and tagging all new trees for installation in the public right-of-way and on public grounds
- Determining site-appropriate tree planting techniques



- Coordination with other divisions of the Department of Public Works, other Town departments, utilities (including Eversource, National Grid and Verizon) and other partner organizations
- Administering a contract tree crew who provides tree pruning, tree removal, stump grinding, and emergency work

In-House Tree Crew Responsibilities:

- Tree inspection and risk assessment
- Tree maintenance, including:
  - Pruning (approximately 1,650 trees annually)
  - Planting (approximately 350-400 trees annually)
  - Tree and stump removal (approximately 180 trees annually)
  - Irrigation of newly planted trees (for two years following planting)
  - Integrated pest management (IPM)
  - Installation of holiday lights
  - Emergency work and storm response

In-house tree crews are not only a cost-effective way to conduct tree planting and management, but they also possess an extensive knowledge of the Town, its policies, and history. Current Forestry staff have been doing their jobs on average almost 20 years, and have been with Brookline on average over 14 years.

In addition, Brookline utilizes contracted tree crews that provide additional support when needed. The contracted trees crews offer a way for the Town to access additional crews when necessary, for example following damaging weather events. Contracted tree crews also enable the Town to access equipment that the Town may need only occasionally, such as log trucks, stump grinders, elevator bucket trucks and cranes for tree pruning, tree removal, stump grinding, and work in response to emergencies, without the overhead costs of purchasing and maintaining that equipment.

Contracted Tree Crews Provide:

- Tree maintenance, including:
  - Pruning
  - Tree and stump removal
  - Emergency work and storm response

However, the services of contracted crews can come at a high cost and that cost varies depending on factors the Town cannot control. In addition, access to contracted crews is not always possible or available at a reasonable cost if there is a regionwide severe weather event.

Average number of trees planted annually by the Town of Brookline

350 to 400

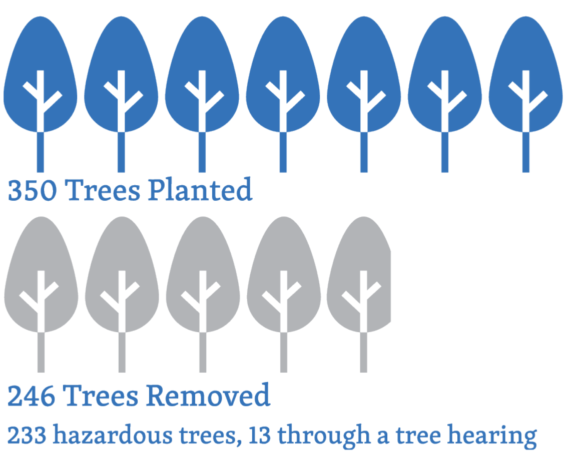
Services & Operations

Planting

The Town plants approximately 350-400 trees annually. In purchasing planting stock, the Town Arborist selects the trees at a nearby nursery and adheres to American Standards for Nursery Stock (ANSI Z60). Brookline purchases nursery-grown, balled and burlapped 2.5 to 3-inch caliper trees, meaning that the diameter of the trunk six inches above the ground is 2.5 to 3 inches. The Town has found that this size tends to be the best balance of initial price and survival rate, while also being large enough to resist vandalism and other mechanical damage from mowers, bicycles, et cetera. The Town places its tree orders well before the upcoming planting season to ensure cost certainty and facilitate tree planning.

Prior to planting, trees are provided drip irrigation at Brookline's own tree nursery. Trees are planted in accordance with the ANSI Z60 standard. Tree pits are typically over-excavated to provide more high-quality soil volume for each newly planted tree, and each planting site receives high quality planting soil and an application of fertilizer with mycorrhizal fungi. The fungi form a beneficial, symbiotic relationship with the roots of the tree. The tree provides sugar and carbon to the fungi, while the tree receives help from the fungi in taking up water and nutrients from the soil.

Tree Balance in Brookline in 2020



New trees are outfitted with tree watering bags whenever possible. The watering bags can be filled once a week and provide approximately 15 gallons of water to each newly planted tree. Small holes in the bottom of the bags slowly release the water to the tree's roots. This type of slow, deep watering helps to encourage root growth. Town staff water the newly-planted

Doorhanger for a Newly Planted Public Tree

Figure 6-1: Doorhanger for Residents Abutting New Street Tree Plantings

Brookline Parks and Open Space Division provides doorhangers to residences near new street tree plantings to familiarize residents with the new plantings and encourage them to help in the tree's upkeep.

trees for two growing seasons, but also rely on residents to support the watering efforts, particularly during dry spells. Trees are supported with wood stakes for their first year, wherever necessary. After a year, the tree roots have grown into the surrounding soil to provide support and the stakes can be removed. Adjacent property owners are supplied materials on care and maintenance of the planted trees (Figure 6-1).

Town staff engage in a variety of approaches to improve establishment and survivability of newly planted trees. The methods follow the "right tree, right place, right time" strategy. Tree species selection, planting locations, and installation techniques are site-specific. The Town's Tree Planting Committee, the longest-standing such group in the country, meets approximately five times per year to provide input on the proposed planting sites and species. Urban tree planting conditions are challenging, so the Town often utilizes structural soil, enlarged planting strips, and sub-surface irrigation to increase tree success. The Town has also partnered with commercial property owners to trial Silva Cells in suitable locations. Forestry staff coordinate regularly with utility companies, the Town Engineering Division, and the Planning and Community Development Department regarding utility work, sidewalk installations, and special projects.

"Back of Sidewalk" Program

The "Back of Sidewalk" Tree Planting Program aims to enhance Brookline's urban canopy by planting trees on private property within 20 feet of the public right-of-way. In many cases with sidewalks too narrow for trees or due to utility conflicts, the backside of the sidewalk is the only feasible location to plant trees that shade the public way. The purpose of the Back of Sidewalk Program is to:

- Expand the diversity of the urban forest to enhance the resiliency of the urban canopy
- Increase the number of trees contributing to and benefiting Brookline's streetscapes
- Utilize land near the public way that is more conducive to tree growth than the public way itself.

Typically a private landowner submits a request for a back of sidewalk tree, which the Town evaluates. If approved as an appropriate location, the Town will purchase and install the tree at no cost to the resident. The tree will be owned and maintained by the Town for the first five years after planting and then relinquished to the homeowner's care and ownership. Through this successful program which began in the 1930s, over 11,000 street trees have been planted in Brookline.

Addressing Common Public Concerns

The most commonly submitted complaints about the Town's public street trees relate to the trees' roots and leaves.

Tree roots can certainly contribute to sidewalk failure, but generally do not cause heaving unless they do not have adequate soil volume. The Town does not remove trees solely because of sidewalk failure. The Highway and Sanitation Division will work in collaboration with the Tree Warden to repair a sidewalk without compromising the health of the tree.

Tree roots can find their way into cracks or failures that already exist in sewer and drain pipes, but do not break pipes on their own. A short term corrective action for landowners is having the pipe cleared by a drain cleaning service. A long term resolution is for the landowner to replace the sections of broken pipe.

The Town will not remove trees because leaves become a nuisance in the maintenance of gutters, drains or walkways. The benefits of shade trees along Town streets (shading and cooling properties and the public way, regulating the flow of stormwater along streets, and their aesthetic value) far outweigh the additional maintenance work created by fallen leaves.

Pruning

Public street trees are generally pruned on a seven-year pruning cycle. Some trees within the public domain are inspected and pruned more frequently due to high visibility, use of the space around the trees, or the age and viability of the trees.

High Traffic Areas:

- Coolidge Corner
- Brookline Village
- Washington Square
- Route 9 Gateway East and Gateway West
- Beacon Street

Public Buildings and Schools:

- School sites are pruned annually; however, trees surrounding most public buildings are pruned on a seven-year cycle.

Boston Marathon Route:

- Beacon Street (inbound side) - trees are inspected on an annual cycle due to the high volume of usage for the Boston Marathon, and pruning occurs as needed.

Historic Trees:

Many of Brookline's open spaces are on the state or national registers of historic parks. As such, many of these parks contain trees of special historical value and require pruning and care from highly skilled workers. Some of the Town's most high-profile historic trees are located within the following parks:

- Longwood Mall trees are inspected and pruned on the standard seven-year cycle.
- Larz Anderson Park trees are inspected and pruned on the standard seven-year cycle.
- Olmsted Park and Riverway Park trees are on a four-year cycle due to the Town's partnership with the Emerald Necklace Conservancy.

Some streets are particularly narrow and require road closures to perform pruning:

- Avon Street
- Beals Street
- Cottage Street
- Elm Street
- Griggs Terrace
- Heath Street

Some streets and parks have trees over 60' tall, which require the use of elevated bucket trucks. These areas include:

- Beals Street
- Laurel Road
- Spooner Road
- Woodland Road

Pruning of woodlands in conservation areas does not require the same regular attention that street and park trees do, although trees along conservation area paths and near parking areas are monitored and pruned as needed.

Trees under utility wires require specific directional pruning to maintain utility air space as well as tree health. The Town works closely with Eversource contractors to ensure their work practices are appropriate and reasonable. The Town strives to limit the planting of trees under transmission lines to species that have a mature height of twenty-five feet or less.

A work permit from the Tree Warden is needed for any private tree contractor to work in the Town. This is helpful because it notifies the Tree Warden of the planned work and helps ensure a high standard of care consistent with Town goals and objectives.

Relevant Tree Care Standards

Brookline adheres to several standards produced in association with American National Standards Institute (ANSI). A consensus of industry stakeholders develops these industry standards that are reviewed and revised every five years.

- Z60. American Standard for Nursery Stock.
- Z133. American Standard for Arboricultural Operations - Safety Requirements.
- A300. American Standard for Tree Care Operations – Tree, Shrub and Other Woody Plan Management – Standard Practices
  - Part 1 - Pruning
  - Part 2 – Soil Management
  - Part 3 – Supplemental Support Systems
  - Part 4 – Lightning Protection Systems
  - Part 5 – Management of Trees on Construction Sites
  - Part 6 – Planting and Transplanting
  - Part 7 – Integrated Vegetation Management
  - Part 8 - Root Management Standard
  - Part 9 – Tree Risk Assessment
  - Part 10- Integrated Pest Management

Pest Management

The Town of Brookline utilizes an Integrated Pest Management (IPM) program. The Tree Warden identifies an “action threshold” for insect pests and diseases. Action thresholds provide guidelines about when pest levels are serious enough to warrant treatment. Tree crews start control measures when the action threshold is exceeded. Any given individual has a different tolerance level for insects or disease on the trees on their properties. As a result, some of the action thresholds that the Town uses may be higher than preferred by a private property owner.

However, the best and most effective course of action for pests is to maintain tree health proactively through cultural practices, such as proper planting, pruning, watering and fertilizing, rather than simply reacting to threats that occur. Proper maintenance results in a stronger tree that can fight off disease and pests better than a tree already weakened by other stresses.

Many pest and disease problems can be related directly or indirectly to stresses imposed upon trees by human activity. Improper planting and pruning, over-application of fertilizer, and failure to water trees during times of drought can result in injury or stress. Mechanical damage from lawn mowers and weed trimmers can damage a tree's bark, creating the opportunity for invasion by disease. Excessive traffic on the soil surrounding a tree results in soil compaction, reducing the oxygen level in the soil, limiting water infiltration, and making root growth more difficult.

In the rare case that a pesticide or other product must be used, the Town administers applications to a specific tree using a closed-system approach. The Town strives to limit chemical exposure to the maximum extent possible, and will only use mist-application products if deemed an appropriate management measure.

Invasive Flora

Invasive species are managed by the Town through removal and control of existing species and monitoring for potential spread. Common Buckthorn and Tree of Heaven are actively removed in parks and open spaces. Norway Maple, Sycamore Maple, Black Locust and Amur Cork-tree are no longer planted but do not warrant removal in most circumstances. These species will be replaced as they die with non-invasive trees.

The latest information from the Massachusetts Department of Agricultural Resources is used for the proper management of these species. Additionally, Brookline's Division of Parks and Open Space helps to educate the public about non-native invasive species through its outreach, volunteer events, and educational programs.

Risk Management

Tree risk identification is woven into everyday activities, often through visual inspections or formal assessments by Town staff. This is usually prompted by routine maintenance and observation, citizen communications, and partnerships with utilities. Staff are tasked with documenting necessary work, prioritizing efforts, and scheduling the work. The risk management program has been tested in the courts and is revered in the community as a model program.

Maintenance records are maintained in PeopleGIS, a maintenance management system used to monitor and track the Town's day-to-day forestry operations. Requests are prioritized by the Town Arborist and/or Forestry Supervisor, who assign the work to the in-house crew or a contract crew, depending on the type of request and the current workload. Due to the volume of requests and the need to balance scheduled tree maintenance with incoming requests, the typical turn-around time for non-emergency maintenance requests is four to six weeks. In the office or out in the field, Forestry staff can search for previous service requests, minimizing the chance of duplicate work orders for the same issue. PeopleGIS can also be integrated with the Town's tree inventory to provide real-time updates.

In the state, all trees in the public way are protected by Chapter 87 of Massachusetts General State Law. As a result, trees in Brookline's public ways are only removed under the guidance of the Tree Warden when a clear hazard exists. Trees located in Town open spaces are typically removed when they are in poor health or are considered hazard trees.

During municipal construction or renovation projects, the Tree Warden will assist in the Design Review process to ensure that shade trees in good condition are protected to the maximum extent possible. When there is no design alternative, trees in good condition may be removed, however replanting efforts are often recommended to replace the removed canopy. Any person can request that a public tree (non-hazard, healthy) be removed by contacting the Tree Warden. The Warden reviews the request and schedules a public hearing, marking the tree proposed for removal with a notice of the public hearing. If there is a written objection to the removal of that specific tree during the public hearing, the tree cannot be removed. The decision at the public hearing can be appealed to the Select Board.

In 2020, the Town removed a total of 246 trees, of which 13 required a tree removal hearing. The other 233 were deemed hazardous and removed as part of the Town's standard tree risk mitigation protocol.

Emergency Response and Accidents

The Town Arborist is responsible for assessing all tree emergencies, determining the severity of the emergency and deciding how to respond with Town or contracted crews. The Town Arborist is one of three liaisons (the others being Brookline's Highway & Sanitation Director and the Emergency Operations Manager) from the Town serving as a point of contact for utility companies. These liaisons coordinate directly with utility companies related to emergency events, in addition to direct emergency coordination between the utilities and the Town's Fire and Police Departments. Tree emergencies often require immediate action regardless of time of day.

All calls, both during and after business hours, that are received by the Police or Fire Departments for emergency tree response are directed to the Town Arborist. The Town Arborist then assesses the threat of the emergency and decides whether to call out in-house crews or to mobilize contracted crews. While Brookline enjoys a relatively high canopy cover, this also means that many large trees are near so-called 'targets.' Targets are people, property, or activities that could be injured, damaged, or disrupted by a tree failure. For example, if a storm caused a large limb to break and hang precariously over a set of streetlights, a sidewalk, or a running path, immediate action may be needed to protect people and property from harm.

Because approximately a quarter of the Town's urban forest is composed of street trees and trees overhanging the public way, public trees are often affected by vehicular accidents. Vehicular accidents are typically reported to the Police Department, which files accident forms and informs the Town Arborist when trees are impacted. Trees deemed hazards are immediately removed. If the tree is not an immediate hazard, the tree will be evaluated for any necessary maintenance, such as removal of a damaged limb. The Arborist assesses the tree's damage based on the species, size, age, health, location and nature of the damage. The Arborist's appraisal is provided to Town Counsel who work with the vehicle owner/operator to obtain payment for the damage. For any incidents that involve Town trees and private property or individuals, the Arborist is required to fill out an incident report, noting the location and nature of the accident, the people present and all other pertinent details. A determination is made whether the tree failure was an "act of God" or caused by some neglect, in which case the Town is responsible for damages.

Sometimes, private trees fall into the public right-of-way during a storm or ice event. Property owners are generally responsible for dealing with these trees, but in emergency situations or where the owners fail to act, the Town may need to respond to maintain public safety. Often the Town's crews will clear the roadway and cut the fallen tree back to the property line. To clear the public way and allow for emergency access, the crew will either remove the debris or give it to the homeowner upon request. In these cases, Town Counsel can seek compensation for any damage to public property from the property owners of the private tree.

2019 Forestry Services Performance Indicators

Indicator	Value
Trees Pruned	1,560
Trees Planted	429
Trees Removed	192
Limbs and Hangers Removed for Safety	220
Responses to Citizen Requests for Pruning	475

Table 6-1: Forestry Services Performance

Forestry Services accomplished a number of important activities in 2019 to protect public safety and maintain the health of the Town's urban forest.

Fiscal Year 2020 Forestry Budget

Capital	Funds
Tree Removal and Replacement/Urban Forestry Management Program	$235,000
Capital Total	*$235,000*
Operating	**Funds**
Personnel	$260,285
Services	$130,015
Supplies	$7,600
Operating Total	*$397,900*

Table 6-2: Brookline's Forestry Budget for Fiscal Year 2020

Record Keeping

Record keeping is an essential aspect of a robust risk management program. Town staff are responsible for responding to citizen communications (via email, phone calls, or through BrookONline). BrookONline is a system used to develop real-time collaboration with citizens. Mobile phone users can become the Town's eyes and ears by reporting pruning needs, dead trees and other issues anywhere in Brookline. Users can pinpoint the location of a problem, take photos, and get updates on resolutions. Additionally, staff log all scheduled and completed tree work. Record keeping protocols are available to Town staff and are reviewed by the Town Arborist regularly.

Forestry Budget

The annual Forestry Landscape Services budget consists of two components: the capital budget and the operating budget. The capital budget funds maintenance of certain parks and open space areas, as well as tree planting and removals. The operating budget funds most of the sector's daily operations including pruning, inspections, the IPM program, et cetera.

Tree Pruning Contractual Cost per Hour

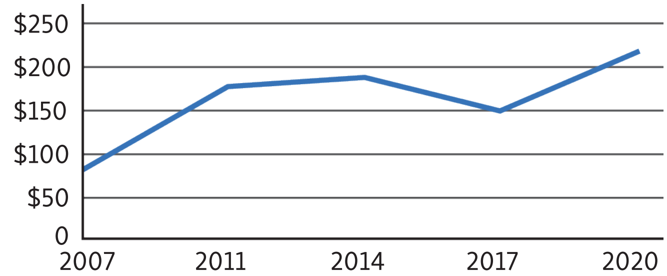


Figure 6-2: Tree Pruning Contractual Cost per Hour by Fiscal Year

Over the past 12 years, costs for contract services have risen almost 300%. During that period, the tree service operating budget has remained relatively stagnant.

Contractual Hours of Street Tree Pruning

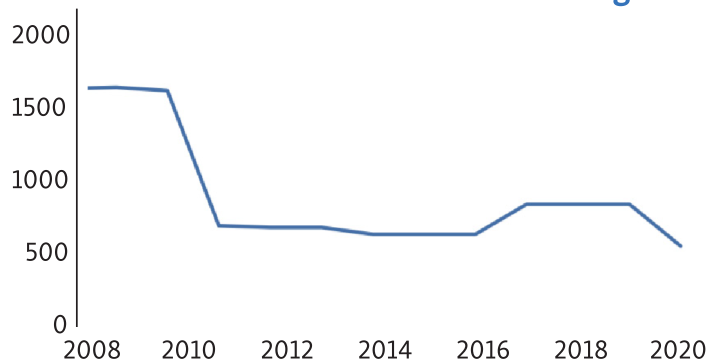


Figure 6-3: Contractual Hours of Street Tree Pruning by Fiscal Year

With the operating budget remaining essentially unchanged over time, rising pruning costs means that the amount of contractual pruning hours available continues to fall.

Street Tree Removal Contractual Costs

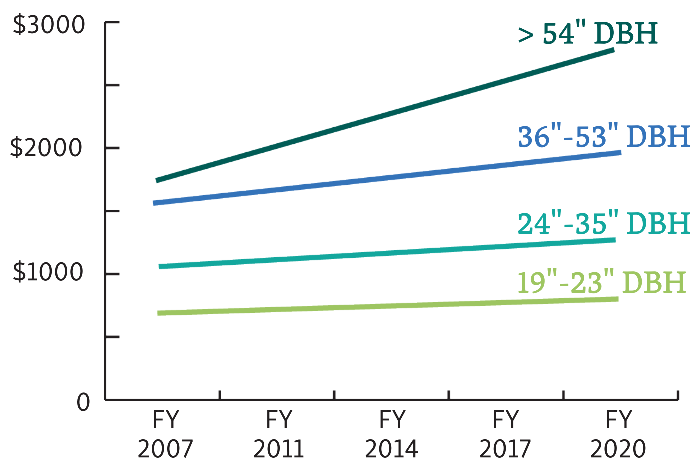


Figure 6-4: Street Tree Removal Contractual Cost per Tree

Costs are higher to remove larger (typically, more mature) trees. The trendlines for multiple tree size classes show the same theme - tree removal costs continue to increase over time.

Tree emergencies resulting from snow events are accounted for within the Town's "snow budget," which does not impact the forestry operating budget. The forestry operating budget, however, covers all tree emergencies resulting from storm events that are not snow-related. As a result, emergency work leads to diminishing funds for routine work. As climate change brings more extreme weather events, there could be an even greater strain on the Town's forestry budget.

Tree-related damages and costs resulting from storm events that are designated State of Emergencies by the governor can be recouped through FEMA. However, reimbursement of the funds can take as long as two years.

The Parks and Open Space Division has leveraged additional funds from other budgets to ensure proper care of all of Brookline's trees, including trees in the Town's parks, cemeteries, school grounds, and other Town properties. Other budgets that have supported tree operations include the Cemetery, Town/School Grounds, Parks and Snow budgets.

The Town's forestry and landscape services budget has remained the same since 2008. Over the course of those 12 years, the costs to perform contracted pruning and tree removal has increased steadily resulting in fewer hours of pruning being completed each year (Figures 6-2 and 6-3). In 2008, a $125,000 operating budget for tree-pruning activities provided 39 40-hour work weeks with a two-person contracted crew. This represents 9 months of full-time work for the crew. Currently, the same $125,000 provides only 14.2 40-hour work weeks with a two-person contracted crew, or approximately 2.5 months of work. Similarly, tree removal costs continue to exceed the budget because a significant portion of trees in the Town are increasingly mature trees approaching the end of life (Figure 6-4).

Projections for future pruning costs illustrate that the budget will need to increase significantly to effectively manage the expanding urban forest and escalating private contracted costs. Adding two Town-employed arborists and purchasing a bucket truck and chipper would allow the Town to do more pruning for less cost than contracted services.

Comparative Analysis of Benchmark Municipalities

As part of this study, peer municipalities from Cambridge and Newton were asked to provide data on their urban forestry management programs to compare the land area, number of trees cared for, staffing, and budgets (See Table 6-3 for the comparison of this data). While many practices and standards are similar, Brookline's budget equates to $55.03 per tree compared to Newton ($75 per tree) or Cambridge ($137 per tree) illustrating that Brookline is stretching each dollar to deliver urban forestry services. Both Cambridge and Newton have tree preservation ordinances that require staff/budget for review and enforcement.

Brookline continues to provide excellent tree care and a robust planting program despite a stagnant budget. With emphasis on expansion of the tree canopy, increased care for existing trees, response to more frequent and intensive storms, and rising costs for contracting tree work, the budget cannot remain the same without impacting the services provided.

A fully-funded program would be able to provide proactive management, anticipating and addressing issues before they become emergencies. When budgets decline, many towns resort to a reactive maintenance program, which ultimately costs municipalities far more than a proactive maintenance program. The challenge of budget limitations translates to an inability

Comparison of Local Urban Forest Management Programs

	Brookline (6.8 mi^2)	Cambridge (7.1 mi^2)	Newton (18.2 mi^2)
Tree Population	12,041 Street Trees	19,000 Street Trees	20,000 Street Trees
Program Budget (2020)	$636,881	$2,600,477	$1,500,000
Tree Pruning Cycle	7 Years	6 years for street trees; 8 years for other municipal grounds	No set pruning cycle
Contract Crews or In-House Crews	Both	Both	Both
ANSI Standards	Yes	Yes	Yes
Trees Planted per Year	Approx. 400	600-900 (primarily contract crews)	Approx. 800 (in-house crews)
New Tree Watering Responsibility	Municipality	Municipality	Municipality
Tree Risk Assessment Program	Yes. Risk is identified through inspection by staff, citizen communications, and other means	No formal program	Yes. Trees are on a regular inspection cycle
Tree Ordinance on Private Property	Brookline's Stormwater Management Bylaw (Article 8.26) includes tree protection measures. A "protected tree" is defined as a tree greater than 8" diameter at breast height (DBH).	Trees 8" and greater are protected. Exceptions: tree is dead or dangerous; removal of the tree is necessary to complete a significant utility infrastructure project; removing a tree may result in a healthier tree canopy; tree poses a significant risk to an adjacent existing structure.	The tree preservation ordinance does not prohibit removal of trees on private property. It places requirements for protection and replacement of trees under certain circumstances.

Table 6-3: Comparison of Urban Forest Management Programs in Similar Municipalities

to respond to changes in the urban forest. This scenario threatens the resiliency of the urban forest and the Town's efforts to adapt to the changing climate. One extreme out-of-season storm could tax already-constrained resources and severely impact the Town's ability to perform routine operations such as tree removal, pest management, and new tree planting.

Tree Preservation Regulations

The Wetlands Protection Act (Massachusetts General Laws (MGL) Chapter 131, Section 40) protects wetlands and the public interests they serve. The law protects not only wetlands, but other resource areas, such as land subject to flooding (100-year floodplains), the riverfront area (added by the Rivers Protection Act), land under water bodies, and waterways.

Acts and Bylaw that include tree protection:

- Wetlands Protection Act (WPA) 310 CMR 10.00
  - Jurisdiction over land within 100’ of a delineated wetland or other resource area
- Rivers Protection Act (RPA)
  - Jurisdiction over land within 200’ of a perennial river or stream
- Brookline Wetland Bylaw (BWB)
  - Jurisdiction over land within 150’ of a delineated wetland and isolated wetlands larger than 2,500 square feet, for vernal pools, and for intermittent streams

Depending on the work proposed, a landowner needs to submit an application to the Brookline Conservation Commission for review and approval of any proposed alterations that would include tree removal.

Private Trees

As a result of the Fall Town Meeting 2001, a Moderator’s Committee was formed to consider drafting a bylaw requiring tree planting as mitigation for tree removal (over a certain size threshold). The committee met eight times, including one public hearing, from 2002-2003 and determined that a tree protection bylaw would be a beneficial and reasonable addition to the Town’s bylaws; however, additional staff would be required to enforce the regulation. Due to the economic climate, hiring new staff was not possible. A draft bylaw was developed for future consideration (See Appendix C). In 2017, a Select Board's Committee studied the possible benefit of a tree protection bylaw. The committee envisioned a two-step process: the first step would modify the existing Stormwater Management Bylaw to enhance protection of trees on private property as a minimum interim measure. The second step would have the committee work with Building and Planning Department staff to consider a Site Plan Review model.

The Stormwater Management Bylaw was revised in 2018 and provided protection for trees on private property when certain disturbance thresholds are exceeded.

TOWN OF BROOKLINE

Section 8.26.2 Erosion And Sediment Control

No person shall excavate, cut, grade or perform any land-disturbing activities of significance, including tree removal, clearing, grubbing, and stripping, without an approved Erosion and Sediment Control Plan.

Activities of significance are those which meet or exceed the following thresholds:

a. *Any change of existing grade of more than 2500 sq. ft. or 25% of the lot whichever is smaller*
b. *Removal of existing vegetation of more than 2500 sq. ft. or 25% of the lot whichever is smaller*
c. *Storage of more than 100 cubic yards of excavate or fill*
d. *Removal of protected tree(s)32” DBH or greater, either in the aggregate or a single tree*

Other municipalities' tree protection ordinances have similar goals to protect privately owned trees for aesthetics, privacy, wildlife habitat, environmental benefits, climate change mitigation, and other reasons. The thresholds that trigger applicability of the ordinance do, however, differ by municipality. Generally trees 8” DBH and higher are protected, which is particularly valuable. From a canopy preservation standpoint, larger trees contribute substantially more environmental and public health services than small trees. Some ordinances provide extra protection for very large trees for this very reason, in addition to their aesthetic and historic values.

In Newton, trees 8” DBH or larger are protected under Sec. 21-80 Tree Preservation, but one, two, three, and four family residences are exempt. The canopy analysis for Brookline showed the largest area of canopy loss from 2014 to 2020 was on one to three family residential parcels. As a result, the residential exemption that Newton includes is not recommended for Brookline. Newton does, however, require tree replacement or payment of a fee for the removal of privately protected trees to discourage tree removal and to provide some canopy replacement when tree removal is necessary. The fees help fund tree planting on public land, but it is important to ensure that any fees generated go to purchase and install replacement trees above and beyond the typical annual tree planting efforts. The review and approval process is administered by the Tree Warden.

In Cambridge under its Tree Protection Ordinance, Title 8, Chapter 8.66, trees 8” DBH or larger can only be removed on private property if they are dead or dangerous, pose a risk to human welfare, interfere with an infrastructure project, compete with another healthy tree or could damage an adjacent structure. Residents may not remove a tree for any other reason. This is much more stringent than the ordinance in Newton and requires greater review and oversight in the application process and for the effective enforcement of this ordinance. Where greater canopy loss has been seen in Cambridge over the past decade, this level of protection is needed in order to stop canopy loss and promote canopy increase.

With any tree preservation ordinance, an increase in staffing is needed for oversight and enforcement of the requirements. This is not always possible because municipal budgets are stressed so greatly already. Ordinances need to respond to the community needs of tree preservation while not impeding building renovation and development. The protection process should be straightforward and not onerous so it will be followed and successfully administered.

Public Trees

In Massachusetts, public shade trees can only be cut, trimmed or removed in whole or in part by the Tree Warden without a public hearing per MGL Chapter 87.

For transportation projects with trees in the public right-of-way, the Massachusetts Environmental Policy Act (MEPA), 301 CMR 11.00 requires environmental review when five or more living public shade trees of 14" DBH are proposed to be removed. This review can be an Environmental Notification Form and any other MEPA review the Secretary of the Executive Office of Energy and Environmental Affairs requires.

Summary and Conclusions

The Town of Brookline has a proactive inspection and maintenance program. Town staff follow an inspection schedule, and, when possible, align block pruning with citizen maintenance requests.

The Town has a small in-house crew that both maintains trees and oversees pruning and removal contracts. Nationally, many other communities have moved exclusively to contract pruning and have eliminated in-house crews, leaving those communities vulnerable to fluctuations in cost. Brookline, for instance, has experienced a 407% increase in tree pruning costs over the past 16 years. The Town and its trees benefit from in-house crews who have both historical knowledge and a sense of ownership of the urban forest. Costs for in-house crews are more predictable and provide consistency.

Through the leveraging of funds from other budgets (town/school grounds, cemetery, and parks), partnerships with local organizations and environmental advocacy groups, allowance of private vendors to conduct work on public trees, and through strong working partnerships with utilities, the Town has been able to maintain services even as costs rise.

The Town is fortunate to have a mature tree canopy populating its rights-of-way. However, as trees mature, pruning and maintenance become more complex and time-consuming, and as a result are increasingly costly.

Urban forest management in the Town of Brookline compared with peers in Newton and Cambridge has a considerably lower budget per public street tree.

Based on the information reviewed, the following recommendations would help minimize risks to the tree program and would enhance service levels, ensuring effective, sustainable tree care.

- Increase funding to support proactive pruning, improve the Town's response to more frequent and more intense storms, and care for the aging tree canopy.
- Hire 2 additional full-time staff to increase the number of in-house tree crews for pruning, planting, watering, and general services. Promotion of in-house crews is a more economical way to enhance services when compared with the rising costs of contracted crews.
- Make the Tree Warden a full-time position. A full-time Tree Warden will not only assist in elevating service levels and allow for the enforcement of a tree protection bylaw, but will also signal to the community the importance of the forestry program and the urban forest.
- Enhance record keeping protocols. Maintaining clear and accurate records is essential to a fortified risk management program.
- Enhance storm budgets to respond to an increasing frequency and severity of storms expected with climate change.

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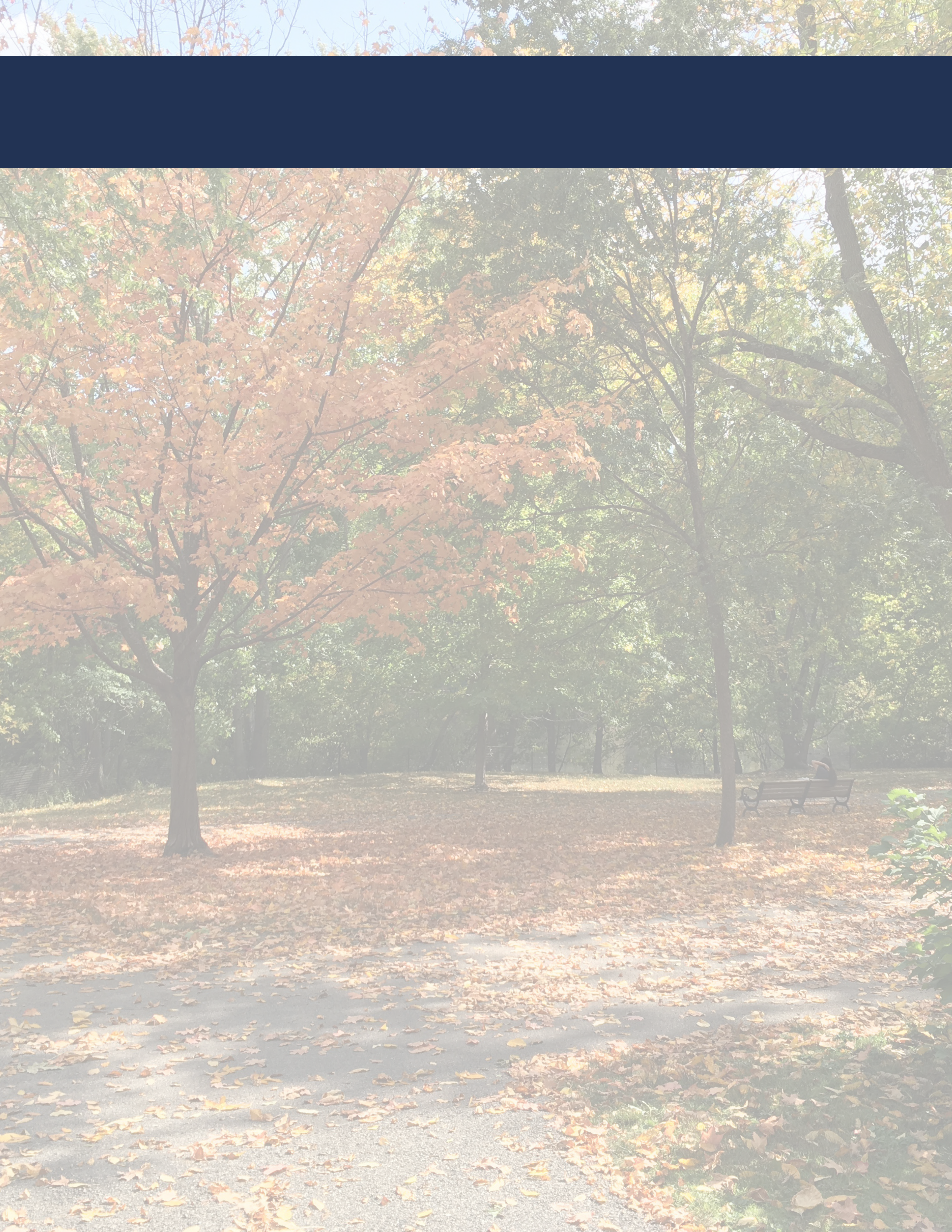


CLIMATE CHANGE MITIGATION AND RECOMMENDATIONS

7

Introduction

The Town of Brookline has a long history of urban forestry planning and management, and has served as a model for other communities for decades. Brookline residents have come to rely on its extensive network of trees for ecosystem services that support their general health, well-being, and recreation. The urban forest cleans the air, provides shade and cooling, and defines the spaces where people live, work and play. Climate change will bring warming temperatures, a decrease in air quality, an increase in stormwater runoff and flooding, and an increase in threats from pests and diseases.

Climate change will put Brookline's urban forest at risk, including its ability to filter groundwater, mitigate intense storms, control erosion, moderate extremes in temperature, supply food, sequester carbon, provide habitat, bolster the economy and frame cultural and natural landscapes. To combat climate-related challenges, the Town must act now to ensure the urban forest is resilient, robust and equitably distributed. The extent to which the Town can mitigate or adapt to climate-related threats will depend on its ability to allocate resources to strategies that will provide the most benefit. This plan recognizes that, ultimately, the health and resilience of the urban forest is key to the health and resilience of the community in the face of climate change.

Developing a Local Strategy

There is no 'one size fits all' strategy for which climate mitigation and adaptation targets cities should focus on. Specific strategies need to consider the local climate risks and uncertainties, and the feasibility of any proposed interventions within the context of town policies.

In Brookline, while localized flooding may be expected with more frequent and intense storms, large-scale flooding from the Muddy or Charles Rivers are not expected to be a major concern Town-wide. The impacts of sea-level rise are best managed on a more regional scale that goes beyond the scope of this plan.

Therefore, it is likely that, in Brookline, higher temperatures will cause the urban heat island (UHI) effect and localized air quality to be the biggest concerns going forward. These effects are expected to be pronounced and will directly affect resident health and well-being. In addition, these impacts disproportionately affect many of Brookline's most vulnerable or at-risk populations. Rising temperatures will also affect the composition of the urban forest, with shifting habitat ranges influencing which species will do well in the future.

Looking ahead, it is expected that by 2030:

- The number of 90 degree days could triple
- Overall average temperatures will be warmer
- More frequent and longer heat waves will occur
- Number of days with "feels like" temperatures at the extreme caution level will increase
- Temperatures will be exacerbated by the urban heat island effect (City of Cambridge, 2015)

Heat Island Impacts in Brookline

Ambient air temperature on a simulated 95°F day

Ambient air temperature on a simulated 100°F day

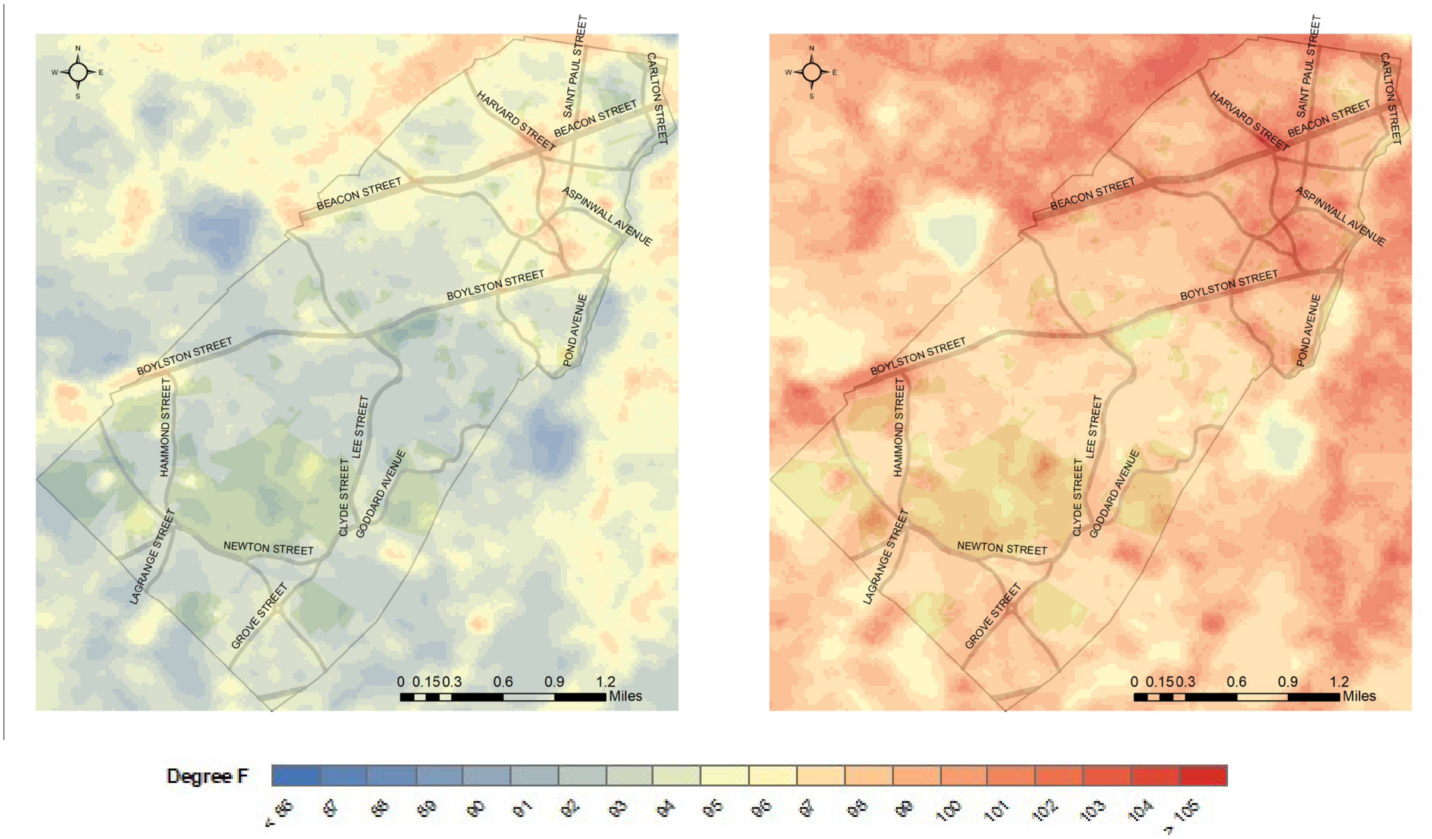


Figure 7-1: Visualization of the Urban Heat Island (UHI) Effect on Simulated 95°F and 100°F Days in Brookline.
Figure source: Weston & Sampson

Using data provided by Northeastern University, Brookline's 2017 Climate Vulnerability Assessment found that by 2030, the areas of Brookline that can expect to see the highest temperatures are in North Brookline, along the Harvard Street corridor. By 2070, very high temperatures could predominate in the entire northern half of the Town. North Brookline is more susceptible to the urban heat island effect due to its high percentage of heat-retaining impervious surfaces and its relatively low canopy coverage, as compared to South Brookline (Figure 7-1). Baseline data show that areas in North Brookline have an average temperature that is 3-5°F higher than areas in South Brookline. The impact is most pronounced on high temperature days.

Higher temperatures also cause more water to evaporate from surfaces and allow the atmosphere to hold more water vapor. The high humidity makes the ambient air temperature feel even hotter. Eventually, the additional water vapor condenses on particles in the atmosphere and the water makes its way back to the ground through precipitation. With climate change, these precipitation events are expected to be more intense and seasonally more frequent. The Northeast and Massachusetts have shown approximately a 50-55% increase in the amount of precipitation falling in rain events from 1958 to 2016.

Inland Flooding

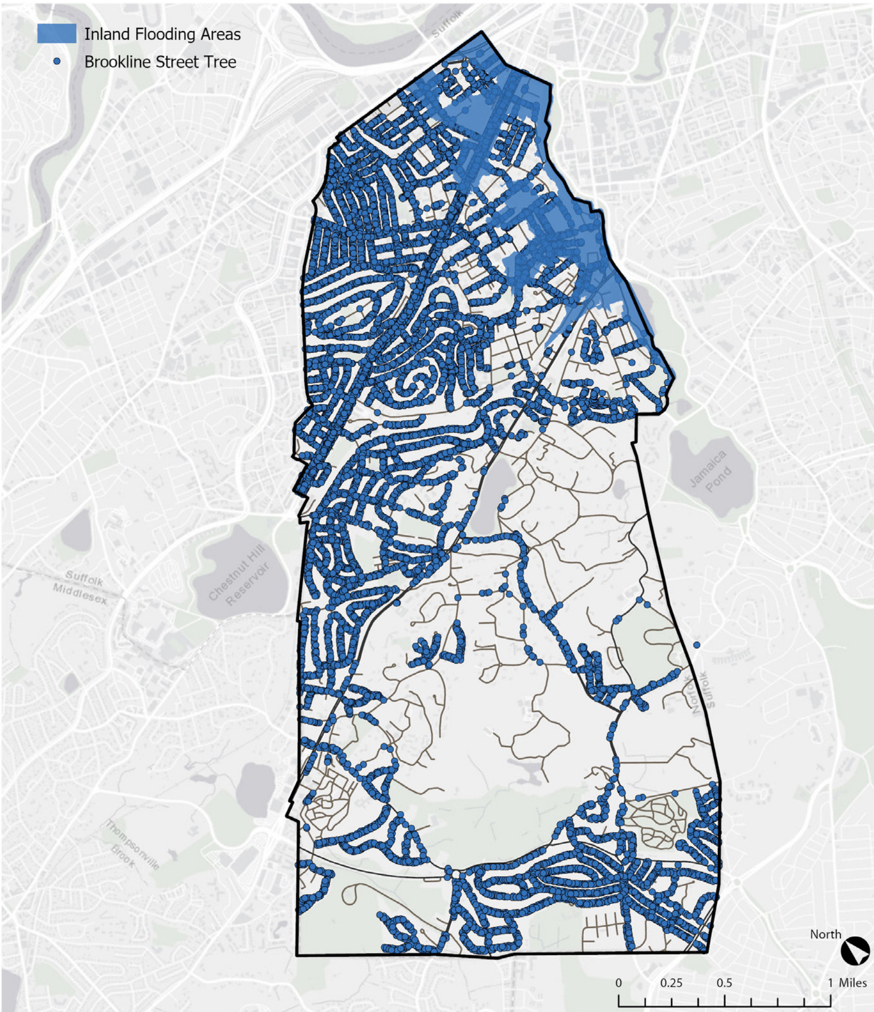


Figure 7-2: Inland Flooding in Brookline
Figure source: Brookline GIS

The Tree Canopy

While climate change will bring challenges, particularly heat, extreme weather, and the human health impacts of those events, Brookline has a substantial resource to combat these threats - its urban forest. Brookline has a substantial canopy, covering approximately 44.7% of the Town, according to the 2020 LiDAR data. This is impressive for an urbanized area. However, this is a decrease from 2014, at which time the Town's canopy cover was 46.3%. This percentage change is a net loss of 71 acres, or the equivalent of 54 football fields, more than 3 Brookline Reservoirs, or about 8 Fenway Parks. Over half of the loss (42 acres) took place on 1-3 family residential properties.

Status Quo

Between 2014 and 2020, Brookline has lost an average of 12 acres of canopy coverage per year. These losses occurred despite proactive planting by the Town of 350-400 trees per year. If no efforts to increase tree canopy are made, and this same level of loss continues, the Town would lose another 113 acres by 2030.

Canopy Distribution

Importantly, canopy coverage is not uniform across the Town. From South Brookline to North Brookline the tree canopy coverage varies from nearly 100% to less than 30%. In general, South Brookline has much greater canopy coverage than North Brookline, and residential neighborhoods are fairly densely planted while commercial neighborhoods are much less so. Chapter 5 discusses the results of the LiDAR-based tree inventory in more detail.

Growing the Canopy

There are fundamentally two ways to increase tree canopy cover. The first way is perhaps the most obvious - to plant new trees. But it is equally, if not more important, to preserve existing trees. A new tree can take a decade or more to develop a sizable canopy to provide significant shading and other ecosystem services. The benefits provided by a mature tree far surpass those provided by a young tree. While the details depend on the particular species

PLANT + PRESERVE = GROW

and location, as one example - it would take more than six newly planted red maple trees with 2" diameter trunks to equal the annual environmental benefits of a single red maple in the same location with a 20" trunk diameter. (USDA Forest Service)

Established and mature trees have for many years made large contributions with their existing tree canopies, and these trees continue to have a greater impact every year as they sequester more carbon in building tree mass. Still, natural mortality, damage, or tree removals will decrease the number of existing trees over time. So, to maintain and grow its tree canopy, both new plantings and maintenance of existing trees must be part of Brookline's urban forestry efforts.

Co-benefits of Increasing Tree Canopy

Increasing the canopy cover of the urban forest has a number of co-benefits beyond providing shade and cooling. Increased canopy improves public health outcomes during extreme heat events, improves stormwater control, improves air and water quality, increases carbon sequestration, reduces energy demands and the resulting production of greenhouse gases, increases property values and provides a way to increase wildlife habitat and plant diversity. Simply put - a greater tree canopy provides increased resilience to climate change impacts.

Trees that Reduce Air Pollution

Trees with Traits Suited to Reduce Air Pollution	
Deciduous	Dawn Redwood (*Metasequoia glyptostroboides*) Ginkgo (*Ginkgo biloba*) Hackberry (*Celtis occidentalis*) Honeylocust (*Gleditsia triacanthos*) Littleleaf Linden (*Tilia cordata*) Maples (*Acer sp.*) Oaks (*Quercus sp.*) Sumac (*Rhus typhina*) Zelkova (*Zelkova serrata*)
Evergreen	Eastern White Pine (*Pinus strobus*) Scotch Pine (*Pinus sylvestris*) Yews (*Taxus baccata*)

Table 7-1: Tree Species with Traits Best Suited for Air-Pollution Reduction

Human Health

- Increase use of trees for mitigating heat in areas most susceptible to urban heat island effect and poor air quality.
- Select tree species for ability to reduce pollution (Table 7-1).
- Utilize species that have low pollen production/spread in densely populated areas.

Ecological

- Create habitat corridors with continuous street tree planting and connections to parks, conservation areas, and other open spaces.
- Improve biodiversity with varied tree species that support wildlife habitat. Plant native trees where appropriate, but acknowledge many urban growing conditions are not replicated in native plant communities and other species may be more appropriate.

Site Strategies for Cooling and Greening

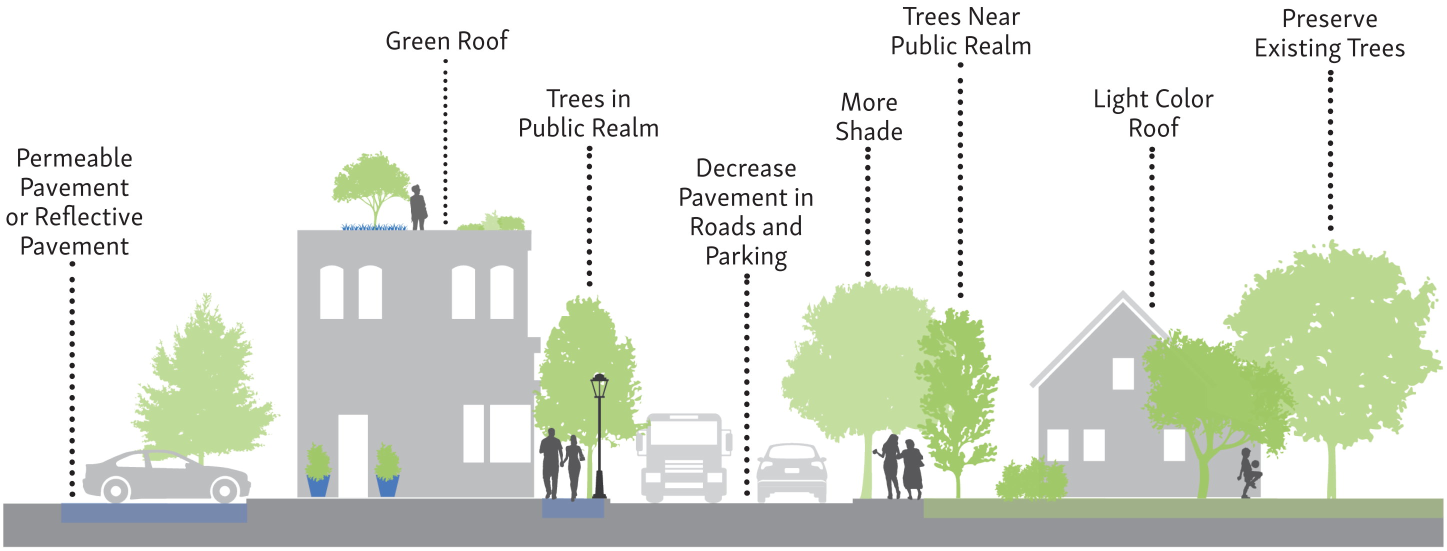


Figure 7-3: Multiple Strategies that Contribute to Cooling
A sampling of site and exterior building strategies that contribute to cooling, mitigation of heat island effects and "greening" of the Town.

Resilience

- Select tree species that absorb stormwater more readily in areas where that is beneficial.
- Utilize tree species suitable for predicted climate change. Many mid-Atlantic tree species are now commonly planted in Brookline successfully, and this trend will continue. Adjust tree species palette accordingly (Table 7-1 and Table 7-5).

Mitigating Climate Change beyond the Tree Canopy

Growing the tree canopy can contribute significantly to mitigating the impacts of climate change, but Brookline cannot rely on the tree canopy alone. While trees provide environmental and health benefits, the addition of other 'green' improvements to the Town's suite of climate change mitigation and adaptation tools can do even more (e.g. converting roofs to green roofs or using light colored roofing materials, reflective pavement, and permeable pavement) (Figure 7-3).

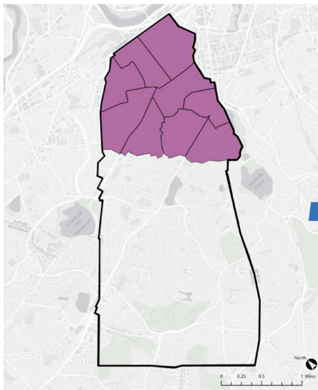
Canopy Goals

An increase in tree canopy coverage is needed Town-wide in order to mitigate the effects of climate change and reverse the trend of decreasing canopy cover seen from 2014-2020. An increase in canopy cover will be most dramatic in urbanized areas. Canopy coverage needs to be equitable, with planting prioritized where the most benefit can be achieved for areas where climate change impacts are anticipated to be greatest, and in areas where at-risk populations could benefit most from an increase in canopy.

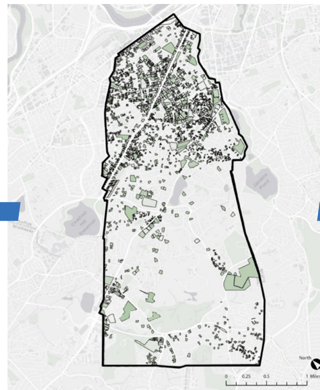
When considering the stem-by-stem inventory results and the available LiDAR data, canopy expansion will be prioritized in three broad categories (Figure 7-4):

- Where the urban heat island (UHI) effect is most pronounced (areas with above average temperatures)
- Where there is below average tree canopy coverage (canopy coverage less than 30%)

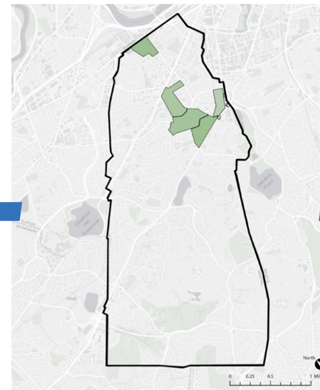
Determining Targeted Tree Canopy Expansion Areas



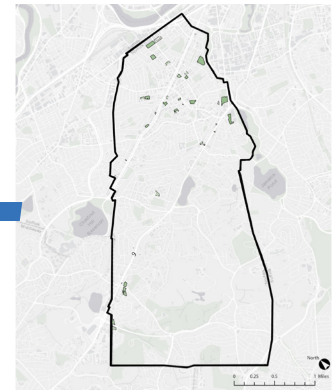
Areas with Above Average Temperatures



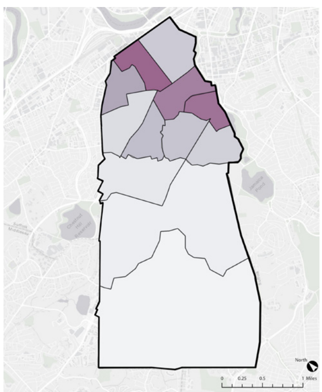
Tree Canopy Coverage Less than 30%



Environmental Justice Areas with Less than 47% Canopy Coverage



Affordable Housing with Less than 30% Canopy Coverage



Priority Planting Areas

Applied to Public Rights of Ways, Considering Available Locations for Planting

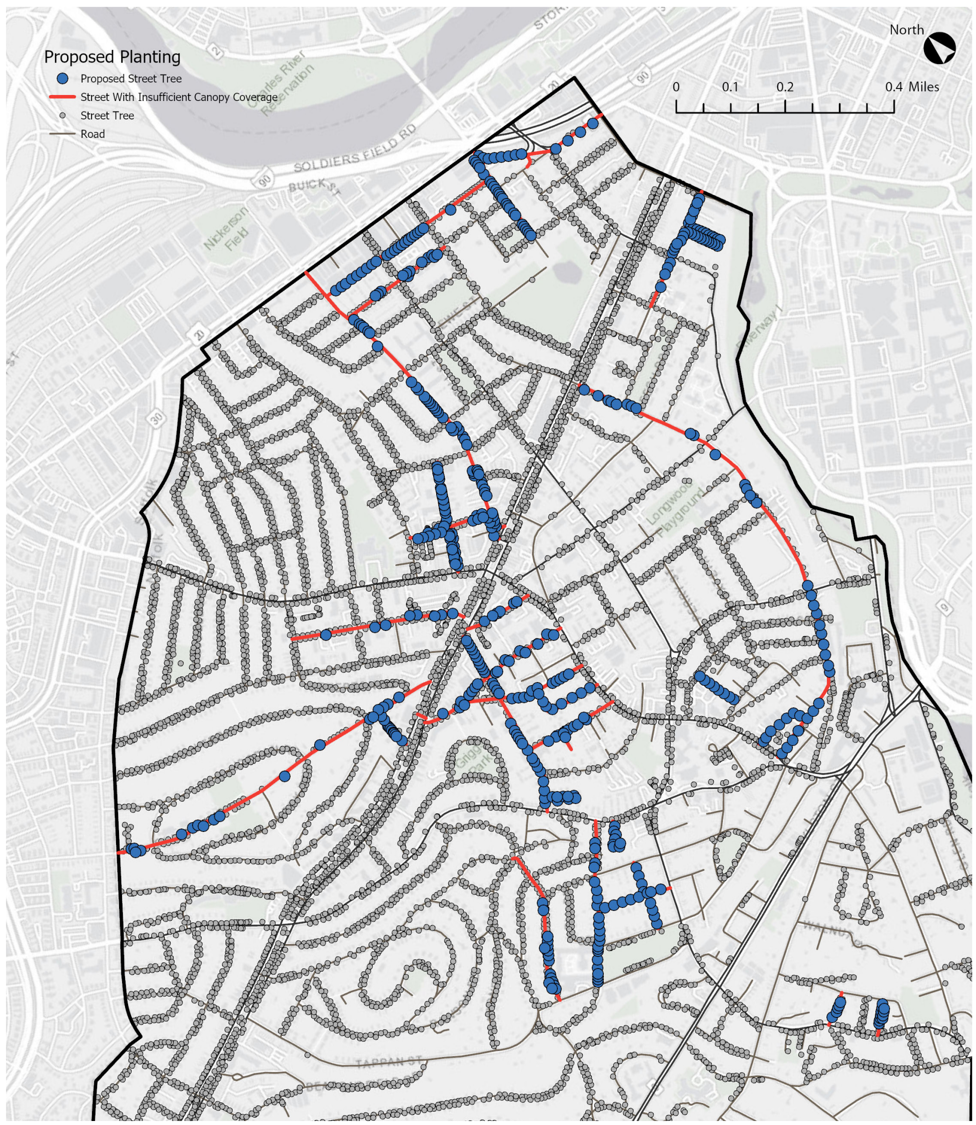


Figure 7-4: Priority Tree Canopy Expansion Areas in North Brookline

Targeted areas for tree canopy expansion include areas with below average tree canopy coverage, those with urban heat island impacts,and areas where there is the greatest percentage of the population, particularly those at-risk and susceptible to the impacts of climate change.

- Where there is the greatest population density, particularly those susceptible to the impacts of climate change

More specifically, given available planting areas and the feasibility of implementation, canopy expansion should target the following areas:

- North Brookline in general
- Environmental justice areas
- Public and affordable housing sites
- Senior center
- Transit stops
- Municipal parking lots
- Specific streets with sparse canopy cover (Figure 7-4, Table 7-4)

Each of these specific areas have unique challenges to increasing the canopy. For example, the public housing sites are not owned by the Town and transit stops require coordination with the MBTA. North Brookline faces challenges in increasing its tree canopy because so much of the land area is urbanized, and there is a high percentage of existing impervious surfaces. While North Brookline may not be able to achieve the same canopy coverage as South Brookline, there are creative ways to bring the benefits of the urban forest to densely urbanized areas. Tree planting efforts that utilize the additional soil and root zone under pavement are one option. There could also be opportunities to plant mini-forests that have higher environmental value than individual trees and provide a more hospitable environment for tree growth and maturity. A mini-forest is a dense planting of native species in a small footprint. Establishing a mini-forest in a public park in North Brookline would be one possibility, since the land is under Town control.

How Many Trees Does Brookline Need?

To reach Town-wide canopy coverage of:	Brookline must plant:
41%	0 trees over next 10 years
44.7%	7,000 trees over next 10 years
47%	8,000 trees over next 10 years
50%	9,000 trees over next 10 years
53%	10,000 trees over next 10 years
55%	10,700 trees over next 10 years

To reach North Brookline canopy coverage of:	Brookline must plant:
33%	0 trees over next 10 years
35%	1,840 trees over next 10 years
37%	1,940 trees over next 10 years
45%	2,340 trees over next 10 years

Table 7-2: Number of Trees To Be Planted Each Year To Meet Canopy Coverage Percentages

Percentage in bold is the 2020 canopy cover percentage. Even to maintain the status quo of canopy cover, trees must be planted to account for removals, storm damage, and tree mortality. Also, keep in mind that 66% of the land is privately owned, while only 32% is publicly owned.

Potential for Tree Canopy Growth

When striving for an increase in canopy coverage, future planting is constrained by the available spaces that can be used for planting. In Brookline, the land cover analysis (see Existing Conditions of the Urban Forest) indicates a potential to expand tree plantings, even in North Brookline. Grass and shrubs cover 22% of the Town and paved areas cover another 13%. This means that 35% of the Town land cover may have opportunities for expanded tree planting. While the full 35% is not likely to be plantable due to land use constraints, only 20% of the land cover in Brookline are occupied by buildings or roads (unavailable for tree canopy expansion). Not all grass, shrub, or paved areas are necessarily appropriate for planting trees. The site-specific conditions and existing land use of each location must be evaluated as the Town determines where

Canopy Coverage Goals by Voting Precinct

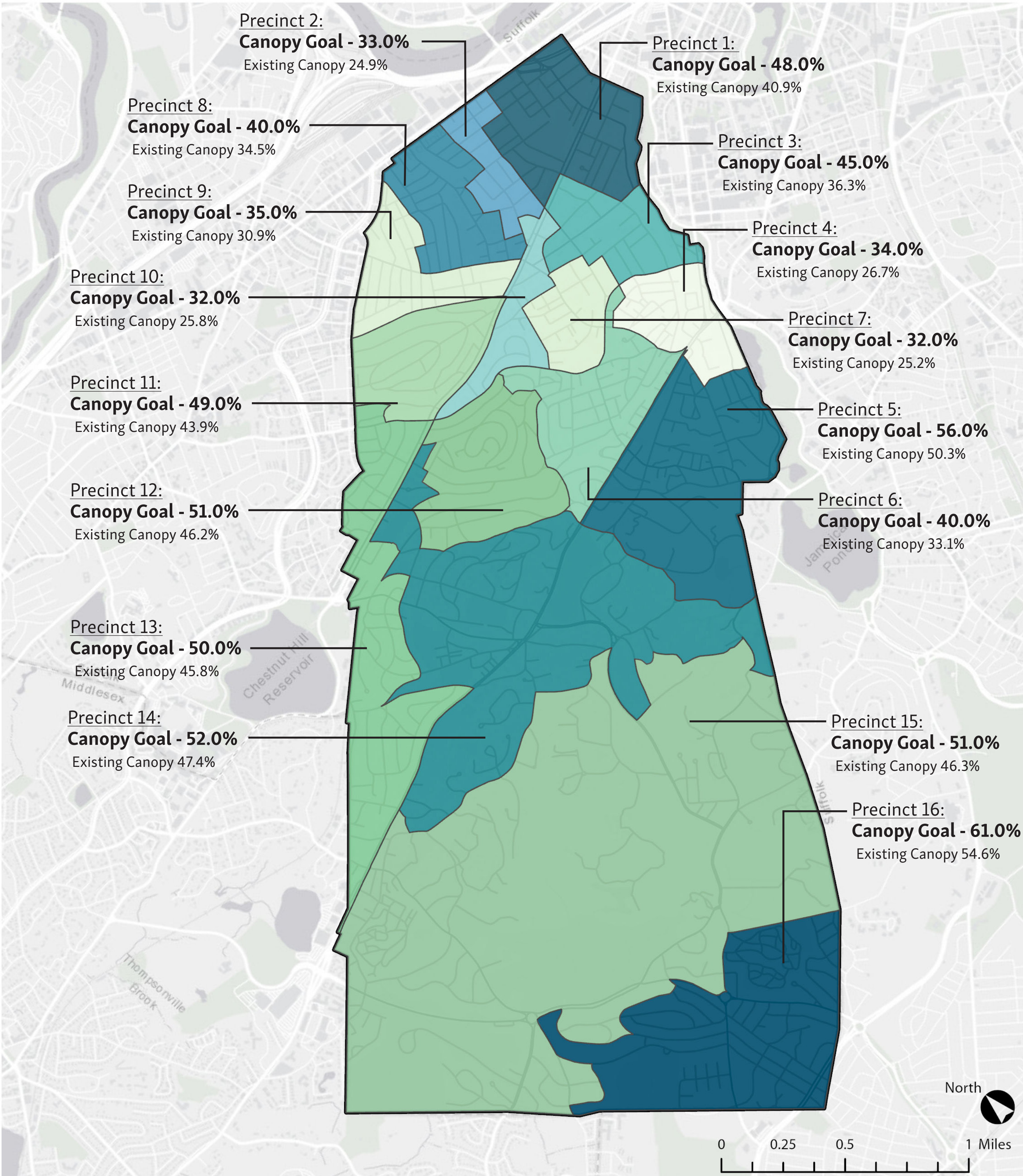


Figure 7-5: Canopy Coverage Goals, by Voting Precinct

Each of Brookline's 16 voting districts was assigned a canopy coverage goal. Goals were based on increasing coverage in low coverage precincts (those with less than 40% tree canopy coverage) by at least 5%, and maintaining or achieving small increases in canopy coverage in all other precincts. The map shows the canopy coverage goal for each precinct as well as the precinct's current percentage of canopy cover.

Data source for existing canopy: CanopyKeeper

Canopy Coverage by Precinct

Name	Size (acres)	Tree coverage (acres)	Current tree canopy %	Goal %	Goal coverage (acres)	Coverage with 1% natural growth x 10 years (acres)	Predicted tree canopy coverage % in 2030
Precinct 1	179	73	40.9%	48.0	85.9	80.6	45.0%
Precinct 2	58	15	24.9%	33.0	19.1	16.6	28.6%
Precinct 3	105	38	36.3%	45.0	47.3	42.0	40.0%
Precinct 4	93	25	26.7%	34.0	31.6	27.6	29.7%
Precinct 5	305	154	50.3%	56.0	170.8	170.1	55.8%
Precinct 6	162	54	33.1%	40.0	64.8	59.6	36.8%
Precinct 7	75	19	25.2%	32.0	24.0	21.0	28.0%
Precinct 8	115	40	34.5%	40.0	46.0	44.2	38.4%
Precinct 9	105	32	30.9%	35.0	36.8	35.3	33.7%
Precinct 10	73	19	25.8%	32.0	23.4	21.0	28.8%
Precinct 11	129	57	43.9%	49.0	63.2	63.0	48.8%
Precinct 12	180	83	46.2%	51.0	91.8	91.7	50.9%
Precinct 13	275	126	45.8%	50.0	137.5	139.2	50.6%
Precinct 14	604	286	47.4%	52.0	314.1	315.9	52.3%
Precinct 15	1531	708	46.3%	51.0	780.8	782.1	51.1%
Precinct 16	375	205	54.6%	61.0	228.8	226.4	60.4%
	Total	*Total*	*Average*	*Average*	*Total*	*Total*	*Average*
	4364	*1934*	*44.3%*	*49.6%*	*2166*	*2136*	*49.0%*

Table 7-3: Canopy Coverage Goals and Projections by Voting Precinct

planting opportunities exist. For example, some grassy areas are athletic fields that are already providing recreational benefits. Other areas may have site constraints such as underground utilities.

Specific Canopy Cover Goals

Specific tree canopy goals were created for each of Brookline's 16 voting precincts. Voting precincts were chosen as the geographic analysis level to provide a relatable way to communicate with residents about canopy coverage. Goals were based on increasing coverage for precincts with less than 40% tree canopy coverage by at least 5%, and maintaining or achieving small increases in canopy coverage in all other precincts (Figure 7-5 and Table 7-3).

Recommendations Framework

To build urban forest canopy cover and Town-wide resiliency, this chapter outlines recommendations for the urban forest that focus on effectively growing the canopy, protecting the investment in existing trees, maximizing new tree success through tree planting and management standards, improving operations, and engaging with partners and the larger community to promote the urban forest. Strategies to implement the recommendations are discussed in the Action Plan in the following chapter.

Recommendations are organized as noted below and are further explored in this chapter:

- Grow
- Protect
- Manage
- Engage

Grow

Public trees

While only 33% of Brookline's trees are on public land, street trees and trees at schools, parks and Town grounds form the backbone of the public landscape. Public tree planting is within the Town's control and can be used to spur private tree planting efforts.

In North Brookline, in particular, there are many public streets that have very few or no street trees. The streets in question are difficult areas in which to plant trees because the sidewalks are narrow, buildings abut the sidewalk, or other modes of transportation have been prioritized. If this section of the Town is to increase its tree canopy coverage significantly, a new vision is needed to balance the competing needs of the streets and integrate street tree planting with accessible pedestrian, bicycle, and vehicular circulation.

Infill planting refers to planting additional trees along streets to achieve more consistent canopy coverage or increase the diversity of tree species. Infill planting is the easiest to achieve since these streets already accommodate trees (Figure 7-6). New trees are planted in available locations that meet the minimum soil volume and sidewalk width standards.

Back of sidewalk planting is a good strategy for narrow sidewalks that cannot accommodate both the minimum sidewalk width and minimum tree pit dimension (Figure 7-7). Generally, back of sidewalk trees are planted by the Town on private property per the Back of Sidewalk Program guidelines.

A road diet is a re-balancing of the public right-of-way to decrease pavement widths for driving lanes and parking, while increasing sidewalk width, bicycle accommodations, tree plantings or a combination of these (Figure 7-8).

Reclaiming parking introduces street tree planting within parallel parking areas because the sidewalk width is too narrow for tree pits or a tree lawn, and no back of sidewalk condition exists (Figure 7-9). Clustering street trees together provides better growing conditions, more visual and shading impact, and is more efficient for safe snow removal in the parking area.

Cycle tracks, raised to be at the sidewalk level, would replace bicycle lanes at the road level and provide the opportunity to add street trees and structural soil for greater rooting area (Figure 7-10).

Infill Planting

Existing Condition: Removals or other circumstances have left uneven tree canopy cover

Recommendation: Maximize tree planting density to provide additional shade

Figure 7-6: Example of Infill Planting Strategy

Back of Sidewalk Planting

Existing Condition: Narrow sidewalk leaves no room for tree pits or a tree lawn.

Recommendation: Implement Back of Sidewalk planting to increase canopy cover

Figure 7-7: Example of Back of Sidewalk Planting Strategy

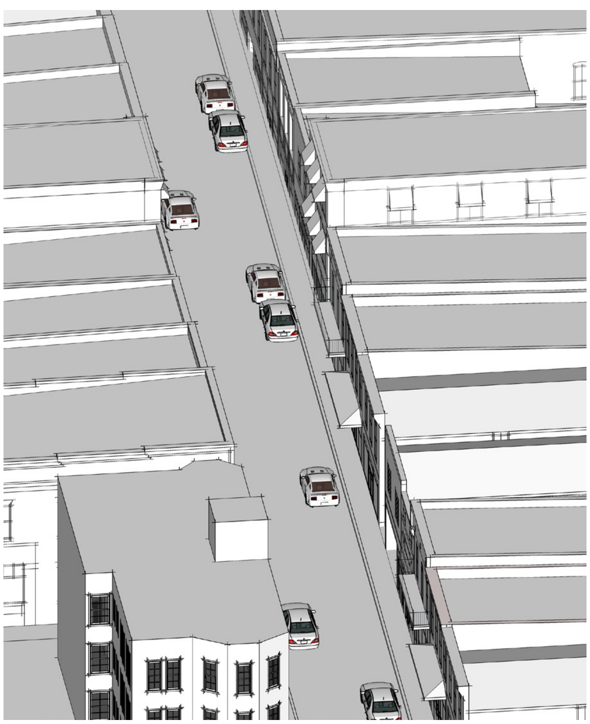
Road Diet

Existing Condition: Wide driving lanes leave a small tree lawn that is insufficient to support trees

Recommendation: Re-balance right-of-way reducing area of pavement to add tree planting

Figure 7-8: Example of Road Diet Planting Strategy

Reclaim Parking



Existing Condition: Street and sidewalk leave no room for tree plantings

Recommendation: Exchange continuous parking spaces for a grouping of trees in raised tree pits

Figure 7-9: Example of Reclaimed Parking Planting Strategy

Cycle Track

Existing Condition: Wide driving lanes and an at-grade bike lane are positioned in a way that leaves no room for tree plantings

Recommendation: Modify paved street to create a raised cycle track and a continuous tree lawn with structural soil

Figure 7-10: Example of Cycle Track Planting Strategy

Street Trees (Residential, Collector, Arterial)

Brookline cares for approximately 12,322 trees that are in, or overhang, the public way. These include residential streets, collector streets, and major traffic arteries such as Route 9 and Beacon Street. Recommendations differ, based on the street type and categories of traffic.

Residential streets:

- Continue infill planting where gaps in the street tree canopy exist. Infill with species similar in size and character.
- Continue successional planting as trees decline. Succession planting is a continual process of replacement planting that considers the useful lifespan of trees. It is a way to bring consistency to the urban forest by ensuring that the tree population does not mature at the same time.
- Replace invasive species (Norway Maple, Tree of Heaven) when the condition dictates.
- Replace species susceptible to pests (e.g. Ash) when the condition dictates.
- Target efforts on residential streets that are generally lacking in canopy (Lagrange St., Lee St., Summit Ave., Fisher Ave.).
- Plant appropriately scaled trees when overhead utilities exist.

Collector streets:

- Many collector streets (Pleasant St., St. Paul St., Amory St., Cypress St., Kent St., Tappan St., Chestnut Hill Ave.) can accommodate an increase in tree planting.
- Brookline Complete Streets policy should be considered as part of any tree canopy improvements, as there is a balance of land use and transportation modes to consider.

Brookline Streets with Below-Average Tree Canopy Coverage

Streets With Tree Canopy Coverage Below the Town Average of 44.7%			
Auburn	Green	Lincoln	Short
Centre (segments)	Greenough	Marion	Summit
Dana	Harris	Monmouth	Vernon
Dummer	Hart	Mountfort	Washburn
Essex	Hurd	Park	Webster
Egmont	John (segments)	Pleasant	Wellman
Gorham	Kent	Rice	

Table 7-4: Streets or Street Segments with Below-Average Tree Canopy Coverage.

- There is not sufficient sidewalk width on some of these streets to support street trees. Consider back of sidewalk planting, structural soils or curb re-alignment.

Many of these streets are mixed use, but take on a more residential character with regular street tree planting. Pleasant Street as an example is lacking in canopy coverage. If the street were studied with Complete Streets design principals, we expect a road diet would yield more sidewalk space and tree planting opportunities.

Arterial streets (Route 9, Beacon Street, Washington Street, Harvard Street, Hammond Pond Parkway):

- Route 9:
  - Has an inconsistent character along its length more often than not appearing almost highway-esque. Increase tree planting generally for pavement cooling and aesthetics.
  - Coordinate with MassDOT regarding tree planting strategies and opportunities to increase soil volume.
- Beacon Street:
  - Expand soil volume for street trees in sidewalks, particularly in the business districts. Structural soil and Silva Cells could be used.
  - Explore options near Coolidge Corner where sidewalks on Beacon Street are narrow. Consider sidewalk width increase to gain space for tree growth.
  - Replace species susceptible to pests (e.g. Ash) that are prevalent along the MBTA reservation near Washington Square, as condition dictates.
  - Coordinate with the MBTA to improve tree planting associated with Green Line stations.
  - MBTA property: maintain the tree canopy along the Green Line corridors.
- Washington Street & Harvard Street:
  - Expand soil volume for street trees in sidewalks. Honeylocusts have tolerated small tree pits, but are heaving sidewalks. Circular tree pits have a portion of highly compacted soil because people encroach on them during sidewalk travel. With a sidewalk renovation project, structural soil or Silva Cells could expand the soil

volume and connect rooting zones from tree to tree.

  - Needs a corridor-wide Complete Streets study on how best to balance uses of the right-of-way (vehicular operations, bicycle use and pedestrian use) and provide sufficient space for successful tree growth.

- Hammond Pond Parkway:

  - Continue to coordinate with DCR regarding water level rise and the planting of trees that can tolerate wet conditions.

  - Needs a Complete Streets study on how to accommodate pedestrians and cyclists. While exploring road re-balancing, also consider wetland restoration work.

Public open space

- Brookline parks have excellent tree coverage. Where there are large artificial turf fields and paved courts, increase perimeter planting to provide cooling effects (example: Downes Field).

- Continue annual planting efforts in parks, schoolyards, Town grounds, conservation areas and other open spaces, in order to offset natural mortality and occasional storm damage.

- Continue public tree inventory to better understand tree species, size and condition of trees in public open spaces. This will allow planning for succession of declining trees, invasive species and species at risk to pests or climate change.

- Emphasize care of existing trees on all Town properties. Large, mature trees contribute the most benefits. Trees in the 20' to 60' range provide the greatest potential for canopy growth. Recent plantings associated with capitol improvement projects at Fisher Hill Reservoir, Brookline Reservoir Park, Skyline Park and the Back Landfill (Lost Pond Sanctuary) will be reflected in the next LiDAR analysis.

- Foresters/arborists and ecologists should assess forested areas in Town Conservation Areas to understand the forest composition, overall health, extent of invasive species and habitat value.

Public housing

- Sites of public housing need increased canopy coverage:

  - Coordinate with land owners and property management to increase perimeter and courtyard tree planting. Also discuss existing tree care practices to sustain the existing canopy.

  - As sites are renovated and expanded for housing opportunities, significant tree planting must be integral to conceptual designs.

  - Discuss with property owners opportunities for planting through the Back of Sidewalk Tree Planting Program.

Town grounds

- Town Hall and the main public library are examples of areas that are well-planted and cared for.

- Denny Health Center needs increased planting, but coordinate so that it will not impact potential solar panels in the future.

School grounds

- Well-planted. Only needs planting when trees are removed.

- Continue pruning cycle yearly before school starts and after storm events.

Public parking

- Increase canopy coverage for cooling effects.
- Look to LEED standards for heat island reduction. Provide shade (within 5 years) and/or use light colored/high-albedo materials (reflectance of at least 0.3) and/or open grid pavement for at least 30% of a site's non-roof impervious surfaces.
- Retrofit Webster Street parking - has lawn islands that can be planted with trees with sufficient soil volume.

Private trees

Of the approximately 204,000 (+/- 10,000) total trees in Brookline, approximately 32% are publicly owned and managed. Nearly 110,000 trees are on single-family and multi-family residential properties. In addition, the biggest loss of tree canopy area from 2014 to 2020 was within the residential (one to three family) private land use category, likely due to renovation and new construction. This data makes it clear that while further protection is needed for privately owned trees, new tree plantings should be promoted on private land to offset the losses seen since 2014.

Residential properties

- Continue to promote the Back of Sidewalk Tree Planting Program, particularly on streets where sidewalks are too narrow for street trees in the right-of-way.
- Increase awareness of canopy loss, and promote the benefits of caring for existing trees and planting new trees among residents.
- During the development review process for new projects, share tree canopy and climate change mitigation goals to encourage tree protection and new tree planting.
- In below-average canopy coverage areas, proactively reach out to landowners, asking for increased tree care and planting on private property.
- Develop canopy-specific guidelines to be adopted under Brookline's Zoning Bylaw, Section 5.09 'Design Review'. (See Appendix C - Tree Protection Bylaw Summary)
- Develop an additional review process that would be triggered following a request from a property owner to increase impervious surface by a certain amount or increase a building footprint to a certain size. Allow property owners to skip the review process if they meet a specific canopy standard or contribute funds to support Town tree work within their precinct.

Commercial Properties

Commercial properties have a tree canopy coverage of 16%. The low coverage on commercial parcels is a product of large building footprints surrounded by pavement for access and parking. With new commercial development, landscaping zoning requirements can help achieve greater tree canopy coverage for the future. However, existing properties are much more difficult to improve because there are no regulatory requirements for improvement. Information sharing and outreach to properties owners about the importance of the tree canopy, and its benefits for business, can lead to change. In addition, as large properties require approval for exterior alterations, roofing and paving materials can be changed to ones that help mitigate climate impacts, diminish heat, improve air quality, or treat stormwater.

Parking lots

- Landscaping plans and conditions attached to special permits containing open air parking lots should be coordinated with the Select Board's office during annual licensing renewals.
- Increased canopy coverage is needed at existing lots (ex. Stop and Shop, Trader Joes, and TJ Maxx).

Commercial Parcels

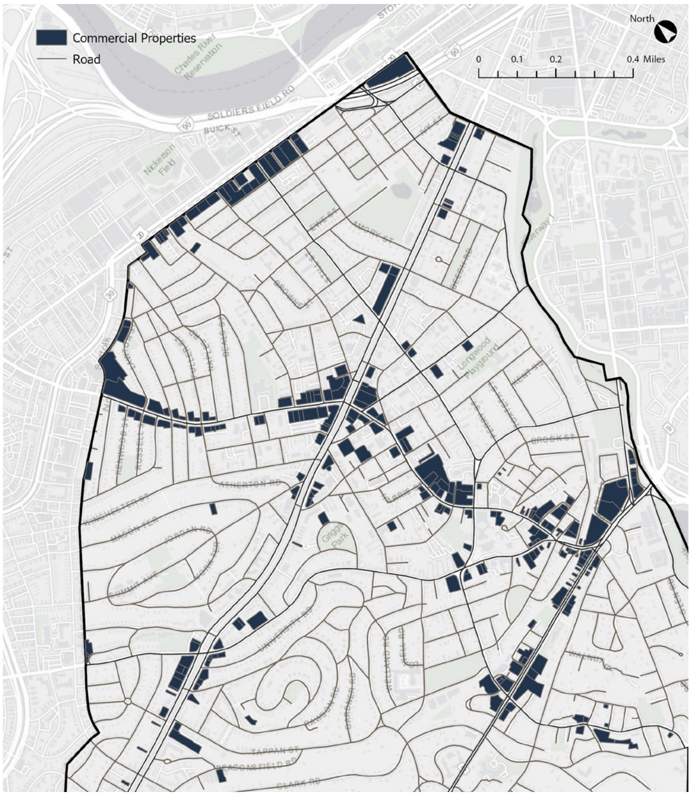


Figure 7-11: Commercial Land Use Parcels in North Brookline

On average, commercial properties have the lowest tree canopy coverage (16%) of all the land use categories. See Existing Conditions of the Urban Forest for more information.

Public street trees and modeling efforts

Weston & Sampson completed modeling studies showing how new tree plantings on streets with below-average canopy coverage could have a big impact on outcomes. Modeling private tree plantings is complicated by factors such as variable demand for development, availability of regulatory mechanisms and the ability to influence individual behavior. Modeling public street tree interventions focuses on land that is under Town control, where plantings can be implemented more predictably. It provides an example of the potential effects of increasing canopy cover can have for the Town (Figure 7-12 through 7-15).

At an even finer scale, a specific precinct was chosen to illustrate how canopy goals can be achieved, even in highly urbanized areas. To achieve the 33% canopy coverage goals in Precinct 2 will require tree planting on both public and private land, including street trees, back of sidewalk planting, planting in private yards, and the conversion of paved areas into vegetated areas (Figure 7-16 Case Study).

Ambient Air Temperature and Percentage of Tree Canopy

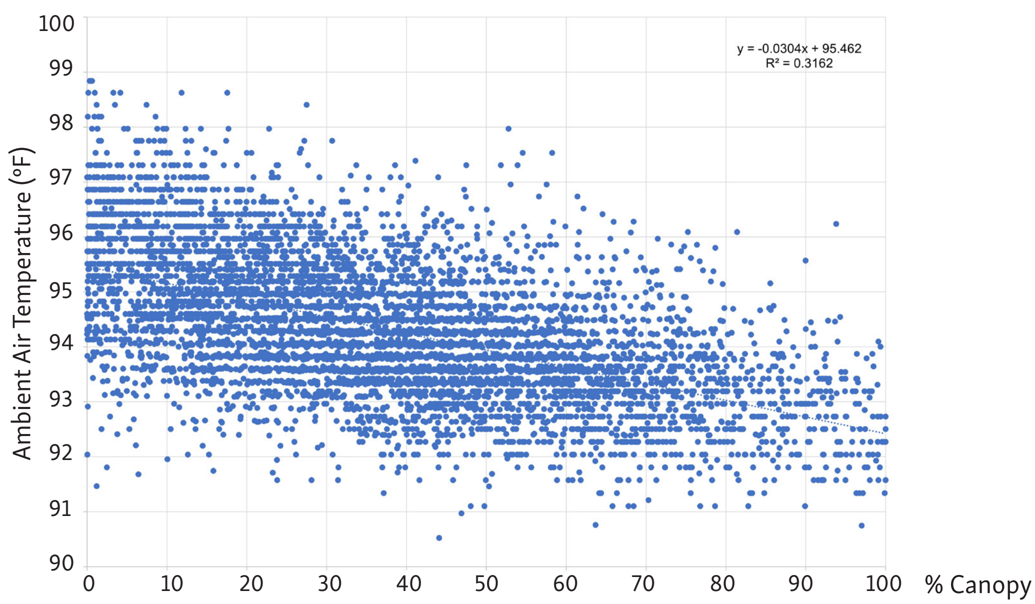


Figure 7-12: Temperature Decreases with Increasing Canopy on a Simulated 95°F Day

Correlation between the percent of canopy cover and ambient air temperature data. Every 10% increase in canopy cover results in a decrease of 1°F in air temperature.

Figure source: Weston & Sampson, scatter plot developed using tree canopy LiDAR data and modeled ambient air temperatures derived from land surface temperature measurements.

Heat Island Impacts in North Brookline

Ambient Air Temperature on a Simulated 95°F Day

Ambient Air Temperature on a Simulated 100°F Day

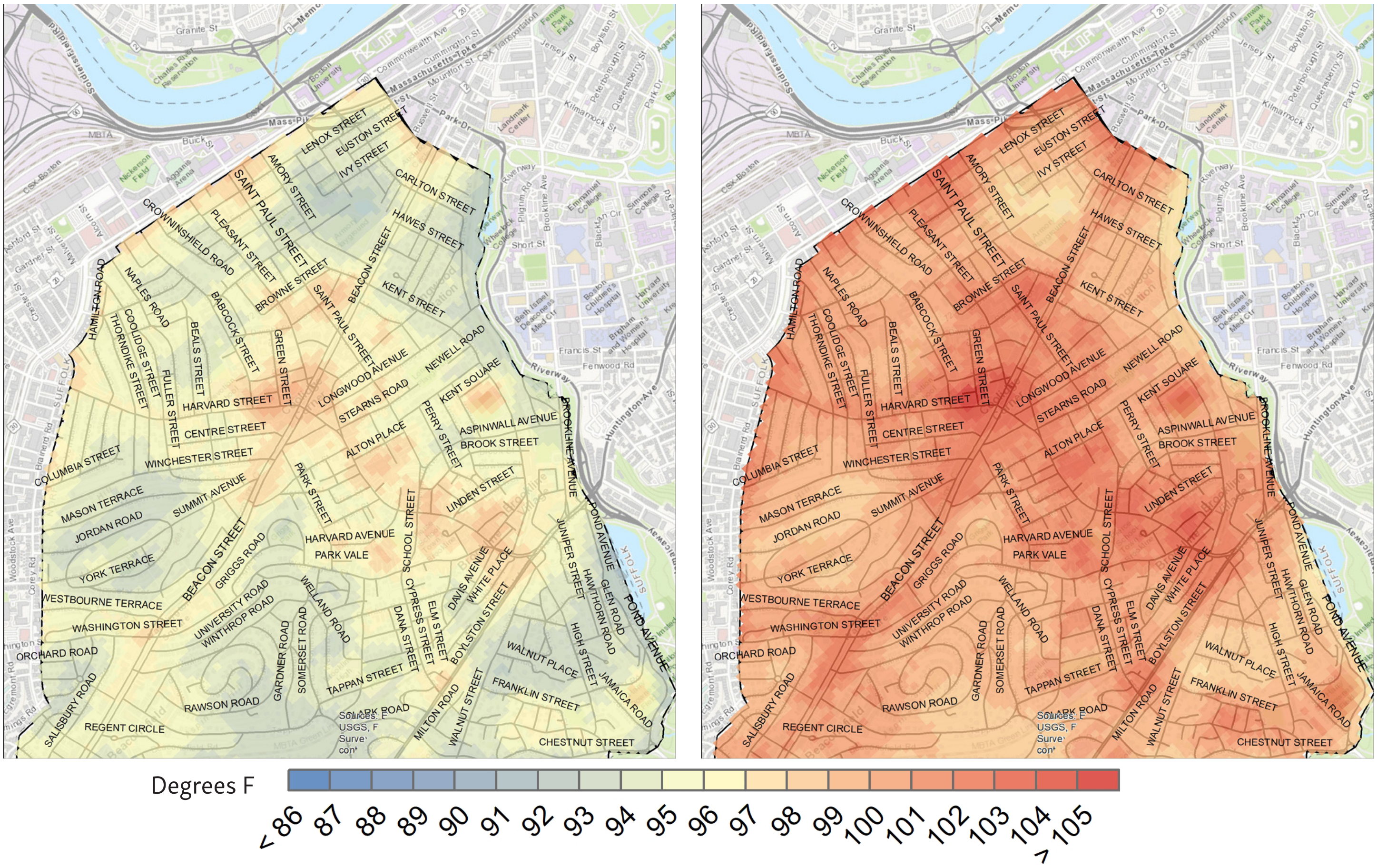


Figure 7-13: Visualization of the Urban Heat Island (UHI) Effect on Simulated 95°F and 100°F Days in Brookline.
Figure source: Weston & Sampson

Cooling Effect of Increased Canopy Cover on North Brookline Streets at 10 Years

Ambient Temperatures with Added Street Trees, after 10 Years

Degrees of Cooling with Added Street Trees, after 10 Years

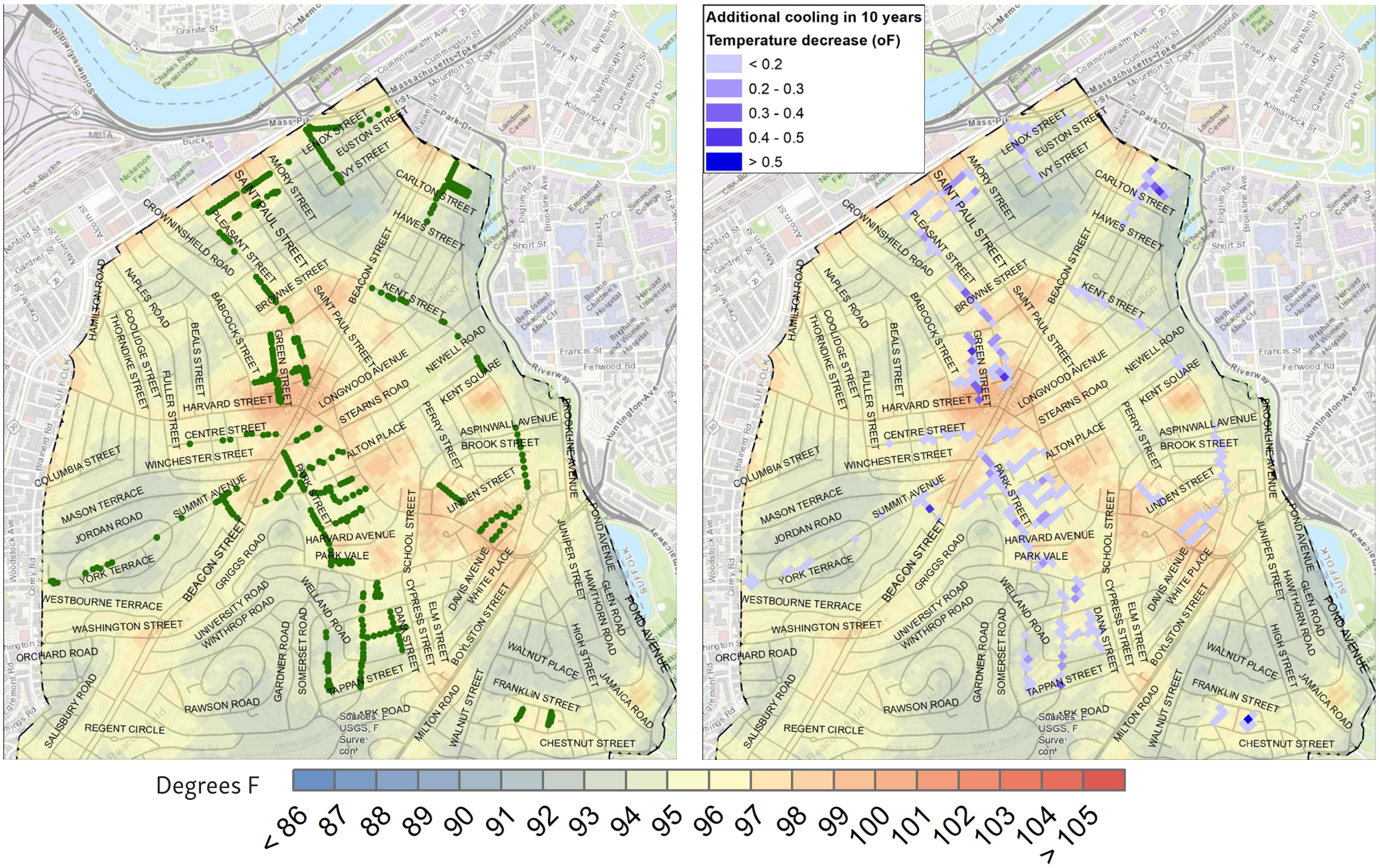


Figure 7-14: Simulated Impact of Additional Street Trees on Streets with Below Average Canopy Coverage after 10 Years

Image on the left shows the ambient air temperature on a simulated 95°F day after 10 years of growth. Image on the right shows the localized cooling impact of the additional tree canopy after 10 years.

Figure source: Weston & Sampson

Cooling Effect of Increased Canopy Cover on North Brookline Streets at 20 years

Ambient Temperatures with Added Street Trees, after 20 Years

Degrees of Cooling with Added Street Trees, after 20 Years

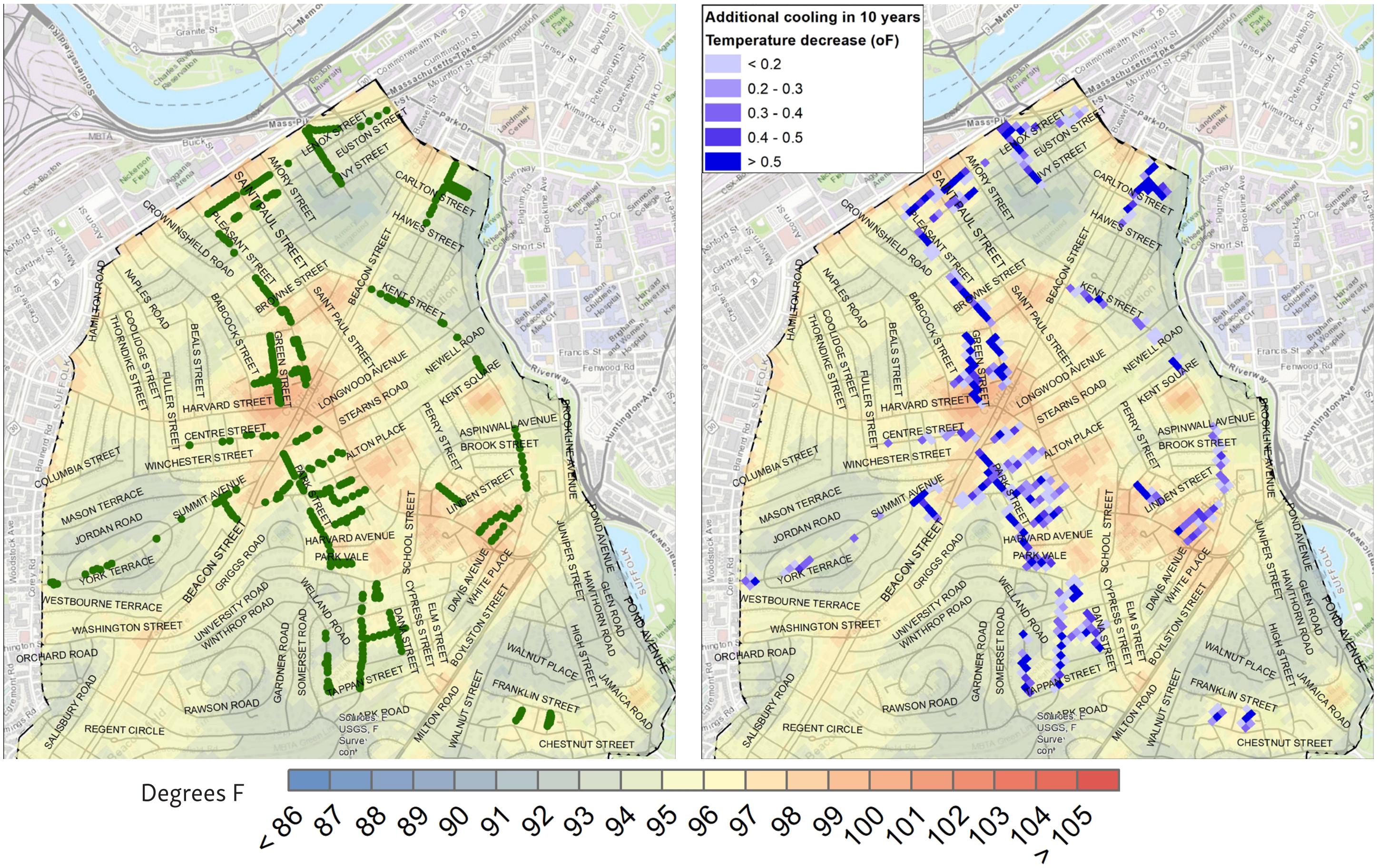


Figure 7-15: Simulated Impact of Additional Street Trees on Streets with Below Average Canopy Coverage after 20 Years

Image on the left shows the ambient air temperature on a simulated 95°F day after 20 years of growth. Image on the right shows the localized cooling impact of the additional tree canopy after 20 years.

Figure source: Weston & Sampson

For every 10% increase in canopy coverage, ambient air temperature decreases 1°F

For every 1°F decrease in temperature, there is 1 fewer heat-related ambulance visit per month

Protect

Protecting and sustaining the existing tree canopy coverage is extremely important to ensuring a resilient urban forest. Mature, large trees do much more to mitigate the effects of climate change than young, small trees. As large trees grow they have exponentially more impact in terms of carbon sequestration, carbon dioxide absorption and stormwater retention.

Recommendations for protecting public and private trees are noted below:

- Reach a goal of Town-wide 49.1% canopy coverage by 2032.
- Achieve an annual net increase in tree canopy through tree protection and new tree plantings. This increase in tree planting should be sustained for the next 10 years to reach the overall canopy coverage goals.
- Integrate tree protection into all Town activities that impact land use. For example:
  - Development review (including guidelines to be considered under the Zoning Bylaw Section 5.09)
  - Health initiatives
  - Utility projects
  - Stormwater ordinances
  - Transportation plans
- Foster stewardship in the community and with allied non-profits who can advocate for protection, notify the Town when protections are being observed or not, et cetera.
- Develop and ensure enforceability or appropriate incentives for all existing urban forestry policies.

Tree Protection Bylaw

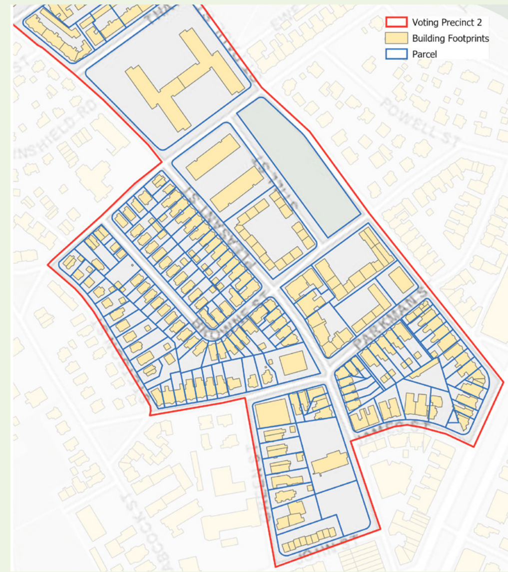
Following the creation of a full-time Tree Warden/Town Arborist position, convene the Select Board's Committee on Tree Protection to review the draft Tree Protection Bylaw as drafted by the Moderator's Committee on a Tree Ordinance and consider preparing a Warrant Article for Town Meeting proposing the adoption of the bylaw. (See Appendix C - Tree Protection Bylaw Summary)

The Draft Tree Protection Bylaw, as drafted by the Moderator's Committee on a Tree Ordinance, is applicable in the following scenarios:

- The proposed demolition of an existing residential structure and its replacement with a new dwelling/structure.
- The proposed construction of an addition to the existing residential structure that constitutes a 10% or greater increase in the building footprint.
- The proposed demolition of an existing non-residential structure and its replacement with a new dwelling/structure.
- The proposed construction of an addition to the existing non-residential structure that constitutes a 10% or greater increase in the building footprint.
- The proposed new construction of a residential or non-residential structure on any lot.
- The proposed removal and replacement of existing public shade trees by the Town or their agents or contractors.
- Section 5.09 or the special permit process.

Under the proposed bylaw, the removal of Protected Trees (defined as any tree that is greater than eight inches in diameter measured at 4.5' off the ground) would be prohibited unless authorized by the Tree Warden. Procedurally, a property owner would submit a proposal for tree removal and mitigation to the

Case Study



Study Area : Voting Precinct 2, southern half

Number of Parcels: 144

Land Use: Predominately multi-family with some affordable housing

Major Streets: Pleasant Street, Parkman Street, Green Street, Dwight Street, St. Paul Street

Analyze Existing Conditions

The southern half of Precinct 2 has 36 acres of land (excluding the public right-of-way). Currently, the tree canopy makes up 10 acres of coverage in this area.

Street trees are limited in this section of Precinct 2.

Most of the canopy coverage comes from private parcels.

Streets often have parallel parking; several streets have bike lanes

Identify Opportunities

Isolating the non-street tree (from the LiDAR data) and street tree (from the inventory) layers, we begin to understand the critical areas that need improvement to the canopy coverage. The southern half of Precinct 2 has 1,390 non-street trees and 191 street trees.

There is an opportunity to increase the canopy coverage by targeting grass areas, bare soil and reclaiming asphalt in areas where canopy coverage is limited. When possible, planting on private land would be along property lines to preserve open space. Reclaiming some parking spaces for tree planting or incorporating raised cycle tracks with tree planting are other viable solutions.

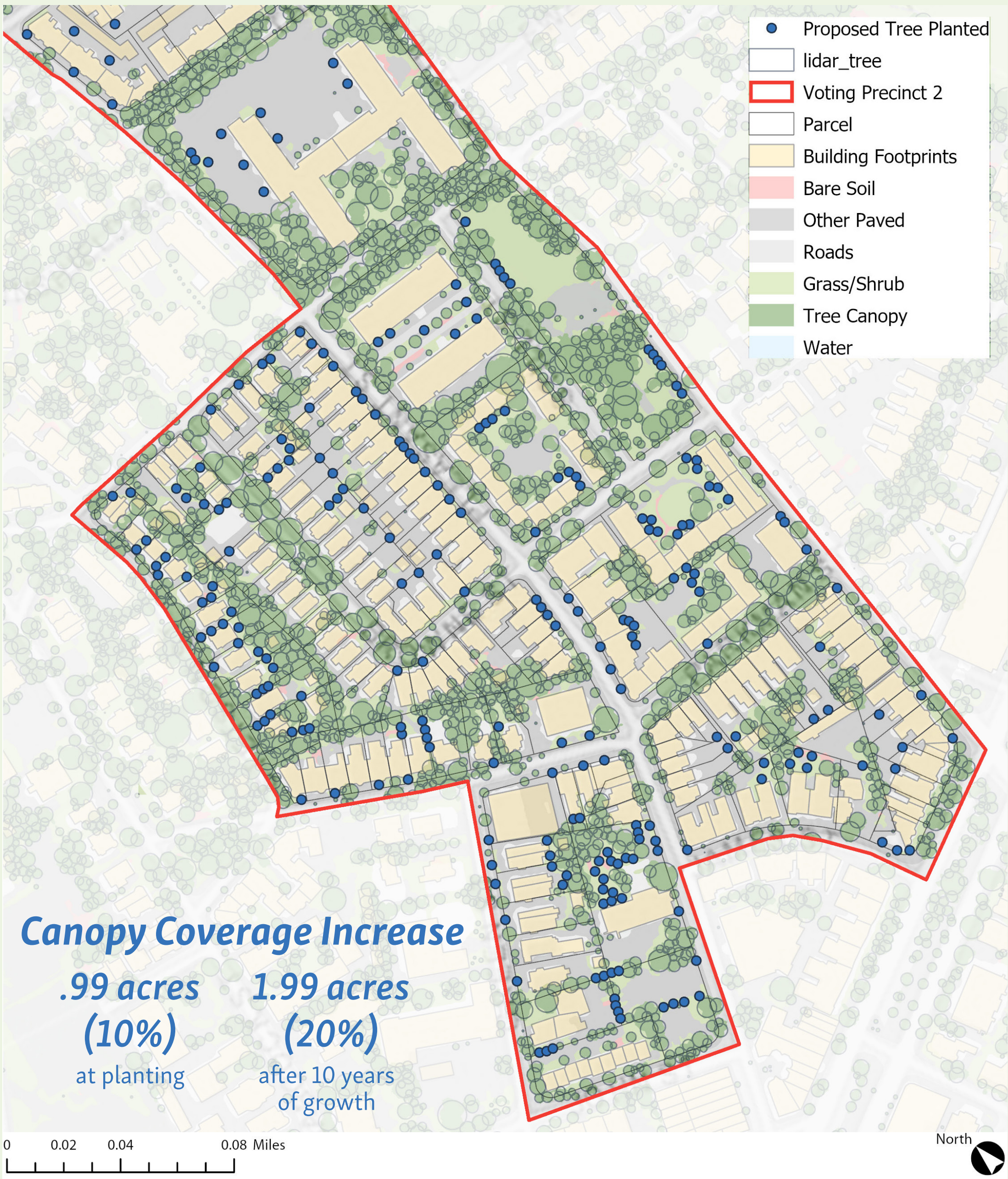
Figure 7-16: Case Study - Determining Feasibility of Tree Canopy Coverage Goals in the Southern Portion of Precinct 2

Strategy for Increasing Canopy Coverage

Planting 244 trees, on both private and public land, would have an initial canopy coverage increase of 4,788.5 square feet. This assumes that at the time of planting, the tree has a 5 foot canopy diameter.

In 10 years, both the newly planted trees and the existing canopy will increase. The new trees will have an estimates 15 foot canopy diameter, increasing their canopy coverage to 43,096.5 square feet (.99 acres). Assuming the existing canopy increases 1% per year for 10 years (from 10 to 11 acres), the total canopy coverage would be 11.99 acres for the area.

Applying this methodology across all of Precinct 2, total canopy coverage would increase from 15 to 17.98 acres, an increase of 20%.



Visualization of new tree planting locations to meet canopy coverage goals in 10 years

Building Commissioner with their application for demolition or a building permit. The Tree Warden would then visit the site and may issue a permit if the applicant's proposal is consistent with the following mitigation requirements:

- A Protected Tree shall not be removed unless at least one of the following provisions is satisfied:
  - Replanting of trees
  - Contribution into the Tree Replacement Fund
  - The applicant demonstrates that the removal of a Protected Tree does not adversely impact the interests identified in section one of the bylaw

If the proposal does not satisfy these requirements, the Tree Warden shall notify the applicant and deny the permit. Any applicant may appeal the denial or grant of a tree permit to the Tree Planting Committee.

Each instance in which a Protected Tree is removed without a Tree Permit would constitute a violation and the property owner would be subject to a fine of $300 and $50 per caliper inch and would result in the revocation of a building permit.

Any person who removes or trims a public shade tree without a permit or hearing as required by law shall be subject to cumulative fines as follows:

- Up to $500 as provided by Massachusetts General Laws Chapter 87, § 6.
- Triple damages as set forth in Massachusetts General Laws Chapter 242, § 7.

This proposed bylaw is not applicable to the following:

- Emergency projects necessary for public safety, health and welfare as determined by the Commissioner of Public Works or the Director of Parks and Open Space; and
- Trees that are hazardous (a threat to life and/or property) as determined in writing by the Tree Warden and/or the Town Arborist; and
- Trees identified by the Commonwealth that pose a risk due to insect/disease infestation.

Zoning

The Parks and Open Space Division should also develop guidelines to be adopted under Brookline's Zoning Bylaw, Section 5.09 'Design Review'. When a project triggers Design Review, the applicant would be provided with the set of guidelines. The guidelines would establish certain canopy-related standards (for example: recommended canopy coverage as it relates to lot size, preservation of trees over a certain size, et cetera). As the applicant works their way through the Design Review process, Town staff can use the opportunity to negotiate opportunities for tree preservation/planting as appropriate. The proposed guidelines should be re-evaluated periodically. The Select Board's Committee on Tree Protection and appropriate Town staff should convene periodically to discuss how the guidelines have been received by applicants and the effectiveness of the provisions of the guidelines. The results can then be used to inform the development of specific requirements as it relates to zoning for projects requiring Design Review under Section 5.09 of the Zoning Bylaw.

Seeing as most of Brookline's canopy loss is on 1-3 family residential properties, the Town should target those areas with regulatory review. To do so, the Town should implement an additional review process that would be triggered following a request from a property owner to 1) increase impervious surface by a certain amount, or 2) increase a building footprint to a certain size. Property owners would, however, have the opportunity to skip the additional review process if they meet a specific canopy standard (to be determined by the precinct-specific canopy goals noted on page 109, and other factors such as lot size, building coverage, zoning considerations, et cetera). If it is not possible for a property owner to plant on their property, they may contribute funds to support Town tree work (including the financing of additional plantings and/or tree maintenance) within their respective precinct (at the discretion of the Town Arborist).

Residential Tree Planting Alternatives

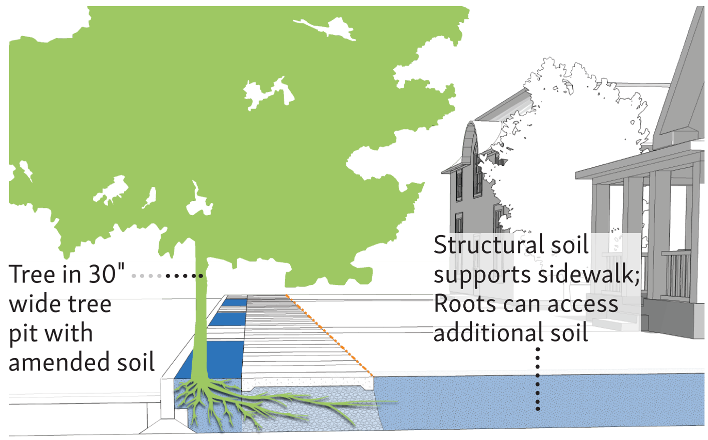
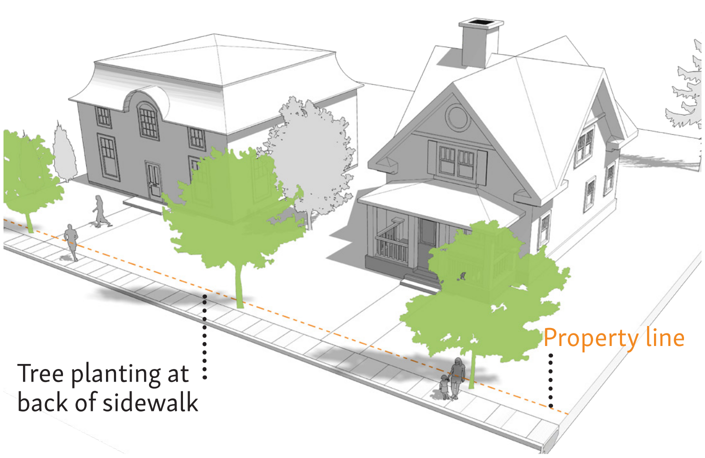


Figure 7-17: Residential Tree Planting in 30" Minimum Tree Lawn
Maintain tree lawn or tree pit of at least 30" in width. Use a continuous tree lawn where possible, or utilize structural soil to provide more rooting area.



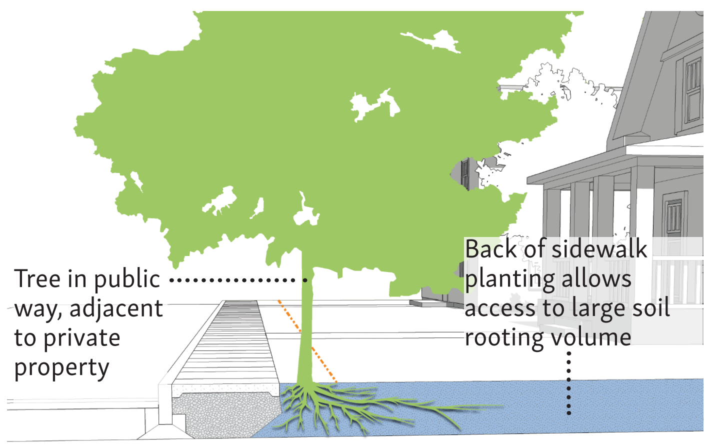


Figure 7-18: Residential Tree Planting at Back of Sidewalk
Where sidewalks are too narrow to support trees right next to the street, consider back of sidewalk planting, structural soils or curb re-alignment.

Manage

The urban forest should be managed with coordinated planning, design and maintenance.

Operations

- Make the Tree Warden a full-time position. Promotion of a full-time Tree Warden will not only assist in elevating service levels, but will also signal to the community the importance of the forestry program and the urban forest.
- Consider hiring 2 more full-time staff to increase the number of in-house tree crews. Promotion of in-house tree crews is a more economical way to enhance services when compared with the rising costs of contracted crews.
- Increase hours of proactive pruning to maintain the desired pruning cycle.
- Increase hours for storm response tree work in anticipation of more frequent and more intense storms (attributed to climate change).
- Return composted leaf litter to tree pits and tree lawns - an increase of just 1% in organic matter enables soils to hold an additional 25,000 gallons of water per acre per year.

Commercial Tree Planting Alternatives

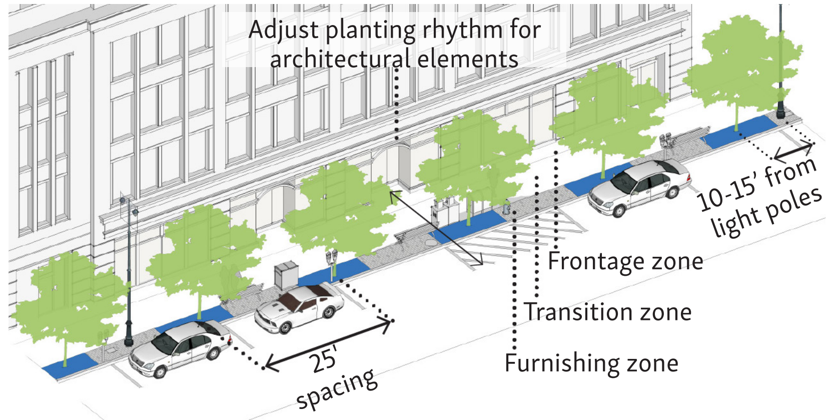


Figure 7-19: Commercial Tree Planting, 25' Spacing

Where possible maximize tree planting in commercial areas with 25' spacing. Adjust the tree planting rhythm for major entrances, architectural features, and utility conflicts. Maintain tree pits of at least 30", maximizing tree pit length or using structural soil to provide more rooting area.

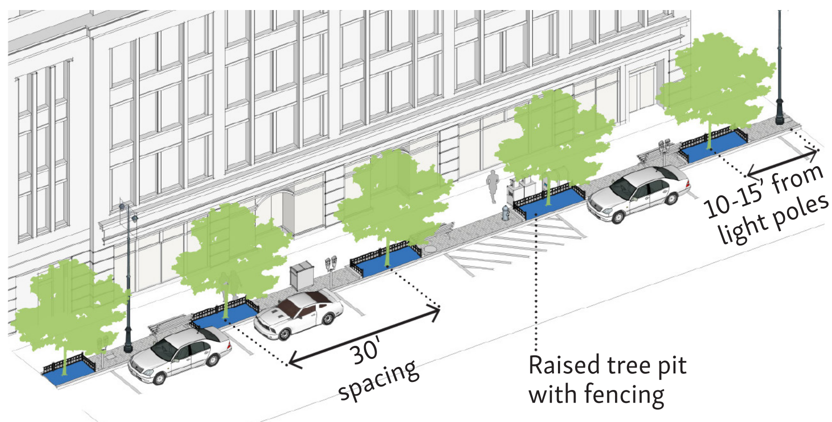


Figure 7-20: Commercial Tree Planting, 30' Spacing

Raised tree pits allow for additional soil volume in urbanized areas where utilities and street furnishings compete for space with tree plantings. Tree fencing also limits soil compaction and contamination, and protects the tree from damage. Spacing of 30' or greater may be necessary where building entrances, pedestrian flow, or architectural features dictate the approach.

- Provide additional aftercare to newly planted trees, including gator bags.
- Duplicate soil testing identified in this report every ten years.
- Enhance record keeping protocols for risk management program.
- Promote interdepartmental coordination to support the urban forest (e.g., integrate urban forestry practices with stormwater management).
- Increase funding for operations. Cost of forestry operations has increased each year and the budget has remained the same, meaning less work is able to be done.

Commercial Tree Planting Alternatives

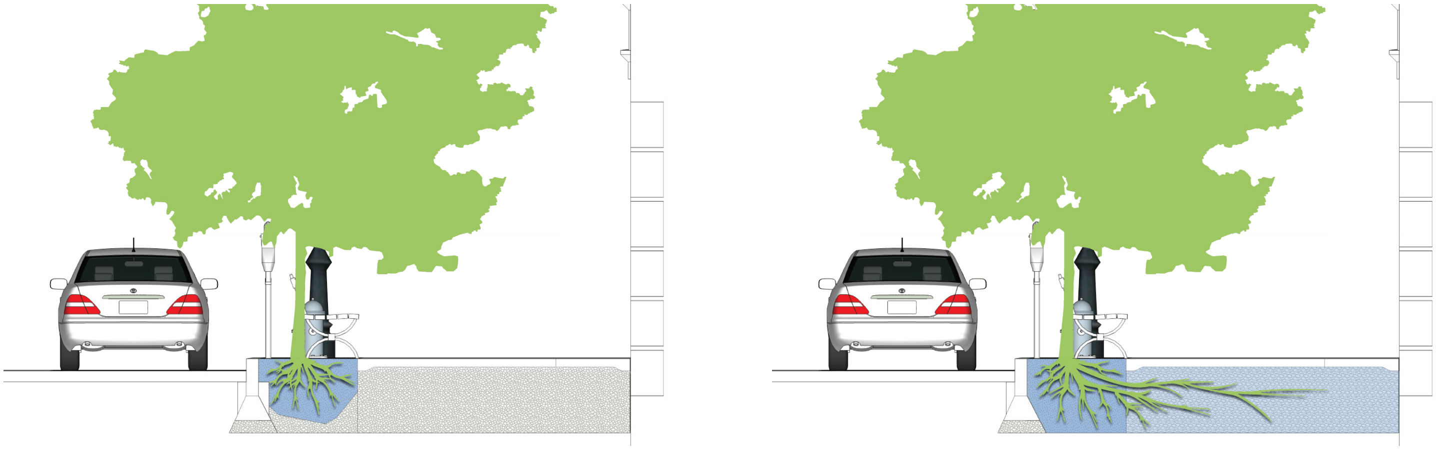


Figure 7-21: Comparison of Typical Commercial Tree Pit (Left) and a Tree Pit Utilizing Structural Soil (Right)
In a typical tree pit, root growth is limited by the small soil volume, stressing the tree and increasing tree mortality. Structural soil supports the sidewalk and provides a way for tree roots to access additional soil volume.

- Increase funding to increase canopy coverage (through Town funding, grant opportunities, non-profits, and donations).
- Improve tree planting standards with area-specific details that include dimensional standards for tree planting, soil volume goals, soil restoration/improvement, et cetera.
  - In residential areas, minimum tree lawn or tree pit width should be 30” while maintaining minimum sidewalk width. Expand soil volume with a continuous tree lawn where possible. If this is not possible, utilize structural soil to allow roots to extend into other rooting areas.
  - In commercial areas, there is no one rule for tree spacing. Regular street tree planting for shading and cooling effects should separate the pedestrian sidewalk from parking or traffic. Strive for 30’ tree spacing. Work around utilities and light poles, with a minimum tree pit width of 30". Extend tree pit length as much as possible. Protect pits with raised edges and/or fencing wherever feasible. Expand soil volume under the sidewalk with structural soil. Include drip irrigation to aid establishment in the first 5 years. Utilize pervious pavements around tree pits to increase access to water. Add flexible pavements in tree pits where sidewalk width encroaches on tree pit. If closer spacing than 30' is possible, it should be pursued. Actual spacing has to be determined with careful planning and understanding of the existing utilities, pedestrian flow, and architectural features of the adjacent buildings. In many cases 25’ or 30’ spacing may not be achievable, particularly when balancing visibility to ground floor retail businesses.

Tree species goals:

- Diversity of species: follow 30:20:10 rule (no more than 30% of urban forest to be from one taxonomic family, 20% from one genus and 10% from one species).
- Age diversity: annual planting of 450 trees on public land (to promote overall canopy coverage increase) will establish the next generation of public trees as older trees decline or are removed.
- Selecting species for climate change: adapt tree species palette by adding more floodplain species and species from the mid-Atlantic (Table 7-5).
- Plant the right tree, in the right place, at the right time.

Climate Change Resilient Trees Suitable for Street Tree Planting in Brookline

Scientific Name	Common Name
Acer rubrum	Red maple
Acer × freemanii "Armstrong"	Armstrong maple
Acer campestre	Hedge maple
Amelanchier laevis	Shadblow
Betula niga	River birch
Carpinus betulus	European hornbeam
Carpinus caroliniana	American hornbeam
Celtis occidentalis	Hackberry
Corylus colurna	Turkish filbert
Eucommia ulmoides	Hardy rubber tree
Ginkgo biloba	Maidenhair tree
Gleditsia triancanthos var. inermis	Thornless honeylocust
Gymnocladus dioicus	Kentucky coffeetree
Koelreuteria paniculata	Golden rain tree
Liquidambar styraciflua	Sweet gum
Liriodendron tulipifera	Tulip tree
Maackia amurensis	Amur maackia
Maclura pomifera (male)	Hedge apple
Metasequoia glyptostroboides	Dawn redwood

Scientific Name	Common Name
Nyssa sylvatica	Tupelo
Ostrya virginiana	Hophornbeam
Prunus sargentii	Sargent cherry
Quercus acutissima	Sawtooth oak
Quercus bicolor	Swamp white oak
Quercus coccinea	Scarlet oak
Quercus imbricaria	Shingle oak
Quercus palustris	Pin oak
Quercus phellos	Willow oak
Quercus robur	English oak
Quercus rubra	Red oak
Syringa pekinensis	Tree lilac
Taxodium distichum	Bald cypress
Tilia americana	Basswood
Tilia cordata	Littleaf linden
Tilia tomentosa	Silver linden
Ulmus americana (DED Resistant)	American elm
Ulmus hybrids	Hybrid elms
Ulmus parviflora	Lacebark elm
Zelkova serrata	Japanese zelkova

Table 7-5: Climate-Resilient Trees for Brookline Street Tree Planting

Trees chosen for their suitability for urban conditions, commercial availability, and hardiness in future temperature ranges. This selection of trees is commercially available and have a range of heights, providing options for large and small planting spaces.

Engage

Engage the community in urban forestry through outreach, events, education and toolkits.

- Education: maintain this project's website for public use with a completed report including interviews with key contributors to the project.
- Outreach: continue project outreach past completion of the report to acknowledge results. Use door hangers for new tree planting and dashboard signs on significant existing trees summarizing the "work" the tree does.
- Provide resources to aid community in tree identification and tree care.
- Educate landowners on the value of privately owned trees.
- Educate business owners and operators on the benefits of the urban forest.
- Support community and volunteer tree planting and inventory efforts.
- Recognize special trees (large size, historic value, designed landscape, unique species).
- Enhance social media presence, particularly in regards to educational content.

When working to engage the community in the care and support of Brookline's urban forest, it is helpful to know the types of engagement and outreach that residents prefer. A community survey conducted by staff of the Parks and Open Space Division during the development of this master plan is available in Appendix B. According to the survey results, the majority of respondents requested additional outreach from the Town on the following tree-related issues:

- Notices regarding the planting and removal of street trees
- Efforts to encourage residents to water young street trees
- Educational programs and opportunities for involvement in forestry work
- Programming for children
- Publicity regarding the Back of Sidewalk Program
- Partnerships with environmental advocacy groups

The same survey found that most residents favored:

- Tree identification walks along streets, parks and sanctuaries
- Virtual and/or in-person talks
- Pamphlets
- Workshops on private tree management and care
- Short videos and photos with educational descriptions on social media.
- Web-based resources
- Volunteer opportunities

ACTION PLAN 8

This Urban Forest Climate Resiliency Master Plan is based on the recommendations outlined in the preceding chapter. Implementation of this master plan will depend upon the active support of many stakeholders. This plan identifies responsible parties and the target years to accomplish each item. Some action items will require monitoring and progress review on a regular basis.

I. URBAN FOREST DEVELOPMENT

A. Grow the Urban Forest

GOAL 1: INCREASE URBAN TREE CANOPY COVERAGE TOWN-WIDE

Objective 1. Mitigate the effects of climate change

Actions:

1. Increase planting where the urban heat island effect is greatest (see list of geographic areas and streets on page 107 and page 114). *Parks and Open Space Division, Tree Planting Committee* (2022-2032)
2. Adapt tree species plant list based on current and future hardiness, biodiversity, stormwater absorption, and air quality improvements (see page 104 and page 128). *Parks and Open Space Division* (2022)

Objective 2. Increase the benefits of trees (ecological, human health, resilience)

Actions:

1. Select tree species suited to reduce air pollution. *Parks and Open Space Division* (2023-2032)
2. Improve biodiversity with varied tree species. *Parks and Open Space Division* (2023-2032)
3. Create connected habitat corridors with tree planting and coordinate the effort with the 2018 Open Space and Recreation Plan. *Conservation Commission, Tree Planting Committee, Parks and Open Space Division* (2025)
4. Replace invasive species (e.g. Norway maple, tree of heaven, et cetera) when the conditions allow. *Parks and Open Space Division* (ongoing)

Objective 3. Provide equitable tree canopy coverage

Actions:

1. Focus new tree planting in North Brookline where most areas are below the Town average for tree canopy coverage. *Parks and Open Space Division* (2022-2032)
2. Prioritize new tree planting in environmental justice neighborhoods (areas with minority populations, non-English speaking populations, and low-income households), affordable and public housing parcels, areas with a high percentage of elderly residents, and public transit stops. *Parks and Open Space Division* (2022-2027)

Objective 4. Reverse trend of tree canopy coverage loss from 2014 to 2020

Actions:

1. Increase staffing and funding to support annual tree planting of 450 trees (see Funding chapter, page 151). *Parks and Open Space Division* (2022-2032)
2. Continue to infill plant and replace dead or storm-damaged trees Town-wide. *Tree Planing Committee, Parks and Open Space Division* (2022-2032)
3. Procure new LiDAR data and analyze tree canopy coverage in 3 to 5 years to measure progress toward canopy goals. *Parks and Open Space Division, Information Technology Department* (2024-2026)
4. Consider/Execute street-specific recommendations for public ways, as discussed in the Recommendations chapter (see Climate Change Mitigation and Recommendations chapter, page 101. *Department of Public Works, Planning and Community Development Department* (2022-2032)
5. Coordinate with MassDOT, MBTA, DCR, et cetera, regarding tree planting strategies and opportunities to increase soil volume, as appropriate. *Department of Public Works* (2022-2032)

Objective 5. Encourage tree planting on private property

Actions:

1. Further advertise the Back of Sidewalk Tree Planting Program to increase the planting of trees on private property within 20 feet of the public right-of-way. Partner with non-profits to organize a coordinated advertisement effort each autumn. Utilize tools such as social media, local newspapers (i.e. Brookline TAB), Brookline's webpage, newsletters, posters/fliers, et cetera, to cultivate interest in the program. *Tree Planting Committee, Parks and Open Space Division, , Allied Non-Profit Organizations* (2022-2023)
2. Educate property owners about the importance of planting new trees (see education, outreach and advocacy objectives in Community Goals, page 138. *Planning and Community Development Department, Tree Planting Committee, Conservation Commission, Parks and Open Space Division* (ongoing)
3. Share tree canopy expansion goals with project proponents during design and development review. *Planning and Community Development Department* (2023)
4. Promote tree planting to mitigate the urban heat island. *Planning and Community Development Department* (2024)

II. URBAN FOREST PROTECTION

A. Protect the Urban Forest

GOAL 1: PROTECT EXISTING TREES THROUGHOUT THE TOWN

Objective 1. Maintain existing public trees so they can continue to grow and increase tree canopy coverage

Actions:

1. Increase funding for the Forestry Sector to achieve more pruning and tree care (see Funding chapter, page 151). By 2032, seek to increase the forestry budget to $1,350,319 to accommodate additional tree crews, increased tree planting and enhanced tree maintenance. *Select Board, Parks and Open Space Division* (2023-2032)
2. Maintain existing inventory of trees overhanging the public way using the Town's maintenance management system (PeopleGIS). *Parks and Open Space Division* (ongoing)
3. Conduct a stem-by-stem inventory of existing park and trees on Town grounds to document their size, condition, and species. *Parks and Open Space Division* (2025)
4. Document and celebrate existing heritage trees (trees with diameters of 32 inches or greater, or trees with historical significance) in Brookline. *Tree Planting Committee, Parks and Open Space Division* (2025)

GOAL 2: CONSIDER PRIVATE TREE PROTECTION IN REGULATORY PROCESSES AND PLANNING

Objective 1. Incorporate canopy-specific guidelines and requirements into the Zoning Bylaw, Section 5.09 'Design Review'

Actions:

1. Convene a working group to develop a list of canopy-related guidelines to be considered under Brookline's Zoning Bylaw, Section 5.09. *Parks and Open Space Division, Planning and Community Development Department, Select Board's Committee on Tree Protection* (2022-2023)
2. Request that the Planning Board formally adopt the guidelines so that they are shared with applicants as part of the 'Design Review' process under the Zoning Bylaw, Section 5.09. *Parks and Open Space Division, Planning and Community Development Department* (2023-2024)
3. After a trial period, reconvene the working group, Select Board's Committee on Tree Protection and appropriate Town staff to discuss how the guidelines have been received by applicants. Utilize this information to develop specific requirements as it relates to zoning for projects requiring Design Review under Section 5.09. *Parks and Open Space Division, Planning and Community Development Department, Select Board's Committee on Tree Protection* (2025-2026)
4. Draft a warrant article to amend the Zoning Bylaw to include canopy-specific requirements as it relates to zoning for projects requiring Design Review under Section 5.09. *Parks and Open Space Division, Planning and Community Development Department, Select Board's Committee on Tree Protection* (2026-2028)

Objective 2. Encourage tree preservation and planting on private property through regulatory review

Actions:

1. Convene a working group to determine the specific triggers relating to increases in impervious surface or general building footprint. Develop precinct-specific canopy standards (to be informed by precinct canopy goals, and other factors such as lot size, building coverage, and zoning considerations, et cetera). *Parks and Open Space Division, Planning and Community Development Department, Select Board's Committee on Tree Protection* (2022-2024)
2. Draft a warrant article to amend either the Zoning Bylaw or General Bylaw to include the additional review process. *Parks and Open Space Division, Planning and Community Development Department, Select Board's Committee on Tree Protection* (2025-2026)

Objective 3. Advance Committee Work on a Tree Protection Bylaw

Action:

1. Following the creation of a full-time Tree Warden/Town Arborist position, convene the Select Board's Committee on Tree Protection to review the draft Tree Protection Bylaw as drafted by the Moderator's Committee and consider preparing a Warrant Article for Town Meeting proposing the adoption of the bylaw. *Select Board's Committee on Tree Protection, Parks and Open Space Division* (2025-2028)

Objective 4. Integrate private property tree protection into all Town activities that impact land use

Actions:

1. Evaluate the potential to expand mitigation funds for major impact projects to include tree canopy management funds for improvements to street trees and park trees. *Parks and Open Space Division, Planning and Community Development Department* (2022-2025)
2. Integrate tree protection principles into health initiatives, utility projects, transportation plans, and stormwater ordinances. *Health Department, Planning and Community Development Department, Department of Public Works* (2022-2026)

B. Encourage Private Tree Maintenance

GOAL 1: ENSURE SUFFICIENT MANAGEMENT AND CARE FOR EXISTING PRIVATE TREES

Objective 1. Encourage maintenance of private trees through education and outreach

Actions:

1. Encourage the community and allied non-profits to advocate for protection of private trees. *Parks and Open Space Division* (2022-2032)
2. Educate property owners about standard tree maintenance and care by providing more detailed web-based resources, workshops regarding private tree management and care, and volunteer opportunities. *Tree Planting Committee, Parks and Open Space Division* (2023-2024)

III. MANAGEMENT GOALS

A. Augment and Support Forestry Sector Operations

GOAL 1: ENHANCE CARE FOR EXISTING TREES

Objective 1. Complete 7-year pruning cycle on Town-owned trees and more frequent cycles for focus areas (annual for schoolyards and Beacon Street inbound, biannual for heritage trees)

Action:

1. Increase funding for the Forestry Sector to achieve more proactive pruning to mitigate risk and minimize storm damage (see Funding chapter, page 151). *Parks and Open Space Division* (2023)

Objective 2. Continue active monitoring for tree pests and diseases

Actions:

1. Make Tree Warden a full-time position to devote more time to planning, protection, advocacy, tree inspection and record keeping. *Parks and Open Space Division* (2023)
2. Continue correspondence and collaboration with local municipalities, the Commonwealth, and the U.S. Forest Service to monitor the status of pests and diseases that are present locally or that may emerge as threats due to the changing climate. *Parks and Open Space Division* (ongoing)
3. Educate the public on pertinent pests and diseases to foster stewardship of the urban forest. *Parks and Open Space Division* (2024)

Objective 3. Increase specialized tree care for mature trees

Action:

1. Increase funding to support decompaction, fertilization, watering, et cetera, for mature trees. *Parks and Open Space Division* (2023)

B. Adopt Resiliency-Focused Urban Forest Tree Standards

GOAL 1: ADJUST TREE PLANTING DETAILS AND SPECIES FOR CLIMATE RESILIENCY

Objective 1. Plant species effective at mitigating climate change impacts and adapting to a warmer climate

Actions:

1. Revise tree species list for public tree planting to include species that are hardy in present and future temperatures and species that improve air quality (see page 104 and page 128). *Tree Planting Committee, Parks and Open Space Division* (2022)
2. Plant trees with 30:20:10 family : genus : species proportions, utilizing PeopleGIS data to run analytics and assess progress (see Recommendations chapter, page 128). *Parks and Open Space Division* (2023-2032)

Objective 2. Standardize public tree planting procedures

Actions:

1. Improve Town tree planting standards (see Recommendations chapter, page 126). *Parks and Open Space Division* (2023)
2. Provide sufficient aftercare, including watering and protection for newly planted trees. *Parks and Open Space Division* (2024)
3. Promote tree establishment in commercial areas using 25' tree spacing, structural soils, maximum tree pit length (see Recommendations chapter, page 126). *Parks and Open Space Division, Planning and Community Development Department, Transportation Division, Highway Division* (2023-2025)

IV. COLLABORATIVE CLIMATE ACTION

A. Better Municipal Coordination

GOAL 1: IMPROVE INTRA-GOVERNMENTAL COORDINATION TO PROTECT THE URBAN FOREST

Objective 1. Improve urban heat island mitigation strategies beyond tree shading to include light color roofing materials, green roofs, light color pavements and permeable pavements.

Actions:

1. Share urban heat island mitigation strategy information with property owners pursuing development and Design Review. *Planning and Community Development Department* (2023)
2. With appropriate staff, determine how these strategies can be encouraged. *Planning and Community Development Department* (2023)
3. Evaluate updating Section 5.09 Design Review in the Zoning Bylaw to include urban heat island impacts that would trigger Design Review. *Planning and Community Development Department, Parks and Open Space Division* (2023)
4. Prepare realistic guidelines (analogous to Transportation Division's Transportation Access Plan guidelines) for Design Review that considers difficult site conditions, including lots with limited rear yards and small setbacks. Integrate heat mitigation and greening strategies. *Parks and Open Space Division, Planning and Community Development Department* (2022-2023)

5. Develop guidelines for Design Review for large surface parking areas to promote stormwater management, solar energy and tree protection. *Parks and Open Space Division, Select Board's Committee on Tree Protection, Planning and Community Development Department* (2022-2023)

Objective 2. Integrate tree protection into all internal Town activities that impact land use.

Actions:

1. Inform applicants of tree canopy expansion goals and specific information on tree preservation, tree planting, construction protection, and planting of surface parking areas during design and development review of 40A and 40B projects. *Parks and Open Space Division, Planning and Community Development Department* (2022-2032)
2. Include tree planting in Town-wide health initiatives. *Health Department, Parks and Open Space Division* (ongoing)
3. Include substantial tree protection measures in utility and transportation projects. *Department of Public Works* (ongoing)
4. Engage the Cross-Division Working Team as identified in Brookline's 2020 Sustainability Final Report (Page 20, Recommendation #5) to identify and coordinate "complete streets" projects, and ensure thorough collaboration across departments throughout the process. *Department of Public Works, Planning and Community Development Department, Council on Aging, Health Department* (2024)

B. Regional Planning

GOAL 1: SHARE TREE CANOPY EXPANSION GOALS WITH ADJACENT MUNICIPALITIES

Objective 1. Collaborate on tree canopy expansion efforts with regional planning agencies and local municipalities

Actions:

1. Work with the Metropolitan Area Planning Council (MAPC) and directly with the City of Boston, the City of Cambridge and the City of Newton to discuss shared and individual tree canopy expansion goals. *Parks and Open Space Division* (2023)
2. Collaborate with adjacent municipalities for LiDAR analysis of tree canopies in 3-5 years. *Parks and Open Space Division, Information Technology Department* (2024-2026)

C. Financing Urban Forest Initiatives

GOAL 1: IDENTIFY MEASURES TO FUND URBAN FOREST NEEDS

Objective 1. Develop municipal funding mechanisms and procedures for urban forest protection, care and expansion

Action:

1. With appropriate staff, evaluate funding sources from Town revenue, development review, partnerships, et cetera, for urban forestry needs. *Select Board, Parks and Open Space Division* (2024)

Objective 2. Encourage public-private partnerships

Action:

1. Work with local groups such as the Brookline GreenSpace Alliance, Emerald Necklace Conservancy, Mothers Out Front, and other regional and national entities to maintain and enhance partnerships. *Parks and Open Space Division* (2023)

V. COMMUNITY GOALS

A. Healthy Urban Forest

GOAL 1: MAINTAIN APPROPRIATE STANDARDS OF CARE FOR THE PUBLIC URBAN FOREST

Objective 1. Hire additional in-house staff and budget more hours for tree care, maintenance, and emergency response

Actions:

1. Work with the relevant Town bodies to focus on budget needs and planning to increase Division staffing by 2.5 FTE (full-time equivalent) (see Funding chapter, page 155). *Select Board, Parks and Open Space Division, Advisory Committee* (2025)
2. Increase Capital Improvements Program (CIP) funding to enhance the urban forest. *Select Board, Parks and Open Space Division, Advisory Committee* (2025)

Objective 2. Evaluate other funding sources for street tree care (insurance reimbursement, development mitigation, et cetera)

Action:

1. Work with staff to evaluate methods to fund street trees. *Tree Planting Committee, Town Administrator, Parks and Open Space Division* (2024)

Objective 3. Coordinate planning strategies for mitigating climate change with urban forest enhancement

Action:

1. Develop coordinated efforts for capital projects, development review and maintenance practices to support mitigating climate change. *Planning and Community Development Department, Conservation Commission, Department of Public Works, Select Board's Climate Action Committee* (2024)

Objective 4. Reduce conflicts between utilities and the urban forest

Actions:

1. Continue testing and monitoring for natural gas leaks and impact on trees. *Department of Public Works, Fire Department, National Grid* (ongoing)
2. Discuss with private utility companies that oversee overhead utilities appropriate procedures and tree concerns. *Department of Public Works, private utility companies.* (ongoing)

B. Education, Outreach and Advocacy

GOAL 1: INCREASE ENGAGEMENT WITH THE COMMUNITY

Objective 1. Collaborate with groups to support trees, open space, and sustainability

Actions:

1. Communicate with organizations and groups to coordinate activities such as tree identification walks, volunteer opportunities, citizen science initiatives, et cetera. *Parks and Open Space Division, Conservation Commission, Tree Planting Committee, Office of Diversity and Inclusion, Select Board Climate Action Committee, Sunrise Movement, Brookline GreenSpace Alliance, Emerald Necklace Conservancy, Mothers Out Front* (2022)
2. Develop strategies to reach Brookline residents who are not affiliated with the above-specified organizations and groups. *Parks and Open Space Division, Conservation Commission, Brookline GreenSpace Alliance, Emerald Necklace Conservancy, Office of Diversity, Inclusion and Community Relations, Select Board Climate Action Committee, Sunrise Movement, Mothers Out Front* (2023)

Objective 2. Increase public awareness of urban forestry issues through print and on-line media, targeted events and programs, annual presentation of Brookline's achievements, and other public awareness activities

Actions:

1. Promote activities and opportunities through social media and newsletters. *Parks and Open Space Division* (ongoing)
2. Prioritize the execution of the outreach/ engagement strategies identified as most desirable in the community survey (see Appendix B - Urban Forest Climate Resiliency Master Plan Survey Summary, page 194). *Parks and Open Space Division* (2022)
3. Direct advertising efforts to areas with particularly low canopy coverage and populations vulnerable to climate change. *Parks and Open Space Division* (2022)

Objective 3. Educate the public about the impacts of climate change on human health and the urban forest

Actions:

1. Work with the Select Board's Climate Action Committee and Climate Action Brookline to ensure appropriate information is disseminated to the public. *Select Board Climate Action Committee, Climate Action Brookline, Select Board, Parks and Open Space Division* (2023)
2. Maintain this project's website for public use with a completed report including interviews with key contributors to the project. *Parks and Open Space Division* (2022)

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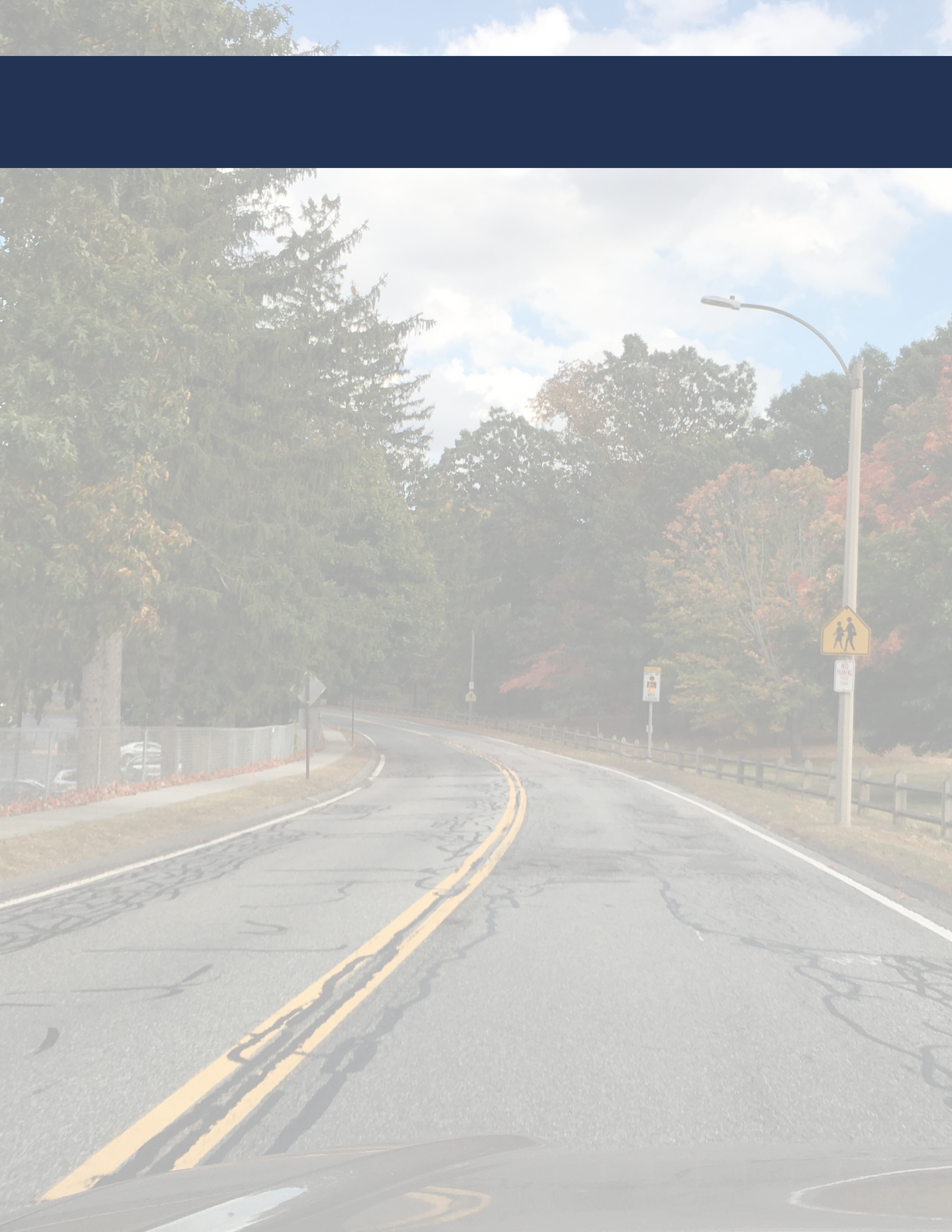
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PARKING

BENCHMARKING AND MEASURING PERFORMANCE

9

What is Benchmarking?

Benchmarking is the process of measuring key metrics and practices, and comparing them within an organization or against industry standards to understand how and where an organization should focus change to improve performance. Most benchmarking is external, comparing performance against peers, but internal benchmarking that identifies metrics and performance standards can be equally as valuable. This chapter provides both external and internal benchmarks for Brookline's Forestry Sector.

Internal Benchmarking

Urban Forest Statistics	2020	2032 Projection
Number of trees in Town (estimated by UVM as part of the Urban Tree Canopy analysis; +/- 10,000 trees)	204,000 trees	213,000 trees
Tree density	47 trees/acre	49 trees/acre
Percentage of tree canopy coverage (average Town-wide)	44.7%	49.1%
Population of Brookline	60,952	63,250 (est.)
Trees per person	3.35	3.37
Publicly owned trees (estimated by UVM as part of the Urban Tree Canopy analysis)	65,150 trees	69,000 trees
Privately owned trees (estimated by UVM as part of the Urban Tree Canopy analysis)	138,850 trees	144,430 trees
Street trees in the right-of-way (Stem-by-Stem Inventory)	12,041	14,741
Street trees per road mile (average)	66	72
Street tree condition		
Excellent	75%	77%
Good	18%	19%
Fair	5%	3%
Poor	2%	1%
Dead	<1%	<1%
Number of different street tree species	93	102

Table 9-1: Internal Benchmarking - Urban Forest Statistics

Internal Benchmarking - Environmental

Environmental Services Provided by the Urban Forest	2020	2032 Projection
Carbon (based on 204,000 trees in Town limits)		
Annual carbon sequestration	2,180 tons	2,198 tons
Carbon stored long-term in trees	65,890 tons	66,437 tons
Air Quality		
Carbon monoxide removed annually	1,485 lbs	1,498 lbs
Nitrogen dioxide removed annually	7,120 lbs	7,179 lbs
Ozone removed annually	112,939 lbs	113,877 lbs
Sulfur dioxide removed annually	4,864 lbs	4,904 lbs
Particulate matter removed annually	16,496 lbs	16,633 lbs
Total	142,905 lbs	114,091 lbs
Hydrology		
Avoided runoff	48,779,657 gallons	49,184,688 gallons
Annual Household Emissions		
Carbon dioxide emitted by a family of four with one car and natural gas home heating (USEPA, 2016)	21,661 lbs	Not available

Table 9-2: Internal Benchmarking - Environmental Services Provided by the Urban Forest

Internal Benchmarking - Inventory and Assessment

Inventory and Assessment of the Urban Forest	2020	2032 Projection
Inventory of all Town-owned street trees	Yes	Yes
Inventory of all Town grounds and park trees	No	Yes
Current forest assessment in conservation areas (within last 10 years)	No	Yes
Up-to-date inventory available on Town website for public viewing	No	Yes
Inventory updated with tree work	Yes	Yes
Current LiDAR tree canopy coverage assessment (within last 5 years)	Yes	Yes

Table 9-3: Internal Benchmarking - Inventory and Assessment of the Urban Forest

Internal Benchmarking - Budget

Fiscal Year 2020 Forestry Budget

Operating Budget			
Personnel		$265,266	3.5 FTE
Services		$130,015	2400 pruned
Supplies		$6,600	
	Subtotal	$401,881	
Capital Budget			
Tree removal/ replacement		$235,000	429 planted 192 removed +
	Subtotal	$235,000	
	TOTAL	**$636,881**	

Table 9-4: Internal Benchmarking - Fiscal Year 2020 Forestry Budget

2032 Forestry Budget (Projected)

Operating Budget			
Personnel		$577,145	6.0 FTE
Services		$583,538	3500 pruned
Supplies		$8,206	
	Subtotal	$1,168,890	
Capital Budget			
Tree removal/ replacement		$325,900	450 planted 180 removed +
	Subtotal	$325,900	
	TOTAL	**$1,365,632**	

Table 9-5: Internal Benchmarking - 2032 Projected Forestry Budget

Fiscal Year 2020 Forestry Expenditures - Contracted Services

Funds Sourced From:	
Tree Removal Capital Budget	$108,905
Forestry Landscape Services Budget	$128,515
Town/School Ground Budget	$65,000
Cemetery Budget	$30,000
Parks Budget	$60,685
TOTAL	**$393,105**

Table 9-6: Internal Benchmarking - Fiscal Year 2020 Forestry Expenditures on Contracted Services

Budget Comparison

Town Budget Elements	
Forestry Sector total budget as a percentage of Public Works budget (2020)	2.9%
Forestry Sector total budget as a percentage of Town budget (2020)	0.15%
Overall Town budget increase from 2014-2020	36.9%
Public Works budget increase from 2014-2020	12.6%
Forestry Sector total budget increase from 2014-2020**	10%

Table 9-7: Internal Benchmarking - Budget Comparison

Budget values are from Town budget books, where: 2014 Town Budget: $222,131,902; 2020 Town Budget: $304,020,392

2014 Public Works Budget: $13,812,488; 2020 Public Works Budget $15,548,095

2014 Forestry Sector Budget $359,830; 2020 Forestry Sector Budget $449,558

**10% Forestry Sector budget increase from 2014-2020 is due to approximately 2% cost of living increase per year on personnel salaries

Internal Benchmarking - Tree Care and Planting

Tree Care and Planting	2020	2032
Town trees pruned each year	2400	3500
Pruning cycle	7 years (with specific areas or tree types pruned more frequently)	7 years (with specific areas or tree types pruned more frequently)
Trees planted by the Town annually	350-400	550
Number of trees managed by the Town	60,000 (estimated)	65,000
Staff dedicated to tree care and planting	3.5	6
Experience in years		
Town Arborist/Tree Warden	32 years; 20 years in Brookline	
Forestry Supervisor	27 years; 20 years in Brookline	
Zone Manager	16 years; 5.5 years in Brookline	
Groundsperson	2 years; 11 years in Brookline	
Trees planted as a percentage of total Town-owned trees	0.75%	*1.06%*

Table 9-8: Internal Benchmarking - Tree Care and Tree Planting

External Benchmarking

Comparison of Local Urban Forest Management Programs

	Brookline	Cambridge	Newton
Tree Population	12,041 Street Trees	19,000 Street Trees	20,000 Street Trees
Program Budget (2020)	$636,881	$2,600,477	$1,500,000
Tree Pruning Cycle	7 Years	6 years for street trees; 8 years for other municipal grounds	No set pruning cycle
Contract Crews or In-House Crews	Both	Both	Both
ANSI Standards	Yes	Yes	Yes
Trees Planted per Year	Approx. 400	600-900 (Primarily Contract Crews)	Approx. 800 (In-House Crews)
New Tree Watering Responsibility	Municipality	Municipality	Municipality
Tree Risk Assessment Program	Yes. Risk is identified through inspection by staff, citizen communications, and other means	No formal program	Yes. Trees are on a regular inspection cycle
Tree Ordinance on Private Property	Brookline's Stormwater Management Bylaw (Article 8.26) includes tree protection measures. A "protected tree" is defined as a tree greater than 8" diameter at breast height (DBH).	Trees 8" and greater are protected. Exceptions: tree is dead or dangerous; removal of the tree is necessary to complete a significant utility infrastructure project; removing a tree may result in a healthier tree canopy; tree poses a significant risk to an adjacent existing structure.	The tree preservation ordinance does not prohibit removal of trees on private property, it places requirements for protection and replacement of trees under certain circumstances.

Table 9-9: External Benchmarking - Comparison of Local Urban Forest Management Programs

U.S. Forest Service Urban Forestry Sustainability and Management Audit

To provide external benchmarking, the U.S. Forest Service (USFS) has developed an urban forestry sustainability and management audit. This audit has been performed on the Brookline urban forestry program.

The USFS Urban Forest Sustainability & Management Review System was developed in 2017 to provide a framework for comprehensively evaluating urban forest management programs, such as that in Brookline.

The outcomes of the review can be used to:

- Engage all parts of the Town's urban forest management team: those responsible for executive, financial, resource, and outreach functions
- Provide program direction that increases the level of professionalism in urban forest management
- Conduct a gap analysis of existing management practices and the health of the Town's green assets
- Increase the health of the green assets managed by the Forestry Sector
- Optimize urban forest management to support targeted ecosystem services by considering benefits and costs

The evaluation system identifies program components that are critical for any community interested in setting and achieving sustainability targets, such as increasing urban tree canopy cover. This is not a financial review, but instead, focuses on program design, capacity, and operations. The review is looking for the presence or absence of critical elements in an urban forest management program that are grouped into ten basic categories.

Each main, numbered category contains a series of components specific to that category, along with a brief description of the component. Components are highlighted in yellow if they represent a "Standard of Care (SOC)" within an urban forest management program. Others are highlighted in green if they are a "Base Practice." The Standard of Care group of components represents the minimum group of urban forestry management "best practices" that a municipality should consider for implementation. They form the core activities necessary to minimize risk and implement a sustainable urban forest management program at a town level. Base practices are the next steps. They are the urban forest management elements that may be used to effectively expand a program beyond the SOC group. Often, the base practices act as precursors to the advanced elements that are shown in white.

The review checklist is shown in Appendix D - USFS Urban Forest Sustainability & Management Review in its entirety, with all ten categories evaluated for a comprehensive evaluation. Some modifications were made to the original USFS materials to ensure applicability to Brookline's structure. In the future, the Town may also choose to use a portion of the checklist to assess and improve program areas of particular interest.

The review also includes an evaluation of Town-managed green assets, the theory and the reality of connecting plan with practice. It evaluates whether practices are actually maintaining healthy, low risk, productive trees.

Audit Summary

The USFS Urban Forest Sustainability & Management Review System is a valuable tool to compare Brookline's Forestry Sector's scope to a national rating system. It illustrates that Brookline achieves most of the standard practices expected, but it also identifies some areas for improvement:

- Formalize the risk management system in writing
- Six-month and annual metrics to compare the progress of related action items
- Policies for urban heat island mitigation
- Utilize USGBC LEED rating for certain development project thresholds
- Benchmark budget with number of trees managed and environmental services provided
- Inventory all publicly managed trees
- Inventory woodland areas; develop and maintain a current management plan for conservation areas
- Ensure at least one Town arborist is trained in ISA Tree Risk Assessment Qualification (ISA TRAQ)
- Develop an urban forestry disaster plan document
- Document construction standards for working around trees
- Create standard details that outline green infrastructure best management practices
- Plant diverse species to achieve an urban forest composition in which no one genus exceeds 20% of the urban forest, and no one species exceeds 10%

The Review System also recommends practices which should be considered and incorporated into Town practices if appropriate:

- Lightning protection measures for the susceptible trees
- Re-use of urban wood (compositing, waste to energy, lumber)
- Incorporate urban food forestry practices
- Gain third party arboretum status


2 HOUR PARKING

Funding and Financing Mechanisms

Most municipal urban forestry is funded through operating and capital budgets, and supplemented with debt financing, grants, philanthropy, partnerships and other creative funding sources. Similar to most national examples, Brookline's Forestry Sector funding comes from the capital budget and operating budget. The Parks and Open Space Division has leveraged additional funds from other budgets to ensure proper care of all of Brookline's trees, including trees in the Town's parks, cemeteries, school grounds, and other Town grounds. Other budgets that have supported tree operations include the Cemetery, Town/School Grounds, Parks and Snow budgets.

Below is a summary of the various funding sources used nationally for urban forestry and their applicability to Brookline.

Municipal Budget

Town budget

The Town budget accounts for expected revenues and allocates resources to particular expenditures. Budgets are determined by Town staff and then reviewed by a financial advisory committee, the Select Board and the public. The capital budget funds park renovations, maintenance of certain parks and open space areas, as well as tree planting and removals. The operating budget funds most of the sector's daily operations including pruning, inspections, the IPM program, et cetera.

Special fund

A special revenue fund is an account established by a government to collect money that must be used for a specific project. Special revenue funds assure taxpayers that their tax dollars will be spent for an intended purpose.

In Brookline a special fund for Parks and Open Space includes reimbursement payments from insurance claims. If a public tree is damaged by an automobile, the replacement costs are transferred to the special fund. This fund can also be used to accept donations approved by the Select Board. Revenue in this fund can be used for tree care or tree planting.

Debt Financing

Municipal bonds

Municipal bonds are debt securities issued by state and local governments. These can be thought of as loans that investors make to local governments, and are used to fund public works such as parks, libraries, bridges, roads and other infrastructure. More recently bonds have been issued for municipal forestry, particularly large-scale tree planting.

Special taxes

Special taxes utilize either all or partial funds from a tax to support a particular effort, generally through a Special Fund rather than the General Budget.

The Community Preservation Act (CPA) is a Massachusetts state law (M.G.L. Chapter 44B) passed in 2000. It enables communities to create a local dedicated fund for open space preservation, preservation of historic resources, development of affordable housing, and the acquisition and development of outdoor recreational facilities. Funds are raised through the imposition of a voter-authorized surcharge on local property tax bills up to 3%.

CPA funds have been successfully used to fund park and open space projects as well as tree planting. The Town of Brookline voted for CPA adoption in May, 2021. The Town will now apply a 1% CPA surcharge on real estate transactions with exemptions for low income and low to moderate income senior homeowners. The local surcharge is expected to raise approximately $2.6 million annually, with additional funding coming from the statewide Community Preservation Trust Fund.

Special assessments

Special assessment districts can distribute payment to support urban forestry. Examples are the Landscape and Lighting Assessment District in Oakland, CA; a Business Improvement District (BID) in Washington DC that funds curb-cut tree trenches for stormwater management, BID Tree Health Program in Denver, CO.

A business improvement district (BID) is a defined area within which businesses are required to pay an additional tax (or levy) to fund projects within the district's boundaries. This could be applicable along the Harvard Street corridor, Brookline Village, Coolidge Corner, or a defined heat island mitigation district to fund the expansion of the tree canopy.

Service fees (stormwater utility fee)

Service fees are charges to property owners for the cost of providing particular services (i.e. stormwater management). This could be applicable to fund green infrastructure, converting impervious surface to pervious surfaces or planting of trees on private land.

User fees (parking fee)

A dedicated percentage of municipal parking revenue could fund tree planting.

Administrative fee (permit review fee)

Charges for the review of development permit applications, plans, and site inspections could be allocated for urban forestry or tree planting.

Impact fee (developer fee)

Developers are charged for disturbances to or increased pressures on municipal landscape, trees, or public facilities and a portion of those fees could fund urban forestry.

Fines

Fines can be issued following illegal, non-permitted, or accidental tree removal, unexpected construction damages and automobile damages, and could pay for the value of the tree, the cost of clean up, and associated administrative costs.

Owners who choose to remove trees from their own property can pay a sum equal to the benefits forgone from those trees. These funds can be used to plant new trees or support the forestry budget.

Carbon offset/Cap-and-trade (City Forest Credits)

Cap-and-trade programs put a legal cap on carbon emissions and allow tradable allowances that authorize the allowance holders to emit a certain quantity of the pollutant. The overall limit ensures the environmental goal is met while the tradable allowances provide flexibility for how they achieve compliance. Compliance can be attained through a combination of decreased emissions and the purchase of allowances or credits. These purchases can be managed through voluntary programs such as City Forest Credits, which issues third-party verified carbon credits from tree planting and preservation projects. https://www.cityforestcredits.org/

In California, the cap-and-trade system directs funds accrued from companies that exceed pollution limits to state-wide and local urban forestry programs. Other municipalities are exploring how to grow dollars from the carbon dioxide absorbed by their trees.

Endowments

While few municipalities can create a permanent endowment to support urban forests, many non-profits do just that. Whether it's called a "tree preservation fund" or a long-term commitment from organizations like the Nature Conservancy, endowments can become a dependable, multi-year source of funds.

Grants and Philanthropy

Grants

Grants are non-repayable funds given by federal or state governments, corporations, or foundations to a recipient.

Below is a list of grants that Brookline could apply for to support urban forestry and tree planting.

Grants from Governmental Agencies

- Community Forest Grant Program (U.S. Forest Service)
  - The Community Forest Program is a U.S. Forest Service competitive grant program whereby local governments, qualified nonprofit organizations, and Indian tribes are eligible to apply for grant funding to establish community forests.
- USDA Forest Service Urban & Community Forestry 2021 Challenge Cost Share Grant Program
  - The USDA Forest Service seeks innovative grant proposals for program development, study, and collaboration that will address urban and community forest resilience and aligns with one or more applicable goals in the National Ten Year Urban and Community Forestry Action Plan (2016-2026).
- U.S. Department of Education Green Ribbon Schools
  - Fund school sustainability practices and resources that can reduce environmental impact and costs. Projects must improve the health and wellness of schools, students, and staff, and provide effective environmental and sustainability education.
- Municipal Vulnerability Preparedness Action Grant (MA Executive Office of Energy and Environmental Affairs)
  - The MVP Action Grant offers financial resources to municipalities that are seeking to advance priority climate adaptation actions to address climate change impacts resulting from extreme weather, sea level rise, inland and coastal flooding, severe heat, and other climate impacts.
- Urban and Community Forestry Challenge Grants (MA DCR)
  - Grants to improve and protect urban forests in Massachusetts. These 50/50 matching grants help develop, grow and sustain programs that plant, protect and maintain a community's public tree resources and develop partnerships with residents and community institutions.

Grants from Non-Profit Foundations

- Barr Foundation
  - Grants to increase the capacity in Metro Boston to prepare for and adapt to the impacts of climate change.
- Grass Roots Fund
  - Grants to strengthen climate resilience at the community level in Metro Boston.
- Solomon Foundation
  - Grants to support programs for greenways in Greater Boston.
- Doris Duke Charitable Foundation (DDCF)
  - The Environment Program awards grants by directly inviting organizations to submit proposals that are then reviewed by the Doris Duke Charitable Foundation staff or board of trustees. DDCF funded the Rhode Island Tree Equity Funding, Financing, and Policy Guide.

Non-Profit Organization Partners

- Emerald Necklace Conservancy Olmsted Tree Society
  - Grants to match Brookline spending for tree care and tree planting dollar for dollar for work in the Emerald Necklace.

Corporate partnerships

Partnerships can involve collaboration between a government agency and a private-sector company, non-profit, or foundation.

Grants from Private Utility Companies

- Urban and Community Forestry Eversource Partnership Challenge Grant (Eversource)
  - Eversource Energy is offering matching grants to municipalities within their service territory.

Grants from Private Corporations

- In cities such as Los Angeles and New York City, large-scale tree campaigns (i.e. Million Trees) have been largely financed through the donations of companies, businesses and individuals. Develop programs for gifts from private companies, groups and individuals.
- TD Bank
  - Communities served by TD Bank are eligible for Arbor Day Foundation Grants to support green infrastructure development, tree planting, forestry stewardship, and community green space expansion.
- Other corporations could be approached to contribute to urban forestry including:
  - The Stop & Shop Supermarket LLC
  - The TJX Companies
  - Marriott International
  - Health care institutions

Fundraising and Donations

Private fundraising from a large pool of donors residing in town could support Brookline urban forestry. Strategies include a multi-month campaign, a fundraising event or non-traditional and technology driven “crowd source” funding. All donations should be designated for the Special Fund for urban forestry.

Forestry Landscape Services Budget, Spending and Cost Projections

An analysis of Landscape Services' past budgeting and spending shows a very consistent services budget year to year, except in FY (fiscal year) 2021 when the services budget increased by $40,000. Personnel costs increased when a forestry supervisor position was added in FY2013. Otherwise it increases regularly to account for cost of living adjustments. The budget for supplies has remained the same for ten years (Table 10-1).

Operating Budget Analysis

The total annual budget for Forestry Landscape Services in fiscal year 2020 was $636,881 ($401,881 in operating expenses and $235,000 in capital expenses) (Table 10-2).

Combining the actual personnel costs with private contractor payments for 2020 indicates a similar total of $647,875 spent (Table 10-3).

Fiscal Year 2020 Forestry Budget

Operating Budget			
Personnel		$265,266	3.5 FTE
Services		$130,015	2400 pruned
Supplies		$6,600	
	Subtotal	$401,881	
Capital Budget			
Tree removal/ replacement		$235,000	429 planted 192 removed +
	Subtotal	$235,000	
	TOTAL	**$636,881**	

Table 10-2: Brookline's Forestry Budget for Fiscal Year 2020

2020 Forestry Budget (Actual Payments)

Category	Actual Payments
Personnel costs	$254,770
Contracted services	$393,105
Total	$647,875

Table 10-3: Actual Forestry Payments for Fiscal Year 2020

Operating Budget Summary

Fiscal Year	Budgeted			Actual		
	Services	Personnel	Supplies	Services	Personnel	Supplies
2011	—	—	—	$129,240	$116,580	$7,752
2012	$127,015	$164,122	$6,600	$307,292	$178,185	$9,316
2013	$127,015	$215,123	$6,600	$226,824	$225,573	$6,161
2014	$127,015	$226,215	$6,600	$130,930	$229,975	$5,682
2015	$127,015	$231,700	$6,600	$123,947	$218,622	$11,574
2016	$158,015	$234,139	$6,600	$158,286	$201,261	$6,002
2017	$130,015	$243,771	$6,600	$128,515	$196,551	$5,785
2018	$130,015	$249,689	$6,600	$128,565	$229,670	$7,374
2019	$130,015	$259,979	$6,600	$146,820	$224,600	$5,245
2020	$130,015	$265,266	$6,600	$130,156	$254,770	$7,120
2021	$171,015	$271,943	$6,600	—	—	—
10-year change	**34.64%**	**65.70%**	**0.00%**	**0.71%**	**118.54%**	**-8.15%**

Table 10-1: Summary of Brookline's Forestry Budget and Expenses for the Last 10 Years

10-Year Historical Spending Summary

Fiscal Year	Streets		Town / School Grounds Removals	Town / School Grounds Pruning	Cemetery	Parks	Snow	Snow - Emergency Work	Invoice Totals
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
	Pruning- Storm Emergency	Removal							
2012	$255,980	$91,359	$20,000	$7,548	$46,577	$0	$0	$0	$421,464
2013	$57,493	$37,427	$0	$20,000	$2,300	$35,664	$0	$0	$152,883
2014	$100,055	$48,360	$14,080	$20,000	$13,960	$38,840	$0	$4,760	$240,055
2015	$120,480	$94,065	$30,000	$20,000	$10,000	$44,223	$0	$2,820	$321,587
2016	$128,480	$94,355	$28,000	$20,000	$20,000	$40,000	$0	$24,963	$355,798
2017	$123,665	$90,000	$15,000	$28,000	$20,000	$52,580	$13,560	$11,938	$354,743
2018	$125,725	$120,000	$15,000	$20,000	$40,000	$62,460	$2,000	$125,350	$510,535
2019	$108,745	$90,000	$20,000	$19,770	$12,930	$25,930	$45,000	$0	$322,375
2020	$128,515	$108,905	$40,000	$25,000	$30,000	$60,685	$0	$0	$393,105
2021	$59,290	$58,740	$21,300	$25,000	$27,280	$44,060	$2,000	$63,625	$301,295
Total	**$1,208,428**	**$833,211**	**$203,380**	**$205,318**	**$223,047**	**$404,441**	**$62,560**	**$233,455**	**$3,406,522**
Average per Year	*$120,843*	*$83,321*	*$20,338*	*$20,532*	*$22,305*	*$40,444*	*$6,256*	*$23,346*	*$340,652*

Table 10-4: Summary of Brookline's Forestry Spending Over the Past 10 Years
Column (8) pulled from monies allocated specifically for snow. This budget item is flexible.

Annual summaries of payments to private tree work companies indicate an average of $340,000 spent per year over the past 10 years (Table 10-4). These payments are funded through budgets for street trees, town/school grounds, cemeteries, and snow budgets.

While the standard of care for public trees is high, there are increasing demands to do more work with this same budget. This is due to higher private contractor costs for tree pruning and removals, increasing maintenance costs associated with a maturing canopy, more frequent storm response and emergency work, and the significant number of trees the Town plants each year (to increase overall Town-canopy cover). The following four tables project what the future budget should be based on differing service levels, personnel, supply charges and the number of trees managed by the Forestry Sector. These options incorporate trends from the 10-year historical budgeting and spending data, as well as the predicted actual costs going forward, based on the anticipated workloads. These options form the basis for a discussion of recommended budget levels.

Over the past 10 years, the services budget has increased about 4% every 5 years and personnel costs have increased 2% per year. Option 1 shows a budget that continues this pattern through 2032, without other changes (Table 10-5).

Option 2 shows a budget where the anticipated expenses for both services and personnel are increased annually by 2% to account for inflation (Table 10-6).

Options 1 and 2 could be appropriate techniques to project future budgets if the current budget covered the quantity of work that is desired in the next ten years, and if, in that time period, the number of trees that Forestry Landscape Services cared for remained static. Given the importance of growing the urban forest in mitigating climate change impacts, that course of action is not recommended.

Option 3 shows a budget analysis that includes the cost for an increase in 0.5 FTE (full-time equivalent) beginning in fiscal year 2023 to pay for a full-time Tree Warden, in addition to an increase of 2% annually to account for inflation (Table 10-7).

The Town could also prune more trees and have more stable costs for tree care if two additional full-time in-house arborists were hired. Option 4 shows a budget analysis that includes the addition of these arborists in addition to the full-time Tree Warden position, and the 2% increase to account for inflation (Table 10-8).

Each of the options shown in the projected scenarios of the operating budget from 2022 to 2032 illustrate that a marked increase from the 2020 operation budget of $401,881 is needed (Table 10-9).

Projected Operating Budget 2022-2032

Option 1: Continue budget pattern from last 10 years

Services: Increase budget 4% every 5 years
Personnel: No change in number of staff; 2% increase in salary per year
Supplies: No change
Trees Managed: No change

Fiscal Year	Services	Personnel	Supplies	Total
2022	$171,015	$277,382	$6,600	$454,997
2023	$171,015	$282,929	$6,600	$460,544
2024	$171,015	$288,588	$6,600	$466,203
2025	$171,015	$294,360	$6,600	$471,975
2026	$177,856	$300,247	$6,600	$484,703
2027	$177,856	$306,252	$6,600	$490,708
2028	$177,856	$312,377	$6,600	$496,833
2029	$177,856	$318,625	$6,600	$503,080
2030	$184,970	$324,997	$6,600	$516,567
2031	$184,970	$331,497	$6,600	$523,067
2032	$184,970	$338,127	$6,600	$529,697

Table 10-5: Operating Budget for 2022-2032, Option 1

Projected Operating Budget 2022-2032

Option 2: Escalate for inflation annually

Services: Increase budget 2% every year for inflation
Personnel: No change in number of staff, 2% increase in salary per year
Supplies: 2% increase per year
Trees Managed: No change

Fiscal Year	Services	Personnel	Supplies	Total
2022	$174,435	$277,382	$6,732	$458,549
2023	$177,924	$282,929	$6,867	$467,720
2024	$181,482	$288,588	$7,004	$477,075
2025	$185,112	$294,360	$7,144	$486,616
2026	$188,814	$300,247	$7,287	$496,348
2027	$192,591	$306,252	$7,433	$506,275
2028	$196,442	$312,377	$7,581	$516,401
2029	$200,371	$318,625	$7,733	$526,729
2030	$204,379	$324,997	$7,888	$537,263
2031	$208,466	$331,497	$8,045	$548,009
2032	$212,636	$338,127	$8,206	$558,969

Table 10-6: Operating Budget for 2022-2032, Option 2

Projected Operating Budget 2022-2032

Option 3: Full-time Tree Warden

Services: Increase budget 2% every year for inflation
Personnel: 2023 Tree Warden is full-time position
Supplies: 2% increase per year
Trees Managed: An increased tree canopy and additional new trees each year

Fiscal Year	Services	Personnel	Supplies	Total
2022	$181,413	$324,997	$6,732	$513,142
2023	$185,041	$381,497	$6,867	$573,405
2024	$188,742	$389,127	$7,004	$584,873
2025	$192,517	$396,909	$7,144	$596,570
2026	$196,367	$404,848	$7,287	$608,502
2027	$200,294	$412,945	$7,433	$620,672
2028	$204,300	$421,204	$7,581	$633,085
2029	$208,386	$429,628	$7,733	$645,747
2030	$212,554	$438,220	$7,888	$658,662
2031	$216,805	$446,985	$8,045	$671,835
2032	$221,141	$455,924	$8,206	$685,272

Table 10-7: Operating Budget for 2022-2032, Option 3

Projected Operating Budget 2022-2032

Option 4: Adjustment in staffing

Services: Increase budget 2% every year for inflation
Personnel: 2023 Tree Warden is full-time and 2 full-time equivalent (FTE) arborists added
Supplies: 2% increase per year
Trees Managed: An increased tree canopy and additional new trees each year

Fiscal Year	Services	Personnel	Supplies	Total
2022	$174,435	$277,382	$6,732	$458,549
2023	$177,924	$482,929	$6,867	$667,720
2024	$181,482	$492,588	$7,004	$681,075
2025	$185,112	$502,440	$7,144	$694,696
2026	$188,814	$512,489	$7,287	$708,590
2027	$192,591	$522,738	$7,433	$722,762
2028	$196,442	$533,193	$7,581	$737,217
2029	$200,371	$543,857	$7,733	$751,961
2030	$204,379	$554,734	$7,888	$767,001
2031	$208,466	$565,829	$8,045	$782,341
2032	$212,636	$577,145	$8,206	$797,987

Table 10-8: Operating Budget for 2022-2032, Option 4

Cost per public tree analysis

While it is helpful to project the budget by utilizing historic data, these projections do not account for the increase in the number of trees required to achieve the tree canopy coverage goals. The following analysis looks at current spending per public tree and utilizes those costs (adjusted for inflation) to calculate spending with the increased number of trees recommended to reach the canopy coverage goals (Table 10-10).

To meet the tree canopy coverage goal for 2032, 450 trees will need to be planted on public streets, and Town grounds per year. In 2020 the Town cares for approximately 47,000 public trees. By 2032, the Town would care for more than 52,000 trees (Table 10-11).

Dividing the services budget in 2020 by the number of street trees provides a cost of $10.80 "spent" per street tree per year. If this cost per tree is increased for inflation by 2% each year and multiplied by the projected increase in trees, a relative increase in the services budget can be determined.

This analysis yields a services budget for 2032 of $255,540 which more accurately reflects the number of trees that would be cared for at that time. The operating budget analysis summarized earlier only yielded a 2032 budget between $180,000 to $220,000.

Summary of Projected Operating Budget Scenarios 2022-2032

Options	2023 Costs	2032 Costs
Option 1	$460,544	$529,697
Option 2	$467,720	$558,969
Option 3	$573,405	$685,272
Option 4	$667,720	$797,987
2020 Operating Budget (For Reference)		$401,881

Table 10-9: Comparison of Operating Budget Options

Projected Number of Public Trees Managed

Add 450 trees per year to meet 49.1% Town-wide canopy goal

Year	Street Trees	Other Public Trees	Town-managed Trees	% Change
2020	12041	47959	60000	
2021	12266	48184	60450	0.75%
2022	12491	48409	60900	0.74%
2023	12716	48634	61350	0.74%
2024	12941	48859	61800	0.73%
2025	13166	49084	62250	0.73%
2026	13391	49309	62700	0.72%
2027	13616	49534	63150	0.72%
2028	13841	49759	63600	0.71%
2029	14066	49984	64050	0.71%
2030	14291	50209	64500	0.70%
2031	14516	50434	64950	0.70%
2032	14741	50659	65400	0.69%
10 year change	**22.42%**	**5.63%**	**9.00%**	

Table 10-10: Projected Number of Public Trees Managed by Landscape Services Over the Next 10 Years

Projected Cost Per Public Street Tree Managed

Add 225 trees per year to meet 49.1% Town-wide canopy goal

Services budget per street tree increased 2% per year (to account for inflation)

Year	Street Trees	Services Budget	Services Budget Per Street Tree
2020	12041	$130,015	$10.80
2021	12266	$171,015	$13.94
2022	12491	$177,635	$14.22
2023	12716	$184,451	$14.51
2024	12941	$191,470	$14.80
2025	13166	$198,694	$15.09
2026	13391	$206,132	$15.39
2027	13616	$213,787	$15.70
2028	13841	$221,666	$16.02
2029	14066	$229,775	$16.34
2030	14291	$238,120	$16.66
2031	14516	$246,706	$17.00
2032	14741	$255,540	$17.34

Table 10-11: Projected Cost per Public Tree Managed by Landscape Services Over the Next 10 Years

Analysis of Pruning Costs

The cost of contracted pruning work has increased dramatically over the past ten years. Projecting those costs through 2032 and accounting for the growth of existing trees and an increase in the number of public trees shows future pruning budgets will need to increase substantially.

In 2020, the pruning budget should be $282,562. This is calculated using current private contracted tree crew day rates, 15 trees per day pruned (production rate), and a 7-year pruning cycle. With the projected increase of 450 trees per year that the Town cares for and escalated private contracted pruning costs, the budget for pruning in 2032 would be $583,538 (Table 10-12).

Pruning Production and Costs

15 trees per day production with day rate of $1760 (esc. 3% per year)

Year	Street Trees	Street Trees to Prune Per Year	Pruning Days Per Year	Pruning cost
2020	12041	2408	161	$282,562
2021	12491	2498	167	$301,916
2022	12941	2588	173	$322,176
2023	13391	2678	179	$343,381
2024	13841	2768	185	$365,568
2025	14291	2858	191	$388,777
2026	14741	2948	197	$413,049
2027	15191	3038	203	$438,428
2028	15641	3128	209	$464,958
2029	16091	3218	215	$492,685
2030	16541	3308	221	$521,657
2031	16991	3398	227	$551,925
2032	17441	3488	233	$583,538

Table 10-12: Pruning Costs Using Private Crews, Projected Over the Next 10 Years

Analysis of private contracted tree work vs. in-house tree work

With the rising costs of private contract tree work, the Town should consider purchasing a bucket truck, log truck and chipper, as well as hiring 2 FTE to perform tree pruning, removals and tree care in-house.

At 2021 costs, a full-time private tree crew at $1760 per day working 260 days has a cost of $457,600.

Purchasing a bucket truck, log truck and chipper has a one time cost of approximately $400,000. This equipment has a 15 year life, so an annual cost would be approximately $27,000. Adding two FTE to perform the tree pruning with this equipment would add approximately $150,000 in personnel costs. The Town's annual cost for personnel and equipment would be approximately $177,000 compared with the $457,600 for private work.

Budget Recommendations

In 2020, $636,881 was spent on private contracted tree work and Town personnel. To meet the goals of this study for increased tree care and tree canopy coverage in 2023 that budget needs to be $974,653, with all pruning work handled by in-house staff. Contracted services would continue to be utilized for tree removal and emergency work, as needed.
By 2032, the budget will need to increase to $1,365,632 (Table 10-13).

2020 Budget and Spending Compared with Phase I and Phase II Projections

Fiscal Year 2020 Forestry Budget

Operating Budget			
Personnel		$265,266	3.5 FTE
Services		$130,015	2400 pruned
Supplies		$6,600	
	Subtotal	$401,881	
Capital Budget			
Tree removal/ replacement		$235,000	429 planted 192 removed +
	Subtotal	$235,000	
	TOTAL	**$636,881**	

Phase I Forestry Budget (Projected 2-5 years)

Operating Budget			
Personnel		$324,997	4.0 FTE
Services		$343,381	2588 pruned
Supplies		$6,867	
	Subtotal	$675,245	
Capital Budget			
Tree removal/ replacement		$249,775	450 planted 190 removed +
	Subtotal	$249,775	
	TOTAL	**$974,653**	

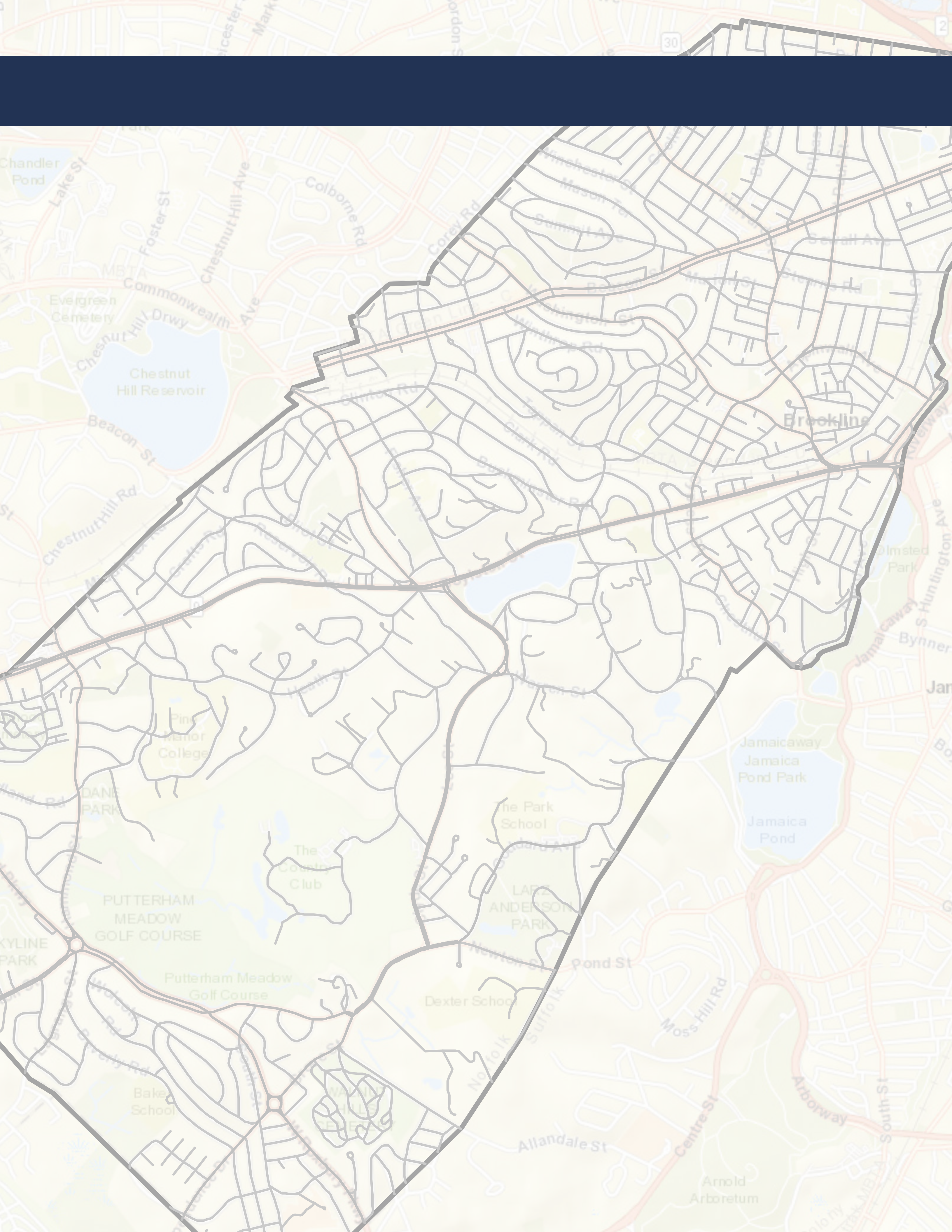
Fiscal Year 2020 Forestry Expenditures - Contracted Services

Source of Funds	
Tree Removal Capital Budget	$108,905
Forestry Landscape Services Budget	$128,515
Town/School Ground Budget	$65,000
Cemetery Budget	$30,000
Parks Budget	$60,685
TOTAL	**$393,105**

Phase II Forestry Budget (Projected 6-10 years)

Operating Budget			
Personnel		$577,145	6.0 FTE
Services		$583,538	3488 pruned
Supplies		$8,206	
	Subtotal	$1,168,890	
Capital Budget			
Tree removal/ replacement		$325,900	450 planted 180 removed +
	Subtotal	$325,900	
	TOTAL	**$1,365,632**	

Table 10-13: Summary Budget Tables
Tables highlighting the discrepancy between current budget funding levels and anticipated budgets in 2023 and 2032


Brookline
Chandler Pond
Lake St
Foster St
Chestnut Hill Ave
Colborne Rd
Corey Rd
Commonwealth Ave
Evergreen Cemetery
Chestnut Hill Drwy
Chestnut Hill Reservoir
Beacon St
Chestnut Hill Rd
Winchester St
Mason Ter
Summit Ave
Sewall Ave
Marion St
Stearns Rd
Washington St
Winthrop Rd
Aspinwall Ave
Clinton Rd
Tappan St
Clark Rd
Buckminster Rd
Boylston St
Reservoir Rd
Heath St
Warren St
Pine Manor College
DANE PARK
The Country Club
PUTTERHAM MEADOW GOLF COURSE
Putterham Meadow Golf Course
SKYLINE PARK
The Park School
LARZ ANDERSON PARK
Newton St
Pond St
Dexter School
Baker School
WALNUT HILLS CEMETERY
Beverly Rd
Olmsted Park
Jamaicaway
Jamaica Pond Park
Jamaica Pond
Moss Hill Rd
Allandale St
Centre St
Arborway
South St
Arnold Arboretum
S Huntington Ave

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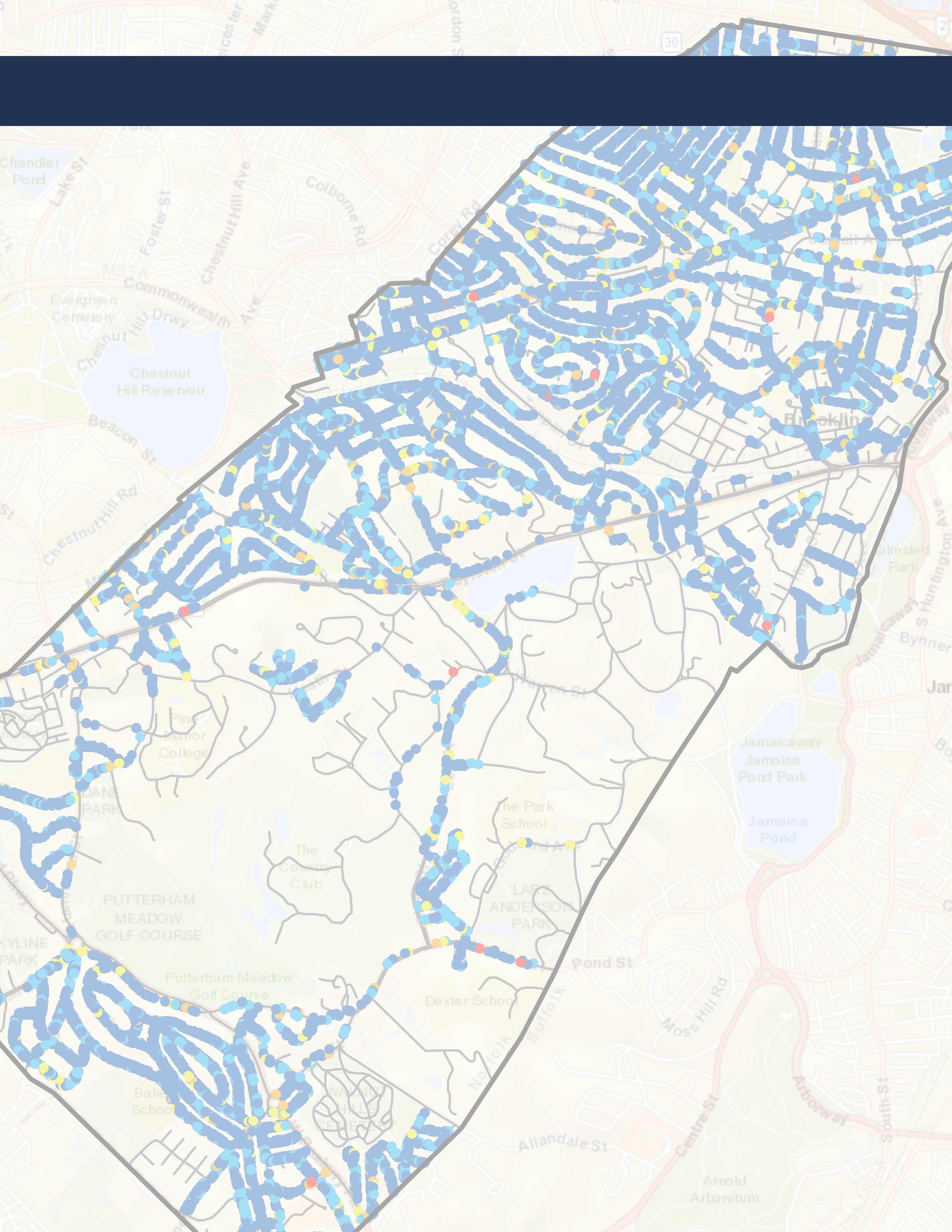

Chandler Pond
Lake St
Foster St
Chestnut Hill Ave
Colborne Rd
Corey Rd
Evergreen Cemetery
MBTA
Commonwealth Ave
Chestnut Hill Drwy
Chestnut Hill Reservoir
Beacon St
Chestnut Hill Rd
Brooklin
Riverway
Olmsted Park
S Huntington Ave
Jamaicaway
Bynner
Warren St
Pine Manor College
DANE PARK
Jamaicaway Jamaica Pond Park
Jamaica Pond
The Park School
The Country Club
PUTTERHAM MEADOW GOLF COURSE
LARZ ANDERSON PARK
SKYLINE PARK
Putterham Meadow Golf Course
Pond St
Dexter School
Moss Hill Rd
Baker School
Arborway
South St
Allandale St
Centre St
Arnold Arboretum

APPENDICES

12

Appendix A

Soil Test Results

Appendix B

Urban Forest Climate Resiliency Master Plan Survey Responses Summary

Appendix C

Tree Protection Bylaw Summary

Appendix D

USFS Urban Forest Sustainability & Management Review

Appendix E

Letters of Comment

Appendix F

Tree Canopy Assessment Report, 2014-2020

Appendix A - Soil Test Results

Physical & Biology Assessment Results						
Site Sample	Bulk Density	Porosity	Infiltration	Slake	Solvita	Electrical Conductivity
Unit of Measure	g cm^{-3}	g cm^{-3}/2.65 x100	minutes per inch	seconds	0-6	dS m^{-1} at 25 C
Optimal		50%+	30-100	50% Struct Loss 30-100 seconds	6	0-0.98
106 Laurel Rd	1.00097	62	10-30	50% Struct Loss 30-100 seconds	2.5	0.13
70 Shaw Road	1.4868	44	2.5	50% Struct Loss 30-100 seconds	6	0.12
Cumberland/Pond	1.1175	58	1.45	50% Struct Loss 30-100 seconds	6	0.1
1351 Beacon St	0.6413	76	45 seconds	50% Struct Loss 30-100 seconds	6	0.04
157 Babcock St	1.4868	44	30-100	50% Struct Loss 30-100 seconds	6	0.03
OOP 50 Summit	1.1564	56	30-100	50% Struct Loss 30-100 seconds	3	0.07
OOP 230 Bckmntr	1.3216	50	2.48	50% Struct Loss 30-100 seconds	4	0.12
Fairway @ Crafts	1.2147	54	16.06	50% Struct Loss 30-100 seconds	6	0.2

Chemistry Assessment Results							
Site Sample	Soil pH	Organic Matter	CEC	Phosphorus	Potassium	Magnesium	Calcium
Unit of Measure		%	cmol$_c$ kg^{-1}	ppm	ppm	ppm	ppm
Optimal	5.8 - 6.6	5	10+	40-100	120-290	130-410	500-3100
106 Laurel Rd	4.8	5.3	16.8	177	27	27	128
70 Shaw Road	7.3	3.2	10.5	140	92	139	2477
Cumberland/Pond	5.2	2.6	7.2	335	54	39	200
1351 Beacon St	7	2.5	8.9	299	103	72	1858
157 Babcock St	6.4	5.1	7.7	167	77	111	1462
OOP 50 Summit	6.5	2.3	2.1	372	72	27	346
OOP 230 Bckmntr	5.5	2.8	7.6	144	111	73	542
Fairway @ Crafts	4.8	5.3	16.8	263	56	48	202

Heavy Metal Assesment Results								
Site Sample	Arsenic (As)	Barium (Ba)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Zinc (Zn)
Unit of Measure	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Max Concentration	16	350	2.5	36	75	40	400	150
106 Laurel Rd	4.02	2.83	0	7.06	2.82	1.19	12	11.8
70 Shaw Road	0.43	3.53	0	2.24	3.33	1.11	6	18.58
Cumberland/Pond	1.68	2.87	0	2.91	4.27	1.49	16	19.1
1351 Beacon St	1.07	3.65	0	3.03	3.98	1.39	16	17.94
157 Babcock St	0.57	4.86	0	3.01	3.7	3.84	3	22.95
OOP 50 Summit	0.88	3.11	0	2.72	4.38	1.22	48	24.65
OOP 230 Bckmntr	0.98	4.31	0	3.41	4.51	1.69	17	51.63
Fairway @ Crafts	0.86	2.72	0	4.23	2.69	1.84	17	13.73

Chemistry Assessment Results							
Site Sample	Soil pH	Organic Matter	CEC	Phosphorus	Potassium	Magnesium	Calcium
Unit of Measure		%	cmol$_c$ kg^{-1}	ppm	ppm	ppm	ppm
Optimal	5.8 - 6.6	5	10+	50-100	120-260	130-370	500-2500
1157 Beacon St	7.4	3.1	2.5	127	39	70	512
1774 Beacon St	6.4	4.5	10.8	92	108	89	1361
198 Harvard St	6.7	2.8	3.8	189	64	75	641
429 Harvard St	6.6	5.3	11.1	57	79	652	1058
334 Washington St	7	3.4	7.2	174	137	134	1328
Billy Ward	5.7	5.4	13.5	114	67	130	1074
Dummer @ Amory	4.7	3.9	8.6	486	165	42	527
Larz Adnrsn Pk	5.6	3.1	9.5	116	50	52	472

Heavy Metal Assesment Results								
Site Sample	Arsenic (As)	Barium (Ba)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Zinc (Zn)
Unit of Measure	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Max Concentration	16	350	2.5	36	75	40	400	150
1157 Beacon St	0.86	4.02	0	3.93	5.19	3.52	33	39.33
1774 Beacon St	1.07	4.9	0	3.28	3.25	1.49	10	22.23
198 Harvard St	0.72	4.07	0	2.86	2.96	1.42	12	23.84
429 Harvard St.	0.45	7.67	0	7.27	17.65	2.84	15	84.16
334 Washington St	0.96	5.6	0	4.05	7.12	1.83	21	40.17
Billy Ward	0.84	3.73	0	5.15	2.84	4.36	5	17.71
Dummer @ Amory	0.21	7.02	0	3,67	7.51	4.15	4	28.24
Larz Adnrsn Pk	0.65	4.38	0	2.09	2.18	0.97	6	12.54

Note: The data results have been color coded as follows Optimal Green, Medium Yellow, Low Red. The optimal values represent proper soil function for that indicator. The medium and low values represent soil function constraints.

Turf and Ornamental Soil Analysis Report

Spectrum Analytic
1087 Jamison Road NW
Washingon Court House, OH 43160-8748

www.spectrumanalytic.com

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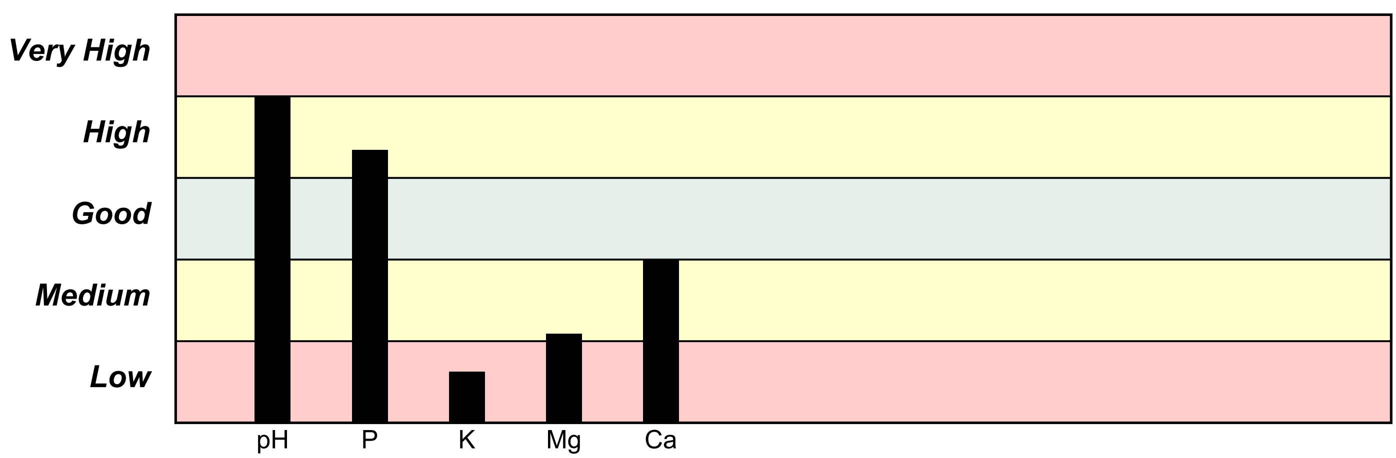
BROOKLINE, MA 02445

Prepared For
TOWN OF BROOKLINE

Sample Information			
Sample	1157 BEACON ST	Sampled	06-02-2020
Lab Number	A07608	Tested	06-05-2020

Analysis		Result	Optimal	Analysis		Result	Optimal
Soil pH		7.4	5.8-6.6	Arsenic	mg/Kg	0.86	
Buffer pH				Barium	mg/Kg	4.02	
Organic Matter	%	3.1		Chromium-Total	mg/Kg	3.93	
CEC		2.5		Nickel	mg/Kg	3.52	
K Saturation	%	3.3	2.0-4.0	Copper	mg/Kg	5.19	
Mg Saturation	%	20.4	10-20	Zinc	mg/Kg	39.33	
Ca Saturation	%	76.3	50-70	Cadmium	ppm	0	
K/Mg Ratio		0.6		Lead	ppm	33	
Ca/Mg Ratio		7.3					
Phosphorus	m3-ppm	127	70-100				
Potassium	m3-ppm	39	120-210				
Magnesium	m3-ppm	70	130-270				
Calcium	m3-ppm	512	500-1000				



Recommendations		Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)									
Yr	Crop	CaCO3	N	P2O5	K2O	Mg	S	B	Cu	Fe	Mn	Zn
20	Trees, Deciduous-Undefined	0	3.0	0.0	3.3	0.8	6.8					

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Sulfur: The S recommendation is the total amount needed to reach the desired soil pH. Do not exceed 5 lb S/1000 sq ft/application or 10 lb S/1000 sq ft/yr on turf. Do not exceed 7 lb S/1000 sq ft/yr on sandy soils. Sample soils annually to monitor pH change.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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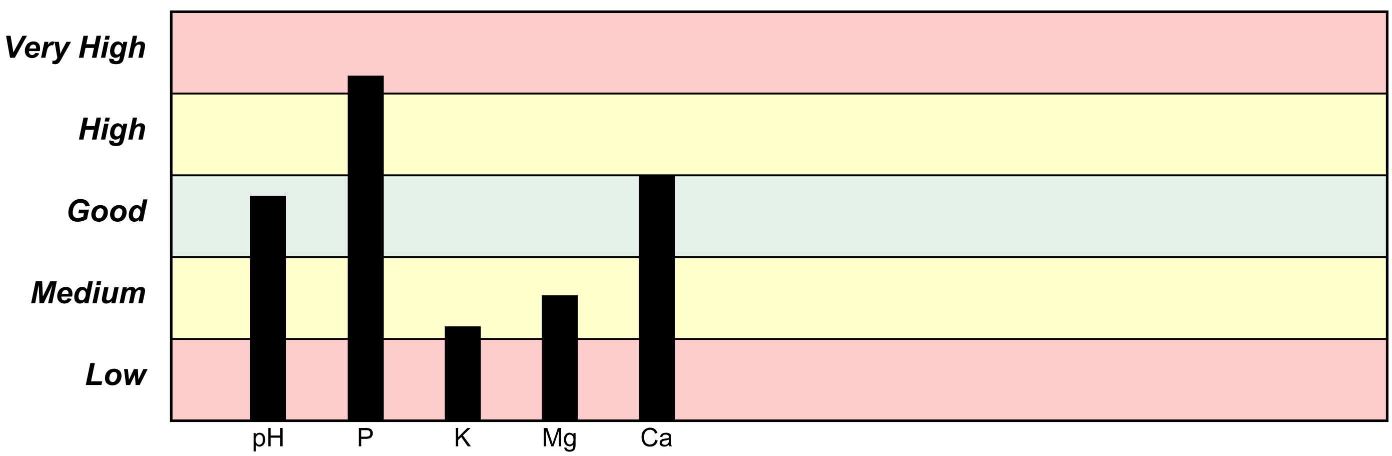
Sample Information			
Sample	157 BABCOCK ST	Sampled	06-02-2020
Lab Number	A07609	Tested	06-05-2020

Analysis		*Result*	*Optimal*	*Analysis*		*Result*	*Optimal*
Soil pH		6.4	5.8-6.6	Arsenic	mg/Kg	0.57	
Buffer pH		6.9		Barium	mg/Kg	4.86	
Organic Matter	%	5.1		Chromium-Total	mg/Kg	3.01	
CEC		7.7		Nickel	mg/Kg	3.84	
K Saturation	%	2.2	2.0-4.0	Copper	mg/Kg	3.70	
Mg Saturation	%	10.6	10-20	Zinc	mg/Kg	22.95	
Ca Saturation	%	71.6	50-70	Cadmium	ppm	0	
K/Mg Ratio		0.7		Lead	ppm	3	
Ca/Mg Ratio		13.2					
Phosphorus	m3-ppm	167	50-80				
Potassium	m3-ppm	77	130-220				
Magnesium	m3-ppm	111	140-280				
Calcium	m3-ppm	1462	900-1500				



Recommendations		*Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*										
Yr	*Crop*	*CaCO3*	*N*	*P2O5*	*K2O*	*Mg*	*S*	*B*	*Cu*	*Fe*	*Mn*	*Zn*
20	Trees, Deciduous-Undefined	0	3.0	0.0	3.0	0.5						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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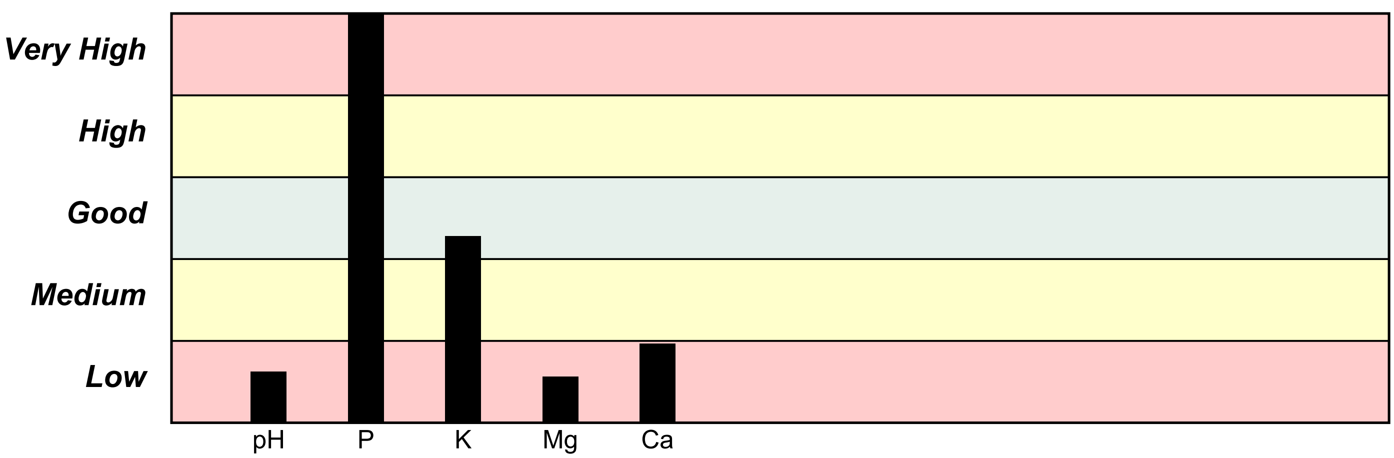
Sample Information			
Sample	DUMMER @ AMORY	Sampled	06-02-2020
Lab Number	A07610	Tested	06-05-2020

Analysis		*Result*	*Optimal*	*Analysis*		*Result*	*Optimal*
Soil pH		4.7	5.8-6.6	Arsenic	mg/Kg	0.21	
Buffer pH		6.5		Barium	mg/Kg	7.02	
Organic Matter	%	3.9		Chromium-Total	mg/Kg	3.67	
CEC		8.6		Nickel	mg/Kg	4.15	
K Saturation	%	4.1	2.0-4.0	Copper	mg/Kg	7.51	
Mg Saturation	%	3.6	10-20	Zinc	mg/Kg	28.24	
Ca Saturation	%	22.9	50-70	Cadmium	ppm	0	
K/Mg Ratio		3.9		Lead	ppm	4	
Ca/Mg Ratio		12.5					
Phosphorus	m3-ppm	486	50-80				
Potassium	m3-ppm	165	140-230				
Magnesium	m3-ppm	42	150-290				
Calcium	m3-ppm	527	1000-1600				



Recommendations *Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*

Yr	*Crop*	*CaCO3*	*N*	*P2O5*	*K2O*	*Mg*	*S*	*B*	*Cu*	*Fe*	*Mn*	*Zn*
20	Trees, Deciduous-Undefined	145D	3.0	0.0	2.2	0.8						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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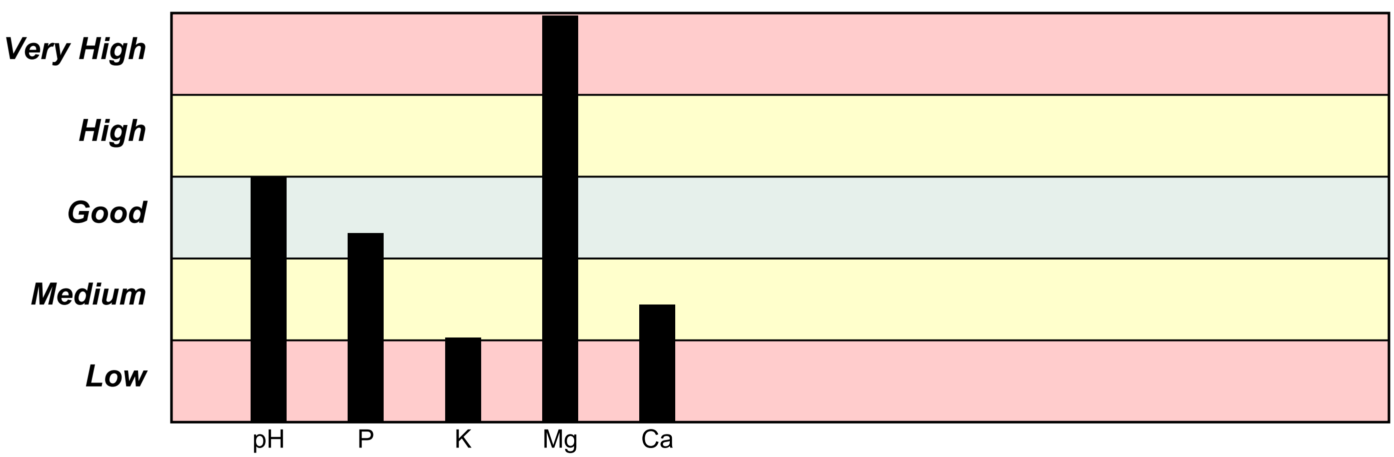
Sample Information			
Sample	429 HARAVRD ST	Sampled	06-02-2020
Lab Number	A07611	Tested	06-05-2020

Analysis		Result	Optimal	Analysis		Result	Optimal
Soil pH		6.6	5.8-6.6	Arsenic	mg/Kg	0.45	
Buffer pH		7.1		Barium	mg/Kg	7.67	
Organic Matter	%	5.3		Chromium-Total	mg/Kg	7.27	
CEC		11.1		Nickel	mg/Kg	2.84	
K Saturation	%	1.5	2.0-4.0	Copper	mg/Kg	17.65	
Mg Saturation	%	42.9	10-20	Zinc	mg/Kg	84.16	
Ca Saturation	%	35.6	50-70	Cadmium	ppm	0	
K/Mg Ratio		0.1		Lead	ppm	15	
Ca/Mg Ratio		1.6					
Phosphorus	m3-ppm	57	50-80				
Potassium	m3-ppm	79	150-250				
Magnesium	m3-ppm	652	180-320				
Calcium	m3-ppm	1058	1500-2100				



Recommendations		*Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*										
Yr	*Crop*	*CaCO3*	*N*	*P2O5*	*K2O*	*Mg*	*S*	*B*	*Cu*	*Fe*	*Mn*	*Zn*
20	Trees, Deciduous-Undefined	0	3.0	0.8	3.1	0.0						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.
Trees, Deciduous-Undefined: Apply 2.0 lbs/1000 sqft Calcium from gypsum and/or fertilizer sources.

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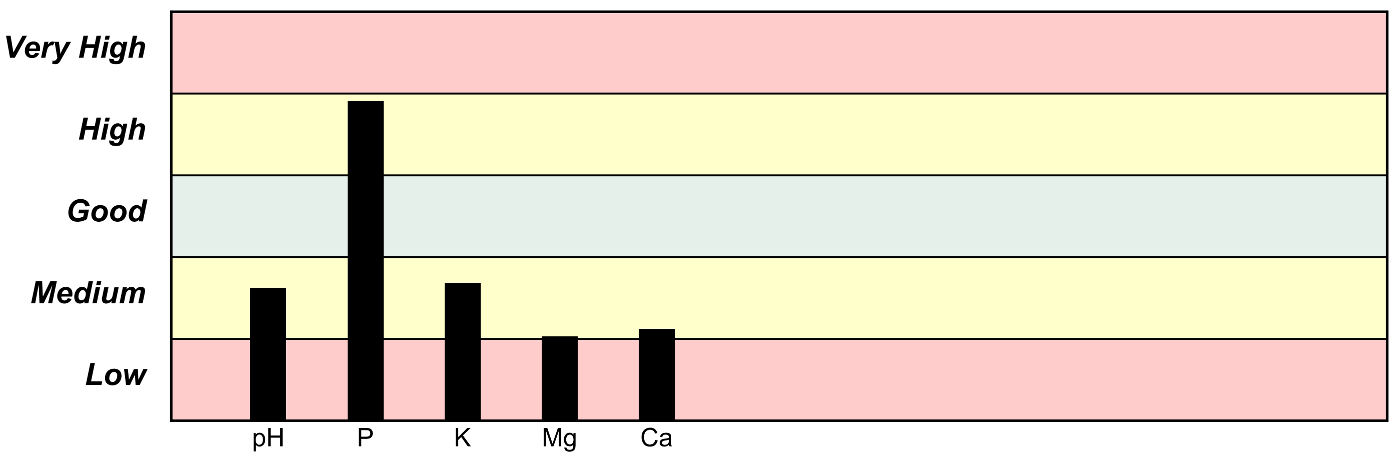
Sample Information			
Sample	OOP 230 BCKMNTR	Sampled	06-02-2020
Lab Number	A07612	Tested	06-05-2020

Analysis		*Result*	*Optimal*	*Analysis*		*Result*	*Optimal*
Soil pH		5.5	5.8-6.6	Arsenic	mg/Kg	0.98	
Buffer pH		6.6		Barium	mg/Kg	4.31	
Organic Matter	%	2.8		Chromium-Total	mg/Kg	3.41	
CEC		7.6		Nickel	mg/Kg	1.69	
K Saturation	%	3.1	2.0-4.0	Copper	mg/Kg	4.51	
Mg Saturation	%	7.0	10-20	Zinc	mg/Kg	51.63	
Ca Saturation	%	26.7	50-70	Cadmium	ppm	0	
K/Mg Ratio		1.5		Lead	ppm	17	
Ca/Mg Ratio		7.4					
Phosphorus	m3-ppm	144	50-80				
Potassium	m3-ppm	111	130-220				
Magnesium	m3-ppm	73	140-280				
Calcium	m3-ppm	542	900-1500				



Recommendations		*Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*										
Yr	*Crop*	*CaCO3*	*N*	*P2O5*	*K2O*	*Mg*	*S*	*B*	*Cu*	*Fe*	*Mn*	*Zn*
20	Trees, Deciduous-Undefined	87D	3.0	0.0	2.6	0.6						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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Turf and Ornamental Soil Analysis Report

Spectrum Analytic
1087 Jamison Road NW
Washingon Court House, OH 43160-8748

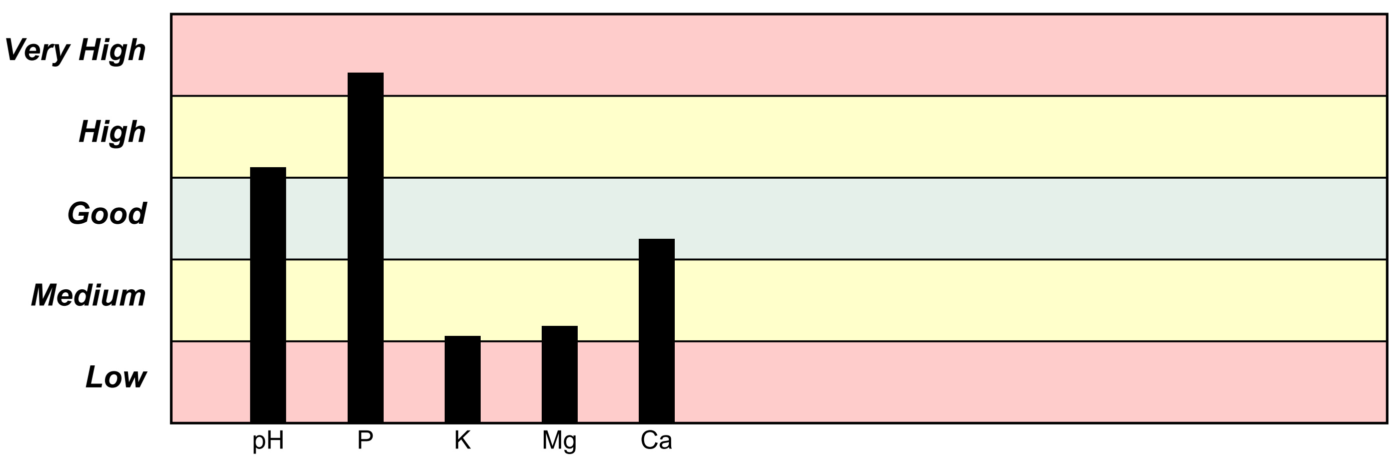
www.spectrumanalytic.com

TOWN OF BROOKLINE
333 WASHINGTON STREET
BROOKLINE, MA 02445

Prepared For
TOWN OF BROOKLINE

Sample Information			
Sample	198 HARVARD ST	Sampled	06-02-2020
Lab Number	A07613	Tested	06-05-2020

Analysis		*Result*	*Optimal*	*Analysis*		*Result*	*Optimal*
Soil pH		6.7	5.8-6.6	Arsenic	mg/Kg	0.72	
Buffer pH		6.8		Barium	mg/Kg	4.07	
Organic Matter	%	2.8		Chromium-Total	mg/Kg	2.86	
CEC		3.8		Nickel	mg/Kg	1.42	
K Saturation	%	3.7	2.0-4.0	Copper	mg/Kg	2.96	
Mg Saturation	%	14.6	10-20	Zinc	mg/Kg	23.84	
Ca Saturation	%	63.7	50-70	Cadmium	ppm	0	
K/Mg Ratio		0.9		Lead	ppm	12	
Ca/Mg Ratio		8.5					
Phosphorus	m3-ppm	189	60-90				
Potassium	m3-ppm	64	120-210				
Magnesium	m3-ppm	75	130-270				
Calcium	m3-ppm	641	500-1000				



Recommendations — *Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*

Yr	*Crop*	*CaCO3*	*N*	*P2O5*	*K2O*	*Mg*	*S*	*B*	*Cu*	*Fe*	*Mn*	*Zn*
20	Trees, Deciduous-Undefined	0	3.0	0.0	3.1	0.8	2.0					

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Sulfur: The S recommendation is the total amount needed to reach the desired soil pH. Do not exceed 5 lb S/1000 sq ft/application or 10 lb S/1000 sq ft/yr on turf. Do not exceed 7 lb S/1000 sq ft/yr on sandy soils. Sample soils annually to monitor pH change.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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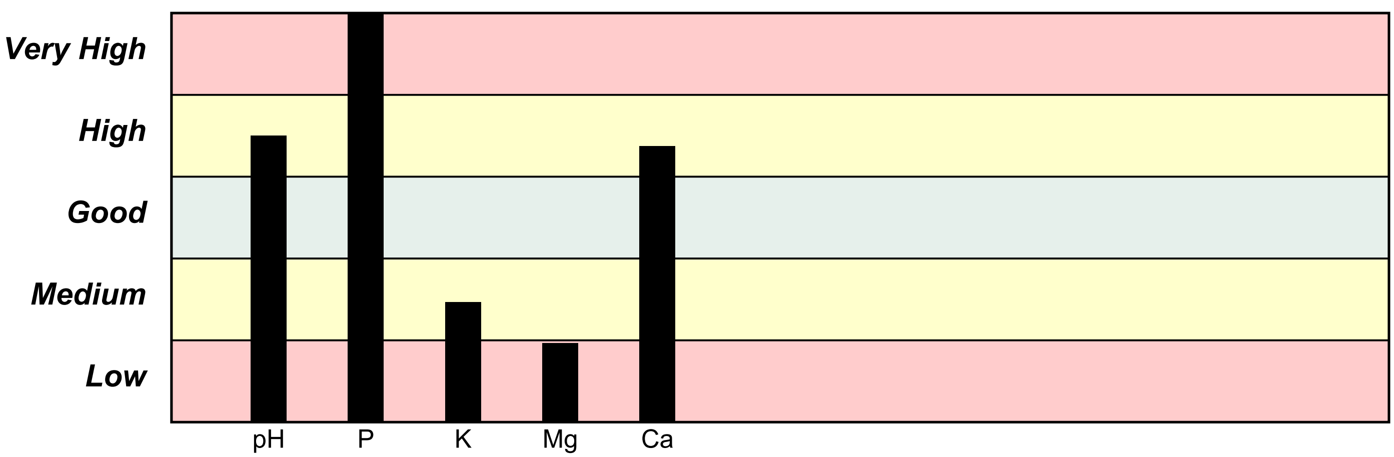
Sample Information			
Sample	1531 BEACON ST	Sampled	06-02-2020
Lab Number	A07614	Tested	06-05-2020

Analysis		Result	Optimal	Analysis		Result	Optimal
Soil pH		7.0	5.8-6.6	Arsenic	mg/Kg	1.07	
Buffer pH				Barium	mg/Kg	3.65	
Organic Matter	%	2.5		Chromium-Total	mg/Kg	3.03	
CEC		8.9		Nickel	mg/Kg	1.39	
K Saturation	%	2.5	2.0-4.0	Copper	mg/Kg	3.98	
Mg Saturation	%	5.9	10-20	Zinc	mg/Kg	17.94	
Ca Saturation	%	78.5	50-70	Cadmium	ppm	0	
K/Mg Ratio		1.4		Lead	ppm	16	
Ca/Mg Ratio		25.8					
Phosphorus	m3-ppm	299	50-80				
Potassium	m3-ppm	103	140-230				
Magnesium	m3-ppm	72	150-290				
Calcium	m3-ppm	1858	1000-1700				



Recommendations — *Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*

Yr	Crop	CaCO3	N	P2O5	K2O	Mg	S	B	Cu	Fe	Mn	Zn
20	Trees, Deciduous-Undefined	0	3.0	0.0	2.8	0.9	4.0					

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Sulfur: The S recommendation is the total amount needed to reach the desired soil pH. Do not exceed 5 lb S/1000 sq ft/application or 10 lb S/1000 sq ft/yr on turf. Do not exceed 7 lb S/1000 sq ft/yr on sandy soils. Sample soils annually to monitor pH change.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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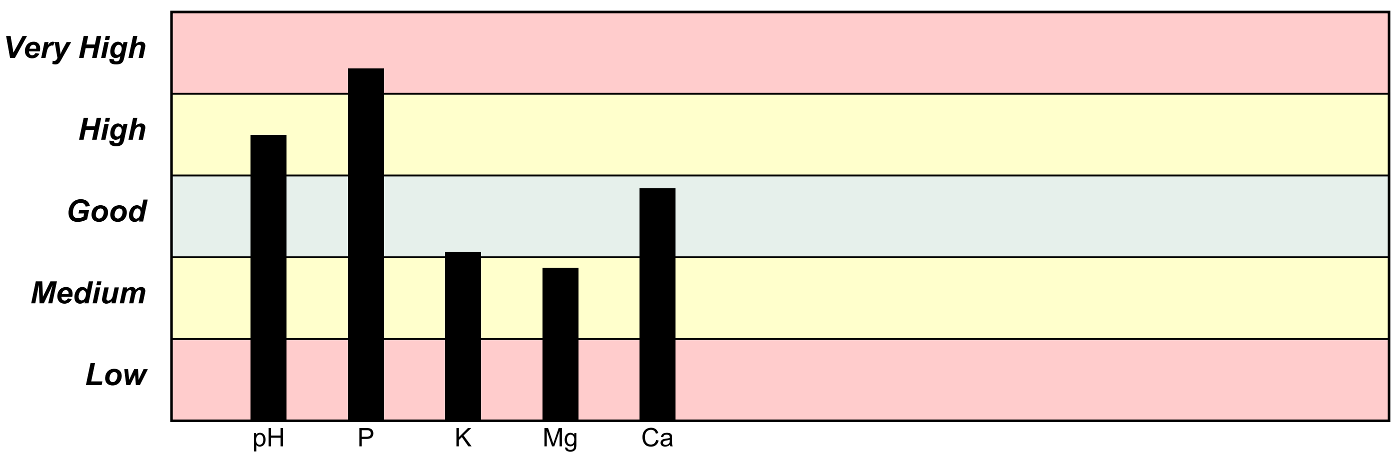
Sample Information			
Sample	334 WASHINGTON	Sampled	06-02-2020
Lab Number	A07615	Tested	06-05-2020

Analysis		Result	Optimal	Analysis		Result	Optimal
Soil pH		7.0	5.8-6.6	Arsenic	mg/Kg	0.96	
Buffer pH				Barium	mg/Kg	5.60	
Organic Matter	%	3.4		Chromium-Total	mg/Kg	4.05	
CEC		7.2		Nickel	mg/Kg	1.83	
K Saturation	%	4.1	2.0-4.0	Copper	mg/Kg	7.12	
Mg Saturation	%	13.7	10-20	Zinc	mg/Kg	40.17	
Ca Saturation	%	69.2	50-70	Cadmium	ppm	0	
K/Mg Ratio		1.0		Lead	ppm	21	
Ca/Mg Ratio		9.9					
Phosphorus	m3-ppm	174	50-80				
Potassium	m3-ppm	137	130-220				
Magnesium	m3-ppm	134	140-280				
Calcium	m3-ppm	1328	900-1400				



Recommendations — *Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*

Yr	Crop	CaCO3	N	P2O5	K2O	Mg	S	B	Cu	Fe	Mn	Zn
20	Trees, Deciduous-Undefined	0	3.0	0.0	2.4	0.4	3.8					

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Sulfur: The S recommendation is the total amount needed to reach the desired soil pH. Do not exceed 5 lb S/1000 sq ft/application or 10 lb S/1000 sq ft/yr on turf. Do not exceed 7 lb S/1000 sq ft/yr on sandy soils. Sample soils annually to monitor pH change.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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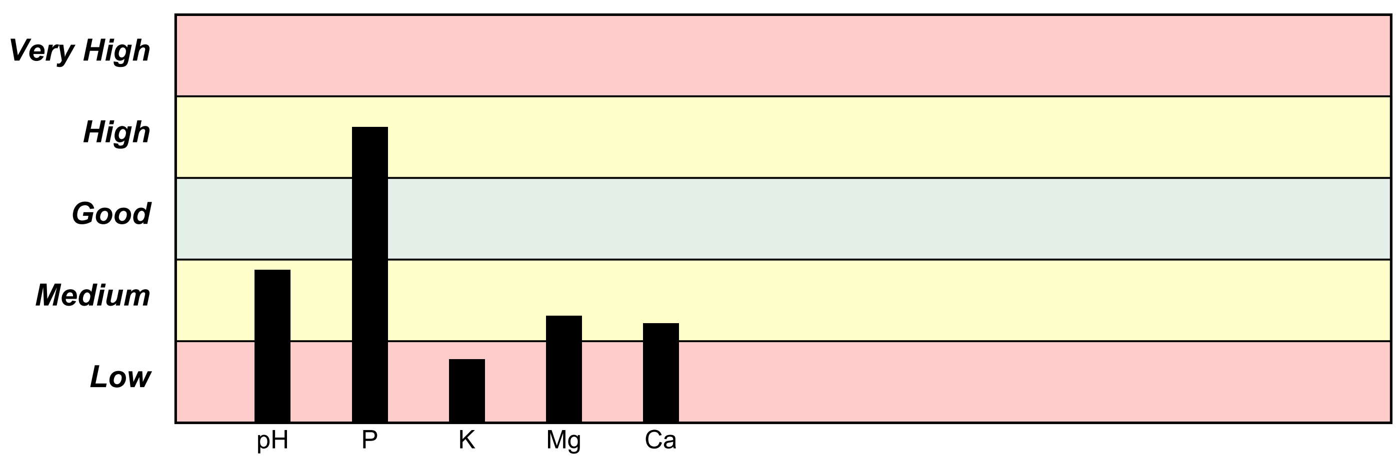
Sample Information			
Sample	BILLY WARD	Sampled	06-02-2020
Lab Number	A07616	Tested	06-05-2020

Analysis		*Result*	*Optimal*	*Analysis*		*Result*	*Optimal*
Soil pH		5.7	5.8-6.6	Arsenic	mg/Kg	0.84	
Buffer pH		6.3		Barium	mg/Kg	3.73	
Organic Matter	%	5.4		Chromium-Total	mg/Kg	5.15	
CEC		13.5		Nickel	mg/Kg	4.36	
K Saturation	%	1.1	2.0-4.0	Copper	mg/Kg	2.84	
Mg Saturation	%	7.0	10-20	Zinc	mg/Kg	17.71	
Ca Saturation	%	29.8	50-70	Cadmium	ppm	0	
K/Mg Ratio		0.5		Lead	ppm	5	
Ca/Mg Ratio		8.3					
Phosphorus	m3-ppm	114	50-70				
Potassium	m3-ppm	67	170-260				
Magnesium	m3-ppm	130	210-370				
Calcium	m3-ppm	1074	1800-2500				



Recommendations		*Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*										
Yr	*Crop*	*CaCO3*	*N*	*P2O5*	*K2O*	*Mg*	*S*	*B*	*Cu*	*Fe*	*Mn*	*Zn*
20	Trees, Deciduous-Undefined	111D	3.0	0.0	3.2	0.3						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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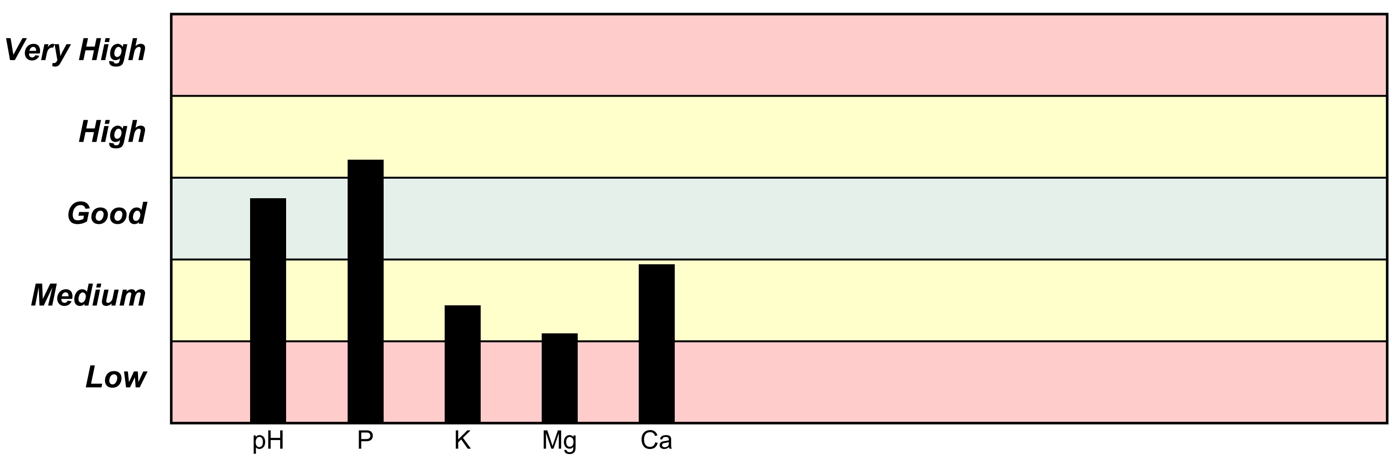
Sample Information			
Sample	1774 BEACON ST	Sampled	06-02-2020
Lab Number	A07617	Tested	06-05-2020

Analysis		Result	Optimal	Analysis		Result	Optimal
Soil pH		6.4	5.8-6.6	Arsenic	mg/Kg	1.07	
Buffer pH		6.6		Barium	mg/Kg	4.90	
Organic Matter	%	4.5		Chromium-Total	mg/Kg	3.28	
CEC		10.8		Nickel	mg/Kg	1.49	
K Saturation	%	2.2	2.0-4.0	Copper	mg/Kg	3.25	
Mg Saturation	%	6.0	10-20	Zinc	mg/Kg	22.23	
Ca Saturation	%	47.3	50-70	Cadmium	ppm	0	
K/Mg Ratio		1.2		Lead	ppm	10	
Ca/Mg Ratio		15.3					
Phosphorus	m3-ppm	92	50-80				
Potassium	m3-ppm	108	150-240				
Magnesium	m3-ppm	89	170-320				
Calcium	m3-ppm	1361	1400-2000				



Recommendations — *Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*

Yr	Crop	CaCO3	N	P2O5	K2O	Mg	S	B	Cu	Fe	Mn	Zn
20	Trees, Deciduous-Undefined	0	3.0	0.2	2.8	0.8						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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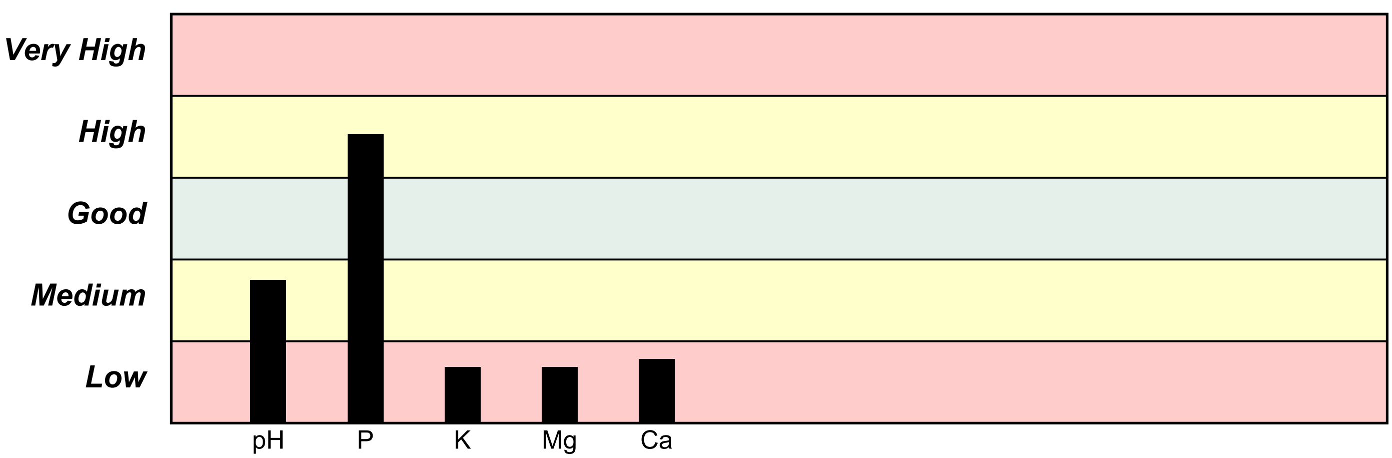
Sample Information			
Sample	LARZ ADNRSN PK	Sampled	06-02-2020
Lab Number	A07618	Tested	06-05-2020

Analysis		Result	Optimal	Analysis		Result	Optimal
Soil pH		5.6	5.8-6.6	Arsenic	mg/Kg	0.65	
Buffer pH		6.4		Barium	mg/Kg	4.38	
Organic Matter	%	3.1		Chromium-Total	mg/Kg	2.09	
CEC		9.5		Nickel	mg/Kg	0.97	
K Saturation	%	1.1	2.0-4.0	Copper	mg/Kg	2.18	
Mg Saturation	%	4.0	10-20	Zinc	mg/Kg	12.54	
Ca Saturation	%	18.7	50-70	Cadmium	ppm	0	
K/Mg Ratio		1.0		Lead	ppm	6	
Ca/Mg Ratio		9.1					
Phosphorus	m3-ppm	116	50-80				
Potassium	m3-ppm	50	140-230				
Magnesium	m3-ppm	52	150-300				
Calcium	m3-ppm	472	1200-1800				



Recommendations — *Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*

Yr	Crop	CaCO3	N	P2O5	K2O	Mg	S	B	Cu	Fe	Mn	Zn
20	Trees, Deciduous-Undefined	108D	3.0	0.0	3.3	0.5						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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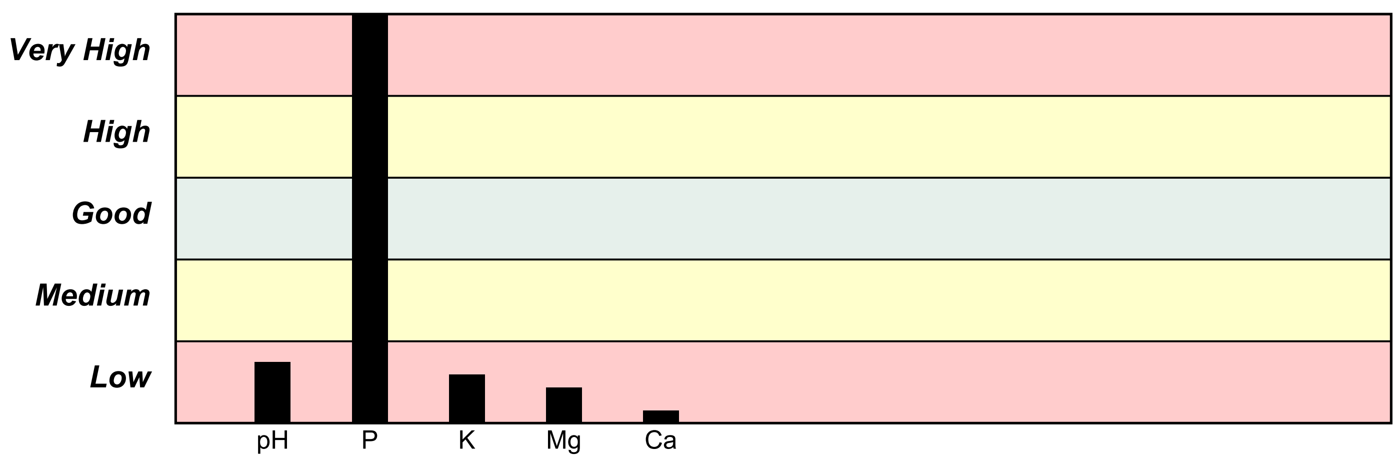
Sample Information			
Sample	FAIRWAY@CRRTS	Sampled	06-02-2020
Lab Number	A07619	Tested	06-05-2020

Analysis		Result	Optimal	Analysis		Result	Optimal
Soil pH		4.8	5.8-6.6	Arsenic	mg/Kg	0.86	
Buffer pH		5.7		Barium	mg/Kg	2.72	
Organic Matter	%	5.3		Chromium-Total	mg/Kg	4.23	
CEC		16.8		Nickel	mg/Kg	1.84	
K Saturation	%	0.7	2.0-4.0	Copper	mg/Kg	2.69	
Mg Saturation	%	2.1	10-20	Zinc	mg/Kg	13.73	
Ca Saturation	%	4.5	50-70	Cadmium	ppm	0	
K/Mg Ratio		1.2		Lead	ppm	17	
Ca/Mg Ratio		4.2					
Phosphorus	m3-ppm	263	40-70				
Potassium	m3-ppm	56	190-290				
Magnesium	m3-ppm	48	250-410				
Calcium	m3-ppm	202	2200-3100				



Recommendations		Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)										
Yr	Crop	CaCO3	N	P2O5	K2O	Mg	S	B	Cu	Fe	Mn	Zn
20	Trees, Deciduous-Undefined	306D	3.0	0.0	3.4	0.6						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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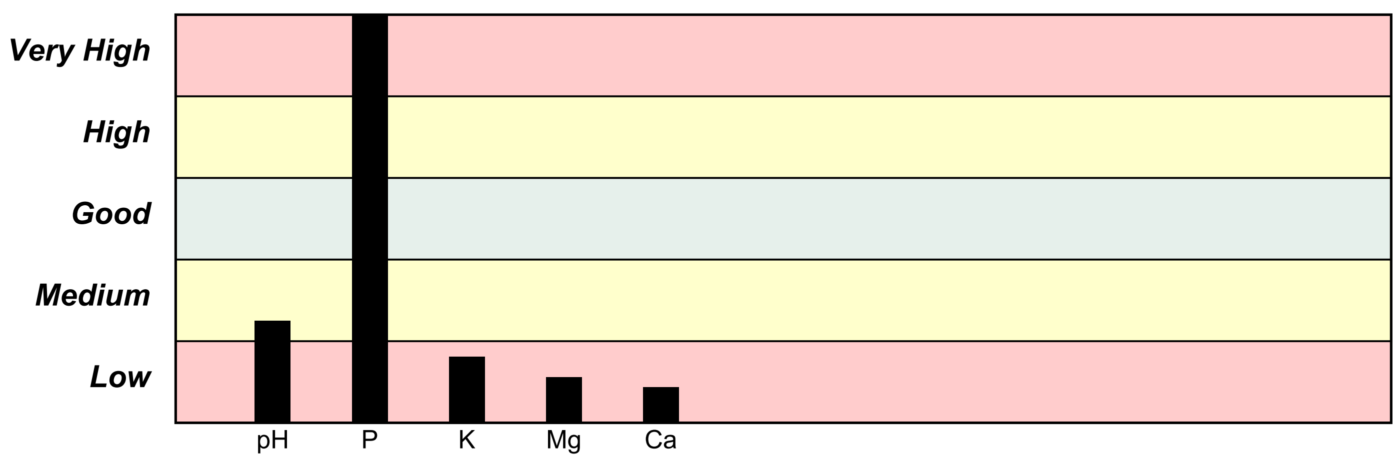
Sample Information			
Sample	CUMBERLAND@POND	Sampled	06-02-2020
Lab Number	A07620	Tested	06-05-2020

Analysis		*Result*	*Optimal*	*Analysis*		*Result*	*Optimal*
Soil pH		5.2	5.8-6.6	Arsenic	mg/Kg	1.68	
Buffer pH		6.5		Barium	mg/Kg	2.87	
Organic Matter	%	2.6		Chromium-Total	mg/Kg	2.91	
CEC		7.2		Nickel	mg/Kg	1.49	
K Saturation	%	1.6	2.0-4.0	Copper	mg/Kg	4.27	
Mg Saturation	%	4.0	10-20	Zinc	mg/Kg	19.10	
Ca Saturation	%	10.5	50-70	Cadmium	ppm	0	
K/Mg Ratio		1.4		Lead	ppm	16	
Ca/Mg Ratio		5.1					
Phosphorus	m3-ppm	335	50-80				
Potassium	m3-ppm	54	130-220				
Magnesium	m3-ppm	39	140-280				
Calcium	m3-ppm	200	900-1400				



Recommendations *Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*

Yr	*Crop*	*CaCO3*	*N*	*P2O5*	*K2O*	*Mg*	*S*	*B*	*Cu*	*Fe*	*Mn*	*Zn*
20	Trees, Deciduous-Undefined	121D	3.0	0.0	3.2	0.6						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

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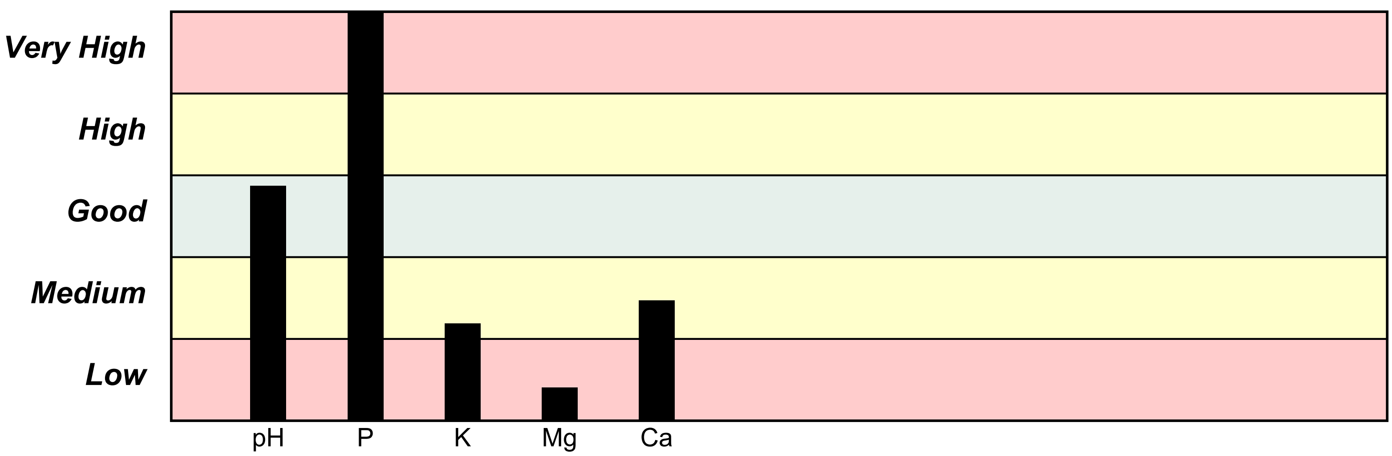
Sample Information			
Sample	OOP 50 SUMMIT	Sampled	06-02-2020
Lab Number	A07621	Tested	06-05-2020

Analysis		Result	Optimal	Analysis		Result	Optimal
Soil pH		6.5	5.8-6.6	Arsenic	mg/Kg	0.88	
Buffer pH		7.0		Barium	mg/Kg	3.11	
Organic Matter	%	2.3		Chromium-Total	mg/Kg	2.72	
CEC		2.1		Nickel	mg/Kg	1.22	
K Saturation	%	7.3	2.0-4.0	Copper	mg/Kg	4.38	
Mg Saturation	%	9.4	10-20	Zinc	mg/Kg	24.65	
Ca Saturation	%	61.4	50-70	Cadmium	ppm	0	
K/Mg Ratio		2.7		Lead	ppm	48	
Ca/Mg Ratio		12.8					
Phosphorus	m3-ppm	372	70-100				
Potassium	m3-ppm	72	120-210				
Magnesium	m3-ppm	27	130-270				
Calcium	m3-ppm	346	500-900				



Recommendations		Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)										
Yr	Crop	CaCO3	N	P2O5	K2O	Mg	S	B	Cu	Fe	Mn	Zn
20	Trees, Deciduous-Undefined	0	3.0	0.0	3.0	1.6						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

Trees, Deciduous-Undefined: Apply 1.2 lbs/1000 sqft Calcium from gypsum and/or fertilizer sources.

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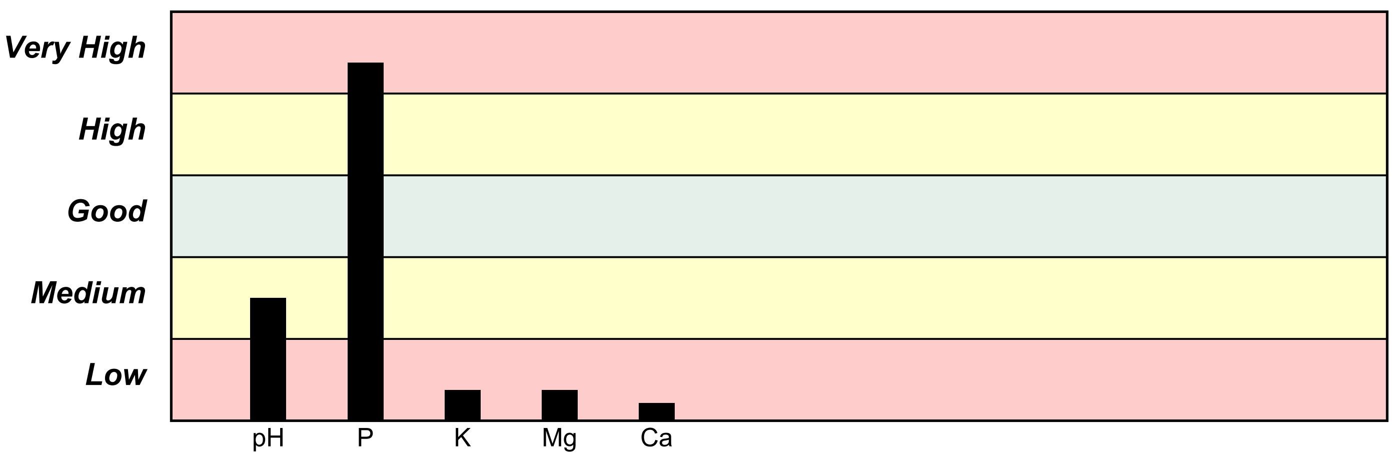
Sample Information			
Sample	OPP 106 LAUREL	Sampled	06-02-2020
Lab Number	A07622	Tested	06-05-2020

Analysis		*Result*	*Optimal*	*Analysis*		*Result*	*Optimal*
Soil pH		5.4	5.8-6.6	Arsenic	mg/Kg	4.02	
Buffer pH		6.4		Barium	mg/Kg	2.83	
Organic Matter	%	2.8		Chromium-Total	mg/Kg	7.06	
CEC		7.9		Nickel	mg/Kg	1.19	
K Saturation	%	0.7	2.0-4.0	Copper	mg/Kg	2.82	
Mg Saturation	%	2.5	10-20	Zinc	mg/Kg	11.80	
Ca Saturation	%	6.0	50-70	Cadmium	ppm	0	
K/Mg Ratio		1.0		Lead	ppm	12	
Ca/Mg Ratio		4.7					
Phosphorus	m3-ppm	177	50-80				
Potassium	m3-ppm	27	130-230				
Magnesium	m3-ppm	27	150-290				
Calcium	m3-ppm	128	900-1500				



Recommendations		*Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*										
Yr	*Crop*	*CaCO3*	*N*	*P2O5*	*K2O*	*Mg*	*S*	*B*	*Cu*	*Fe*	*Mn*	*Zn*
20	Trees, Deciduous-Undefined	124D	3.0	0.0	3.4	0.6						

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

Analyzed by Spectrum Analytic Inc.
www.spectrumanalytic.com

HID:5511-5994-5661-0005

Turf and Ornamental Soil Analysis Report

Spectrum Analytic
1087 Jamison Road NW
Washingon Court House, OH 43160-8748

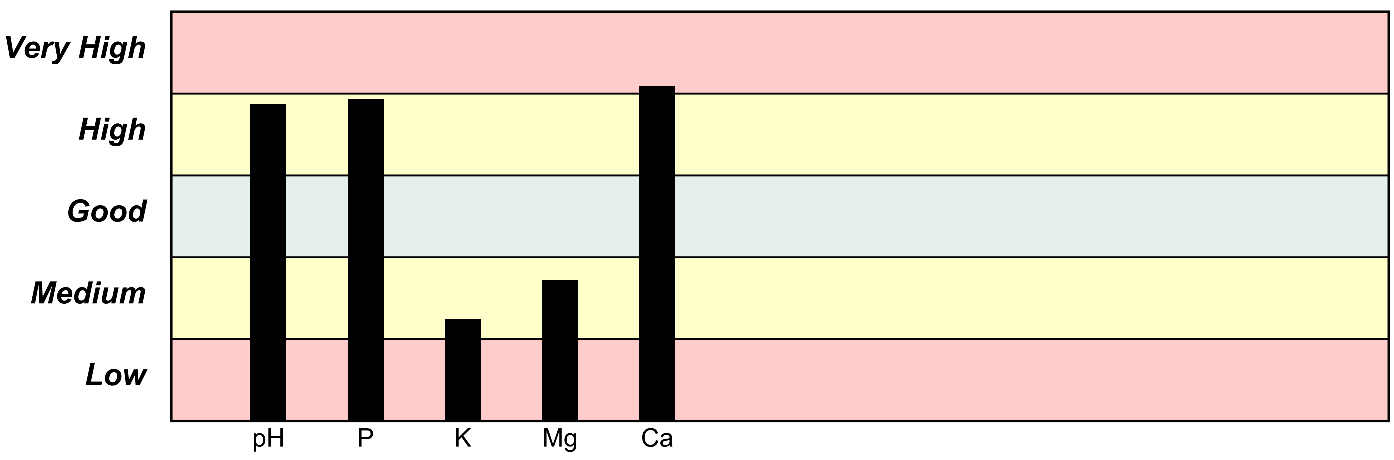
www.spectrumanalytic.com

TOWN OF BROOKLINE
333 WASHINGTON STREET
BROOKLINE, MA 02445

Prepared For
TOWN OF BROOKLINE

Sample Information			
Sample	70 SHAW RD	Sampled	06-02-2020
Lab Number	A07623	Tested	06-05-2020

Analysis		Result	Optimal	Analysis		Result	Optimal
Soil pH		7.3	5.8-6.6	Arsenic	mg/Kg	0.43	
Buffer pH				Barium	mg/Kg	3.53	
Organic Matter	%	3.2		Chromium-Total	mg/Kg	2.24	
CEC		10.5		Nickel	mg/Kg	1.11	
K Saturation	%	1.9	2.0-4.0	Copper	mg/Kg	3.33	
Mg Saturation	%	9.7	10-20	Zinc	mg/Kg	18.58	
Ca Saturation	%	88.4	50-70	Cadmium	ppm	0	
K/Mg Ratio		0.7		Lead	ppm	6	
Ca/Mg Ratio		17.8					
Phosphorus	m3-ppm	140	50-80				
Potassium	m3-ppm	92	150-240				
Magnesium	m3-ppm	139	170-310				
Calcium	m3-ppm	2477	1400-2000				



Recommendations — *Nutrients expressed in broadcast lbs/1000 sqft, except Fe (foliar) and Mn (row)*

Yr	Crop	CaCO3	N	P2O5	K2O	Mg	S	B	Cu	Fe	Mn	Zn
20	Trees, Deciduous-Undefined	0	3.0	0.0	2.9	0.4	7.7					

Lime expressed in 100% pure CaCO3. Adjust accordingly. D=Dolomitic. C=Calcitic.

Sulfur: The S recommendation is the total amount needed to reach the desired soil pH. Do not exceed 5 lb S/1000 sq ft/application or 10 lb S/1000 sq ft/yr on turf. Do not exceed 7 lb S/1000 sq ft/yr on sandy soils. Sample soils annually to monitor pH change.

Trees, Deciduous-Undefined: Limit N to 1 lb./1000 sq. ft. within dripline in year 1. Split N 50% early spring and 50% late summer. Fertilized area under tree starts 2 ft. from trunk, to 3 ft. outside of dripline. Adjust future fertilizer rates based on annual leaf analysis.

Analyzed by Spectrum Analytic Inc. *HID:5511-5994-5661-0005*
www.spectrumanalytic.com

Appendix B - Urban Forest Climate Resiliency Master Plan Survey Summary

Urban Forest Climate Resiliency Master Plan Survey

June 9, 2021, 10:21 AM

Contents

Urban Forest Climate Resiliency Master Plan Survey

Help guide our efforts to develop an Urban Forest Climate Resiliency Master Plan!

Introduction

The Town of Brookline is developing an Urban Forest Climate Resiliency Master Plan and would sincerely appreciate your input. This Master Plan is intended to position the Town to proactively and equitably prepare for and protect against the impacts of climate change on the urban forest, and in turn prepare for and mitigate impacts to the community and environment overall. An “Urban Forest” consists of all the trees that populate a town or city - including park trees, street trees, even the trees in your front yard. In addition to enhancing community character, providing shade and improving property value, a municipality's public and private trees reduce flooding, energy consumption and air pollution; mitigate the urban heat island effect (the phenomenon of built areas absorbing and retaining heat); sequester carbon; reduce stormwater runoff and soil erosion; provide wildlife habitat; protect biodiversity; and improve water quality. As such, the urban forest is a considerable asset to the Town of Brookline in offsetting the impacts of climate change!

The intention of this survey is to allow the project team to hear directly from you, the residents of Brookline, and determine community priorities and goals regarding the urban forest. We hope that you are able to take 5 minutes to complete this 10-question survey and share your insights with us. At the end of the survey, there will be 5 optional demographic questions which we invite you to answer, if you are comfortable doing so.

Urban Forest Climate Resiliency Master Plan Survey
Help guide our efforts to develop an Urban Forest Climate Resiliency Master Plan!

Summary Of Responses

As of June 9, 2021, 10:21 AM, this forum had:		Topic Start
Attendees:	817	July 17, 2020, 11:53 AM
Responses:	408	
Hours of Public Comment:	20.4	

QUESTION 1

Please rate the degree to which you agree or disagree with each of the following statements.

I have been/am currently an active participant in Parks and Open Space Division projects/planning processes or community-based environmental advocacy groups/organizations (ie. park friends groups, Mothers Out Front, Greenspace Alliance, Climate Action Committee/Brookline etc.)

	%	Count
Strongly disagree	26.2%	107
Disagree	27.5%	112
Neither agree nor disagree	15.0%	61
Agree	16.7%	68
Strongly agree	14.7%	60

I have a deep understanding of the relationship that exists between urban forests and climate change.

	%	Count
Strongly disagree	2.5%	10
Disagree	8.8%	36
Neither agree nor disagree	21.3%	87
Agree	40.7%	166
Strongly agree	26.7%	109

Urban Forest Climate Resiliency Master Plan Survey

Help guide our efforts to develop an Urban Forest Climate Resiliency Master Plan!

Brookline's canopy is consistent in its health and overall quality across Town.

	%	Count
Strongly disagree	9.6%	39
Disagree	39.2%	160
Neither agree nor disagree	30.9%	126
Agree	12.7%	52
Strongly agree	7.6%	31

Brookline's forestry operations are substantial and effective.

	%	Count
Strongly disagree	3.2%	13
Disagree	14.2%	58
Neither agree nor disagree	54.2%	221
Agree	24.0%	98
Strongly agree	4.4%	18

QUESTION 2

Please identify which issues below are of greatest concern to you regarding the health and quality of the urban forest. Prioritize your concerns based on which issues you believe require the most immediate attention.

1. Climate change (increasing temperatures, more frequent/intense storm events, etc.)
2. Natural gas leaks (from underground gas mains)
3. Budget limitations for the care, protection and maintenance of public trees
4. Lack of soil volume for street trees

5. Invasive species/Pests/Diseases
6. Commercial/Institutional development
7. Private property development for single/multi family homes
8. Conflict with overhead utility wires

QUESTION 3

How would you rank the health and quality of Brookline's public trees?

	%	**Count**
Excellent	3.2%	13
Very good	29.9%	122
Good	51.5%	210
Fair	14.5%	59
Poor	1.0%	4

QUESTION 4

You've got 12 dots to 'spend'. What are your main priorities in enhancing/bettering Brookline's urban forest?

	%	**Count**
Planting street trees (trees located along the public way)	12.9%	633
Planting park/playground/school & town ground trees	8.5%	414
Increasing frequency of public tree assessments (for general health and pest/disease management)	6.2%	304
Planting for climate resiliency	13.1%	641
Planting traditionally native species	6.8%	333
Enhancing biodiversity	5.8%	282

	%	Count
Developing green corridors/wildlife corridors	8.8%	433
Increasing frequency of routine pruning efforts on public shade trees	3.9%	193
Preserving existing forested, naturalized areas	10.6%	518
Protecting trees on private/commercial/institutional property	4.9%	238
Planting wherever there are gaps in the canopy	8.3%	408
Removal of invasive species	5.0%	244
Other	1.1%	54

QUESTION 5

The Parks and Open Space Division recognizes the importance of community education and involvement in efforts to protect and improve our urban canopy. Which of the below community engagement techniques would be most appealing to you? (Select all that apply)

	%	Count
Tree identification walks (along streets and/or within nature sanctuaries and parks)	66.9%	273
Seminars/talks (either virtual or in-person)	47.3%	193
Pamphlets/Brochures	23.3%	95
Workshops regarding private tree management and care	40.0%	163
Social media posts (Pictures with educational descriptions and/or short videos)	41.4%	169
More web-based resources	39.7%	162
Volunteer opportunities	46.3%	189
Other	5.6%	23

Urban Forest Climate Resiliency Master Plan Survey

Help guide our efforts to develop an Urban Forest Climate Resiliency Master Plan!

QUESTION 6

Do you face any obstacles/challenges relating to private tree planting and/or maintenance? (Select all that apply. If not applicable, please leave blank.)

	%	Count
Don't understand what regular maintenance needs to be done	39.4%	119
Prohibitive costs	32.1%	97
Lack of available land	39.4%	119
Lack of/limited sunlight	17.2%	52
Difficulty contacting/scheduling service with a private tree company	8.3%	25
Concerns regarding potential property damage	15.2%	46
Presence of underground utilities	11.3%	34
Conflict with overhead utilities	20.5%	62
Other	15.6%	47

QUESTION 7

The Back of Sidewalk Planting Program (see www.brooklinema.gov/trees for more information) encourages residents to partner with the Town to plant shade trees on private property in close proximity to the sidewalk (at no cost to the resident). Please answer the below questions.

Are you familiar with the Program?

	%	Count
Yes	21.6%	88
No	74.3%	303
Not Applicable	4.2%	17

Urban Forest Climate Resiliency Master Plan Survey

Help guide our efforts to develop an Urban Forest Climate Resiliency Master Plan!

Are you currently/have you previously been a participant in the Program?

	%	Count
Yes	2.7%	11
No	86.3%	352
Not Applicable	11.0%	45

If you responded "No" to the question above, are you interested in possibly participating in the future?

	%	Count
Yes	53.7%	219
No	21.1%	86
Not Applicable	25.2%	103

QUESTION 8

If, in the previous question, you responded that you would NOT like to participate in this program, please briefly explain why.

Answered	126
Skipped	282

any available building condo do don enough from front house land large live m more near need one plant planted property public room s shade sidewalk sidewalks small space street t think tiny town tree trees two very where yard

Urban Forest Climate Resiliency Master Plan Survey

Help guide our efforts to develop an Urban Forest Climate Resiliency Master Plan!

QUESTION 9

Which strategies, if any, would you like the Town to consider in private tree protection/management? (Select all that apply)

	%	Count
Education – Provide programs/opportunities for property owners to learn about how to care for and maintain their trees	67.7%	273
Incentives – ie. Offering developers incentives in exchange for tree preservation	69.5%	280
Regulatory Measures – Adopt and enforce tree protection ordinances (ie. require 1:1 replanting of any healthy tree removed)	73.7%	297
None – The Town should focus on protecting/managing public trees	6.2%	25
Other	5.0%	20

QUESTION 10

Please share any additional thoughts, comments or concerns that you may have regarding this Master Plan, or the maintenance and management of Brookline's urban canopy below.

Answered	109
Skipped	299

all also been brookline canopy could do from gas important like more most need new other plant planted planting program property public s see sidewalk so some space street t them they think town tree trees very was water where

QUESTION 11

If you would like to be included in the ListServ for future communications regarding this project, please enter your name and email below OR contact Katie Weatherseed at kweatherseed@brooklinema.gov

Answered	159
Skipped	249

QUESTION 12

What is your precinct/Where do you typically vote? Please note that these multiple choice answers show REGULAR polling locations (certain locations have changed for the 2020 election season due to Covid-19).

	%	Count
Precinct 1 / BU-Wheelock College	4.0%	16
Precinct 2 / Coolidge Corner Branch Library	3.2%	13
Precinct 3 / Theresa Morse Apartments (90 Longwood Avenue)	5.7%	23
Precinct 4 / Town Hall	5.2%	21
Precinct 5 / (New) Lincoln School	18.9%	76
Precinct 6 / BHS Schluntz Gymnasium	12.9%	52
Precinct 7 / Arthur A. O'Shea House (61 Park Street)	3.5%	14
Precinct 8 / Coolidge Corner School	7.5%	30
Precinct 9 / Senior Center (Winchester St.)	6.0%	24
Precinct 10 / John W. Kickham Apartments (190 Harvard Street)	2.2%	9
Precinct 11 / Driscoll School New Gymnasium	4.2%	17
Precinct 12 / Runkle School Gymnasium	7.5%	30
Precinct 13 / Runkle School Gymnasium	6.2%	25
Precinct 14 / Heath School Gymnasium	3.0%	12
Precinct 15 / Fire Station #6 (962 Hammond Street)	3.7%	15
Precinct 16 / Putternham Branch Library	3.2%	13
I do not live in Brookline	1.7%	7
I do not know my precinct/polling location	1.2%	5

QUESTION 13

In what capacity do you reside in Brookline?

	%	Count
Residential property owner	82.8%	333
Renter	12.9%	52
Tenancy in public housing	0.7%	3
Tenancy in elder housing/assisted living facility	0.2%	1
I don't live in Brookline	1.7%	7
Other	1.5%	6

QUESTION 14

What is your age?

	%	Count
18-24 years old	1.7%	7
25-34 years old	9.0%	36
35-44 years old	13.0%	52
45-54 years old	19.5%	78
55-64 years old	20.0%	80
65-74 years old	26.9%	108
75 years or older	10.0%	40

Urban Forest Climate Resiliency Master Plan Survey

Help guide our efforts to develop an Urban Forest Climate Resiliency Master Plan!

QUESTION 15

Which ethnicity(s) do you identify with? (Select all that apply)

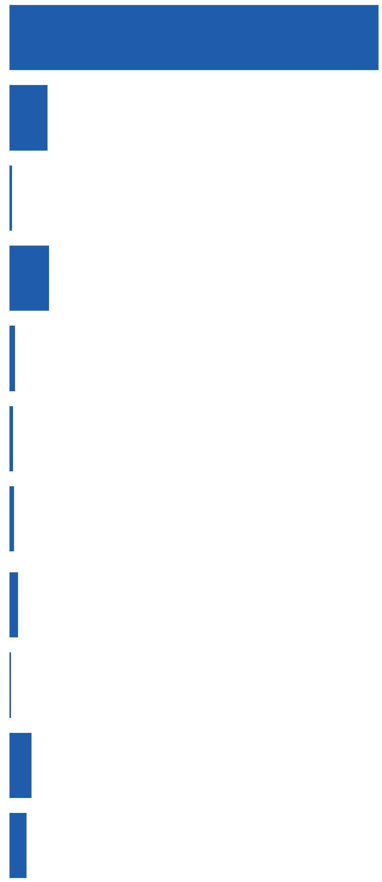
	%	Count
Asian	5.9%	23
Black/African American	0.3%	1
White/Caucasian	86.0%	338
Hispanic/Latinx	3.3%	13
Native American	0.3%	1
Pacific Islander	0.3%	1
Other	1.0%	4
Prefer not to answer	6.6%	26

Urban Forest Climate Resiliency Master Plan Survey

Help guide our efforts to develop an Urban Forest Climate Resiliency Master Plan!

QUESTION 16

Which languages are you capable of speaking fluently? (Select all that apply)



	%	Count
English	94.9%	376
Spanish	9.6%	38
Portuguese	0.5%	2
French	10.1%	40
Russian	1.3%	5
Hebrew	0.8%	3
Japanese	1.0%	4
Chinese	2.0%	8
Arabic	0.3%	1
Other	5.6%	22
Prefer not to answer	4.3%	17

Appendix C - Tree Protection Bylaw Summary

PLEASE NOTE: DOCUMENT IS FROM MAY TOWN MEETING, 2003

Report of the Moderator's Committee on a Tree Ordinance

Findings: The Moderators Committee concludes that both public and private trees add significant value to the community and that a tree protection bylaw similar in scope and purpose to that attached as part of this report would be a beneficial and reasonable addition to the Town's bylaws. However, despite the value of protecting both public and private trees in Brookline, the Committee does not believe that a tree protection bylaw should shift existing resources from the maintenance and management of over 50,000 existing public trees or cause undue delay in development projects.

The Committee researched the staff time required to administer tree protection bylaws in other communities such as Newton and Lexington and determined that an additional staff person would be necessary to manage the permitting, inspections, mitigation and enforcement required for private tree protection in Brookline. Due to the current economic climate and the Town's "no-net hire" policy, the Committee was informed that additional staff can not be hired in the near future for the purpose of implementing this bylaw. Without sufficient staff administration, implementation of the tree protection bylaw would be both cumbersome and ineffective. The Committee recommends that a bylaw be adopted as soon as the Town has the financial resources to afford the personnel (estimated as .75-time equivalent) required for enforcement of the bylaw.

The Committee prepared a draft bylaw that it believes fairly balances trees' value to the community with other concerns, which could be proposed at a later date if staff resources become available to allow for adequate administration and enforcement. In the absence of a bylaw, the Committee recommends that the Planning Board, Conservation Commission, Zoning Board of Appeals, Preservation Commission and other town boards consider the value of trees to the community when settling policies and procedures and otherwise when such considerations are legally before them.

Report: As a result of the Fall Town Meeting 2001, a Moderator's Committee was established to evaluate the feasibility, effectiveness and possible benefits of a tree protection bylaw in Brookline. In Massachusetts, any person must obtain a permit to remove any tree in the public right-of-way, commonly referred to as street trees, however no such permit is required for the removal of trees on private property. The Committee held more than eight working meetings and one public hearing to consider the purpose, applicability, jurisdiction, implementation and enforcement of a tree protection bylaw in Brookline.

The Committee and the public engaged in extended discussions regarding potential goals of a bylaw, the necessary level of protection for private trees and the extent to which a bylaw might impact the rights of the property owner and impact development activity. As a guiding principle the Committee agreed that mature trees have aesthetic appeal, contribute to the distinct character of the community, improve air quality, provide glare and heat protection, reduce noise, aid in the stabilization of soil, provide natural flood and climate control, create habitats for wildlife, enhance property values and provide natural privacy to neighbors. The Committee attempted to balance those values against anticipated concerns regarding private property rights, as well as the perceived statutory limits of authority with respect to such a bylaw. Finally, the Committee considered whether a bylaw could be implemented in an efficient and effective manner.

The Committee determined that the process of drafting a bylaw would help clarify whether such a bylaw would be desirable and would help the Committee better understand implementation and effectiveness issues in Brookline.

The Committee reviewed a wide range of categories that could be protected including heritage trees, residential landscape trees, natural wooded areas and unique trees. The draft tree protection bylaw does not discriminate between residential and non-residential properties, but rather sets conditions based upon the magnitude of the development project in comparison to existing development on the site and its associated impact on the community. The draft bylaw requires that roots, trunks and canopies of trees be protected during construction and that pruning of protected trees adhere to appropriate arboricultural standards. The draft bylaw requires that trees 8" caliper or greater being removed for construction or development purposes be replaced on an inch-per-inch basis. The bylaw permits a contribution to a tree replacement fund if trees cannot be maintained or planted on the site. This fund would be used to plant and maintain trees on public property.

The draft bylaw requires permits for removal of protected trees. The tree removal permit process would have a 20 business day turnaround, which would balance the need for timely issuance of permits with the need to properly administer the bylaw. The bylaw creates enforcement options including a notice, a stop-work order, and injunctive relief. It also sets penalties for removal of protected trees without a permit and failure to replace protected trees.

The tree protection bylaw provides for the creation of a Tree Preservation Plan, and a combination of pre-construction planning, onsite monitoring and mitigation measures during construction and post-construction, monitoring and maintenance. Mitigation requirements need to be strong, comprehensive and fair. Without these components the tree protection bylaw would be ineffective. The bylaw also contains provisions for replacing trees that cannot be saved, and obligations to maintain and monitor the replacement trees.

The policies created by the bylaw need to be flexible and responsive to a variety of situations. The Committee decided that the bylaw should be supplemented with a set of Rules and Regulations established by the Tree Planting Committee. The rules would allow for more detailed consideration of the issues identified in the bylaw.

Finally, the Moderator's Committee evaluated the viability of a more stringent tree protection bylaw, however concluded the public will to pass such a bylaw did not exist in light of competing considerations.

Conclusion: A tree protection bylaw in Brookline would establish trees as a valued resource that is threatened by development pressures and recognize that continued, uncontrolled loss of trees has broad public health, economic, and quality of life implications for the entire Town. The bylaw would set community-based procedures and incentives for retaining and protecting trees during development, whenever reasonably possible.

The Committee considered the success and viability of existing tree bylaws in other communities and concluded that if permitting is difficult, costly and time-consuming it can potentially discourage compliance with the tree bylaw. The Tree Warden should be vested with the authority and time necessary to carry out his or her responsibilities associated with this bylaw. Without the infrastructure and related programs to support this bylaw its effectiveness will be quite limited.

The Committee evaluated the possible avenues for implementation, including the use of existing permitting and bylaw mechanisms within the Town. The Town should not implement a tree protection bylaw until there is appropriate staffing in place that can ensure the process is fair, equitable, performed within a realistic time period and adds value to the community. With careful thought, implementation and public education, the tree protection bylaw can be effective in preserving trees that are determined to be significant to the Town. The Committee recommends that at some future point this bylaw be presented to Town Meeting for adoption with consideration of appropriate staffing. Again, in the absence of a bylaw, the Committee recommends that all Town Boards and Commissions consider the value of trees to the community when settling policies and procedures and otherwise when such considerations are legally before them.

Town of Brookline DRAFT Tree Bylaw

Section 1: Preamble

The Town of Brookline finds that mature trees have aesthetic appeal, contribute to the distinct character of the community, improve air quality, provide glare and heat protection, reduce noise, aid in the stabilization of soil, provide natural flood- and climate-control, create habitats for wildlife, enhance property values and provide natural privacy to neighbors.

Section 2: Intent and Purpose

This by-law is enacted for the purpose of preserving and protecting both Public Shade Trees pursuant to General Law Chapter 87 and certain designated trees on private property. It is desirable to plant more public shade trees than are removed to compensate for tree losses and the length of time to maturity.

Section 3: Definitions

When used in this by-law, the following definitions shall apply:

3.1 Demolition: Any act of pulling down, destroying, removing or razing a building or commencing the work of total or substantial destruction with the intent of completing the same.

3.2 Caliper: Diameter of a tree trunk (in inches) measured 6 inches above the ground for trees up to and including 4-inch diameter, and 12 inches above the ground for larger trees.

3.3 DBH ("Diameter at Breast Height"): The diameter (in inches) of the trunk of a tree (or, for multiple trunk trees, the aggregate diameters of the multiple trunks) measured 4 ½ feet from the existing grade at the base of the tree.

3.4 Person: Any person, firm, partnership, association, corporation, company or organization of any kind including public utility and municipal department.

3.5 Public Shade Tree: Any tree within the public right-of-way except for state highways that, as determined by the Tree Warden, has any portion of the stem between 6 inches and 4 ½ feet above grade actively growing into the public right-of-way.

3.6 Tree Removal: Any act that will cause a tree to die within a three (3) year period.

3.6.1 A protected tree is any tree that is greater than eight inches in diameter measured at 4.5' off the ground.

3.6.2 Strucuture: A combination of any materials, whether portable or fixed, having a roof, to form a structure for the shelter of persons, animals or property. For the purpose of this definition "roof" shall include an awning or any similar covering, whether or not permanent in nature. The word "building" shall be construed where the context allows as though followed by the words "or part or parts thereof".

Section 4: Applicability of the By-law

4.1 Applicability: The circumstances under which the tree removal and replacement regulatory process delineated in this by-law shall apply are as follows:

(a) the proposed demolition of an existing residential structure and its replacement with a new dwelling/structure.

(b) the proposed construction of an addition to the existing residential structure that constitutes a 10% or greater increase in the building footprint

(c) the proposed demolition of an existing non-residential structure and its replacement with a new dwelling/structure.

(d) the proposed construction of an addition to the existing non-residential structure that constitutes a 10% or greater increase in the building footprint.

(e) the proposed new construction of a residential or non-residential structure on any lot.

(f) the proposed removal and replacement of existing public shade trees by the town or their agents or contractors.

(g) Section 509 or special permit process.

Section 5: Tree Warden

The duties or responsibilities of the Tree Warden shall conform to General Law Chapter 87 and shall include, but not be limited to the following: management of all trees within public rights-of-way and adjacent to public buildings and commons; care and control of trees on Town property if so requested by the Commissioner of Public Works or the Director of Parks and Open Space

(a) expending funds, in coordination with the Tree Planting Committee, appropriated for planting trees on Town land under the jurisdiction of the Tree Warden;

(b) enforcement of this by-law;

(c) work with the Building Commissioner his or her designee to review proposed tree removals as regulated by this by-law.

Moreover, the Commissioner of Public Works or the Director of Parks and Open Space may authorize the Tree Warden to undertake other responsibilities consistent with the intent of this by-law.

Section 6: Regulation of Public Shade Trees

6.1 Scope

A Public Shade Tree may not be cut, pruned, removed or damaged by any person other than the Tree Warden or his or her designee until and unless the Tree Warden issues a written permit pursuant to this section.

6.2 Procedures

Any person seeking to remove a Public Shade Tree shall submit an application to the Tree Planting Committee in accordance with any application requirements issued by the Warden. The Tree Planting Committee shall hold a public hearing on applications for removal, at the expense of the applicant, in accordance with the provisions outlined within General Law Chapter 87. The permit issued by the Tree Planting Committee may specify schedules, terms, and conditions, including requiring the planting of replacement trees.

6.3 Planting of Trees on Public Land

Any person seeking to plant a Public Shade Tree on Town land under the jurisdiction of the Tree Warden must obtain written permission from the Tree Warden. Such permission may specify schedules, terms, and conditions as deemed appropriate by the Tree Warden.

Section 7: Regulation of Protected Trees

7.1 Scope

The removal of Protected Trees is prohibited unless authorized by the Tree Warden or the Tree Planting Committee as set forth below.

7.2 Procedures

In connection with Major Construction or Demolition, the owner of the property shall submit a proposal for tree removal and mitigation to the Building Commissioner with the application for a demolition or building permit. As part of the permit process, the property owner shall submit to the building commissioner a site plan drawn and stamped by a registered land surveyor showing all existing trees 8" DBH or greater.

The Building Commissioner shall refer the tree proposal to the Tree Warden. The Tree Warden shall conduct a site visit. If the applicant's proposal is consistent with the mitigation requirements herein, the Tree Warden will issue a permit within twenty (20) business days of receipt to authorize the tree work. If the proposal does not meet or satisfy these requirements, the Tree Warden shall so notify the applicant and deny the permit.

An applicant may appeal the denial or grant of a tree permit to the Tree Planting Committee. The Tree Planting Committee shall conduct a public hearing on the appeal and shall give the public notice thereof, at the expense of the applicant. Public notice shall include all persons owning land within 300 feet of any part of applicant's land at least fourteen (14) days before said hearing. The Tree Planting Committee shall rule within twenty business (20) days of the public hearing.

Appeals of final decisions of the Tree Planting Committee shall be to the Board of Selectmen.

7.3 Mitigation

A Protected Tree shall not be removed unless at least one of the following provisions is satisfied:

(a) Replanting of trees: such replanting shall be on the basis of ½ inch caliper of new tree(s) for each inch of DBH of tree(s) removed, and each replanted tree must have a minimum caliper of 3 inches. The replanting shall occur no later than 12 months after completion of the construction work, either on applicant's land or on land abutting applicant's land with express approval of the owner of such abutting land; or other site as approved by the Tree Warden

(b) Contribution into the Tree Replacement Fund: such contribution shall be $50 per DBH inch of Protected Tree removed not already mitigated as per section 7.3 (a); or

(c) The applicant demonstrates that the removal of a Protected Tree does not adversely impact the interests identified in section one of this by-law.

7.4 Tree Replacement Fund
The Director of Parks and Open Space with input from the Tree Warden, shall have sole discretion concerning the use of funds from the Tree Replacement Fund which shall be disbursed by the Tree Warden for the planting (and maintenance, as necessary) of trees on public land or private property with express approval of the owner of such private property.

Section 8: Emergencies and Exemptions

Provisions of this by-law shall not apply to:

(a) emergency projects necessary for public safety, health and welfare as determined by the Commissioner of Public Works or the Director of Parks and Open Space; and
(b) trees that are hazardous (threat to life and/or property) as determined in writing by the Tree Warden and/or the Town Arborist; and
(c) trees identified by the Commonwealth that pose a risk due to insect/disease infestation.

Section 9: Enforcement/Penalties

9.1 Enforcement:
Any person violating this by-law is subject to the penalties under Article I, Section 6 as amended in this warrant article; General Law Chapter 87 (for violating Section 6 of this by-law); and other legal enforcement action by the Town. The Tree Warden is authorized to enforce the provisions of Article I of the General By-laws and the provisions of General Law Chapter 87. Any other legal enforcement action shall be determined by the Board of Selectmen in consultation with the Tree Planting Committee, the Tree Warden and Town Counsel.

9.2 Penalties:
Any person who removes or trims a public shade tree without a permit or hearing as required by law shall be subject to cumulative fines as follows:

- up to $500 as provided by Massachusetts General Laws Chapter 87, § 6.

- Triple damages as set forth in Massachusetts General Laws Chapter 242, § 7.

Each instance in which a Protected Tree is removed without a Tree Permit shall constitute a violation of this by-law and shall be subject to a fine of $300 and $50 per caliper inch.

A violation of the provisions of this by-law shall result in the revocation of a building permit.

Section 10: Rules and Regulations

The Selectmen may promulgate, after public notice and hearing, Rules and Regulations to effectuate the purposes and intent of this By-law. Failure by the Selectmen to promulgate such Rules and Regulations shall not act to suspend or invalidate the effect of this By-law.

Section 11: Severability

If any section, paragraph or part of this by-law is for any reason declared invalid or unconstitutional by any court, every other section, paragraph and part shall continue in full force.

Section 12: <u>Relationship to Other By-laws</u>

Nothing in this by-law shall be construed to restrict, amend, repeal, or otherwise limit the application or enforcement of existing Town of Brookline by-laws or Commonwealth of Massachusetts laws.

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Appendix D - USFS Urban Forest Sustainability & Management Review

Summary: Overall Management Evaluation

		Sum of Evaluations			
Category	Description	SOC (% Achieved)	Base (% Achieved)	Overall Rating	Overall (% Achieved)
1	Management Policy and Ordinances	75.0%	66.7%	19	67.9%
2	Professional Capacity and Training	116.7%	NA	11	91.7%
3	Funding and Accounting	100.0%	NA	8	66.7%
4	Decision and Management Authority	100.0%	100.0%	8	100.0%
5	Inventories	NA	66.7%	15	75.0%
6	Urban Forest Management Plans	NA	50.0%	11	61.1%
7	Risk Management	83.3%	100.0%	14	87.5%
8	Disaster Planning	NA	100.0%	8	100.0%
9	Practices, Standards, and BMPs	75.0%	75.0%	37	68.5%
10	Community	100.0%	NA	14	53.8%
11	Green Asset Evaluation (Observed Outcomes)	NA	NA	18	90.0%
	Total	92.9%	79.8%	163	73.4%

Scoring Guide: Sustainability and Management Attainment Levels

Level	Description	Attainment
One	Meets prerequisites for classification as an urban forest management program. Needs improvement in multiple areas to achieve minimal overall competency	Is operating with several "key" elements
Two	Meets minimal level of overall competency, notwithstanding multiple opportunities for improvement within individual categories.	Base Practices at 80% attainment.
Three	Exceeds minimal level of overall competency, with commendable performance in some individual categories. In addition, has adopted some elements beyond Base and SOC elements.	Base Practices (≥80%) and Standard of Care (≥80%).
Four	Greatly exceeds minimal level of overall competency, with best-in-class performance in several individual categories. In addition, has adopted significant elements beyond Base and SOC elements.	Base Practices (≥90%) and Standard of Care (100%).

1 Management Policy and Ordinances

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
1.00	Approved Policy Statements	Written policy statements approved by a governing body.	
1.01	Climate Change (Sustainability)	Also referred to as Sustainability. With reference to urban trees. Addresses the long-term health and productivity of the natural resource.	**2) Adopted Common Practice**
1.02	No Net Loss	Can refer to trees, basal area, or canopy.	**1) In Development**
1.03	Risk Management	Should reference: ANSI A300 Part 9, ISA BMP, and prioritization funding mechanisms.	**1) In Development**
1.04	Tree Canopy Goals	Overall community/campus goal, or by designated "zone".	**1) In Development**
1.05	Tree Protection	Construction and/or landscape maintenance.	**2) Adopted Common Practice**
1.06	Utility	Utility pruning, planting, and installation policy (e.g. boring vs. trenching).	**2) Adopted Common Practice**
1.07	Human Health – Physical & Psychological	Recognizes and addresses the human health benefits of the natural resource (e.g. exercise, air quality, stress management, shade). Could also include Urban Heat Island (UHI) policies.	**1) In Development**
1.08	Wildlife Diversity/Habitat/Protection	Mammals, birds, or reptiles.	**2) Adopted Common Practice**
1.09	Performance Monitoring	Recognizes the annual or biennial calculation of metrics (e.g. some component of ecosystem services) for the purpose of tracking management performance.	**1) In Development**
1.10	Ordinance (Private) ⊗	Tree protection and management for trees on private property.	**2) Adopted Common Practice**
1.11	Ordinance (Public)	Tree protection and management for public trees.	**2) Adopted Common Practice**
1.12	Development Standards	US Green Building Council's LEED® rating systems (or similar internationally) LEED v4 BD+C (Sustainable Sites) LEED 4 ND (Neighborhood Pattern & Design, Green Infrastructure) ASLA's SITES® Rating System	**0) Not Practiced**
1.13	High-Conservation Value Forests	Programs or policies for identification, acquisition, and/or protection of groups of trees or forests that provide unique public benefits.	**2) Adopted Common Practice**
1.14	Urban Interface (WUI)	Programs or policies that improve management of the urban interface for fire and/or invasive species.	**2) Adopted Common Practice**

Line Items Applicable (Count):	14
Catagory Goal (Sum):	28
Category Evaluation (Sum):	**19**
Category Percent Attained:	**67.9%**

SOC Applicable (Count):	2
SOC Goal (Sum):	4
SOC Sum:	**3**
% Category SOC Attained:	**75.0%**

BP Applicable (Count)	3
BP Goal (Sum):	6
BP Sum:	**4**
% Category BP Attained:	**66.7%**

2 Professional Capacity and Training

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
2.00	Professional Management	Provision for professional consultation.	
2.01	Certified Arborist - Staff		3) Exceeds Common Practice
2.02	Certified Arborist - Contracted		2) Adopted Common Practice
2.03	Certified Arborist - Other Resource		2) Adopted Common Practice
2.04	Other Professional - Advising/directing UF management	This could be a professional in an allied field like: LA.	2) Adopted Common Practice
2.05	Organizational Communications	Process, procedures, and protocol for cross-professional communications within the organization (all departments "touching" trees).	2) Adopted Common Practice

Line Items Applicable (Count):	6
Catagory Goal (Sum):	12
Category Evaluation (Sum):	**11**
Category Percent Attained:	**91.7%**

SOC Applicable (Count):	1
SOC Goal (Sum):	6
SOC Sum:	**7**
% Category SOC Attained:	**116.7%**

BP Applicable (Count)	0
BP Goal (Sum):	0
BP Sum:	**NA**
% Category BP Attained:	**NA**

3 Funding and Accounting

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
3.00	Urban Forestry Budget		
3.01	Budgeted Annually	Budget authorized/required for tree board, tree maintenance, and/or tree planting.	**2) Adopted Common Practice**
3.02	Contingency Budget Process	A protocol is in place to prioritize urban forestry management activities during budget shortfalls; e.g. during times of limited funding for: 1) risk management, 2) young tree care, 3) mulching.	**2) Adopted Common Practice**
3.03	Funding Calculated from Community Attribute	Budget in terms of per capita, per tree, or for performance (e.g. per tree weighted by size class or age.)	**1) In Development**
3.04	Funding Based on Performance Monitoring	Budget connected with/based on ecosystem service (ES) monitoring and performance.	**1) In Development**
3.05	Urban Forestry Line Item	Is the budget specific to urban forest management?	**2) Adopted Common Practice**
3.06	Green Asset Accounting	Maintain green infrastructure data in the "unaudited supplementary disclosure of an entity's comprehensive annual financial report (CAFR)". GASB 34 implementation for municipalities.	**0) Not Practiced**

Line Items Applicable (Count):	6
Catagory Goal (Sum):	12
Category Evaluation (Sum):	**8**
Category Percent Attained:	**66.7%**

SOC Applicable (Count):	1
SOC Goal (Sum):	4
SOC Sum:	**4**
% Category SOC Attained:	**100.0%**

BP Applicable (Count)	0
BP Goal (Sum):	0
BP Sum:	**NA**
% Category BP Attained:	**NA**

4 Decision and Management Authority

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
4.00	Authority		
4.01	Urban Forest Manager	Professional urban forest manager with authority over the program and day-to-day activity. Including designated budget line item.	**2) Adopted Common Practice**
4.02	Staff Authority	Designated staff with authority over the program and day-to-day activity. Including designated line item.	**2) Adopted Common Practice**
4.03	Communication Protocol	Established protocol and mechanism(s) for communication among all members of the urban forest management "community" in your municipality or organization (e.g. manager, department under control, advisory board, finance, field operations, public, NGOs, business community, developers).	**2) Adopted Common Practice**
4.04	Tree Board. Commission, or Advisory Council	Establishes a board for public participation (advisory or with authority).	**2) Adopted Common Practice**

Line Items Applicable (Count):	4
Catagory Goal (Sum):	8
Category Evaluation (Sum):	**8**
Category Percent Attained:	**100.0%**

SOC Applicable (Count):	2
SOC Goal (Sum):	4
SOC Sum:	**4**
% Category SOC Attained:	**100.0%**

BP Applicable (Count)	1
BP Goal (Sum):	2
BP Sum:	**2**
% Category BP Attained:	**100.0%**

5 Inventories

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
5.00	Inventories and Assessments		
5.01	Canopy Inventory (UTC)	Periodic (≤5 year) canopy inventory and assessment. Public & private.	**2) Adopted Common Practice**
5.02	Ecosystem Services	Is there a recent (≤5 year) ecosystem services (ES) inventory & assessment. Public: 100% or street trees; Public & Private: Sample; or Campus. Or, are ES calculated annually or biennially based on partial re-inventory and projected growth as a monitoring tool.	**1) In Development**
5.03	Public Trees	The publicly controlled urban forest.	
5.04	•Street Trees	Is there a recent (5 year) inventory?	**2) Adopted Common Practice**
5.05	•Parks Areas	Is there a recent (5 year) inventory?	**0) Not Practiced**
5.06	•Conservation Areas	Is there a recent (5 year) inventory?	**0) Not Practiced**
5.07	Continuous inventory on a cycle (≤5 years; i.e. panel)	Partial re-inventory to support continuous forest inventory, growth projections, and the calculation of ecosystem services for the purpose of long-term monitoring of urban forest management performance (e.g. carbon or leaf surface).	**2) Adopted Common Practice**
5.08	Continuous inventory on a cycle (≤5 years; i.e. panel)	Partial re-inventory to support continuous forest inventory, growth projections, and the calculation of ecosystem services for the purpose of long-term monitoring of urban forest management performance (e.g. carbon or leaf surface).	**1) In Development**
5.09	Green Stromwater Infrastructure (GSI)	BMP stormwater mitigation practices and locations (e.g. Washington DC)	**2) Adopted Common Practice**
5.10	Spatial	Inventory data includes Lat/Long (i.e. GIS). Should address the spatial relationship between the natural resource and people (i.e. residents, visitors, activities) that would help manage the resource for benefits associated with proximity (air quality, recreation, stress mitigation, improved educational opportunity).	**2) Adopted Common Practice**
5.11	Maintenance and Planting Records Maintained	Planting details (nursery, species, size, cost, contractor, etc.) maintained with inventory or as separate database or recordkeeping system. Also pruning and removal histories.	**2) Adopted Common Practice**

Line Items Applicable (Count):	10
Catagory Goal (Sum):	20
Category Evaluation (Sum):	**14**
Category Percent Attained:	**70.0%**

SOC Applicable (Count):	0
SOC Goal (Sum):	0
SOC Sum:	**NA**
% Category SOC Attained:	**NA**

BP Applicable (Count)	2
BP Goal (Sum):	6
BP Sum:	**4**
% Category BP Attained:	**66.7%**

6 Urban Forest Management Plans

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
6.00	Management Planning Activities		
6.01	Annual Maintenance Calendar	An annual calendar that defines typical activity by season. To support scheduling.	**2) Adopted Common Practice**
6.02	Public Trees	The publicly controlled urban forest.	
6.03	Street Tree Management	Is there a recent (5 year) plan for street trees?	**1) In Development**
6.04	Parks Management	Is there a recent (5 year) plan ?	**0) Not Practiced**
6.05	Conservation Areas Management	Is there a recent (5 year) plan ?	**0) Not Practiced**
6.06	Green Infrastructure	Is there a plan for green infrastructure (i.e. nodes & linkages)? Large-scale projects.	**1) In Development**
6.07	Other Written Plans	Other natural resource plans (e.g. tree canopy). May be a component of another plan.	**2) Adopted Common Practice**
6.08	Tree Planting	Is there a recent (3 year) tree planting plan?). May be a component of another plan.	**2) Adopted Common Practice**
6.09	UF as Part of a Comprehensive Plan	Is any UF management plan referenced in the comprehensive plan (i.e. county or municipality) or master plan (i.e. Campus)?	**2) Adopted Common Practice**
6.10	Urban Forest Planning and Management Criteria and Performance Indicators	Criteria and indicators based on *A Model of Urban Forest Sustainability* (Clark, J.R., Matheny, N.P., Cross, G., and Wake, V. 1997 Journal of Arboriculture.) or on work of W.A. Kenney, P.J.E. van Wassenaer, and A.L. Satel in *Criteria and indicators for strategic urban forest planning and management* . (2011)	**0) Not Practiced**

Line Items Applicable (Count):	9
Catagory Goal (Sum):	18
Category Evaluation (Sum):	**10**
Category Percent Attained:	**55.6%**

SOC Applicable (Count):	0
SOC Goal (Sum):	0
SOC Sum:	**NA**
% Category SOC Attained:	**NA**

BP Applicable (Count)	2
BP Goal (Sum):	4
BP Sum:	**1**
% Category BP Attained:	**25.0%**

7 Risk Management

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
7.00	Risk Management Activities		
7.01	TRAQ Attained	At least one staff or consultant is TRAQ.	**0) Not Practiced**
7.02	Annual Level 1 (ANSI A300 Part 9 & ISA BMP)	All trees in high occupancy areas visited annually.	**2) Adopted Common Practice**
7.03	Mitigation Prioritization	A protocol for prioritizing mitigation following Level 1 and Level 2 assessments. Reflects the controlling agency's threshold for risk.	**2) Adopted Common Practice**
7.04	Recordkeeping, Reporting, and Communications	A process has been put in place to maintain records on requests, inspections, evaluations, and mitigation of risk; and on the communications among the managers related to those risk assessments.	**2) Adopted Common Practice**
7.05	Standard of Care Adopted	Controlling authority has adopted a Standard of Care (SOC) or risk management policy.	**2) Adopted Common Practice**
7.06	Tree Risk Specification	Is there a written specification that meets requirements of ANSI A300 (Part 9)? **And**, has it been discussed with the controlling authority with relevance to the controlling authority's threshold for acceptable risk?	**2) Adopted Common Practice**
7.07	Urban Tree Risk Management	The community has prepared and follows a comprehensive program for urban tree risk management.	**2) Adopted Common Practice**
7.08	Invasive Management	Plan to address and manage invasive: plants, insects, and disease.	**2) Adopted Common Practice**

Line Items Applicable (Count):	8
Catagory Goal (Sum):	16
Category Evaluation (Sum):	**14**
Category Percent Attained:	**87.5%**

SOC Applicable (Count):	6
SOC Goal (Sum):	12
SOC Sum:	**10**
% Category SOC Attained:	**83.3%**

BP Applicable (Count)	1
BP Goal (Sum):	2
BP Sum:	**2**
% Category BP Attained:	**100.0%**

8 Disaster Planning

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
8.00	Disaster Planning Activities		
8.01	Response/Recovery Mechanism	Staff knowledge of the municipality’s protocol for requesting disaster resources through the county or state with access to mutual aid.	**2) Adopted Common Practice**
8.02	Urban Forestry Disaster Plan	A separate/specific plan within the urban forestry management program (i.e. who to call, priorities).	**2) Adopted Common Practice**
8.03	Pre-disaster Contracts	Contracts are in place for critical needs.	**2) Adopted Common Practice**
8.04	Mitigation Plan	A mitigation plan has been developed for pre-disaster, recovery, and post-disaster.	**2) Adopted Common Practice**

Line Items Applicable (Count):	4
Catagory Goal (Sum):	8
Category Evaluation (Sum):	**8**
Category Percent Attained:	**100.0%**

SOC Applicable (Count):	0
SOC Goal (Sum):	0
SOC Sum:	**NA**
% Category SOC Attained:	**NA**

BP Applicable (Count)	3
BP Goal (Sum):	6
BP Sum:	**6**
% Category BP Attained:	**100.0%**

9 Practices, Standards and Best Management Practices

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
9.00	ANSI Standard & BMP Activities		
9.01	ANSI Standards	Reference and adherence to ANSI Standards for arboricultural practices (A300), safety (Z133), or Nursery Stock (ANSI Z60.1) (any or all).	**2) Adopted Common Practice**
9.02	Ages/Diameter Distribution	Specific management for the development of an age-diverse tree population	**1) In Development**
9.03	Arborist Standards	Standards of practice for arborists (i.e. Certification).	**2) Adopted Common Practice**
9.04	Best Management Practices (BMPs)	Establishes or references tree maintenance BMPs (i.e. written comprehensive standards & standards).	1) In Development
9.05	Fertilization and Mulching	Fertilization or mulching standards required for conserved & planted trees.	**2) Adopted Common Practice**
9.06	Lightning Protection Systems	BMP written to the ANSI A300 Standard.	**0) Not Practiced**
9.07	Planting	Planting and transplanting standards required/specified.	**2) Adopted Common Practice**
9.08	Pruning	Pruning standards required for conserved & planted trees.	**2) Adopted Common Practice**
9.09	Removal	Infrastructure damage, stump grinding, etc.	**2) Adopted Common Practice**
9.10	Support Systems (Guying and Bracing)	BMP written to the ANSI A300 Standard.	**2) Adopted Common Practice**
9.11	Tree Risk	Tree risk assessment procedures; ISA BMP or equivalent.	**2) Adopted Common Practice**
9.12	Construction Management Standards	Written standards for: tree protection, trenching/boring in CRZs, pre-construction mulching, root or limb pruning, watering (any or all).	**1) In Development**
9.13	Design Standards	Standards for design that specifically require trees; standards for tree placement (i.e. location), soil treatment, and/or drainage.	**2) Adopted Common Practice**
9.14	Genus/Species Diversity	Suggests or requires diversity of plant material.	**1) In Development**
9.15	Green Stormwater Infrastructure (GSI)	BMPs for site level GI practices like rain gardens and swales. Small-scale projects.	**0) Not Practiced**
9.16	Inventory Data Collection	Community has adopted or developed applicable (written) standards for local urban tree inventory data collection to support QA/QC. Currently, there is no identified national standard. But, the following have components and elements worth noting.	**2) Adopted Common Practice**
9.17	Minimum Planting Volume	Minimum required root zone volume.	**2) Adopted Common Practice**
9.18	Minimum Tree Size	Minimum caliper for tree replacements, and/or minimum size of existing trees to receive tree density or canopy credit.	**2) Adopted Common Practice**
9.19	Root Protection Zone (CRZ)	Defines adequate root protection zone; Critical Root Zone (CRZ).	**2) Adopted Common Practice**
9.20	Topping	Prohibits topping or other internodal cuts (public & private).	**2) Adopted Common Practice**
9.21	Tree Species List	Identifies and publishes a list of the most desirable, recommended, and/or preferred species (may include native and non-native species); alternatively, a list of species prohibited.	**2) Adopted Common Practice**

Continued on next page

9 Practices, Standards and Best Management Practices, continued

9.22	Tree Quality Standards	Written standards for tree selection at nursery in addition to Z60.1.	**2) Adopted Common Practice**
9.23	Utility Right-of-Way (ROW) Management	Requirements for planting, pruning, and/or removal of trees within a utility ROW.	**2) Adopted Common Practice**
9.24	Urban Agriculture	Enabled urban food forestry practices.	**0) Not Practiced**
9.25	Wood Utilization	Larger diameter material is processed for wood products.	**0) Not Practiced**
9.26	Third-party forest products certification compliance	Adoption of one of the international standards for production of wood products (for example): American Tree Farm System (ATFS) Forest Stewardship Council™ (FSC®) Programme for the Endorsement of Forest Certification (PEFC) Sustainable Forestry Initiative (SFI) Sustainable Forest Management Standard (Canada)Adoption of one of the international standards for production of wood products (for example): American Tree Farm System (ATFS) Forest Stewardship Council™ (FSC®) Programme for the Endorsement of Forest Certification (PEFC) Sustainable Forestry Initiative (SFI) Sustainable Forest Management Standard (Canada) Standards can apply to any/all publicly owned and managed trees; parks, street trees, and/or community forests.	**0) Not Practiced**
9.27	Energy generation	Local or regional use of chips or other woody debris for co-generation facilities.	**0) Not Practiced**
9.28	Composting of Leaf and/or Other Woody Debris	Leaves and small woody debris are captured and used on-site or processed by someone by composting for reuse.	**2) Adopted Common Practice**

Line Items Applicable (Count):	27
Catagory Goal (Sum):	54
Category Evaluation (Sum):	**37**
Category Percent Attained:	**68.5%**

SOC Applicable (Count):	2
SOC Goal (Sum):	4
SOC Sum:	**3**
% Category SOC Attained:	**75.0%**

BP Applicable (Count)	7
BP Goal (Sum):	16
BP Sum:	**12**
% Category BP Attained:	**75.0%**

10 Community

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
10.00	Activities That Build Community		
10.01	American Grove	Does your community/campus use American Grove to document and publicize your urban forestry program, activity, or events?	**0) Not Practiced**
10.02	Education	The urban forest is used as an educational laboratory for class activity; Kids in the Woods, PLT, high school, or college level.	**2) Adopted Common Practice**
10.03	Open Tree Map	Public access to the community tree resource via an on-line mapping program (i.e. any Web Map Service; WMS).	**2) Adopted Common Practice**
10.04	Public Perception	Is public management consistent with private property requirements for tree protections and care? Does the Campus/public tree management reflect neighborhood norms?	**2) Adopted Common Practice**
10.05	Recognition Programs	Programs that raise awareness of trees or that use trees to connect the community to significant events or activities.	
10.06	Arbor Day Celebration	Whether or not associated with Tree City USA.	**2) Adopted Common Practice**
10.07	Arboretum designation	Internal or third party arboretum designation.	**0) Not Practiced**
10.08	Significant trees	For example: size, history.	**1) In Development**
10.09	Memorial/Honorarium	Tree planting or tree care programs than honor/memorialize individuals, organizations, or events.	**2) Adopted Common Practice**
10.10	Social Media	Does your community/campus make use of Twitter, Facebook, Blogs for internal or external outreach?	**2) Adopted Common Practice**
10.11	Active Communications	Press releases, regular news articles (print), “State of the Urban Forest” reports, periodic analysis of threats and opportunities.	**2) Adopted Common Practice**
10.12	Tree Care	Are volunteers trained and used for basic tree care (e.g. mulching, pruning, planting).	**2) Adopted Common Practice**
10.13	Tree Campus USA®, Tree City USA®, Tree Line USA®	Community/campus meets current qualifications for any of these programs.	**2) Adopted Common Practice**
10.14	Volunteer Opportunities	Ad hoc or scheduled. Any/all age groups. Tree Campus USA student activities.	**1) In Development**

Line Items Applicable (Count):	13
Catagory Goal (Sum):	26
Category Evaluation (Sum):	**20**
Category Percent Attained:	**76.9%**

SOC Applicable (Count):	1
SOC Goal (Sum):	2
SOC Sum:	**2**
% Category SOC Attained:	**100.00%**

BP Applicable (Count)	0
BP Goal (Sum):	0
BP Sum:	**NA**
% Category BP Attained:	**NA**

11 Green Asset Evaluation (Observed Outcomes)

Category	Component Evaluated	Description or Criteria for Evaluation	Evaluation
11.00	Observed Outcomes (Activity, Health)		
11.01	Deadwood	Look for evidence of periodic or ad-hoc deadwood removal (i.e. lack of dead limbs ≥ 2" in the trees or on the ground).	**2) Adopted Common Practice**
11.02	Genus Diversity	No genera exceed **20%** of population; make specific observations for *Acer* , *Quercus* , and *Ulmus* .	**1) In Development**
11.03	Mature Tree Care	Mature trees are retained in the landscape, and are of acceptable risk; i.e. veteran tree management.	**2) Adopted Common Practice**
11.04	Mulching	Evidence of adequate (i.e. spatial extent, depth, and material) roots zone mulching for all age classes.	**2) Adopted Common Practice**
11.05	Planting Site Volume Optimization	Are species & sites matched for optimization of above ground canopy; right tree in the right spot concept.	**2) Adopted Common Practice**
11.06	Rooting Volume Optimization	Are species & sites matched for optimization for below ground rooting volume; right tree in the right spot concept.	**2) Adopted Common Practice**
11.07	Species Diversity	No species/cultivars exceed **10%** of population; make specific observations for *Acer* , *Quercus* , and *Ulmus* genera. Also evaluate the role of regionally local native species.	**1) In Development**
11.08	Soil Compaction	Observe evidence of soil compaction by users or staff during maintenance. Include "desire" lines and construction activity at time of evaluation.	**2) Adopted Common Practice**
11.09	Tree Health	Rate the overall tree health in all size (age) classes; look for crown dieback, decay, foliage density & color.	**2) Adopted Common Practice**
11.10	Young Tree Pruning	Look for evidence of periodic (e.g. every 3 years to year 9) structural pruning (e.g. subordination cuts, dominant central leader, co-dominant stems lower that 20').	**2) Adopted Common Practice**

Line Items Applicable (Count):	10
Catagory Goal (Sum):	20
Category Evaluation (Sum):	**18**
Category Percent Attained:	**90.0%**

SOC Applicable (Count):	0
SOC Goal (Sum):	0
SOC Sum:	**NA**
% Category SOC Attained:	**NA**

BP Applicable (Count)	0
BP Goal (Sum):	0
BP Sum:	**NA**
% Category BP Attained:	**NA**

Summary: Standard of Care (SOC) Evaluation

Category	Item	Description	Evaluation	Total
Management Policy and Ordinances	1.03	Risk Management	1) In Development	1
	1.11	Ordinance (Public)	2) Adopted Common Practice	2
Professional Capacity and Training	2.01	Certified Arborist - Staff	3) Exceeds Common Practice	3
	2.02	Certified Arborist - Contracted	2) Adopted Common Practice	2
	2.03	Certified Arborist - Other Resource	2) Adopted Common Practice	2
Funding and Accounting	3.01	Budgeted Annually	2) Adopted Common Practice	2
	3.02	Contingency Budget Process	2) Adopted Common Practice	2
Decision and Management Authority	4.01	Urban Forest Manager	2) Adopted Common Practice	2
	4.02	Staff Authority	2) Adopted Common Practice	2
Risk Management	7.01	TRAQ Attained	0) Not Practiced	0
	7.02	Annual Level 1 (ANSI A300 Part 9 & ISA BMP)	2) Adopted Common Practice	2
	7.03	Mitigation Prioritization	2) Adopted Common Practice	2
	7.04	Recordkeeping, Reporting, and Communications	2) Adopted Common Practice	2
	7.05	Standard of Care Adopted	2) Adopted Common Practice	2
	7.06	Tree Risk Specification	2) Adopted Common Practice	2
Practices, Standards, and BMPs	9.01	ANSI Standards	2) Adopted Common Practice	2
	9.10	Support Systems (Guying and Bracing)	2) Adopted Common Practice	2
Community	10.12	Active Communications	2) Adopted Common Practice	2
		Total		34
		Percent SOC Achieved		94.4%

Summary: Base Urban Forest Management Practices (BP)

Category	Item	Description	Evaluation	Total
Management Policy and Ordinances	1.02	No Net Loss	1) In Development	1
	1.04	Tree Canopy Goals	1) In Development	1
	1.06	Utility	2) Adopted Common Practice	2
Decision and Management Authority	4.04	Tree Board. Commission, or Advisory Council	2) Adopted Common Practice	2
Inventories	5.04	Is there a recent (5 year) inventory?	2) Adopted Common Practice	2
	5.05	•Parks Areas	0) Not Practiced	0
	5.06	•Conservation Areas	0) Not Practiced	0
	5.07	Continuous inventory on a cycle (≤5 years; i.e. panel)	2) Adopted Common Practice	2
	5.12	Continuous inventory on a cycle (≤5 years; i.e. panel)	1) In Development	1
Urban Forest Management Plans	6.03	Street Tree Management	1) In Development	1
	6.04	Parks Management	0) Not Practiced	0
	6.05	Conservation Areas Management	0) Not Practiced	0
Risk Management	7.07	Urban Tree Risk Management	2) Adopted Common Practice	2
Disaster Planning	8.02	Urban Forestry Disaster Plan	2) Adopted Common Practice	2
	8.03	Pre-disaster Contracts	2) Adopted Common Practice	2
	8.04	Mitigation Plan	2) Adopted Common Practice	2
Practices, Standards, and BMPs	9.03	Arborist Standards	2) Adopted Common Practice	2
	9.05	Fertilization and Mulching	2) Adopted Common Practice	2
	9.06	Lightning Protection Systems	0) Not Practiced	0
	9.07	Planting	2) Adopted Common Practice	2
	9.08	Pruning	2) Adopted Common Practice	2
	9.09	Removal	2) Adopted Common Practice	2
	9.10	Support Systems (Guying and Bracing)	2) Adopted Common Practice	2
		Total		31
		Percent BP Achieved		67.4%

Summary: Overall Management Evaluation

Category	Description	SOC (% Achieved)	Base (% Achieved)	Overall Rating	Overall (% Achieved)
1	Management Policy and Ordinances	75.0%	66.7%	19	67.9%
2	Professional Capacity and Training	116.7%	NA	11	91.7%
3	Funding and Accounting	100.0%	NA	8	66.7%
4	Decision and Management Authority	100.0%	100.0%	8	100.0%
5	Inventories	NA	66.7%	15	75.0%
6	Urban Forest Management Plans	NA	50.0%	11	61.1%
7	Risk Management	83.3%	100.0%	14	87.5%
8	Disaster Planning	NA	100.0%	8	100.0%
9	Practices, Standards, and BMPs	75.0%	75.0%	37	68.5%
10	Community	100.0%	NA	14	53.8%
11	Green Asset Evaluation (Observed Outcomes)	NA	NA	18	90.0%
	Total	92.9%	79.8%	163	73.4%

Urban Forest Sustainability and Management Review

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Appendix E - Letters of Comment

Brookline Housing Authority

90 Longwood Ave. Ste. 1
Brookline, MA 02446

TEL 617 277 2022
FAX 877 485 5549
TTD 800-545-1833 Ext. 213

October 15, 2021

Alexandra Vecchio
Brookline Parks and Open Space Division
333 Washington Street
Brookline, MA 02445

Re: Urban Forest Climate Resiliency Master Plan

Dear Ms. Vecchio:

The Brookline Housing Authority is pleased to voice our support for the Urban Forest Climate Resiliency Master Plan, including its 10-Year Action Plan. The Master Plan concluded that Brookline's urban canopy is not equitably distributed, and that certain areas across Town (primarily located in North Brookline) are canopy deficient. We firmly believe that Brookline's urban planning process must include the equitable distribution of trees across Town to ensure that vulnerable populations receive the multitude of benefits that trees provide, including positive impacts on public health, noise reduction, air quality, economic development, and climate resiliency. As discussed in the Master Plan, low income communities are typically more susceptible to urban heat island effect and other climate change stressors than other communities. The implementation of the goals and recommendations identified in the Urban Forest Climate Resiliency Master Plan are critical to ensure that Brookline's most vulnerable communities are not disproportionately impacted by the impacts of climate change.

The Brookline Housing Authority works in collaboration with the government and civic organizations to support and encourage the well-being and economic self-sufficiency of BHA residents; to sustain a diverse population in Brookline; and to maintain attractive residential neighborhoods. We look forward to supporting the Town of Brookline's Parks and Open Space Division in building a more resilient, equitable urban forest to benefit all Brookline residents.

Sincerely,

Michael Alperin, Executive Director

Town of Brookline

Conservation Commission

Associates
Marian Lazar

Marcus Quigley, Chair
Roberta Schnoor, Vice Chair
Werner Lohe
Pallavi Kalia Mande
Pamela Harvey
Samuel Burrington
Will Corrdin

August 3, 2021

Erin Gallentine
Commissioner of Public Works
333 Washington Street
Brookline, MA 02445

Re: Brookline Urban Forest Climate Resiliency Master Plan

Dear Commissioner Gallentine:

As chair of the Conservation Commission, I am writing to inform you that the Commission voted unanimously at our meeting on August 3, 2021 to accept and support the 10-Year Action Plan of the Brookline Urban Forest Climate Resiliency Master Plan. A representative of the Commission, Vice Chair Roberta Schnoor, served on the Select Board's Committee on Tree Protection - we are deeply appreciative of her efforts, as well as those of the entire Project Team and Committee.

Several years ago, the Conservation Commission led the extensive process of working with the community to create the Town's *2018 Open Space and Recreation Plan* to build on new and emerging concerns that will impact open space in the future. The UFCRMP directly addresses several of the proposed objectives listed in the plan, particularly: "Evaluate medium and long-term effects of climate change on the urban forest, and identify synergies in planning for climate change and protection of the urban forest".

The Conservation Commission recognizes the importance of utilizing nature-based solutions to address climate change impacts, and views the UFCRMP as a significant step towards protecting and enhancing one of Brookline's most significant natural resources. We are thrilled to have a comprehensive Master Plan to guide Brookline's urban forestry planning efforts, and look forward to supporting the implementation of the 10-Year Action Plan.

Sincerely,

Marcus Quigley
Chair

Town Hall ◆ 333 Washington Street ◆ Brookline ◆ Massachusetts 02445
Tel: (617) 730-2088 ◆ Fax: (617) 713-5727

Grassroots Support for a Green Community

October 22, 2021

Alexandra Vecchio

Brookline Parks and Open Space Division

333 Washington Street

Brookline, MA 02445

Re: Urban Forest Climate Resiliency Master Plan

Dear Ms. Vecchio:

The Brookline GreenSpace Alliance is in strong support of the Town's Urban Forest Climate Resiliency Master Plan and its corresponding 10-Year Action Plan. This Master Plan allows Brookline to strategically enhance its urban forest to combat the consequences of climate change and ensure the long-term viability of the Town's tree canopy and important benefits such as flood mitigation and decreasing the urban heat island effect.

The Brookline GreenSpace Alliance's mission is to preserve, protect and enhance the open spaces of Brookline, and we believe that protecting the urban tree canopy is an integral component to achieving this goal. We share the Parks and Open Space Division's vision of a healthy, resilient urban canopy in Brookline. The Brookline GreenSpace Alliance is excited to support the Town in implementing the goals and recommendations outlined in the Master Plan, and to see Brookline's urban forest thrive for years to come.

Sincerely,

Arlene Mattison, President

P.O. Box 470514 Brookline, MA 02447 Phone 617.277.4777
info@brooklinegreenspace.org www.brooklinegreenspace.org

TOWN of BROOKLINE

Massachusetts

Park and Recreation Commission

Park and Recreation Commission
John Bain, Chairperson
Nancy O'Connor, Vice Chairperson
Clara Batchelor
James Carroll
Daniel Lyons
Antonia Bellalta
Wendy Sheridan Ames

Director of Parks and Open Space
Alexandra Vecchio

Director of Recreation
Leigh Jackson

Erin Gallentine
Commissioner of Public Works
333 Washington Street
Brookline, MA 02445

October 12, 2021

Alexandra Vecchio
Brookline Parks and Open Space Division
333 Washington Street
Brookline, MA 02467

Re: Brookline Urban Forest Climate Resiliency Master Plan

Dear Commissioner Gallentine and Director Vecchio:

On October 12, 2021, the Park and Recreation Commission unanimously voted to accept and support the 10-Year Action Plan of the Urban Forest Climate Resiliency Master Plan. We recognize and appreciate the time and effort that Commissioner Batchelor dedicated to the one and a half-year long master planning process as a member of the Select Board's Committee on Tree Protection. We believe this Master Plan will serve as a comprehensive guide for the long- and short-term planning of Brookline's urban forest and ensure the long-term viability of this critical resource.

The Commission was excited to learn from the Master Plan that Brookline's parks and open spaces have "excellent" tree coverage, and look forward to implementing the action items identified in the plan to further bolster canopy in the Town's open spaces, while planning for the succession of declining trees and species at risk of pests or climate change. The Commission also firmly values the importance of environmental education and appreciated the robust community engagement process for this project, including five public forums, seven committee meetings, a community survey, yard signs, site visits, and an electronic mailing list.

The Park and Recreation Commission is confident that the Urban Forest Climate Resiliency Master Plan will provide significant benefits to the community and environment. We look forward to helping implement the Master Plan's 10-Year Action Plan and supporting the Parks and Open Space Division's efforts to preserve and enhance our urban forest for current and future generations.

Sincerely,

John T Bain

John Bain, Chair

333 Washington Street Street ✦ Brookline, Massachusetts 02445
https://www.brooklinema.gov

SELECT BOARD'S CLIMATE ACTION COMMITTEE

Heather Hamilton, Co-Chair
Werner Lohe, Co-Chair

Town of Brookline
Massachusetts

Town Hall, 3rd Floor
333 Washington Street
Brookline, MA 02445-6899
(617) 730-2130 Fax (617) 730-2442

October 26, 2021

Alexandra Vecchio, Director
Brookline Parks and Open Space Division
333 Washington Street
Brookline, MA 02445

Re: Urban Forest Climate Resiliency Master Plan

Dear Ms. Vecchio:

We are pleased to inform you that the Select Board's Climate Action Committee voted at its meeting on October 25, 2021 to accept and support the goals and objectives of the Urban Forest Climate Resiliency Master Plan. The Climate Action Committee enthusiastically supports the Department of Public Works' efforts to develop a more robust, equitable, and resilient urban canopy, and it believes that this plan is an essential step toward mitigating and adapting to climate change.

The Climate Action Committee serves to promote and implement resiliency measures to better prepare the Brookline community to adapt to climate change, and to help advance Brookline as a leader in diverse sustainable practices that contribute to environmental health, positive social impact, and economic development. The Town's urban forest, the product of over a century of maintenance and care, provides invaluable benefits to Brookline. The Committee is grateful to have participated in the planning process for this Master Plan and looks forward to continuing its role by working with the Select Board's Committee on Tree Protection and the Department of Public Works, Parks and Open Space Division to implement the goals and recommendations outlined in the master plan.

Sincerely,

Heather Hamilton, Co-Chair

Werner Lohe, Co-Chair

Nancy Heller, Chair
Select Board's Committee on Tree Protection
333 Washington Street
Brookline, MA 02445

Erin Gallentine
Commissioner of Public Works
333 Washington Street
Brookline, MA 02445

June 22, 2021

Re: 2021 Urban Forest Climate Resiliency Master Plan

Dear Ms. Heller and Commissioner Gallentine:

The Select Board is deeply appreciative of the work of the Select Board's Committee on Tree Protection and professional staff in providing the Town with a comprehensive Urban Forest Climate Resiliency Master Plan. Protecting and promoting a healthy, equitable and resilient urban forest is especially critical at the present moment, when the challenges associated with future climate change and vulnerability are immense. The Master Plan is laudable for its innovative, yet practical and actionable, canopy goals and recommendations, and will be an effective tool for urban forest planning and management for the next 10 years.

The Select Board hereby adopts the 2021 Urban Forest Climate Resiliency Master Plan for the Town of Brookline as presented on June 22, 2021. All of Town government and the entire community have much work ahead in executing the 10-year action plan contained within the Master Plan. We look forward to being part of that process.

Sincerely,

Select Board

333 Washington Street ✦ Brookline, Massachusetts 02445-6863
Telephone: (617) 730-2088 Facsimile: (617) 730-2258
www.brooklinema.gov

Town of Brookline

Dept. of Planning and Community Development
Sustainability
Tel: (617) 730-2130

333 Washington Street
Brookline, MA 02445

October13, 2021

Alexandra Vecchio
Brookline Parks and Open Space Division
333 Washington Street
Brookline, MA 02467

Re: Urban Forest Climate Resiliency Master Plan

Dear Ms. Vecchio:

I am pleased to support the Parks and Open Space Division's Urban Forest Climate Resiliency Master Plan, including its 10-Year Action Plan. The need for this Master Plan was not only voiced by the public at Brookline's first annual Sustainability and Climate Action Summit, but also constitutes a significant step towards achieving multiple priority actions identified in Brookline's 2017 Climate Vulnerability Assessment and Action Plan, including (but not limited to):

- Increase our tree planting efforts and thereby the percentage of beneficial canopy coverage across the community. This will boost climate resiliency by increasing tree diversity by selecting varieties well-adapted to warming temperatures and those that produce less allergens further supporting public health.
- Strategically deploy trees and landscaping efforts for heat relief based on heat mapping data.
- Incorporate climate resiliency into open space planning using strategic considerations that include:
    - protecting large and/or connected green spaces to foster resilience and biodiversity;
    - maintaining or creating open space buffers to protect water quality and provide flood protection; and
    - identifying locations where soils will support stormwater infiltration to replenish groundwater and support stream flow.
- Review and update the Comprehensive Emergency Management Plan to incorporate changes in emergency situations and response activities that may result from climate impacts.

The outcomes of this Master Plan will not only provide the Town of Brookline with a road map forward for developing a resilient and equitable urban canopy but will also provide the Town with a tailored set of tools to ensure that the goals and recommendations are actionable. This Master Plan is a terrific asset to the Town of Brookline and aligns firmly with the goals of the Town of Brookline's Climate Action Plan. I look forward to working with the Parks and Open Space Division in the implementation of the 10-Year Action Plan.

Sincerely,

Thomas Barrasso
Director of Sustainability

Town of Brookline

Massachusetts

Department of Planning and Community Development

Town Hall, 3rd Floor
333 Washington Street
Brookline, MA 02445
(617) 730-2130

Kara Brewton
Director

November 1, 2021

Alexandra Vecchio
Brookline Parks and Open Space Division
333 Washington Street
Brookline, MA 02445

Re: Urban Forest Climate Resiliency Master Plan

Dear Ms. Vecchio:

As the Director of Planning and Community Development for the Town of Brookline, I am pleased to support the Parks and Open Space Division's Urban Forest Climate Resiliency Master Plan, including its 10-Year Action Plan. Both Maria Morelli, Senior Planner, and I were involved in this planning process, and have appreciated the opportunity to collaborate with the Parks and Open Space Division on this important document.

The 10-Year Action Plan outlines several action-oriented objectives pertaining to regulatory processes and planning, including the incorporation of canopy-specific guidelines and requirements into the Zoning Bylaw, Section 5.09 'Design Review' and the development of an additional review process targeted at tree preservation and planting for any project that increases impervious surface or building footprint. The recommendations outlined in the Action Plan are the product of five public forums, seven committee meetings, and countless inter-departmental discussions. We feel that the recommended action items comprise necessary and pragmatic steps for the Town to effectively protect the urban forest across Brookline.

It is our hope that the outcomes of this Master Plan will not only serve the Town of Brookline, but also other municipalities that are facing similar climate-related challenges. We look forward to continuing to coordinate with the Parks and Open Space Division and Select Board's Committee on Tree Protection on implementing the goals and action items outlined in this Master Plan.

Sincerely,

Kara Brewton

Kara Brewton
Director of Planning and Community Development

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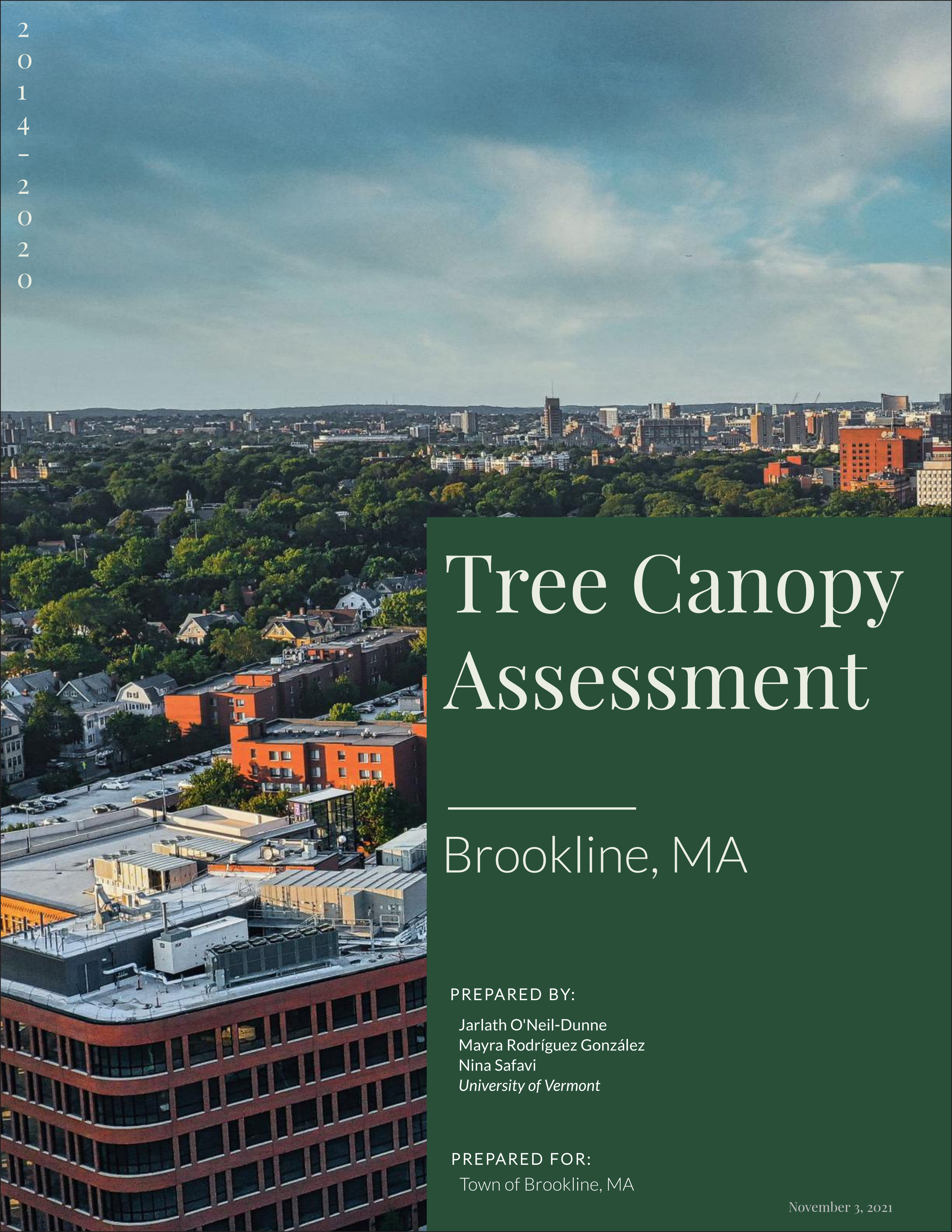
Appendix F - Tree Canopy Assessment, 2014-2020



2014–2020

Tree Canopy Assessment

Brookline, MA

PREPARED BY:

Jarlath O'Neil-Dunne
Mayra Rodríguez González
Nina Safavi
University of Vermont

PREPARED FOR:

Town of Brookline, MA

November 3, 2021

THE NEED FOR GREEN

Trees provide essential ecosystem services in Brookline, from reducing stormwater runoff to cooling the pavement in the summer to providing wildlife habitat. Trees are an indispensable part of Brookline's infrastructure. Research shows that these green assets can improve social cohesion, reduce crime, and raise property values. A healthy and robust tree canopy is crucial to building a more livable and prosperous town.

As with any community, Brookline faces a host of environmental challenges while seeking to maintain a balance between development and conservation. A healthy and robust tree canopy is crucial for maintaining this balance, providing Brookline's residents with a resource that will impact the health and well-being of generations to come.

TREE CANOPY ASSESSMENT

For decades governments have mapped and monitored their infrastructure to support effective management practices. Traditionally, that mapping has primarily focused on gray infrastructure, including features such as roads and buildings. Left out of this mapping has been an accounting of the green infrastructure.

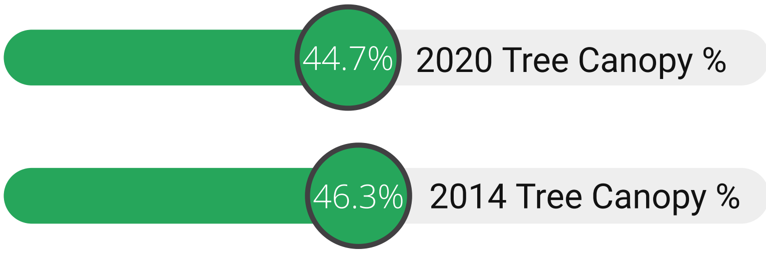
The Tree Canopy Assessment protocols were developed by the USDA Forest Service to help communities better understand their green infrastructure through tree canopy mapping and analytics. Tree canopy is the layer of leaves, branches, and stems that provide tree coverage of the ground when viewed from above. A Tree Canopy Assessment can provide vital information to help governments and residents chart a greener future by helping them understand the tree canopy they have, how it has changed, and where there is room to plant trees. Tree Canopy Assessments have been carried out for over 80 communities in North America. This study assessed tree canopy for the Town of Brookline over the 2014-2020 period.

TREE CANOPY BY THE NUMBERS

Change in tree canopy from 2014-2020.

204,000

Number of trees Brookline was estimated to have in 2020



Gain

153 acres of gain

Loss

224 acres of loss

-1.6%

Absolute change in tree canopy

-3.5%

Relative change in tree canopy

71 acres of net loss in tree canopy coverage.

The net amount of tree canopy loss is the equivalent of 34 football fields.

Key Terms

Existing Tree Canopy: The amount of tree canopy present when viewed from above using aerial or satellite imagery.

Possible Tree Canopy - Vegetated: Grass or shrub area that is theoretically available for **the** establishment of tree canopy.

Possible Tree Canopy - Impervious: Asphalt, **concrete** or bare soil surfaces, excluding roads and buildings, that are theoretically available for the establishment of tree canopy

Not Suitable: Areas where it is highly unlikely that new tree canopy could be established (primarily buildings and roads).

Measuring Tree Canopy Change

Area Change - the change in the area of tree canopy between the two time periods.

Relative % Change -the magnitude of change in tree canopy based on the amount of tree canopy in 2014.

Absolute % Change - the percentage point change between the two time periods.

FINDINGS

Brookline's tree canopy decreased from 2014 to 2020, with a relative loss of 3.5%.

There were 153 acres of tree canopy gained and 224 acres of tree canopy lost from 2014 to 2020.

Although tree canopy decreased, gains have also been observed. For example, affordable housing properties are actually experiencing an increase in tree canopy.

Tree canopy loss is neither evenly distributed nor similar. It varies from removal of individual trees in backyards to clearing of patches for new construction.

Residents control more tree canopy than other land use types and more tree canopy was lost on residential land than any other land use type

Tree canopy in the rights-of-way is increasing, proving that the town's investment in its street trees is paying off.

Land use history, urban forestry initiatives, natural processes, and landowner decisions, all play a role in influencing the current state of tree canopy in the town.

Despite the overall loss, there are gains indicating that tree planting and preservation efforts are effective and paying dividends as trees mature.

RECOMMENDATIONS

Preserving existing tree canopy is the most effective means for securing future tree canopy, as loss is an event but gain is a process.

Planting new trees in areas where tree canopy is low or in locations where there has been tree canopy removed will also help the town grow canopy.

Having trees with a broad age distribution and a variety of species will ensure that a robust and healthy tree canopy is possible over time.

Community education is crucial if tree canopy is to be maintained over time. Residents that are knowledgeable about the value and services trees provide will help the town stay green for years to come.

Integrate the tree canopy change assessment data into planning decisions at all levels of government.

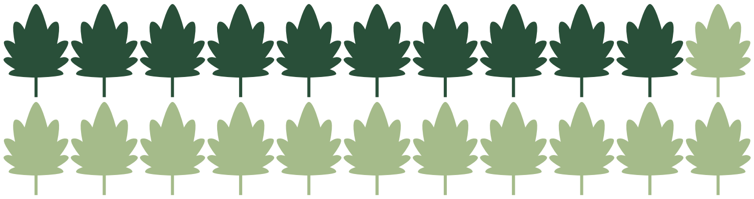
Reassess the tree canopy at 3-5 year intervals to monitor change.

Tree canopy assessments require high-quality, high-resolution data. Continue to invest in LiDAR and imagery to support these assessments and other mapping needs.

Field data collection efforts should be used to compliment this assessment as information on tree species, size, and health can only be obtained through on-the-ground inventories.

TREE CANOPY METRICS

44.7% *of Brookline's land is covered by tree canopy*



Tree canopy and tree canopy change were summarized at various geographical units of analysis, ranging from land use and property parcels to neighborhood boundaries. These tree canopy metrics provide information on the area of Existing and Possible Tree Canopy for each geographical unit.

Existing Tree Canopy

Brookline, like most municipalities, has an uneven distribution of tree canopy. There are some 5-hectare hexagons with less than 30% tree canopy and others with nearly 100% tree canopy (Figure 1). This unequal distribution can be traced back decades and reflects everything from development patterns to the placement of parks. Those residents living and working in more treed areas (darker green hexagons) benefit disproportionately from the ecosystem services that trees provide. Conversely, the more urbanized regions in the northern part of the town, have lower amounts of tree canopy and therefore receive fewer ecosystem services from trees.

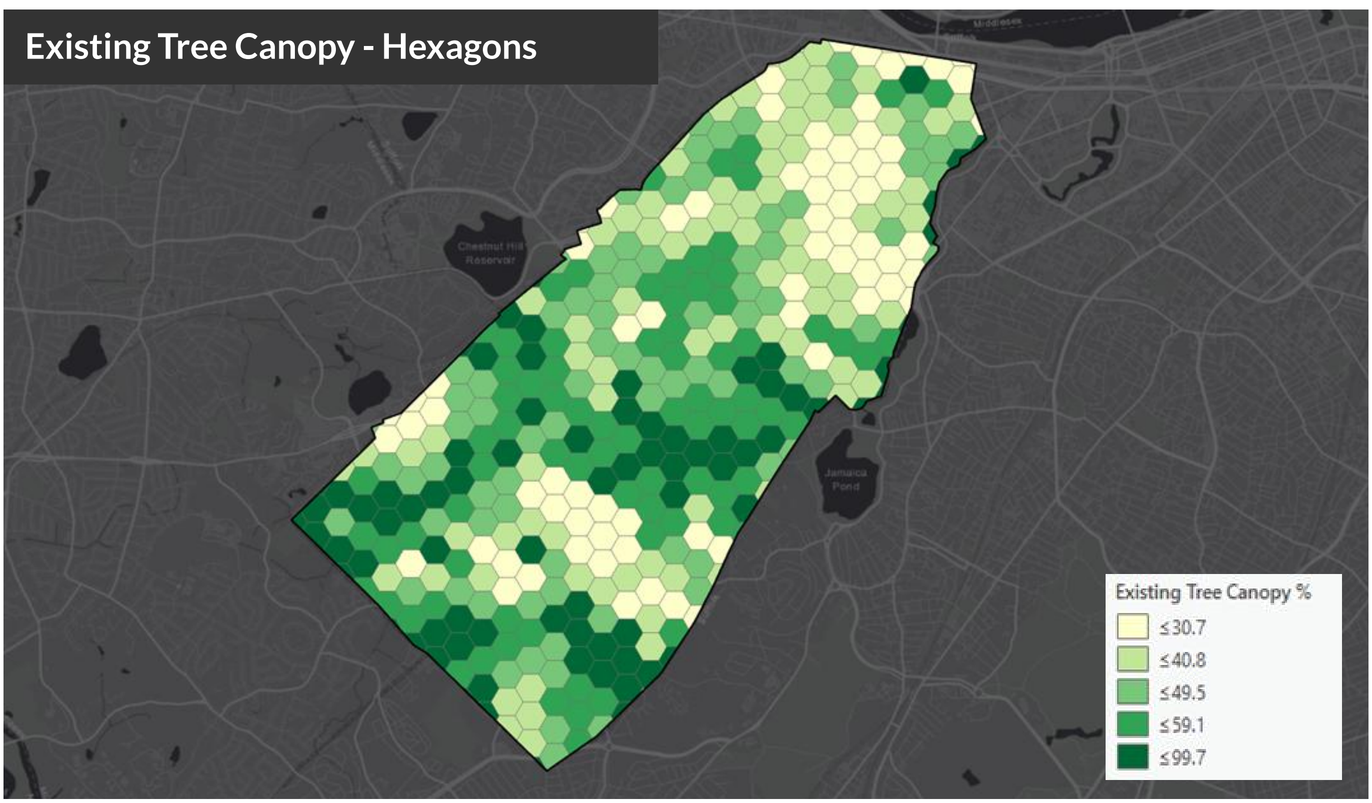


Figure 1. Existing tree canopy percentage for 2020 conditions summarized using 5-hectare hexagons. For each of the hexagons, the percent tree canopy was calculated by dividing the amount of tree canopy by the land area, which excludes water. Using hexagons as the unit of analysis provides a standard mechanism for visualizing the distribution of tree canopy without the constraints of other geographies that have unequal area (e.g., zip codes).

Possible New Tree Canopy

There is room in Brookline to plant more trees. In this assessment, any areas with no trees, buildings, roads, or bodies of water are considered Possible-Vegetation and represent locations in which trees could theoretically be established without having to remove paved surfaces. It should be noted that many other factors go into deciding where a tree can be planted and has the necessary conditions to flourish, including land use, landscape, social, and financial considerations. Examples include golf courses and recreational fields. While there is open space to plant trees, there is a direct conflict in use; thus, the Possible-Vegetation category should serve as a guide for further analysis, not a prescription of where to plant trees. With 967 acres of land (comprising 22% of the town's land base) falling into the Possible-Vegetation category, there remain significant opportunities for planting trees and preserving canopy that will improve the town's total tree canopy in the long term.

In Brookline's most densely urbanized areas, such as the commercial sectors, significantly increasing the tree canopy will be difficult; nevertheless, it remains vitally important to strive for canopy gains. In the town's residential areas, attention must be paid to ensure healthy natural regeneration of the existing tree canopy and planting new trees. This is particularly important given that a "plant and forget" cycle often exists, with trees on residential land primarily being planted when the land is developed.

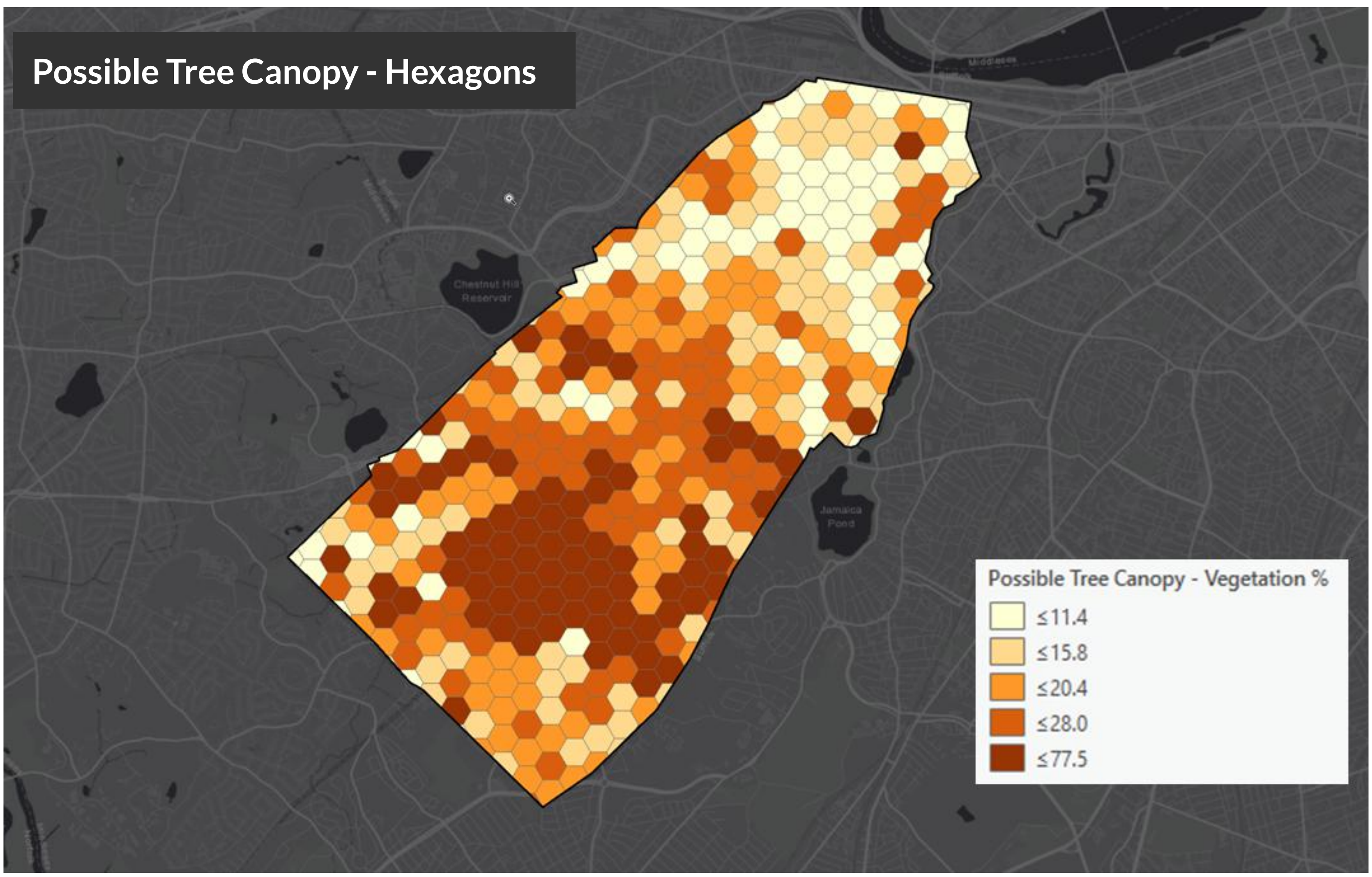


Figure 2. Possible Tree Canopy consisting of non-treed vegetated surfaces summarized by 5-hectare hexagons. These vegetated surfaces that are not currently covered by tree canopy represent areas where it is biophysically feasible to establish new tree canopy. It may be financially challenging or socially undesirable to establish new tree canopy on much of this land. Examples include golf courses, recreational and agricultural fields. Maps of the Possible Tree Canopy can assist in strategic planning, but decisions on where to plant trees should be made based on field verification. Surface, underground, and above surface factors ranging from sidewalks to utilities can affect the suitability of a site for tree canopy planting.

Canopy Change Distribution

The relative tree canopy change percentage shows the magnitude of change throughout the town over the 2014-2020 period. The relative change is calculated by taking the tree canopy area in 2014, subtracting the tree canopy area in 2020, then dividing this number by the area of tree canopy in 2014. Areas with the greatest change indicate that the canopy is markedly different in 2020 as compared to 2014. In some of the commercial and urbanized areas with little tree canopy in 2014, the growth of street trees resulted in a sizeable relative gain. Conversely, the removal of trees as a result of construction in sparsely treed areas resulted in substantial relative reductions in tree canopy.

The trajectory of Brookline's tree canopy in the future is uncertain. There are both environmental and anthropogenic risks facing canopy cover. Invasive species could pose a serious threat if not identified and controlled early. Natural events such as storms can have a mixed impact on the canopy. In conserved areas, tree canopy will return through natural growth, but in urbanized areas, trees lost to storms will need to be replanted. Climate change may cause trees to grow more quickly but could also result in inhospitable conditions for native species. Anthropogenic factors include preservation and conservation efforts, the strength of tree ordinances, and the conversion of agricultural land use to urbanized land use. Managing these risks will be key to achieving canopy growth.

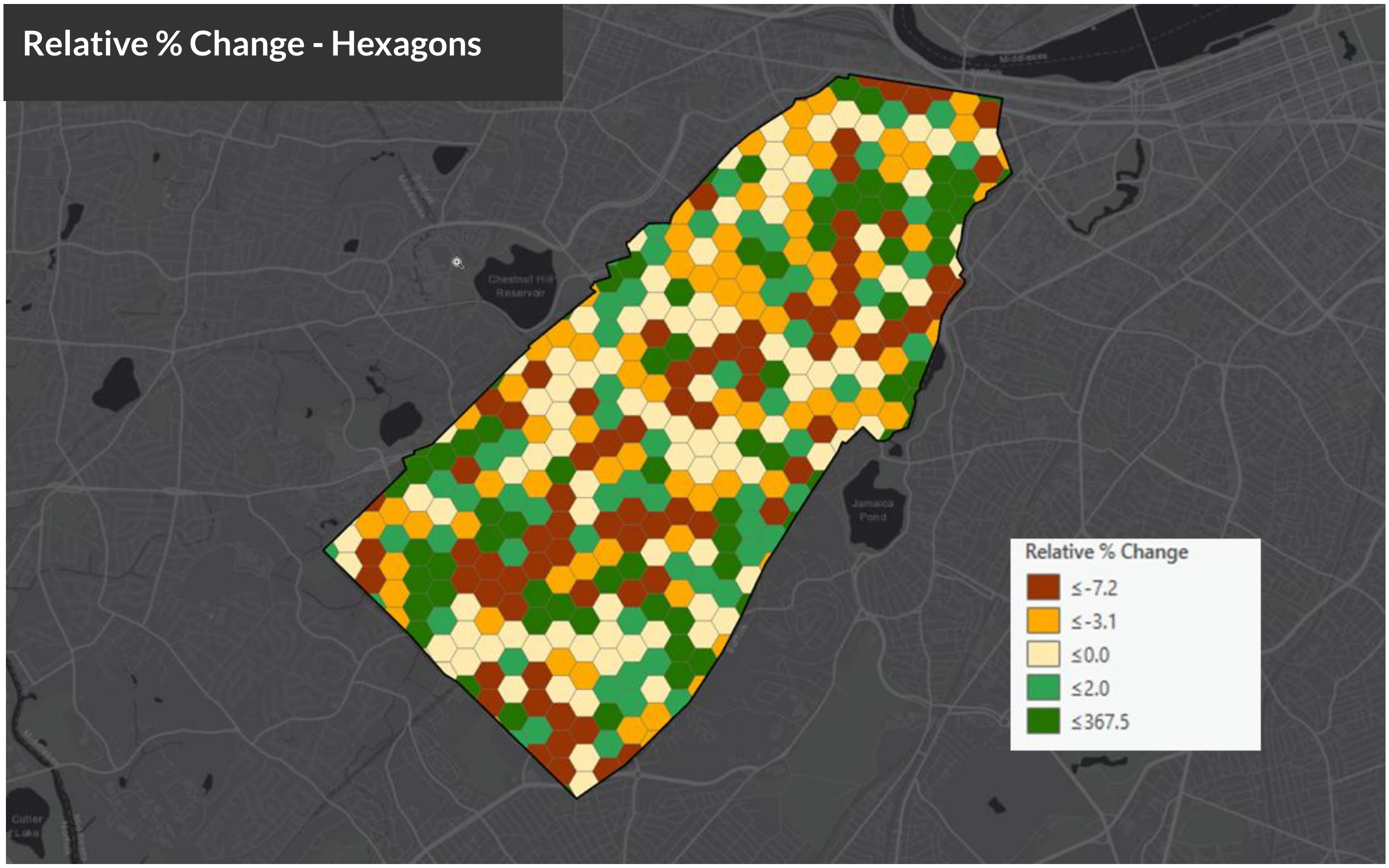


Figure 3: Tree canopy change metrics summarized by 5-hectare hexagons. Relative tree canopy is calculated by using the formula (2014-2020)/2020. Colors are categorized by data quantiles. Darker greens indicate greater relative gain, while darker orange reflects increasing magnitude of losses.

Change Examples

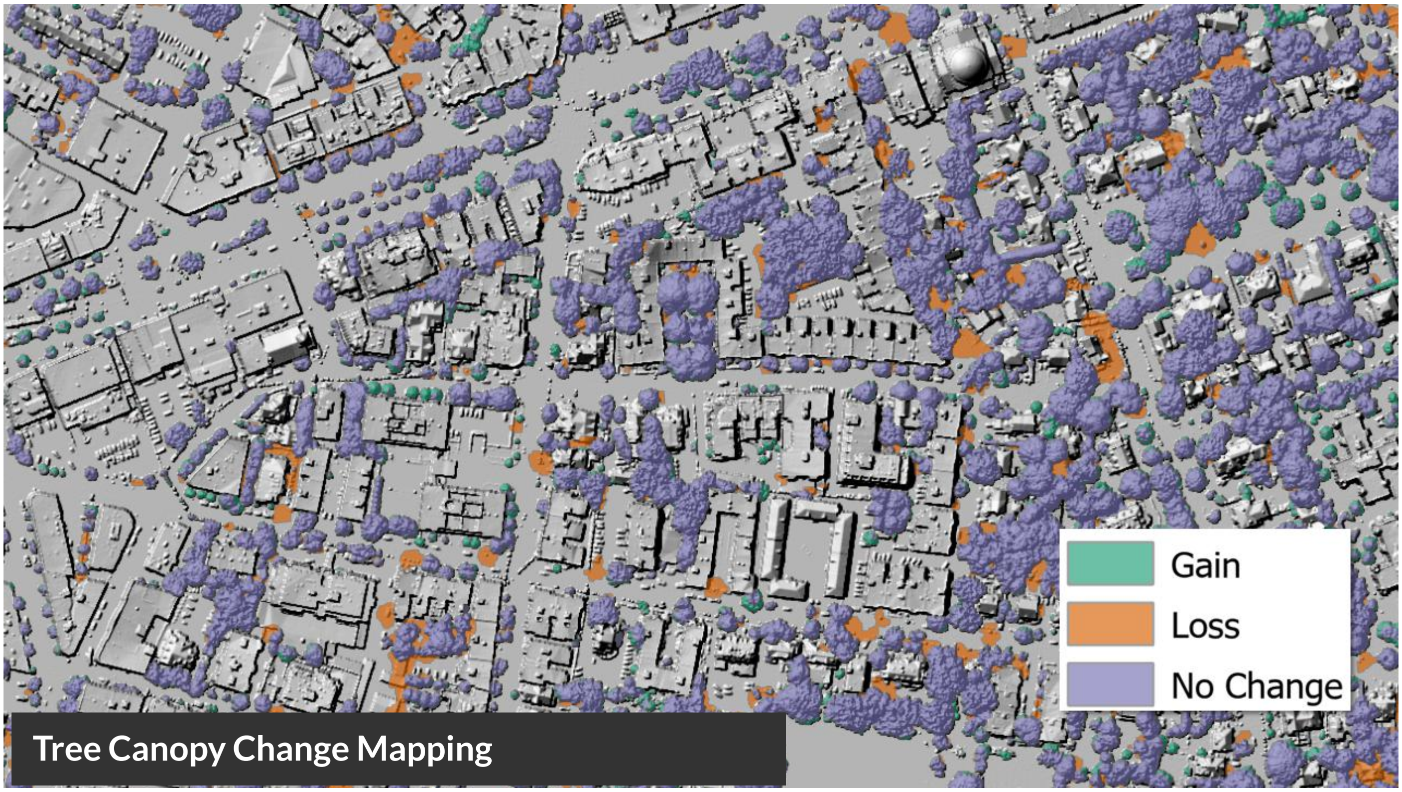


Figure 4: Tree canopy change mapping for the area in the vicinity of St. Paul Street and Sewall Ave. This area mainly experienced tree canopy loss (orange) due to the removal of reasonably mature trees. Gains (green) can be noted along the edges of existing trees but are most pronounced in recently planted trees. Tree canopy change is overlaid on a hillside layer derived from the 2020 LiDAR.

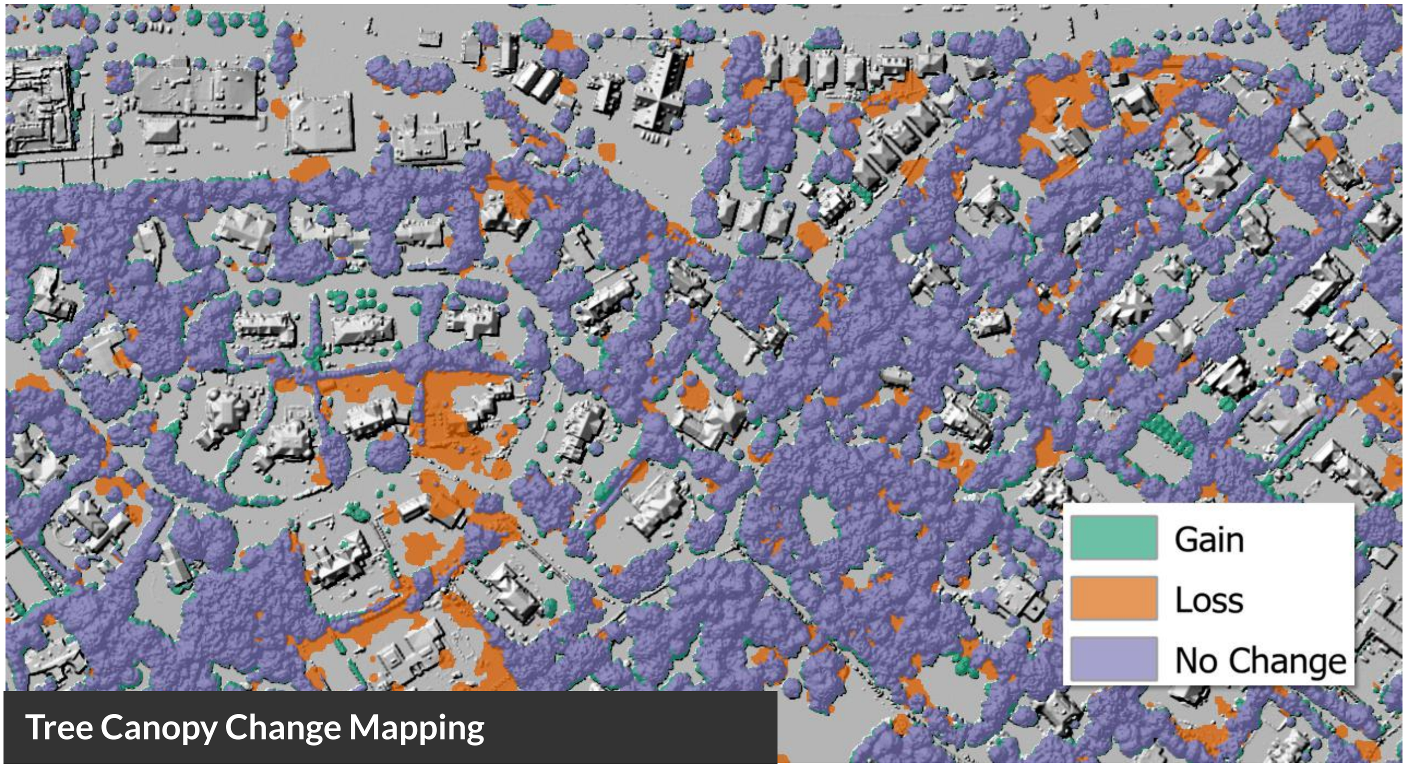


Figure 5: Tree canopy change mapping in the vicinity of Lyman Road and Heath Street. Despite the substantial growth, the removal of significant urban patches of tree canopy resulted in a large net loss. Tree canopy change is overlaid on a hillside layer derived from the 2020 LiDAR.

Land Use

Land use is how we, as humans, make use of the land. Land use is different from land cover. Land cover refers to the features, such as the trees, buildings, and other classes mapped as part of this study. For example, residential land use can contain tree, building, impervious, grass, and other land cover features. Land use can significantly influence the amount of tree canopy and the room available to establish new tree canopy.

Residential 1-3 family land controls twice as much tree canopy (844 acres) as the next highest land use class, the rights-of-way (ROW - 302 acres). In general, Brookline's 1-3 residential land has excellent tree coverage, with 51% of the land covered by tree canopy. The large amount of loss on 1-3 residential is cause for concern. 103 acres of tree canopy were lost in the six-year period, which could not be offset by the 64 acres of gain, resulting in a net loss of nearly 40 acres. The magnitude of loss was greatest on commercial land, but this had a near-negligible impact given how little tree canopy is on commercial land. Of all the land uses, only the ROW showed an increase.

Although the ROW consists of both public and private land, the majority is public. Trees in the ROW and urbanized areas face inhospitable conditions associated with their close proximity to roads. Regular salting, compaction, limited space, clearance pruning, and plow collisions are some of the challenges that limit canopy establishment and growth in these environments. The gain in the ROW is a sign of the town's effective maintenance and planting efforts. While the ROW experienced a net gain, it was small, with the 33 acres of gain only slightly outpacing the 32 acres of loss. Street trees not only make roads more aesthetically pleasing, but they also play an important role in reducing stormwater runoff and decreasing the urban heat island effect.

Figure 6: Land use.

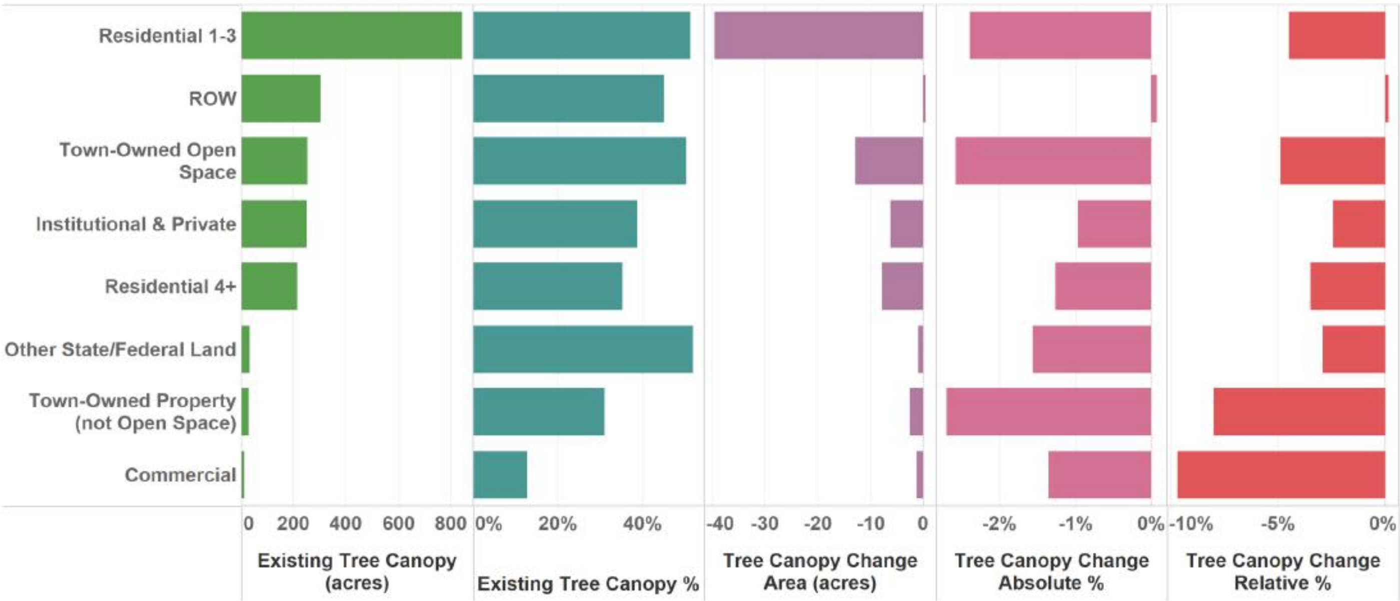


Figure 7: Tree canopy and change metrics for generalized land use categories.

Land Use (continued)

Institutional land and town-owned open space have the greatest proportion of their land available for establishing new tree canopy (possible-vegetation). Establishing new canopy in the rights-of-way (ROW) will be costly due to the modifications that need to be required but are worthwhile investments given the critical ecosystem services that street trees provide. There are clear signs across all land uses that development pressures are colliding with maintaining a robust tree canopy. In order for Brookline to grow its tree canopy into the future, organizations, institutions, businesses, and residents must see the value in this crucial green infrastructure asset.

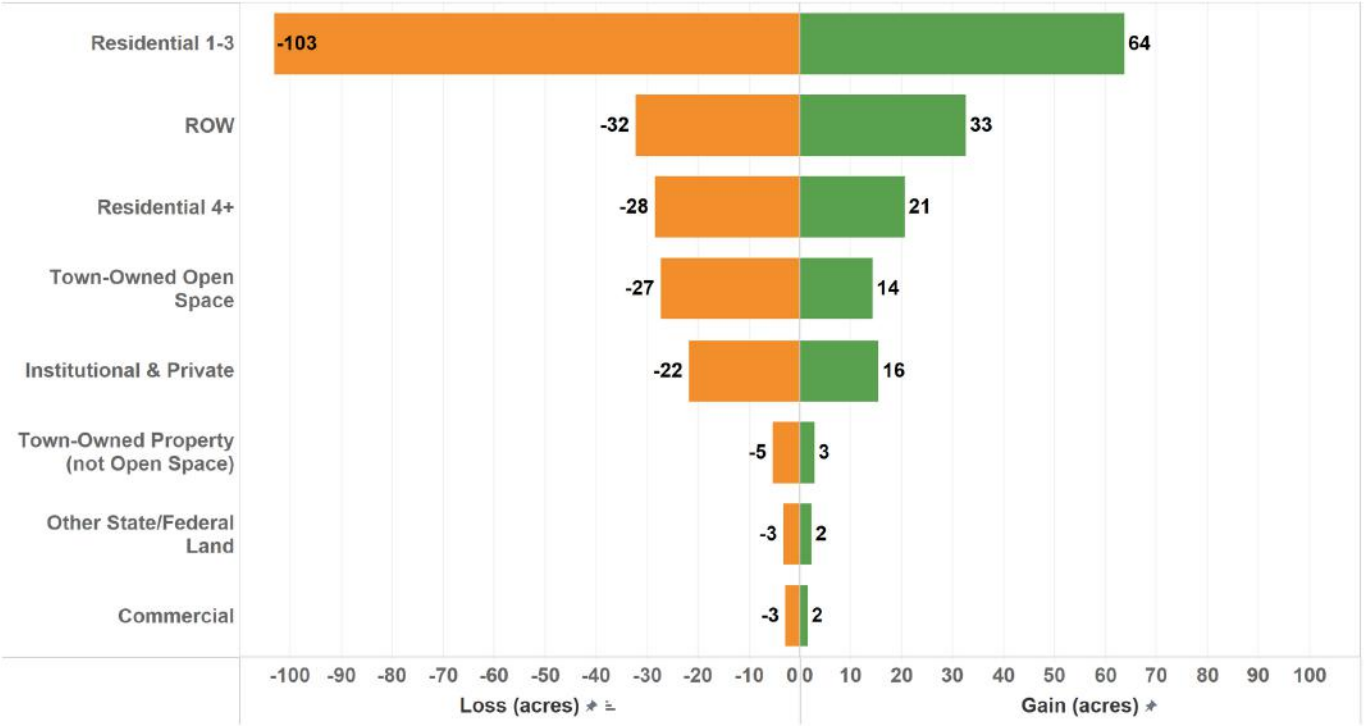


Figure 8: Tree canopy gain (green) and loss (orange) by generalized land use class.

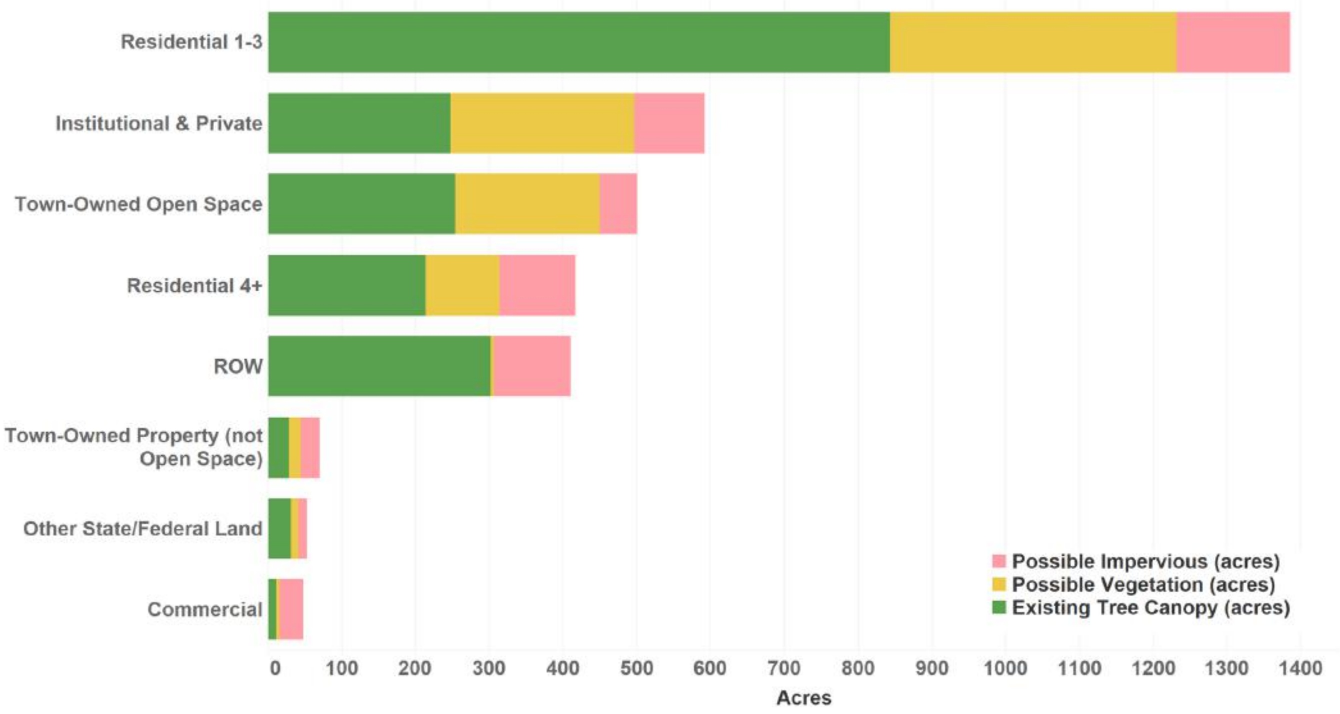


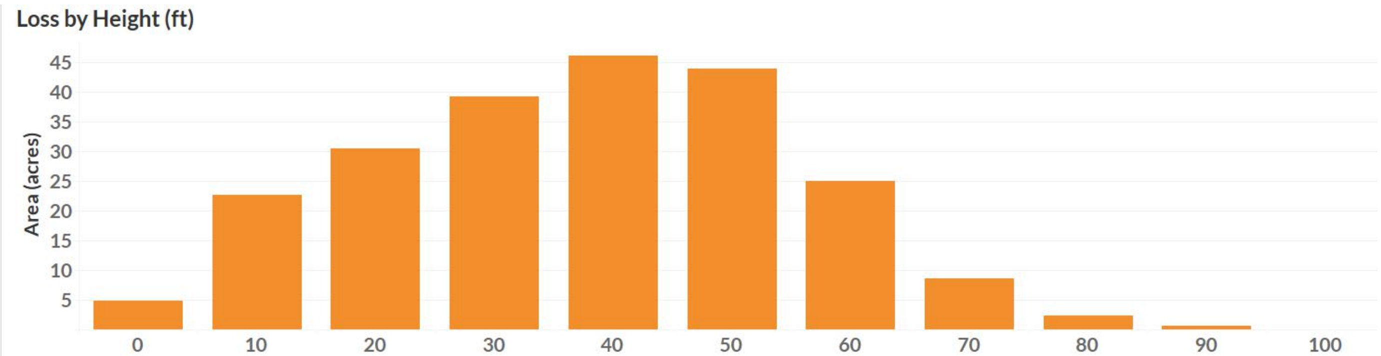
Figure 9: Existing and possible tree canopy metrics by generalized land use.

Tree Height

Removing trees before they reach maturity hampers the potential for a community to retrieve its full canopy potential. There is no easier way to increase tree canopy than retaining the trees that are present. This assessment used the LiDAR from the two time periods to quantify the height of the canopy that was lost and gained. Tree height also serves as a useful proxy for tree age and can provide insights into the age distribution of trees. Even aged urban tree canopy, stemming from tree plantings done around the same time creates a situation in which the trees may all die off around the same period, resulting in a sudden loss of canopy.

Of the 224 acres of tree canopy loss, 187 of those acres were from trees 50 feet or less. The removal of trees in these high classes means that many trees never have the opportunity to reach their full canopy potential and provide the peak amount of ecosystem services they are capable of delivering. Trees in the under 50-foot high class are also the ones that show the greatest growth and thus their removal at a time when they could be contributing measurably to the overall canopy is cause for concern. The lack of tree canopy gain in the tallest type classes, over 60 feet, is understandable given the challenges of retaining large trees and urban areas. Nevertheless, it is these large trees that can provide the greatest benefits for everything from wildlife habitat to reducing the urban heat island. Efforts to maintain large trees particularly near structures can help to reduce building cooling costs.

Nearly 40% of Brookline's tree canopy is within the 50 to 60-foot height class. It is likely that this consolidation of trees in a similar age range is rooted in the town's land use history. Trees are typically planted at the conclusion of new construction, and with neighborhoods springing up at similar times, the canopy will tend to be close in age. It will be important to not only allow younger trees to flourish but also to plant new trees to create an uneven age distribution. This will be most crucial on residential lands where many owners may not be considering the impact of having an even-aged canopy.



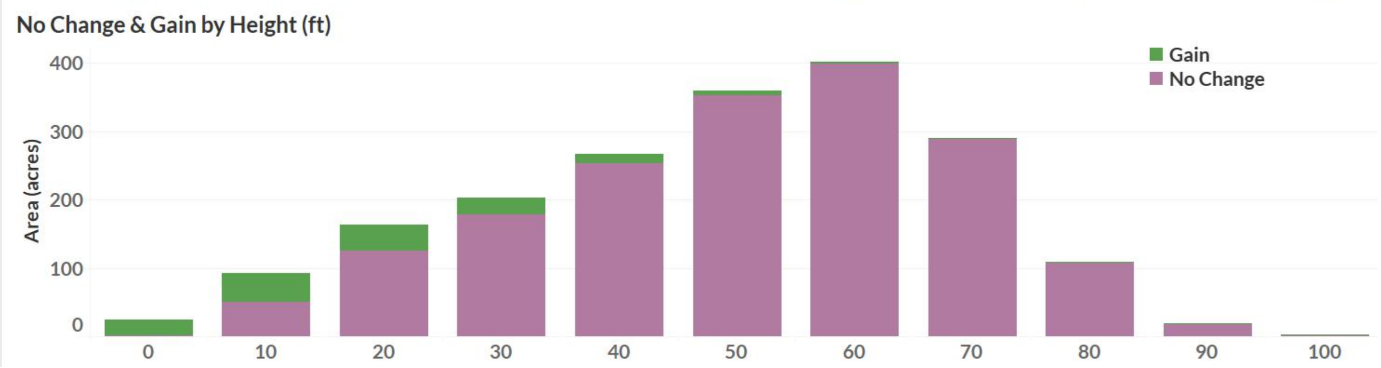


Figure 10: The tree canopy was segmented into polygons approximating individual trees. Each of these polygons was then attributed with the height from both the 2014 and 2020 LiDAR data. The height from the 2014 LiDAR was used to understand loss (top orange), whereas the height from the 2020 LiDAR was used to understand the gains (bottom green).

Change Type

Connected tree canopy forms patches that provide greater ecosystem services. These clumps of urban trees serve as important refuges for wildlife and have more measurable impacts on reducing the urban heat island. Examining the spatial distribution of tree canopy change provides insights into the fragmentation of the tree canopy along with an understanding of where the new growth comes from. The vast majority of the tree canopy loss broke up previously connected tree canopy. At the same time, most of the gains in tree canopy occurred either on the periphery of the existing canopy or from new connections between adjacent tree canopies. Unfortunately, the losses of connected tree canopy outpaced those of the gains. The fact that most of the gains occurred along the edges of existing trees lends further weight to the importance of preserving the existing canopy. The small amount of growth from newly planted individual trees (gain-unconnected) is to be expected as these trees represent a small fraction of the town's overall tree canopy. They should not be dismissed as unimportant for as they mature their canopies may connect to form larger, more functional patches of tree canopy. These newly planted trees also constitute the future of Brookline's forest.

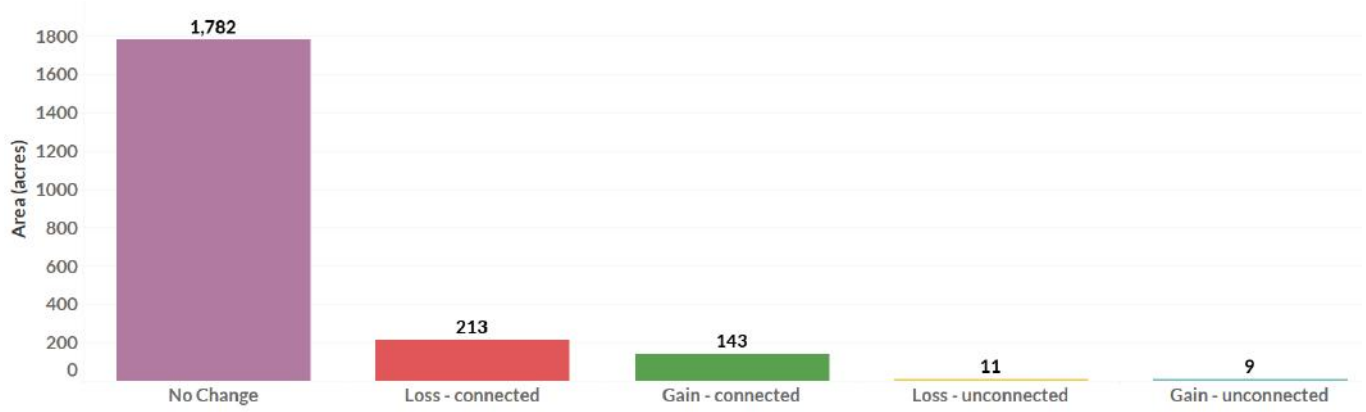


Figure 11: Tree canopy change type , which summarizes whether the acres of no change, gain, and loss are connected or unconnected to other tree canopies.

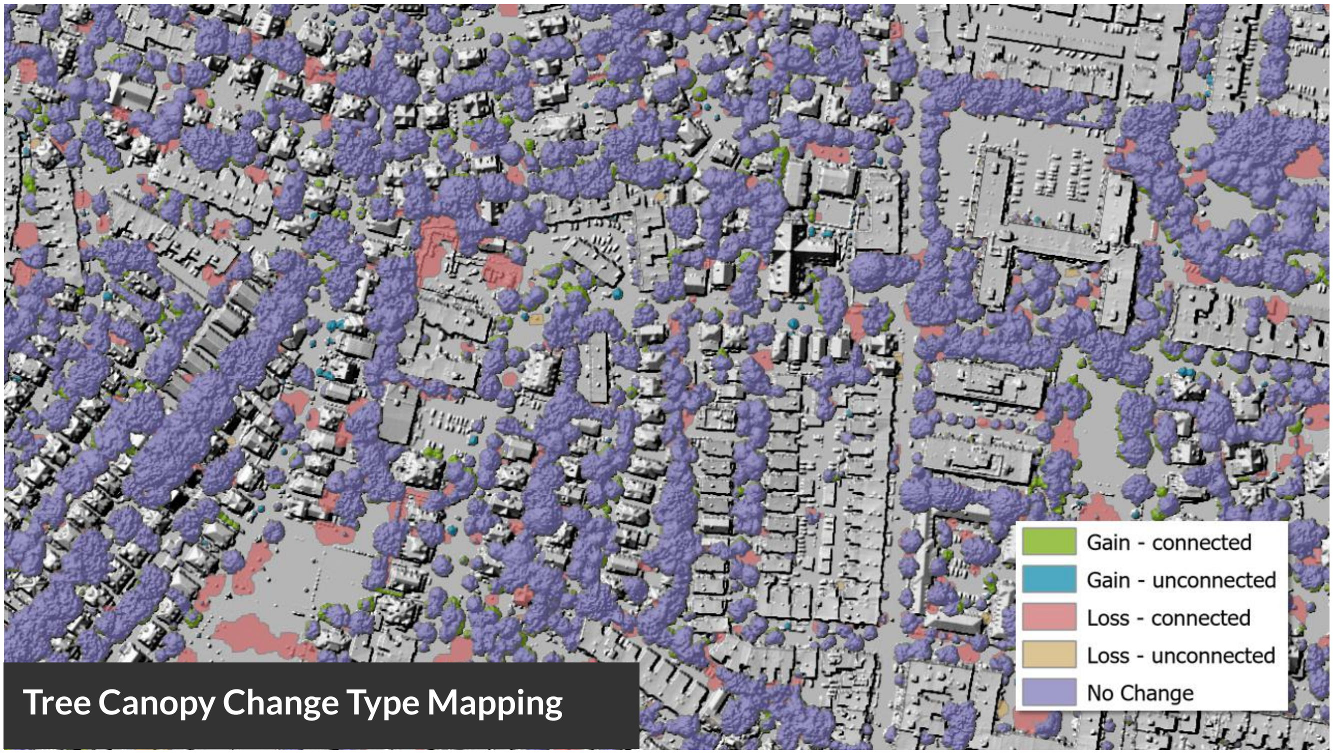


Figure 12: Visual example of the tree canopy change type mapping that categorizes whether no change, gain, and loss are connected or unconnected to other tree canopies.

EQUITY & ENVIRONMENTAL JUSTICE

Environmental Justice Neighborhoods

Tree canopy coverage in Brookline's environmental justice (EJ) neighborhoods is higher than the town average and greater than those neighborhoods that are not classified as EJ. In addition, tree canopy loss, while still occurring in EJ neighborhoods, is less than in other neighborhoods. Both of these indicators are positive signs that Brookline is committed to ensuring that the ecosystem services that trees provide are available to all residents. EJ neighborhoods are defined using state criteria (https://go.uvm.edu/l5wq0).

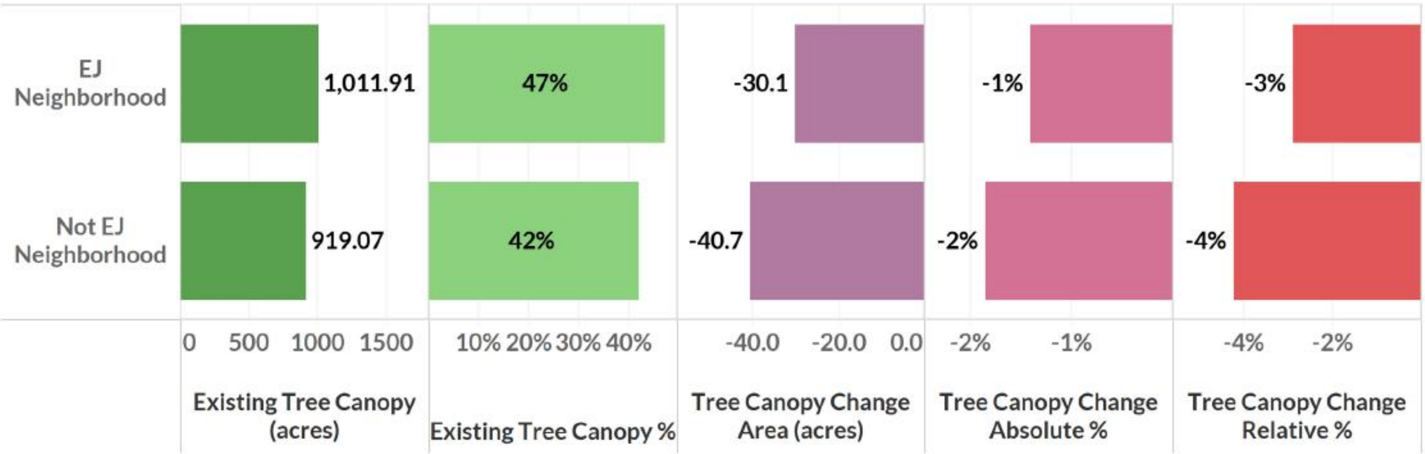


Figure 13. Tree canopy metrics for EJ and non-EJ neighborhoods.

Affordable Housing

Affordable housing properties constitute a small percentage of Brookline's residential land. They are in more urbanized areas, so it is not surprising that their canopy coverage (29%) is far lower than the town average. The positive news is that tree canopy on affordable housing lands has been increased (3% relative to 2014), while tree canopy on non-affordable housing lands declined by 4% (relative to 2014). The town's efforts to improve tree canopy equity on affordable housing properties are paying off.

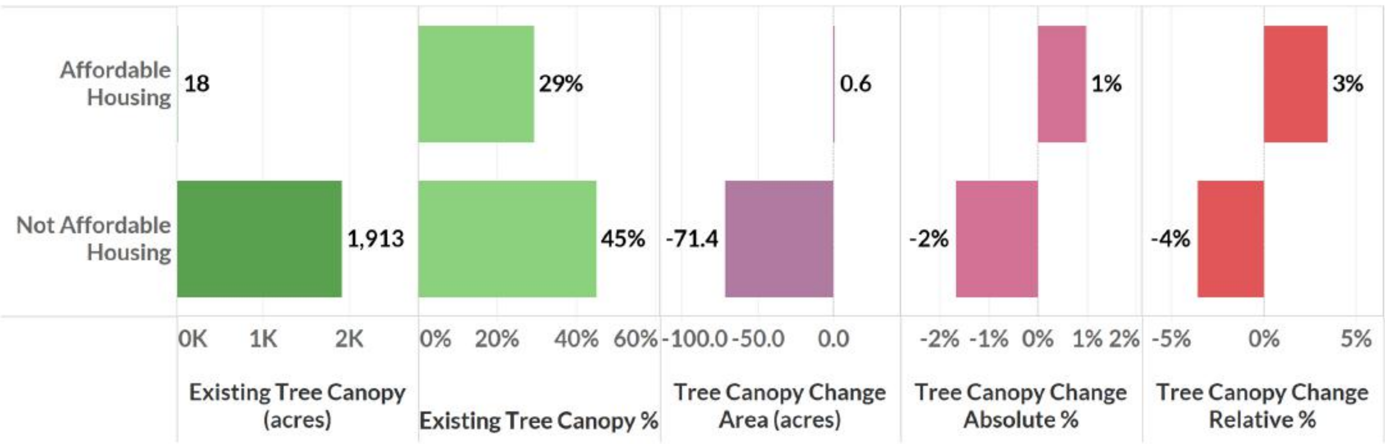


Figure 14. Tree canopy metrics for affordable housing properties.

TREE COUNT

204 thousand
trees in Brookline

Brookline has over 204,000 individual trees in the town, an estimate that was derived from the 2020 LiDAR data.

Tree Crowns & Centroids

Trees, particularly individual ones located in parks, on streets, on college greens, and on residential lands, require attention, care, and maintenance to thrive. In addition to quantifying the town's tree canopy acreage and percent coverage, this study produced an estimate of the number of individual trees in Brookline. This analysis was performed using the 2020 LiDAR data. While not a replacement for field-based inventories, LiDAR provides a unique advantage in that all of Brookline's trees can be counted. With Brookline having an estimated over 204,000 trees, it is important that the town adequately fund tree maintenance. Tree maintenance and care activities will ensure that these critical green infrastructure assets thrive in a challenging urban environment.

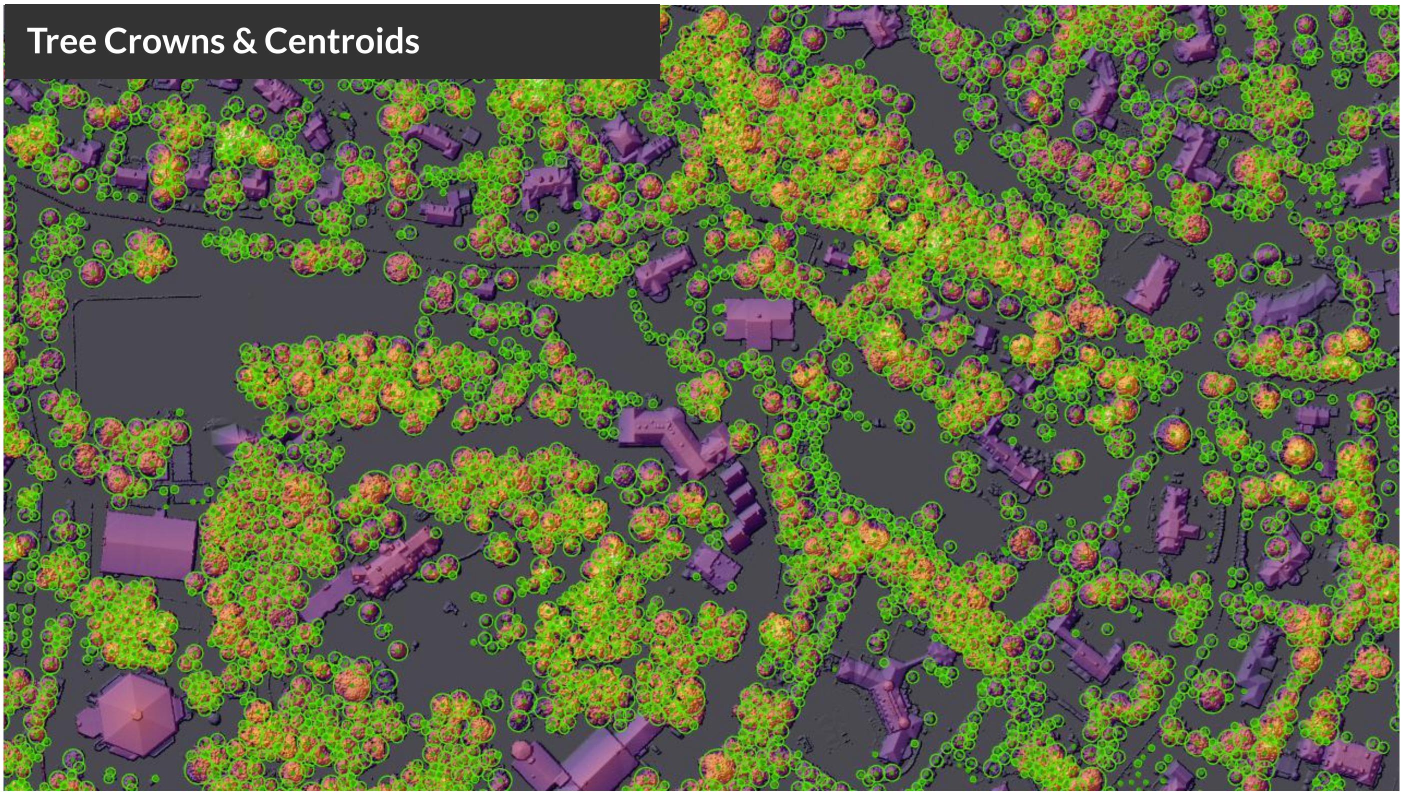


Figure 15. Tree centroids (dots) and tree crowns (circles) mapped from the 2020 LiDAR. Tree mapping from LiDAR involves finding relative high points for each tree, then tracing down until a height inflection point is reached, marking the edge of the crown. This approach to individual tree mapping is most accurate where there is a clear differentiation in tree crowns and is less accurate in forested stands where crowns may overlap.

Land Use Tree Count

Over 109,400 trees are located on residential lands (Residential 1-3 & Residential 4+), equating to over 44% of Brookline's trees. In addition, over 34,150 trees (17%) are located in the rights-of-way. 27,600 (14%) are on town-owned open space, and 3,400 (2%) are on other town-owned lands. Maintaining the trees on land managed by the town requires funding and trained staff.

Figure 16: Individual trees size according to their height overlaid on generalized land use.

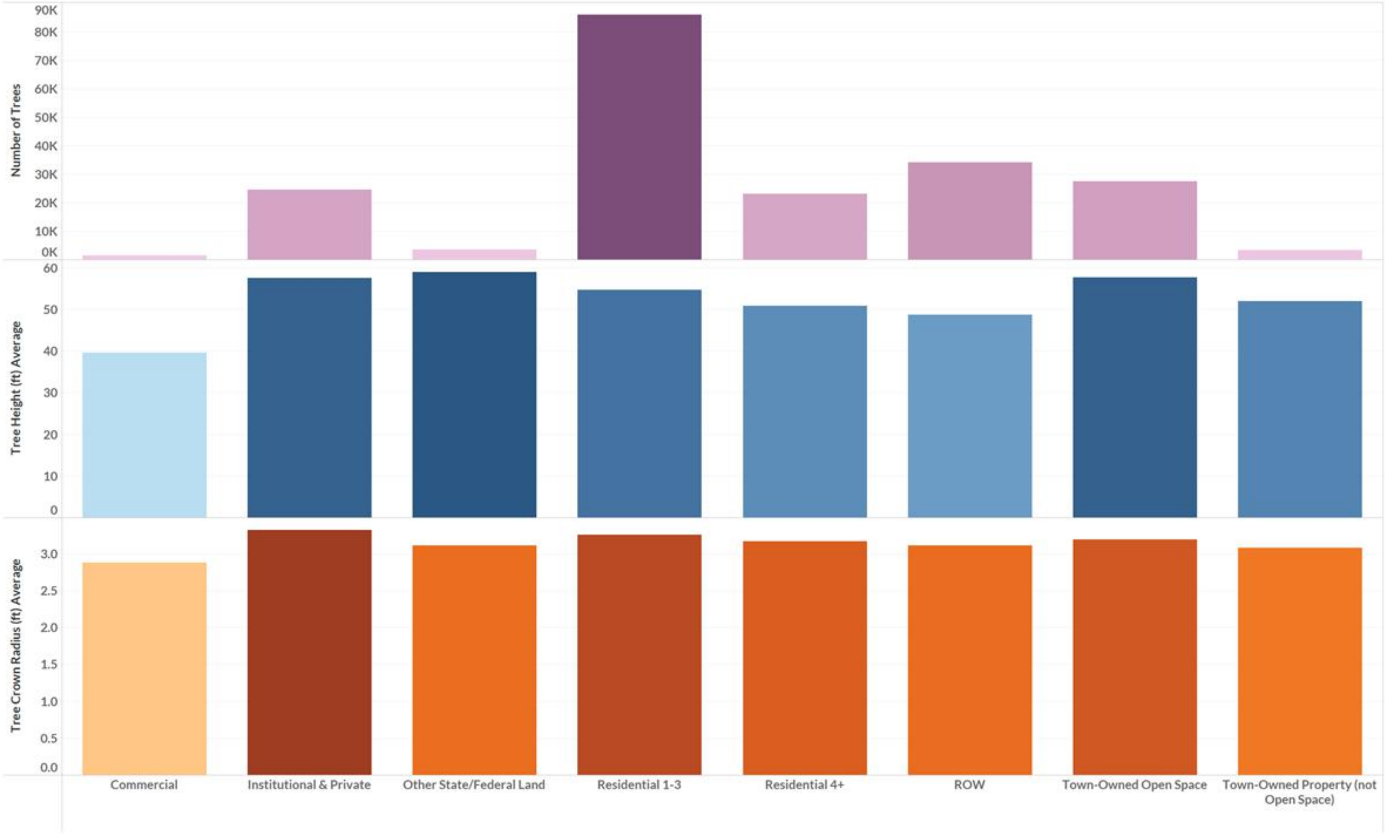


Figure 17: Tree count, height, and radius summarized by generalized land use categories.

THE TREE CANOPY ASSESSMENT PROCESS

This project employed the USDA Forest Service's Urban Tree Canopy assessment protocols and made use of federal, state, and local investments in geospatial data. Tree canopy assessments should be completed at regular intervals, every 3-5 years.

Remotely sensed data forms the foundation of the tree canopy assessment. We use high-resolution aerial imagery and LiDAR to map tree canopy and other land cover features.

The land cover data consist of tree canopy, grass/shrub, bare soil, water, buildings, roads/railroads, and other impervious features.

The land cover data are summarized by various geographical units, ranging from the property parcel to the watershed to the municipal boundary.

These summaries, in the form of tree canopy metrics, are an exhaustive geospatial database that enables the Existing and Possible Tree Canopy to be analyzed.

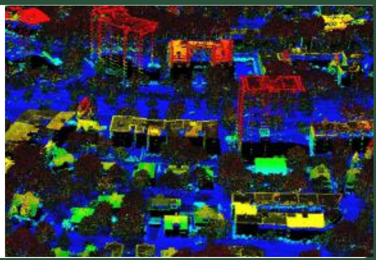
The tree canopy metrics data analytics provide basic summary statistics in addition to inferences on the relationship between tree canopy and other variables.

The report (this document) summarizes the project methods, results, and findings.

The presentation, given to partners and stakeholders in the region, provides the opportunity to ask questions about the assessment.

The Importance of Good Data

This assessment would not have been possible without the town's investment in high-quality geospatial data, particularly LiDAR. These investments pay dividends for a variety of uses, from stormwater management to solar potential mapping. Good data supports good governance.



MAPPING THE TREE CANOPY FROM ABOVE

Tree canopy assessments rely on remotely sensed data in the form of aerial imagery and light detection and ranging (LiDAR) data. These datasets, which have been acquired by various governmental agencies in the region, are the foundational information for tree canopy mapping. Imagery provides information that enables features to be distinguished by their spectral (color) properties. As trees and shrubs can appear spectrally similar, or obscured by shadow, LiDAR, which consists of 3D height information, enhances the accuracy of the mapping. Tree canopy mapping is performed using a scientifically rigorous process that integrates cutting-edge automated feature extraction technologies with detailed manual reviews and editing. This combination of sensor and mapping technologies enabled the town's tree canopy to be mapped in greater detail and with better accuracy than ever before. From a single street tree along a roadside to a patch of trees in a park, every tree in the town was accounted for.

Tree Canopy Mapping

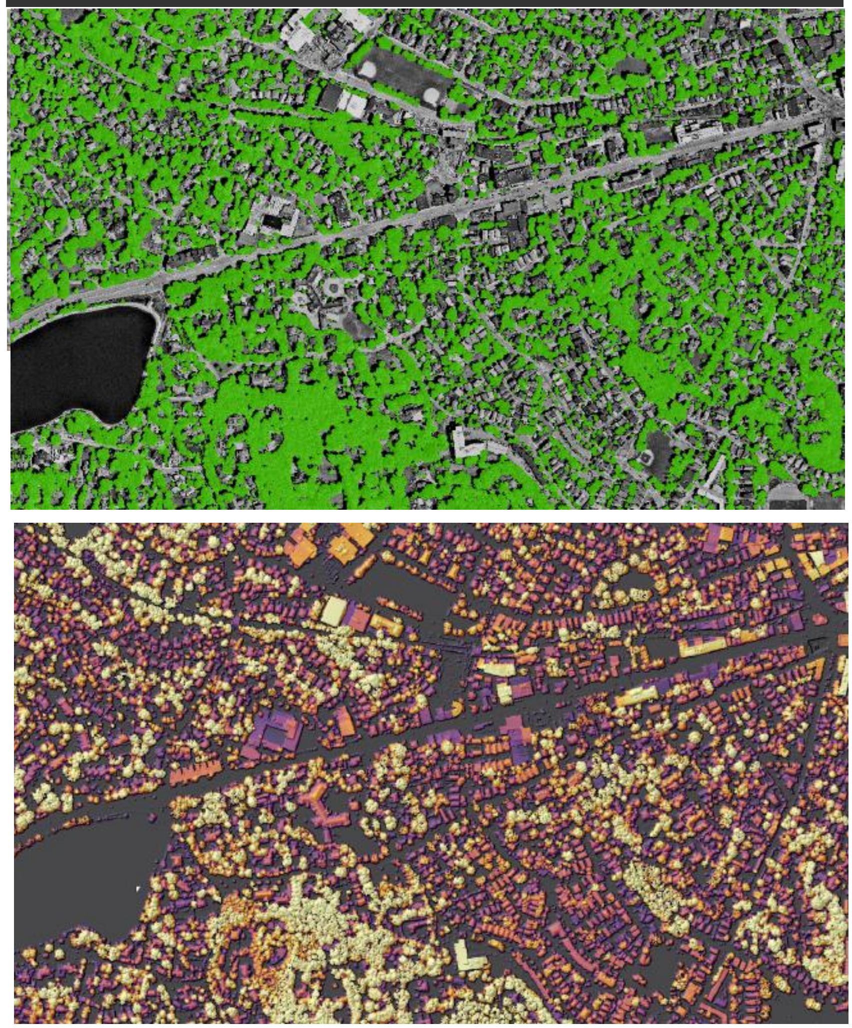


Figure 18: High-resolution tree canopy overlaid on imagery (top) and LiDAR (bottom).

The high-resolution land cover that forms the foundation of this project was generated from the most recent LiDAR, which was acquired in 2020. Compared to national tree canopy datasets, which map at a resolution of 30-meters, this project generated maps that were over 1,000 times more detailed and better account for all of the town's tree canopy.

Land Cover Mapping

Figure 19: High-resolution land cover developed for this project.

This assessment was carried out by the University of Vermont Spatial Analysis Lab in collaboration with the Town of Brookline. The methods and tools used for this assessment were developed in partnership with the USDA Forest Service. The source data used for the mapping came from Brookline and the USDA. The project was funded by the Town of Brookline, in part through a grant from the Commonwealth of Massachusetts. Additional support for data analytics came from a Catalyst Award from the Gund Institute for Environment at the University of Vermont. Computations were performed on the Vermont Advanced Computing Core supported in part by NSF award No. OAC-1827314.

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