TREE MANAGEMENT PLAN

City of Indianapolis, Indiana

December 2016

Prepared for:
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Department of Public Works
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ACKNOWLEDGMENTS

Indianapolis' vision to promote and preserve the urban forest and improve the management of public trees was a fundamental inspiration for this project. This vision will ensure canopy continuity, which will reduce stormwater runoff and improve aesthetic value, air quality, and public health.

Indianapolis is thankful for the grant funding it received for the inventory from the 2011 and 2012 Indiana Department of Natural Resources, Division of Forestry, Community and Urban Forestry (CUF) Grant Program in cooperation with the U.S. Forest Service and 2013 USDA United States Forest Service, Competitive Grant Programs. These grant programs are designed to encourage communities to create and support long-term and sustained urban and community forestry programs.

EXECUTIVE SUMMARY

This plan was developed for the City of Indianapolis by Davey Resource Group with a focus on addressing short-term and long-term maintenance needs for inventoried public trees. Davey Resource Group completed a tree inventory to gain an understanding of the needs of the existing urban forest and to project a recommended maintenance schedule for tree care. Analysis of inventory data and information about the city's existing program and vision for the urban forest were utilized to develop this *Tree Management Plan*. Also included in this plan are economic, environmental, and social benefits provided by street trees in Indianapolis.

State of the Existing Urban Forest

The May 2016 inventory included trees, stumps, planting sites, and brush segments along public street rights-of-way (ROW). A total of 227,269 sites were recorded during the inventory: 182,801 trees, 8,041 stumps, 31,616 planting sites, and 4,811 brush segments. Analysis of the tree inventory data found the following:

- No single species comprises more than 10% of the street ROW.
- On the street ROW, *Acer* (maple) was found in abundance (21%), which is a concern for the city's biodiversity.
- The diameter size class distribution of the inventoried tree population trends towards the ideal, with a greater number of young trees than established, maturing, or mature trees.
- The overall condition of the inventoried tree population is rated Fair or better.
- Conflict with overhead utilities and street trees occurs among 6% of the population.
- Hardscape lifting from street ROW trees occurs among 3% of the population.
- The majority of street trees is located in close proximity to single-family residential homes (70%) and the highest distribution grows in the front yard (37%).
- Of potential threats from pests, looper complex [(*Erannis tiliaria*) and (*Phigalia titea*)], forest tent caterpillar (*Malacosoma disstria*), and Asian longhorned beetle (ALB or *Anoplophora glabripennis*), pose the biggest threats to the health of the inventoried population.
- Of the 19,313 inventoried ash trees, 68% were infested with EAB.
- Indianapolis' trees have an estimated replacement value of $166,569,813.
- Trees provide approximately $9,970,035 in the following annual benefits:
  - *Aesthetic and other benefits*: valued at $4,832,549 per year.
  - *Air quality*: 283,293 pounds of pollutants removed valued at $351,332 per year.
  - *Carbon sequestered and avoided*: 45,286,518 pounds valued at $149,446 per year.
  - *Energy*: 10,656 megawatt-hours (MWh) and 241,199 therms valued at $1,311,515 per year.
  - *Stormwater*: 536,321,425 gallons valued at $3,325,193 per year.
  - *Return on investment:* $3.95 in benefits for every $1 spent on municipal forestry program.

Tree Maintenance and Planting Needs

Trees provide many environmental and economic benefits that justify the time and money invested in planting and maintenance. Recommended maintenance needs include: Tree Removal (12%); Stump Removal (4%); Large and Small Tree Clean (Routine Pruning) (60%); Young Tree Train (8%); Plant Tree (14%); and Brush Removal (2%). Maintenance should be prioritized by addressing trees with the highest risk first. The inventory noted many Extreme, High, and Moderate Risk trees (less than 1%, 4%, and 10% of trees assessed, respectively); these trees should be removed or pruned immediately to promote public safety. Low Risk trees should be addressed after all elevated risk tree maintenance has been completed. Trees should be planted to mitigate removals and create canopy.

REMOVAL

- Total = 26,709 trees
- Extreme Risk = 169 trees
- High Risk = 5,068 trees
- Moderate Risk = 8,492 trees
- Low Risk = 12,980 trees
- Stumps = 8,041

HIGH RISK PRUNING

- Total = 11,128 trees
- Extreme Risk = 17 trees
- High Risk = 1,434 trees
- Moderate Risk = 9,677 trees

ROUTINE PRUNING CYCLE

- Total = 125,877 trees
- Number of trees in cycle each year = approximately 13,987

YOUNG TREE TRAINING CYCLE

- Total = 17,616 trees
- Number of trees in cycle each year = at least 6,359

TREE PLANTING

- Number of trees each year = at least 3,475

Indianapolis' urban forest will benefit greatly from a three-year young tree training cycle and a nine-year routine pruning cycle. Proactive pruning cycles improve the overall health of the tree population and may eventually reduce program costs. In most cases, pruning cycles will correct defects in trees before they worsen, which will avoid costly problems. Based on inventory data, at least 6,359 young trees should be structurally pruned each year during the young tree training cycle, and approximately 13,987 trees should be cleaned each year during the routine pruning cycle.

Planting trees is necessary to maintain and increase canopy cover, and to replace trees that have been removed or lost to natural mortality (expected to be 1–3% per year) or other threats (for example, construction, invasive pests, or impacts from weather events such as drought, flooding, ice, snow, storms, and wind). Davey Resource Group recommends planting at least 5,035 trees (to replace all inventory recommended removals in five years and replace natural mortality removals) of a variety of species each year to offset these losses, increase canopy, maximize benefits, and account for ash tree loss.

Citywide tree planting should focus on replacing tree canopy recommended for removal and establishing new canopy in areas that promote economic growth, such as business districts, recreational areas, trails, parking lots, areas near buildings with insufficient shade, and areas where there are gaps in the existing canopy. Various tree species should be planted; however, the planting of maple should be limited until the species distribution normalizes. Due to the species distribution and impending threats from emerald ash borer (EAB, *Agrilus planipennis*), all *Fraxinus* spp. (ash) trees should be temporarily removed from the planting list.

Urban Forest Program Needs

Adequate funding will be needed for the city to implement an effective management program that will provide short-term and long-term public benefits, ensure that priority maintenance is performed expediently, and establish proactive maintenance cycles. The estimated total cost for the first year of this five-year program is $8,980,593. This total will decrease to approximately $7,532,753 by Year 2021 and $5,830,854 per year by Year 2022 when all inventory recommended removals have been completed. High-priority removal and pruning is costly; since most of this work is scheduled during the first three years of the program, the budget is higher for those years. After high-priority work has been completed, the urban forestry program will mostly involve proactive maintenance, which is generally less costly. Budgets for later years are thus projected to be lower.

Over the long term, supporting proactive management of trees through funding will reduce municipal tree care management costs and potentially minimize the costs to build, manage, and support certain city infrastructure.

Indianapolis has many opportunities to improve its urban forest. Planned tree planting and a systematic approach to tree maintenance will help ensure a cost-effective, proactive program. Investing in this tree management program will promote public safety, improve tree care efficiency, and increase the economic and environmental benefits the community receives from its trees.

FY 2017 — **$8,980,593**

- 2,925 Extreme, High, or Moderate Risk Removals
- 11,128 Extreme, High, or Moderate Risk Prunes
- 8,041 Stump Removals
- YTT Cycle: 1/3 of Public Trees Trained
- 3,475 Trees Recommended for Planting and Follow-Up Care
- Approximately 1,560 Tree Removals, 1,560 Stump Removals, and 1,560 Tree Planting (mortality 1%)

FY 2018 — **$8,164,632**

- 3,548 Extreme, High, or Moderate Risk Removals
- 5,237 Stump Removals
- RP Cycle: 1/9 of Public Trees Cleaned
- YTT Cycle: 1/3 of Public Trees Trained
- 3,475 Trees Recommended for Planting and Follow-Up Care
- Approximately 1,560 Tree Removals, 1,560 Stump Removals, and 1,560 Tree Planting (mortality 1%)

FY 2019 — **$8,057,343**

- 6,538 Extreme, High, or Moderate Risk Removals
- 7,774 Stump Removals
- RP Cycle: 1/9 of Public Trees Cleaned
- YTT Cycle: 1/3 of Public Trees Trained
- 3,475 Trees Recommended for Planting and Follow-Up Care
- Approximately 1,560 Tree Removals, 1,560 Stump Removals, and 1,560 Tree Planting (mortality 1%)

FY 2020 — **$7,365,389**

- 718 Extreme, High, or Moderate Risk Removals
- 1,400 Low Risk Removals
- 2,118 Stump Removals
- RP Cycle: 1/9 of Public Trees Cleaned
- YTT Cycle: 1/3 of Public Trees Trained
- 3,475 Trees Recommended for Planting and Follow-Up Care
- Approximately 1,560 Tree Removals, 1,560 Stump Removals, and 1,560 Tree Planting (mortality 1%)

FY2021 — **$7,532,753**

- 11,580 Low Risk Removals
- 11,580 Stump Removals
- RP Cycle: 1/9 of Public Trees Cleaned
- YTT Cycle: 1/3 of Public Trees Trained
- 3,475 Trees Recommended for Planting and Follow-Up Care
- Approximately 1,560 Tree Removals, 1,560 Stump Removals, and 1,560 Tree Planting (mortality 1%)

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INTRODUCTION

The City of Indianapolis is home to more than 853,000 full-time residents who enjoy the beauty and benefits of their urban forest. The city's forestry program manages and maintains trees on public property, including trees, stumps, and planting sites along the street ROW. For many years, Indianapolis has maintained staff committed to developing a strong urban forest. The forestry program is in the Department of Public Works. Forestry program personnel includes a Manager of Urban Forestry, a Senior Forestry Analyst, a Forestry Inspector, a Forestry Operations Supervisor, and 14 Forestry Operations Laborers. A Department of Code Enforcement Forestry Inspector assists with forestry inspections. Education and training credentials in the forestry program include a Board Certified Master Arborist, a licensed Landscape Architect, three Certified Arborists, four Tree Risk Assessment Qualified personnel, and many OSHA 10-hour training personnel.

City staff, volunteers, and contractors perform tree maintenance work. Tree removals (more than 100 per year) and young tree pruning occur annually. Watering occurs as needed. The city has a strong tree planting and young tree pruning partnership with Keep Indianapolis Beautiful. The non-profit organization plants between 2,000 and 2,500 trees a year.

The forestry program engages the public through outreach and education. Forestry staff visit schools to share tree knowledge and work with city public relations to disperse tree information through phone calls, door hangers, email, and via the city website. During Arbor Day, a declaration is publicly read, city staff plant trees with school children, and the city partners with local utilities to give away seedlings and promote tree care.

Funding for Indianapolis' urban forestry program comes from stormwater, transportation, and general funds from the parks. In 2004, Indianapolis conducted a partial inventory of street trees in Center Township. As of 2016, Indianapolis has completed a full street tree inventory of all nine townships. The city maintains the street tree inventory with a city software system. The city has a tree ordinance, maintains a budget of more than $2 per capita for tree-related expenses, celebrates Arbor Day, and has been a Tree City USA community for 28 years.

Approach to Tree Management

The best approach to managing an urban forest is to develop an organized, proactive program using tools (such as a tree inventory and a tree management plan) to set goals and measure progress. These tools can be utilized to establish tree care priorities, generate strategic planting plans, draft cost-effective budgets based on projected needs, and ultimately minimize the need for costly, reactive solutions to crises or urgent hazards.

From June 2013 to May 2016, Indianapolis worked with Davey Resource Group to inventory trees and develop a management plan. This plan considers the diversity, distribution, and general condition of the inventoried trees, but also provides a prioritized system for managing public trees. The following tasks were completed:

- Inventory of trees, stumps, planting sites, and brush segments along the street ROW.
- Analysis of tree inventory data.
- Development of a plan that prioritizes the recommended tree maintenance.

This plan is divided into three sections:

- *Section 1: Tree Inventory Analysis* summarizes the tree inventory data and presents trends, results, and observations.
- *Section 2: Benefits of the Urban Forest* summarizes the economic, environmental, and social benefits that trees provide to the community. This section presents statistics of an i-Tree Streets benefits analysis conducted for Indianapolis.
- *Section 3: Tree Management Program* utilizes the inventory data to develop a prioritized maintenance schedule and projected budget for the recommended tree maintenance over a five-year period.

SECTION 1: TREE INVENTORY ANALYSIS

From 2013 to 2016, Davey Resource Group arborists assessed and inventoried trees, stumps, planting sites, and brush segments along the street ROW. A total of 227,269 sites were collected during the inventory: 182,801 trees, 8,041 stumps, 31,616 planting sites, and 4,811 brush segments. Figure 1 provides a detailed breakdown of the number and type of sites inventoried.

The city's public street rights-of-way were selected by Indianapolis for the inventory. All nine townships were included in the inventory. Appendix A explains data collection and site location methods. Data collection data field definitions are located in the glossary.

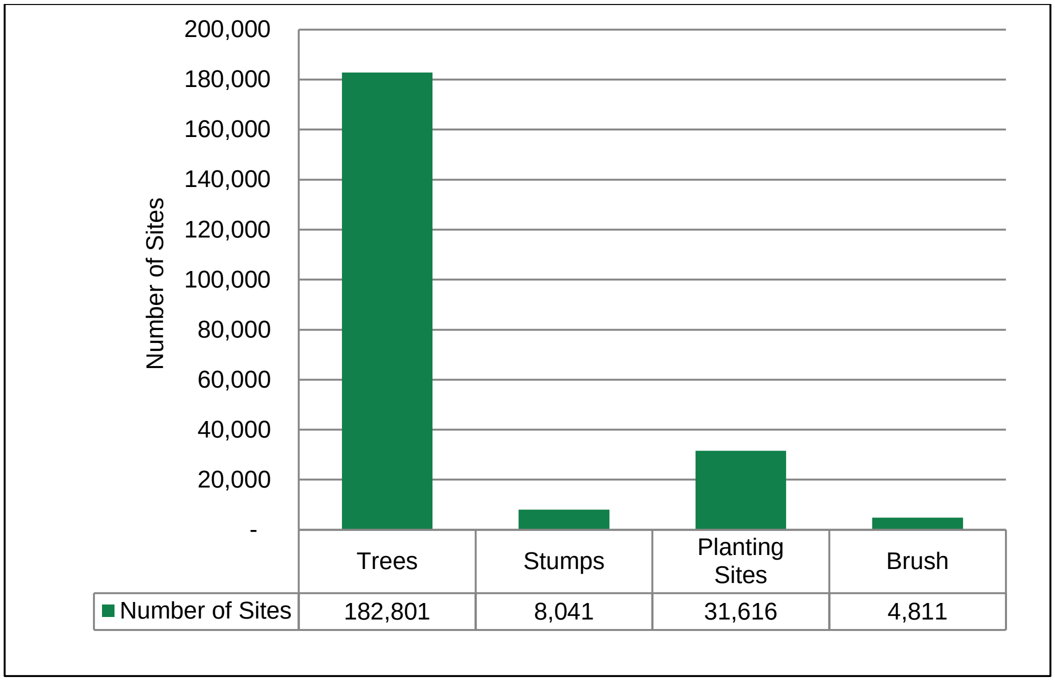


Figure 1. Sites collected during the 2016 inventory.

Assessment of Tree Inventory Data

Data analysis and professional judgment are used to make generalizations about the state of the inventoried tree population. Recognizing trends in the data can help guide short-term and long-term management planning. In this plan, the following criteria and indicators of the inventoried tree population were assessed:

- *Species Diversity*, the variety of species in a specific population, affects the population's ability to withstand threats from invasive pests and diseases. Species diversity also impacts tree maintenance needs and costs, tree planting goals, and canopy continuity.
- *Diameter Size Class Distribution*, the statistical distribution of a given tree population's trunk-size class, is used to indicate the relative age of a tree population. The diameter size class distribution affects the valuation of tree-related benefits as well as the projection of maintenance needs and costs, planting goals, and canopy continuity.
- *Condition*, the general health of a tree population, indicates how well trees are performing given their site-specific conditions. General health affects both short-term and long-term maintenance needs and costs as well as canopy continuity.

- *Stocking Level* is the proportion of existing street ROW trees compared to the total number of potential street ROW trees (number of inventoried trees plus the number of potential planting spaces); stocking level can help determine tree planting needs and budgets.
- *Other Observations* include inventory data analysis that provides insight into past maintenance practices and growing conditions; such observations may affect future management decisions.

Species Diversity

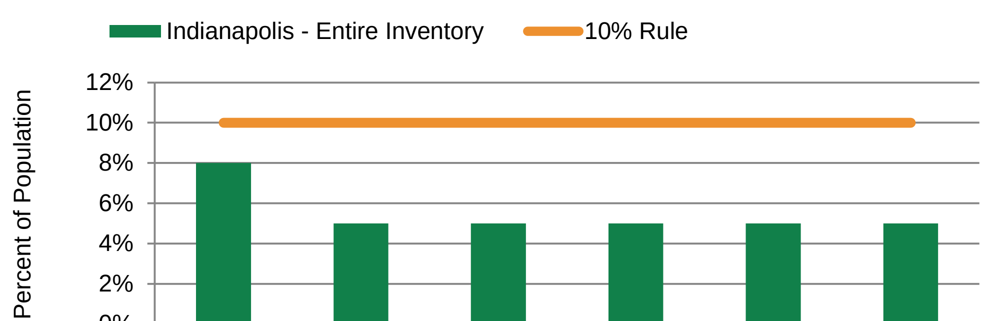
Species diversity affects maintenance costs, planting goals, canopy continuity, and the forestry program's ability to respond to threats from invasive pests or diseases. Low species diversity (large number of trees of the same species) can lead to severe losses in the event of species-specific epidemics such as the devastating results of Dutch elm disease (*Ophiostoma novo-ulmi*) throughout New England and the Midwest. Due to the spread of Dutch elm disease in the 1930s, combined with the disease's prevalence today, massive numbers of *Ulmus americana* (American elm), a popular street tree in Midwestern cities and towns, have perished (Karnosky 1979). Several Midwestern communities were stripped of most of their mature shade trees, creating a drastic void in canopy cover. Many of these communities have replanted to replace the lost elm trees. Ash and maple trees were popular replacements for American elm in the wake of Dutch elm disease. Unfortunately, some of the replacement species for American elm trees are now overabundant, which is a biodiversity concern. EAB and Asian longhorned beetle (ALB, *Anoplophora glabripennis*) are non-native insect pests that attack some of the most prevalent urban shade trees and certain agricultural trees throughout the country.

The composition of a tree population should follow the 10-20-30 Rule for species diversity: a single species should represent no more than 10% of the urban forest, a single genus no more than 20%, and a single family no more than 30%.

Findings

Analysis of Indianapolis' tree inventory data indicated that the street tree population had 92 genera and 249 species represented.

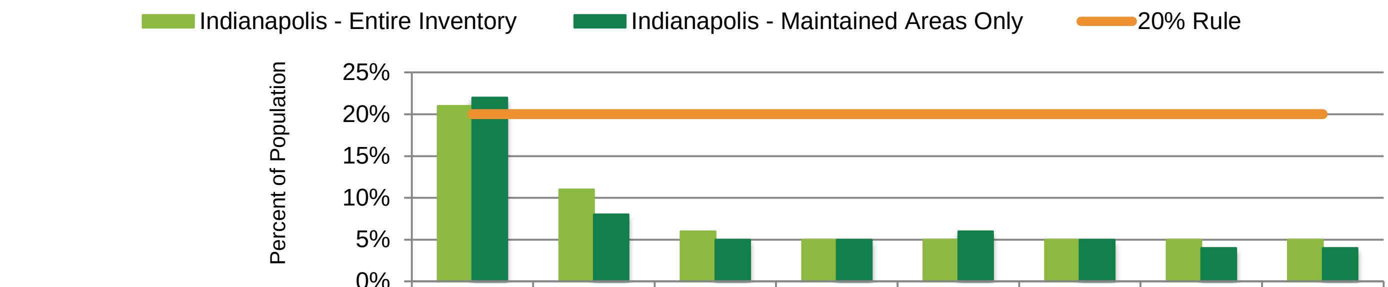
Figure 2 uses the 10% Rule to compare the percentages of the most common species identified during the inventory to the street tree population. The street tree population has a good distribution of trees among species. None of the species exceed the recommended 10% maximum for a single species in a population.



	silver maple	white mulberry	white ash	sugar maple	callery pear	common hackberry
Indianapolis - Entire Inventory	8%	5%	5%	5%	5%	5%
10% Rule	10%	10%	10%	10%	10%	10%

Figure 2. Most abundant species of the inventoried population compared to the 10% Rule.

Figure 3 uses the 20% Rule to compare the percentages of the most common genera identified during the inventory to the street tree population. The figure also shows the distribution of trees in maintained areas along the street ROW and excludes wooded edges and unmaintained areas. *Acer* (maple) slightly exceeds the recommended 20% maximum for a single genus in a population, comprising 21% of the entire inventoried street tree population and 22% of the maintained area street tree population.



	maple	ash	mulberry	oak	spruce	pear	elm	hackberry
Indianapolis - Entire Inventory	21%	11%	6%	5%	5%	5%	5%	5%
Indianapolis - Maintained Areas Only	22%	8%	5%	5%	6%	5%	4%	4%
20% Rule	20%	20%	20%	20%	20%	20%	20%	20%

Figure 3. Most abundant genera of the inventoried population compared to the 20% Rule.

Discussion/Recommendations

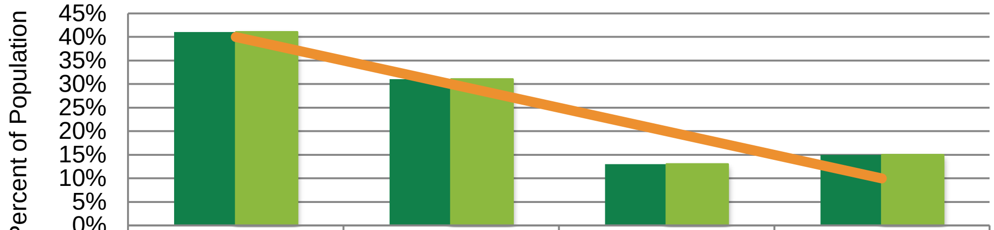
Maple dominates the streets. This is a biodiversity concern because its abundance in the landscape makes it a limiting species. Continued diversity of tree species is an important objective that will ensure Indianapolis' urban forest is sustainable and resilient to future invasive pest infestations.

Considering the large quantity of maple in Indianapolis' population, along with its susceptibility to ALB, the planting of maple should be limited to minimize the potential for loss in the event that ALB threatens the city's urban tree population. See Appendix B for a recommended tree species list for planting.

Diameter Size Class Distribution

Analyzing the diameter size class distribution provides an estimate of the relative age of a tree population and offers insight into maintenance practices and needs.

The inventoried trees were categorized into the following diameter size classes: young trees (0–8 inches DBH), established (9–17 inches DBH), maturing (18–24 inches DBH), and mature trees (greater than 24 inches DBH). These categories were chosen so that the population could be analyzed according to Richards' ideal distribution (1983). Richards proposed an ideal diameter size class distribution for street trees based on observations of well-adapted trees in Syracuse, New York. Richards' ideal distribution suggests that the largest fraction of trees (approximately 40% of the population) should be young (less than 8 inches DBH), while a smaller fraction (approximately 10%) should be in the large-diameter size class (greater than 24 inches DBH). A tree population with an ideal distribution would have an abundance of newly planted and young trees, and lower numbers of established, maturing, and mature trees.



	0"–8" Young	9"–17" Established	18"–24" Maturing	>24" Mature
Indianapolis - Entire Inventory	41%	31%	13%	15%
Indianapolis - Maintained Areas Only	41%	31%	13%	15%
Ideal	40%	30%	20%	10%

Figure 4. Comparison of diameter size class distribution for inventoried trees to the ideal distribution.

Findings

Figure 4 compares Indianapolis' diameter size class distribution of the inventoried tree population to the ideal proposed by Richards (1983). The city's distribution trends towards the ideal. There are more young trees than established, maturing, and mature trees. The diameter size class distributions of the entire inventory are nearly identical to the maintained areas of the street tree population.

Discussion/Recommendations

One of Indianapolis' objectives is to have an uneven-aged distribution of street trees. Davey Resource Group recommends that the city support a strong planting and maintenance program to ensure that young, healthy trees are in place to fill in gaps in tree canopy and replace older declining trees. Indianapolis must promote tree preservation and proactive tree care to ensure the long-term survival of older trees. Tree planting and tree care will allow the distribution to normalize over time.

Planting trees is necessary to increase canopy cover and replace trees lost to natural mortality (expected to be 1%–3% per year) and other threats (for example, invasive pests or impacts from weather events such as storms, wind, ice, snow, flooding, and drought). Planning for the replacement of existing trees and identifying the best places to create new canopy is critical.

Caring for trees is necessary to increase canopy cover and have healthy trees to reduce air and noise pollution, save energy with shade and windbreaks, mitigate stormwater costs, make habitat for wildlife, enhance aesthetics and property values, and contribute to community image, pride, and quality of life.

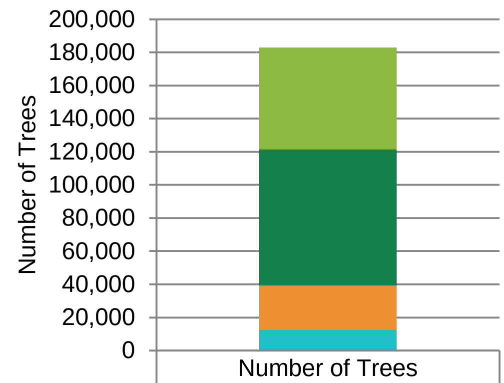
Condition

Davey Resource Group assessed the condition of individual trees based on methods defined by International Society of Arboriculture (ISA). Several factors were considered for each tree, including: root characteristics, branch structure, trunk, canopy, foliage condition, and the presence of pests. The condition of each inventoried tree was rated Good, Fair, Poor, or Dead.

In this plan, the general health of the inventoried tree population was characterized by the most prevalent condition assigned during the inventory.

Comparing the condition of the inventoried tree population with relative tree age (or size class distribution) can provide insight into the stability of the population. Since tree species have different lifespans and mature at different diameters, heights, and crown spreads, actual tree age cannot be determined from diameter size class alone. However, general classifications of size can be extrapolated into relative age classes. The following categories are used to describe the relative age of a tree: young (0–8 inches DBH), established (9–17 inches DBH), maturing (18–24 inches DBH), and mature (greater than 24 inches DBH).

Figures 5 and 6 illustrate the general health and distribution of young, established, mature, and maturing trees relative to their condition.



	Number of Trees
Good	61,538
Fair	81,903
Poor	26,814
Dead	12,546

Figure 5. Conditions of inventoried trees.

Findings

Most (78%) of the inventoried trees were recorded to be in Fair or Good condition (Figure 5). Based on these data, the general health of the overall inventoried tree population is rated Fair or better. Figure 6 illustrates that most of the young trees were rated to be in Good condition, and most established, maturing, and mature trees were rated to be in Fair condition.

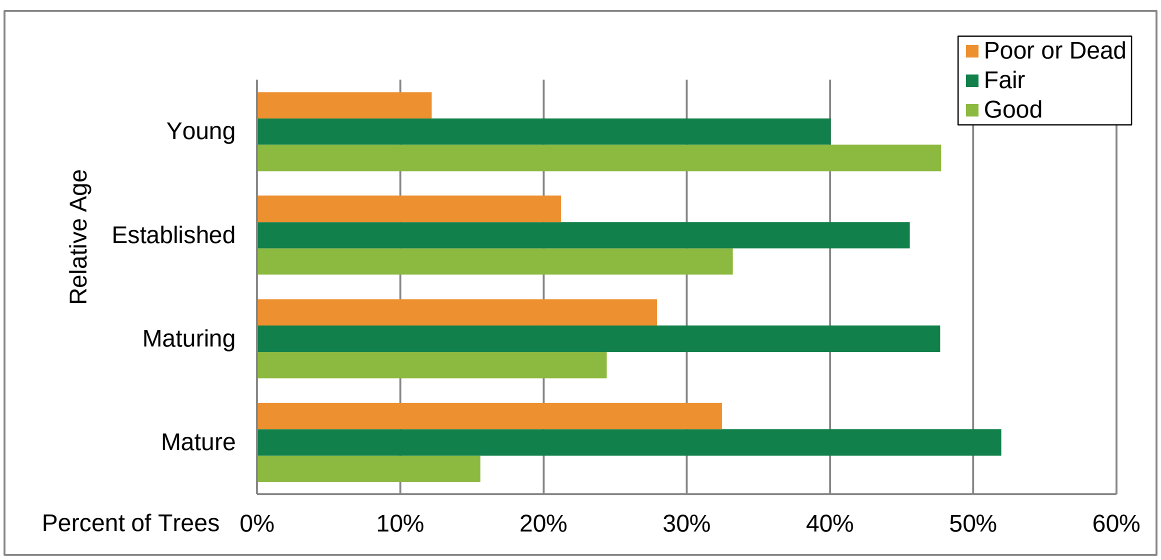


Figure 6. Tree condition by relative age during the 2016 inventory.

Discussion/Recommendations

Even though the condition of Indianapolis' inventoried tree population is typical, data analysis has provided the following insight into maintenance needs:

- Dead trees should be removed because of their failed health; these trees will likely not recover, even with increased care.
- Young trees rated in Fair or Poor condition may benefit from improvements in structure that may improve their health over time. Pruning should follow *ANSI A300 (Part 1)* (ANSI 2008).
- Poor condition ratings among mature trees were generally due to visible signs of decline and stress, including decay, dead limbs, sparse branching, or poor structure. These trees will require corrective pruning, regular inspections, and possible intensive plant health care to improve their vigor.
- Proper tree care practices are needed for the long-term general health of the urban forest. Following guidelines developed by ISA and those recommended by *ANSI A300 (Part 6)* (ANSI 2012) will ensure that tree maintenance practices ultimately improve the health of the urban forest.

Street ROW Stocking Level

Stocking is a traditional forestry term used to measure the density and distribution of trees. For an urban forest such as Indianapolis, stocking level is used to estimate the total number of sites along the street ROW that could contain trees.

Stocking level is the ratio of street ROW spaces occupied by trees to the total street ROW spaces suitable for trees. For example, a street ROW tree inventory of 1,000 total sites with 750 existing trees and 250 planting sites would have a stocking level of 75%.

For an urban area, Davey Resource Group recommends that the street ROW stocking level be at least 90% so that no more than 10% of the potential planting sites along the street ROW are vacant.

Street ROW stocking levels may be estimated using information about the community, tree inventory data, and common street tree planting practices. Inventory data that contain the number of existing trees and planting sites along the street ROW will increase the accuracy of the projection. However, street ROW stocking levels can be estimated using only the number of trees present and the number of street miles in the community.

To estimate stocking level based on total street ROW miles and the number of existing trees, it is assumed that any given street ROW should have room for 1 tree for every 50 feet along each side of the street. For example, 10 linear miles of street ROW with spaces for trees to grow at 50-foot intervals along each side of the street account for a potential 2,110 trees. If the inventory found that 1,055 trees were present, the stocking level would be 50%.

The potential stocking level for a community with 10 street miles is as follows:

5,280 feet/mile ÷ 50 feet = 106 trees/mile

106 trees/mile × 2 sides of the street = 212 trees/mile

212 trees per street mile × 10 miles = 2,120 potential sites for trees

1,055 inventoried trees ÷ 2,110 potential sites for trees = 50% stocked

When the estimated stocking level is determined using theoretical assumptions, the actual number of planting sites may be significantly less than estimated due to unknown growing space constraints, including inadequate growing space size, proximity of private trees, and utility conflicts.

Indianapolis' inventory data set included planting sites, but did not include all possible planting sites. Only possible planting sites for large-growing trees adjacent to residential addresses were inventoried, and only one site was inventoried if there were multiple sites possible at a single side of an address. Since the data included partial vacant planting sites, only the theoretical stocking level for the city is presented.

Findings

Based on a theoretical stocking level, the city has 3,781 linear miles of street ROW (City of Indianapolis 2016) and 182,801 trees, which comes to an average of 48 trees per street mile. In theory, any given street should have growing space for 1 tree every 50 feet along each side of a street, or 212 trees per mile. This suggests that there is room for an additional 618,771 street trees in Indianapolis to reach full stocking potential.

Discussion/Recommendation

Fully stocking the street ROW with trees is an excellent goal. Inadequate tree planting and maintenance budgets, along with tree mortality, will result in lower stocking levels. Nevertheless, working to attain a fully stocked street ROW is important to promote canopy continuity and environmental sustainability. The city should consider improving its street ROW population's stocking level of 23% and work towards achieving the ideal of 90% or better. Generally, this entails a planned program of planting, care, and maintenance for the city's street trees.

Another way to analyze stocking level is to apply information gathered from an Indiana statewide study of 21 communities (Davey Resource Group 2009). The Indiana state average stocking level is 52%. Indianapolis' inventory found 31,616 planting sites for large-growing trees. There are many more planting sites along Indianapolis' streets. Based on the data collected during the statewide study, vacant sites for large-growing trees could compose approximately 17% of an Indiana community's street tree potential. If Indianapolis' stocking level is 52% and 17% of possible vacant sites for large-growing trees, it is estimated that there could be 167,800 vacant sites along Indianapolis' streets. Of these sites, 59,600 could be designated for large-growing trees. About 53% of large vacant sites have been inventoried.

The City of Indianapolis estimates that it plants approximately 2,250 trees per year. With a current total of 167,800 planting sites along the street ROW, it would take approximately 59 years for the city to reach the recommended stocking level of 90%. If budgets allow, Davey Resource Group recommends that Indianapolis increase the number of trees planted to 3,475. This will allow for planting 2% of 167,800 planting sites and take approximately 40 years for the city to reach the recommended stocking level of 90%. If possible, exceed this recommendation to better prepare for impending threats and to increase the benefits provided by the urban forest.

Calculations of trees per capita are important in determining the density of a city's urban forest. The more residents and greater housing density a city possesses, the greater the need for trees to provide benefits. Indianapolis' ratio of street trees per capita is 0.21, which falls below the mean ratio of 0.37 reported for 22 U.S. cities (McPherson and Rowntree 1989). According to the citywide study, there is 1 tree for every 4.7 residents. Indianapolis' potential is 1 tree for every 2.4 residents.

Secondary Maintenance

Secondary maintenance describes a recommended maintenance activity to be performed. Trees with recorded secondary maintenance of Raise, Reduce, Replant, Restoration, Thin, or Utility are categorized based on the presence of potentially high-risk conditions in the canopy or to improve the health and longevity of the tree.

Findings

There were 38,267 trees recorded with some type of secondary maintenance. Most of those (65%) were related to conflicts with vehicles, pedestrians, or traffic signs/signals. When the bottom of a tree's canopy over the road was less than 14 feet over the street surface, or rubbing from vehicles or the bottom of a tree's canopy over the sidewalk was less than 8 feet, raising of the canopy was recommended and recorded.

Table 1. Secondary Maintenance Recorded During the Street Tree Inventory

Secondary Maintenance	Number of Trees	Percent of Trees
None	144,534	79%
Raise	24,913	14%
Reduce	9,837	5%
Replant	2,700	1%
Restoration	341	<1%
Thin	37	<1%
Utility	439	<1%
Total	182,801	100%

Discussion/Recommendations

Tree canopy should not interfere with vehicular or pedestrian traffic, nor should it rest on buildings or block signs, signals, or lights. Pruning to avoid clearance issues and raise tree crowns should be completed in accordance with *ANSI A300 (Part 9)* (2011). Davey Resource Group's clearance distance guidelines are as follows: 14 feet over streets; 8 feet over sidewalks; and 5 feet from buildings, signs, signals, or lights.

Replacement Value

Replacement value describes the historical investment in trees over time. Replacement value on a species level gives urban forest managers a glimpse into the landscape value of their species populations. Values will reflect species population, stature, and condition.

Findings

Indianapolis' street trees are an important municipal asset valued at $166,569,813. Over time, this value could increase as trees mature and the number of trees increases, provided the trees are properly maintained. The average replacement value is approximately $911 per tree. Silver maple has the highest replacement value of all inventoried species at $17,916,610, or 11% of Indianapolis' historical investment.

Discussion/Recommendations

A healthy, well-placed tree will become more valuable over time as it grows from a young tree to a mature tree. Davey Resource Group recommends that the city focus on tree care practices that will optimize species diversity, size distribution, and the health of the urban forest. Focusing on these components can provide a greater return on investment.

Other Observations

Observations were recorded during the inventory to further describe a tree's health, structure, or location when more detail was needed.

Findings

Multi-stem was recorded most frequently (18% of the inventoried trees). The top five species most commonly recorded with multi-stems were *Acer saccharinum* (silver maple), *Celtis occidentalis* (hackberry), *Juniperus virginiana* (eastern redbud), *Malus* spp. (crabapple), and *Morus alba* (white mulberry). The majority of trees recorded with multi-stem were found to be in poor condition (74%) and were recommended for routine pruning (47%).

Table 2. Observations Recorded During the Street Tree Inventory

Observations	Number of Trees	Percent of Trees
Multi-stem	32,052	18%
EAB Infested	13,145	7%
Cavity or Decay	9,821	5%
Poor Structure	6,138	3%
Trunk Wound	5,906	3%
Poor Location	4,040	2%
Excessive Deadwood	3,152	2%
Signs of Stress	3,212	2%
Serious Decline	2,133	1%
Remove Hardware	1,938	1%
Completely Topped	1,431	1%
Partially Topped	1,202	1%
Improperly Mulched	1,109	1%
Trees in Series	875	0%
Improperly Pruned	737	0%
Poor Root System	549	0%
Adventitious/Epicormic Growth	498	0%
Girdling Roots	498	0%
Pest Problem	460	0%
Mower Damage	384	0%
Improperly Installed	250	0%
Utility Pruned	199	0%
Nutrient Deficiency	194	0%
Construction Damage	119	0%
Vandalism/Abuse	85	0%
Sight Distance Issue	57	0%
Grate or Guard	48	0%
Lightning Damage	34	0%

Signs and symptoms of emerald ash borer (EAB, *Agrilus planipennis*) were observed on 13,145 ash trees (68% of the ash tree population). This total accounts for 7% of the entire street tree population. The majority of trees recorded with EAB infestation were found to be in poor condition (54%) and were recommended for removal (60%).

Cavity or decay was frequently observed and recorded (5%). The majority of trees recorded with cavity or decay were assessed in poor condition (74%), recommended for removal (49%), and were rated to be Low Risk (51%) trees.

Discussion/Recommendations

Trees noted as having large diameter multi-stems, cavity or decay, and EAB signs and symptoms should be regularly inspected. Corrective actions should be taken when warranted. If their condition worsens, removal may be required.

Infrastructure Conflicts

In an urban setting, space is limited both above and below ground. Trees in this environment may conflict with infrastructure such as buildings, sidewalks, and utility wires and pipes, which may pose risks to public health and safety. Existing or possible conflicts between trees and infrastructure recorded during the inventory include:

- *Overhead Utilities*—The presence of overhead utility lines above a tree or planting site was noted; it is important to consider these data when planning pruning activities and selecting tree species for planting.
- *Hardscape Damage*—Trees can adversely impact hardscape, which affects tree root and trunk systems. The inventory recorded damage related to trees, causing sidewalks to lift. These data should be used to schedule and plan repairs to damaged infrastructure.

Findings

There were 37,731 trees with utilities directly above, or passing through, the tree canopy. Of those trees, 29% were conflicting with overhead utilities.

Hardscape damage was minimal: only 3% of the tree population raised sidewalk slabs or curbs. Most hardscape damage was between ¾ and 1-½ inch lift.

Table 3. Trees Noted to be Conflicting with Infrastructure

Conflict	Presence	Number of Sites	Percent
Overhead Utilities	Present and Conflicting	10,829	5.92%
	Present and Not Conflicting	26,902	14.72%
	Not Present	145,070	79.36%
Hardscape Damage	High (Heaved >3 inch)	728	0.40%
	Low (heaved 3/4 to 1-1/2 inch)	2,938	1.61%
	Medium (Heaved 1-1/2 to 3 inch)	1,239	0.68%
	None (heaved <3/4 inch)	177,896	97.32%
Total		**182,801**	**100%**

Discussion/Recommendations

To limit trees conflicting with utilities, trees should only be planted in growing spaces where adequate above ground space is provided. Planting only small-growing trees within 20 feet of overhead utilities, medium-size trees within 20–40 feet, and large-growing trees outside 40 feet will help improve future tree conditions, minimize future utility line conflicts, and reduce the costs of maintaining trees under utility lines.

When planting around hardscape, it is important to give the tree enough growing room at and below ground. Guidelines for planting trees among hardscape features are as follows: give small-growing trees 4–5 feet, medium-growing trees 6–7 feet, and large-growing trees at least 8 feet between hardscape features. In most cases, this will allow for the spread of a tree's trunk taper, root collar, and immediate larger-diameter structural roots.

Growing Space and Land Use

Information about the type and size of the growing space was recorded. Growing space types are categorized as follows:

- Island—surrounded by pavement or hardscape (for example, parking lot divider).
- Median—located between opposing lanes of traffic.
- Open/Restricted—open sites with restricted growing space on two or three sides.
- Open/Unrestricted—open sites with unrestricted growing space on at least three sides.
- Raised Planter—in an above-grade or elevated planter.
- Tree Lawn/Parkway—located between the street curb and the public sidewalk.
- Unmaintained/Natural Area—located in areas that do not appear to be regularly maintained.
- Well/Pit—at grade level and completely surrounded by sidewalk.

Information about the type of land use was recorded. Land use types are categorized as follows:

- Industrial/large commercial.
- Multi-family residential - duplex, apartments, condos.
- Park/vacant/other - agricultural, riparian areas, greenbelts, park, etc.
- Small commercial - minimart, retail boutiques, etc.
- Single-family residential.

Findings

Most (31%) of the tree population is located in residential front lawns.

Table 4. Trees Noted by Growing Space and By Land Use Type

	Industrial/Large Commercial	Multi-Family Residential	Park/Vacant	Single-Family Residential	Small Commercial	Total
Backyard	262	448	476	4,764	291	6,241
Cutout/pit	13	12	7	35	53	120
Front yard	2,607	2,710	5,772	53,228	2,504	66,821
Median	164	174	2,580	1,134	149	4,201
Other maintained locations	2,026	1,869	5,150	4,863	2,310	16,218
Other unmaintained areas	1,288	1,423	4,982	13,623	1,036	22,352
Planting strip	1,311	1,604	3,267	24,993	1,744	32,919
Side yard	941	1,194	1,939	19,868	1,278	25,220
Wooded edge	376	264	3,054	4,809	206	8,709
Total	8,988	9,698	27,227	127,317	9,571	182,801

Discussion/Recommendations

Trees provide economic, environmental, and social benefits. Well-placed trees on single-family residential parcels generate greater tax revenue, slow vehicular traffic, increase community pride, clean the air of pollutants, improve public health, save energy, and reduce ambient air temperatures. Indianapolis should define tree planting objectives based on potential benefits that may come from planting trees; efforts may produce results that greatly improve the quality of life in the city.

Further Inspection

This data field indicates whether a particular tree requires further inspection, such as a Level III risk inspection in accordance with ANSI A300, Part 9 (ANSI, 2011), or periodic inspection due to particular conditions that may cause it to be a safety risk and, therefore, hazardous. If a tree was noted for further inspection, city staff should investigate as soon as possible to determine corrective actions.

Findings

Davey Resource Group recommended 156 trees for further inspection. The majority of these trees had vines climbing tree trunks and branches causing difficulty viewing tree defects along trunks and branches. Trees with cavity or decay and poor structure were also common for need of further inspection.

Discussion/Recommendations

An ISA-Certified Arborist should perform additional inspections of the 156 trees. If a tree is determined to exceed the threshold for acceptable risk, the defective part(s) of the trees should be corrected or removed, or the entire tree may need to be removed.

Potential Threats from Pests

Insects and diseases pose serious threats to tree health. Awareness and early diagnosis are essential to ensuring the health and continuity of street trees. Appendix C provides information about some of the current potential threats to Indianapolis' trees and includes websites where more detailed information can be found.

Many pests target a single species or an entire genus. The inventory data were analyzed to provide a general estimate of the percentage of trees susceptible to some of the known pests in Indiana (Figure 7). It is important to note that the figure only presents data collected from the inventory. Many more trees throughout Indianapolis, including those on public and private property, may be susceptible to these invasive pests.

Findings

Looper complex [(*Erannis tiliaria*) and (*Phigalia titea*)], forest tent caterpillar (*Malacosoma disstria*), and Asian longhorned beetle are known threats to a large percentage of the inventoried street trees. These pests were not detected in Indianapolis, but if they were detected, Indianapolis could see severe losses in its tree population.

- Looper complex, linden looper (*Erannis tiliaria*), and spiny looper (*Phigalia titea*) feed on many species and cause widespread defoliation. These insects may not directly kill trees, but they can severely damage tree health. These insects threaten 51% of the street tree population. The potential loss equates to approximately $84 million in replacement value.

- Forest tent caterpillar feeds on many species and causes widespread defoliation. These insects may not directly kill trees, but they can severely damage tree health. Forest tent caterpillar threatens 33% of the street tree population. The potential loss equates to approximately $55 million in replacement value.
- Asian longhorned beetle is an insect that bores into and kills a wide range of hardwood species. ALB poses a threat to 25% of the street tree population, which represents a potential loss of approximately $42 million in replacement value.

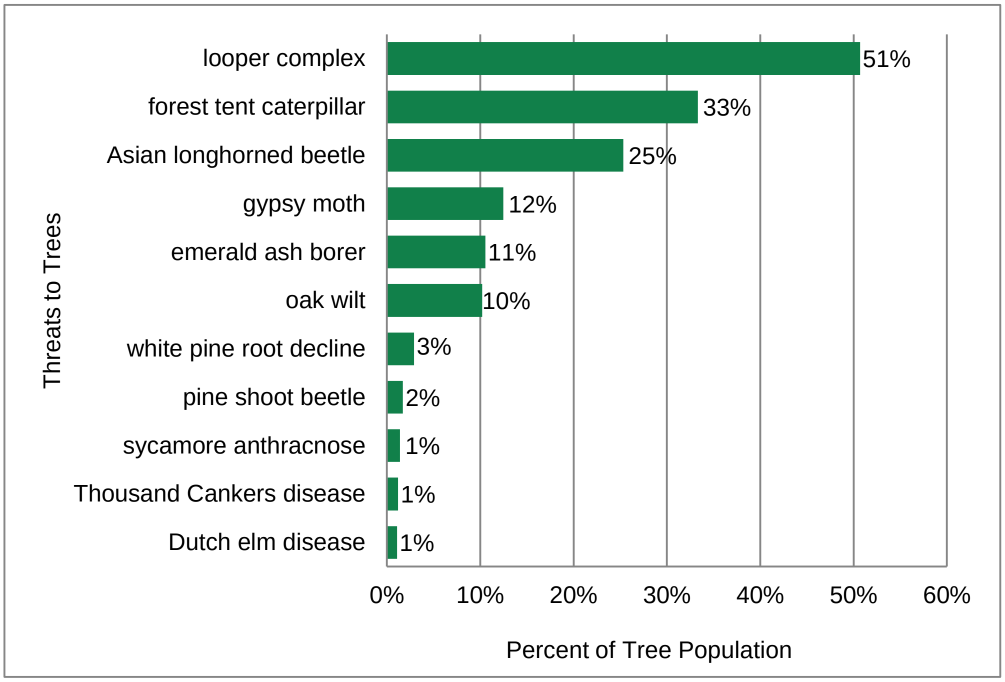


Figure 7. Potential impact of insect and disease threats noted during the 2016 inventory.

Discussion/Recommendations

Of the 19,313 ash trees that were inventoried, 68% was infested with EAB. EAB is an insect that bores into and kills most *Fraxinus* species. All other ash trees may need to be monitored for EAB because potential signs and symptoms were observed. EAB poses a threat to 11% of the street tree population, which represents a potential loss of $18 million in replacement value. The city has been reactively removing ash trees as they die.

Indianapolis should be aware of the signs and symptoms of potential infestations and should be prepared to act if a significant threat is observed in its tree population or a nearby community. An integrated pest management plan should be established. The plan should focus on identifying and monitoring threats, understanding the economic threshold, selecting the correct treatment, properly timing management strategies, recordkeeping, and evaluating results.

Brush Segments

Brush segments were inventoried when unmaintained woody vegetation encroached the pavement edge of the street or sidewalk. The type of vegetation, type of job, length of job, severity of encroachment, and other data fields were recorded.

Findings

There were 4,811 brush segments. Brush clearance is recommended along 109 miles (55 centerline miles) of inventoried street ROW. This is equal to 2% of all 3,781 centerline street miles. Most (44%) encroachments are Priority 3. Table 5 lists the vegetation and type of job and severity of encroachment.

Table 5. Brush Segments Noted During the 2016 Inventory

Job Type	Vegetation Type	Severity of Encroachment					
		Priority 1	Priority 2	Priority 3	Potential	Total	Percent of Total
Line of Site Clearance	Brush Only	14	129	109	40	292	6%
	Forest Edge/Tree Hedgerow	-	12	16	5	33	1%
	Forest Edge/Tree Hedgerow and Brush Combination	41	162	135	18	356	7%
Roadside Clearance	Brush Only	35	113	243	313	704	15%
	Forest Edge/Tree Hedgerow	19	57	67	99	242	5%
	Forest Edge/Tree Hedgerow and Brush Combination	84	337	746	741	1,908	40%
Sidewalk/Trail Clearance	Brush Only	35	83	304	107	529	11%
	Forest Edge/Tree Hedgerow	7	41	203	34	285	6%
	Forest Edge/Tree Hedgerow and Brush Combination	20	80	277	85	462	10%
Total		255	1,014	2,100	1,442	4,811	100%
Percent of Total		5%	21%	44%	30%	100%	

Discussion/Recommendations

Priority 1 and 2 encroachments threaten the safety of citizens and motorists, and can result in other damages. The brush from these segments should be reduced or removed from road and sidewalk edges before Priority 3 encroachments.

SECTION 2: BENEFITS OF THE URBAN FOREST

The urban forest plays an important role in supporting and improving the quality of life in urban areas. A tree's shade and beauty contributes to a community's quality of life and softens the often hard appearance of urban landscapes and streetscapes. When properly maintained, trees provide communities abundant environmental, economic, and social benefits that far exceed the time and money invested in planting, pruning, protection, and removal.

Environmental Benefits

- Trees decrease energy consumption and moderate local climates by providing shade and acting as windbreaks.
- Trees act as mini-reservoirs, helping to slow and reduce the amount of stormwater runoff that reaches storm drains, rivers, and lakes. One hundred mature tree crowns intercept roughly 100,000 gallons of rainfall per year (U.S. Forest Service 2003a).
- Trees help reduce noise levels, cleanse atmospheric pollutants, produce oxygen, and absorb carbon dioxide.
- Trees can reduce street-level air pollution by up to 60% (Coder 1996). Lovasi (2008) suggested that children who live on tree-lined streets have lower rates of asthma.
- Trees stabilize soil and provide a habitat for wildlife.

Economic Benefits

- Trees in a yard or neighborhood increase residential property values by an average of 7%.
- Commercial property rental rates are 7% higher when trees are on the property (Wolf 2007).
- Trees moderate temperatures in the summer and winter, saving on heating and cooling expenses (North Carolina State University 2012, Heisler 1986).
- On average, consumers will pay about 11% more for goods in landscaped areas, with this figure being as high as 50% for convenience goods (Wolf 1998b, Wolf 1999, and Wolf 2003).
- Consumers also feel that the quality of products is better in business districts surrounded by trees than those considered barren (Wolf 1998b).
- The quality of landscaping along the routes leading to business districts had a positive influence on consumers' perceptions of the area (Wolf 2000).

Social Benefits

- Tree-lined streets are safer; traffic speeds and the amount of stress drivers feel are reduced, which likely reduces road rage/aggressive driving (Wolf 1998a, Kuo and Sullivan 2001a).
- Chicago apartment buildings with medium amounts of greenery had 42% fewer crimes than those without any trees (Kuo and Sullivan 2001b).
- Chicago apartment buildings with high levels of greenery had 52% fewer crimes than those without any trees (Kuo and Sullivan 2001a).
- Employees who see trees from their desks experience 23% less sick time and report greater job satisfaction than those who do not (Wolf 1998a).
- Hospital patients recovering from surgery who had a view of a grove of trees through their windows required fewer pain relievers, experienced fewer complications, and left the hospital sooner than similar patients who had a view of a brick wall (Ulrich 1984, 1986).
- When surrounded by trees, physical signs of personal stress, such as muscle tension and pulse rate, were measurably reduced within three to four minutes (Ulrich 1991).

Trees growing along public streets constitute a valuable community resource. They provide numerous tangible and intangible benefits such as pollution control, energy reduction, stormwater management, property value increases, wildlife habitat, education, and aesthetics.

The services and benefits of trees in the urban and suburban setting were once considered to be unquantifiable. However, by using extensive scientific studies and practical research, these benefits can now be confidently calculated using tree inventory information. The results of applying a proven, defensible model and method that determines tree benefit values for the City of Indianapolis' tree inventory data are summarized in this report using the i-Tree's Streets application. The results of Indianapolis' tree inventory provide insight into the overall health of the city's public trees and the management activities needed to maintain and increase the benefits of trees into the future.

Tree Benefit Analysis

i-Tree Streets

In order to identify the dollar value provided and returned to the community, the city's street tree inventory data were formatted for use in the i-Tree Streets benefit-cost assessment tool.

i-Tree Streets, a component of i-Tree Tools, analyzes an inventoried tree population's structure to estimate the costs and benefits of that tree population. The assessment tool creates an annual benefit report that demonstrates the value street trees provide to a community:

These quantified benefits and the reports generated are described below.

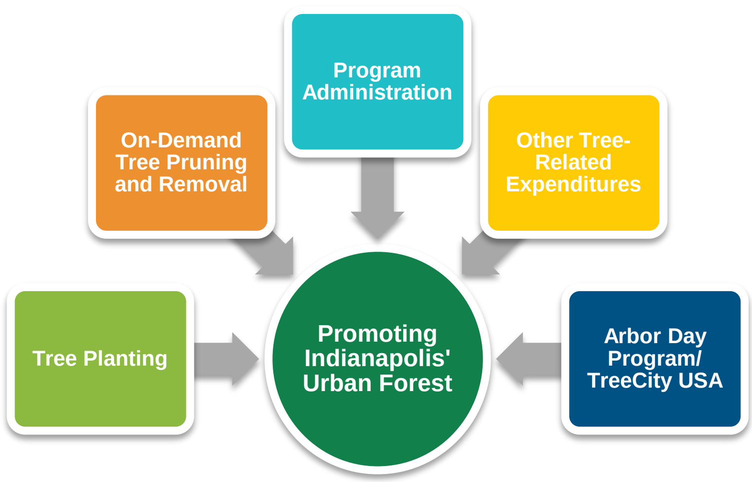
- **Aesthetic/Other Benefits:** Shows the tangible and intangible benefits of trees reflected by increases in property values (in dollars).
- **Stormwater:** Presents reductions in annual stormwater runoff due to rainfall interception by trees measured in gallons.
- **Carbon Stored:** Tallies all of the carbon dioxide (CO_2) stored in the urban forest over the life of its trees as a result of sequestration. Carbon stored is measured in tons.
- **Energy:** Presents the contribution of the urban forest towards conserving energy in terms of reduced natural gas use in the winter (measured in therms [thm]) and reduced electricity use for air conditioning in the summer (measured in Megawatt-hours ([MWh]).
- **Carbon Sequestered:** Presents annual reductions in atmospheric CO_2 due to sequestration by trees and reduced emissions from power plants due to reductions in energy use measured in pounds. The model accounts for CO_2 released as trees die and decompose and CO_2 released during the care and maintenance of trees.
- **Air Quality:** Quantifies the air pollutants (ozone [O_3], nitrogen dioxide [NO_2], sulfur dioxide [SO_2], particulate matter less than 10 micrometers in diameter [PM_{10}]) deposited on tree surfaces, and reduced emissions from power plants (NO_2, PM_{10}, volatile organic compounds [VOCs], SO_2) due to reduced electricity use in pounds. The potential negative effects of trees on air quality due to biogenic volatile organic compounds (BVOC) emissions is also reported.

- **Importance Value (IV):** IVs are calculated for species that comprise more than 1% of the population. The Streets IV is the mean of three relative values (percentage of total trees, percentage of total leaf area, and percentage of canopy cover) and can range from 0 to 100, with an IV of 100 suggesting total reliance on one species. IVs offer valuable information about a community's reliance on certain species to provide functional benefits. For example, a species might represent 10% of a population but have an IV of 25% due to its substantial benefits, indicating that the loss of those trees would be more significant than just their population percentage would suggest.

i-Tree Tools

i-Tree Tools software was developed by the U.S. Department of Agriculture, Forest Service (USDA FS) with the help of several industry partners, including The Davey Tree Expert Company. Learn more at www.itreetools.org.

i-Tree Streets Inputs



In addition to tree inventory data, i-Tree Streets requires cost-specific information to manage a community's tree management program—including administrative costs and costs for tree pruning, removal, and planting. Regional data, including energy prices, property values, and stormwater costs, are required inputs to generate the environmental and economic benefits trees provide. If community program costs or local economic data are not available, i-Tree Streets uses default economic inputs from a reference city selected by USDA FS for the climate zone in which your community is located. Any default value can be adjusted for local conditions.

Indianapolis' Inputs

Local data were available at the time of this plan and were used to the greatest extent possible with i-Tree Streets to calculate the benefits Indianapolis' trees provide its citizens. For Indianapolis' benefit analysis, energy prices and property values were adjusted for local conditions, and air quality and stormwater costs were left as default regional values. The city provided their urban forest management costs.

The Benefits of Indianapolis' Urban Forest

Annual Benefits

The i-Tree Streets model estimated that the inventoried street trees provide a total annual benefit of $9,970,035. Essentially, $9,970,035 was saved to cool buildings, manage stormwater, and clean the air. In addition, community aesthetics were improved and property values increased because of the presence of trees. On average, one of Indianapolis' trees provide an annual benefit of $54.54.

The assessment found that aesthetic and other tangible benefits trees provide were the greatest value to the community. Aesthetic and other tangible and intangible benefits comprise 48% of the annual benefits street trees provide. A city street tree increases property value by $26.44, which equates to a city tax revenue of $4,832,549 annually. In addition to property value increases, trees also play a major role in stormwater management and energy conservation. The city's street trees improve economic growth through stormwater management by $3,325,193 (33% of the total annual benefits). The city's trees mitigate the use of energy by $1,311,515 (13% of the total annual benefits). Carbon and air quality contributions are also important and account for a combined 5% of the annual benefits.

Figure 8 summarizes the annual benefits and results for the street tree population. Table 6 presents results for individual tree species from the i-Tree Streets analysis.

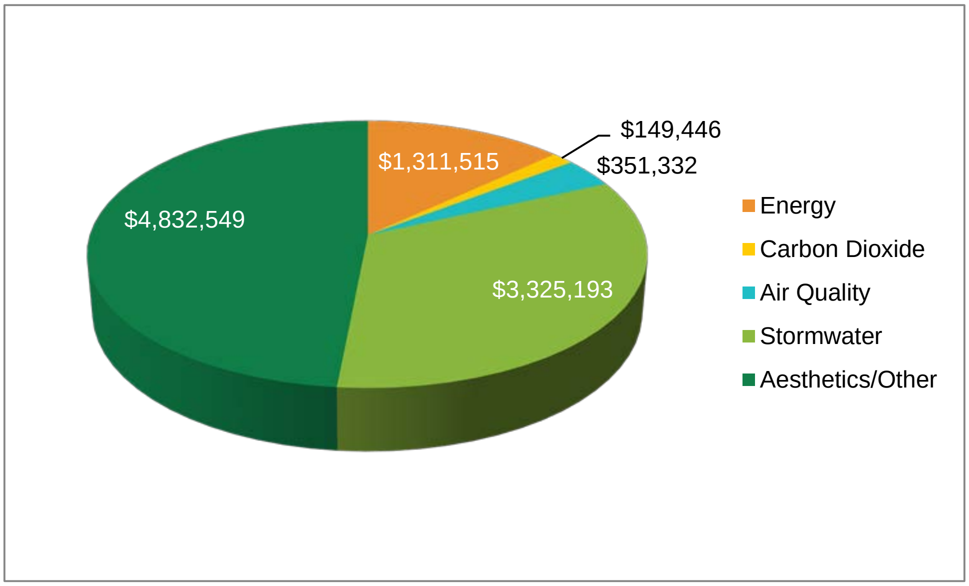


Figure 8. Breakdown of total annual benefits provided to Indianapolis.

Table 6. Benefit Data for Common Street Trees by Species

Most Common Trees Collected During Inventory		Number Trees on the ROW	Percent of Total Trees	Canopy Cover	Benefit Provide By Street Trees					Importance Value (IV)
					Aesthetic/ Other	Stormwater	Energy	Carbon Sequestered	Air Quality	
Common Name	Botanical Name		(%)	(ft^2)	Average/$/Tree					0–100 (higher IV = more important species)
silver maple	*Acer saccharinum*	13,779	7.54	17,335,743.63	28.02	34.73	12.71	1.67	3.36	12.16
white mulberry	*Morus alba*	9,756	5.34	6,838,995.88	41.76	20.67	7.16	0.65	1.91	5.84
white ash	*Fraxinus americana*	9,573	5.24	6,962,647.43	29.26	18.70	7.81	0.98	2.08	5.32
sugar maple	*Acer saccharum*	9,420	5.15	7,487,065.70	29.27	21.76	8.58	0.79	2.10	5.95
callery pear	*Pyrus calleryana*	8,800	4.81	2,642,647.95	10.42	6.28	3.20	0.32	0.87	2.71
northern hackberry	*Celtis occidentalis*	8,302	4.54	8,451,877.13	49.85	27.32	9.91	1.27	2.79	5.91
green ash	*Fraxinus pennsylvanica*	7,028	3.84	6,889,328.96	29.48	20.30	10.02	1.14	2.63	4.44
red maple	*Acer rubrum*	6,817	3.73	4,459,538.72	29.55	16.31	7.17	0.61	1.83	3.51
flowering crabapple	*Malus species*	6,363	3.48	2,552,670.26	11.33	7.14	4.45	0.48	1.16	2.17
Siberian elm	*Ulmus pumila*	5,379	2.94	5,912,248.22	44.71	28.22	9.88	1.11	2.91	3.95
eastern white pine	*Pinus strobus*	5,335	2.92	2,929,266.96	18.92	20.63	4.96	0.41	1.59	2.49
blue spruce	*Picea pungens*	4,627	2.53	853,176.92	14.85	7.79	1.64	0.19	0.52	1.32
eastern redbud	*Cercis canadensis*	4,186	2.29	1,290,665.25	9.76	6.56	2.72	0.23	0.85	1.33
Norway spruce	*Picea abies*	3,676	2.01	1,069,652.11	13.31	11.46	2.63	0.27	0.82	1.23
northern red oak	*Quercus rubra*	3,676	2.01	4,940,875.92	42.22	33.29	12.96	2.22	3.21	3.15
plum species	*Prunus species*	3,498	1.91	871,270.62	11.83	5.27	2.20	0.20	0.69	1.02
eastern red cedar	*Juniperus virginiana*	3,296	1.80	799,931.52	15.24	8.77	2.10	0.26	0.69	1.01
arborvitae species	*Thuja species*	3,175	1.74	434,821.88	12.74	4.95	1.14	0.12	0.36	0.80
Norway maple	*Acer platanoides*	3,119	1.71	2,348,224.74	25.14	19.18	7.95	0.69	2.09	1.74
black walnut	*Juglans nigra*	2,816	1.54	2,738,845.00	28.89	18.66	8.39	0.99	2.33	1.91
thornless honeylocust	*Gleditsia triacanthos inermis*	2,796	1.53	2,873,756.56	31.61	21.17	8.91	1.07	2.69	1.76
ash species	*Fraxinus species*	2,389	1.31	2,236,803.53	30.04	19.32	9.61	1.11	2.52	1.46
hawthorn species	*Crataegus species*	2,245	1.23	699,146.23	9.99	6.66	2.74	0.24	0.86	0.72
black locust	*Robinia pseudocacia*	2,220	1.21	2,174,484.60	30.08	20.30	10.04	1.17	2.63	1.40
boxelder	*Acer negundo*	2,197	1.20	1,729,288.25	29.02	19.93	8.53	0.69	2.18	1.29
black cherry	*Prunus serotina*	2,108	1.15	2,096,155.64	29.87	20.59	10.17	1.17	2.66	1.35
American elm	*Ulmus americana*	1,976	1.08	1,220,613.01	50.02	16.55	5.85	0.91	1.71	1.00
sweetgum	*Liquidambar styraciflua*	1,915	1.05	1,951,011.20	29.96	21.31	10.40	1.27	2.72	1.25
tulip tree	*Liriodendron tulipifera*	1,890	1.03	1,957,521.28	24.33	21.67	10.30	1.12	2.72	1.25
American sycamore	*Platanus occidentalis*	1,882	1.03	2,564,791.20	20.27	28.45	13.26	1.14	3.52	1.53
eastern cottonwood	*Populus deltoides*	1,867	1.02	2,410,499.09	29.24	38.36	13.25	0.88	2.45	1.78
other street trees	~215 species of varying genera	36,695	20.07	88,339,125.71	19.62	10.80	4.23	0.48	1.17	17.26
ROW Total	92 genera and ~249 species on the ROW	182,801	100.00	198,062,691.10	26.44	18.19	7.17	0.82	1.92	100.00

Aesthetic/Other Benefits

The total annual benefit associated with property value increases and other tangible and intangible benefits of street trees was $4,832,549. The average benefit per tree equaled $26.44 per year.

Stormwater Benefits

Trees intercept rainfall, which helps lower costs to manage stormwater runoff. The inventoried trees in Indianapolis intercept 536,321,425 gallons of rainfall annually (Table 7). On average, the estimated annual savings for the city in stormwater runoff management is $3,325,193.

Of all species inventoried, silver maple contributed most of the annual stormwater benefits. The silver maple population (8% of ROW) intercepted approximately 77 million gallons of rainfall. On a per-tree basis, large trees with leafy canopies provided the most value. Silver maple and northern hackberry are large-statured trees. Flowering crabapple is a small-statured tree. Northern hackberry comprised 5% of the ROW population, and flowering crabapple comprised roughly 3% of the ROW population. On a per-tree basis, silver maple and northern hackberry absorbed five and four times more gallons of rainfall than flowering crabapple. These large-statured trees with big canopies offered the greatest benefits.

- *Trees reduce stormwater runoff by capturing and storing rainfall in their canopy and releasing water into the atmosphere.*
- *Tree roots and leaf litter create soil conditions that promote the infiltration of rainwater into the soil.*
- *Trees help slow down and temporarily store runoff and reduce pollutants by absorbing nutrients and other pollutants from soils and water through their roots.*
- *Trees transform pollutants into less harmful substances.*

Air Quality Improvements

The inventoried tree population annually removes 142,022 pounds of air pollutants (including ozone, nitrogen dioxide, sulfur dioxide, and particulate matter) through deposition. The population also avoids 183,219 pounds annually.

While trees do a great deal to absorb air pollutants, they also contribute negatively to air pollution. Trees emit various Biogenic Volatile Organic Compounds (BVOCs) such as isoprenes and monoterpenes, which can also contribute to formation of ozone, a harmful gas that pollutes the air and damages vegetation. A common example of a natural BVOC is the gas emitted from pine trees, which creates the distinct smell of a pine forest. These BVOC emissions (41,949 pounds) are accounted for in the air quality net benefit.

The inventoried trees removed or avoided more pollutants than they emitted, resulting in a positive economic value (283,292 pounds). Using the annual per-tree values in Table 6, silver maple, *Quercus rubra* (northern red oak), and *Platanus occidentalis* (American sycamore) provided the most benefits based on their annual per-tree average values, which ranged from $3.21 to $3.52.

Table 7. Stormwater Benefits Provided by Street Trees

Most Common Trees Collected During Inventory		Number of Trees on the ROW	Percent of Total Trees	Total Rainfall Interception
Common Name	Botanical Name		(%)	(gal.)
silver maple	*Acer saccharinum*	13,779	7.54	77,190,631.64
white mulberry	*Morus alba*	9,756	5.34	32,530,301.38
white ash	*Fraxinus americana*	9,573	5.24	28,876,969.81
sugar maple	*Acer saccharum*	9,420	5.15	33,053,873.33
callery pear	*Pyrus calleryana*	8,800	4.81	8,919,910.80
northern hackberry	*Celtis occidentalis*	8,302	4.54	36,580,005.31
green ash	*Fraxinus pennsylvanica*	7,028	3.84	23,006,326.29
red maple	*Acer rubrum*	6,817	3.73	17,936,992.31
flowering crabapple	*Malus species*	6,363	3.48	7,327,301.39
Siberian elm	*Ulmus pumila*	5,379	2.94	24,481,523.55
eastern white pine	*Pinus strobus*	5,335	2.92	17,751,622.03
blue spruce	*Picea pungens*	4,627	2.53	5,810,001.34
eastern redbud	*Cercis canadensis*	4,186	2.29	4,431,975.87
Norway spruce	*Picea abies*	3,676	2.01	6,795,910.37
northern red oak	*Quercus rubra*	3,676	2.01	19,735,566.68
plum species	*Prunus species*	3,498	1.91	2,970,507.55
eastern red cedar	*Juniperus virginiana*	3,296	1.80	4,662,700.66
arborvitae species	*Thuja species*	3,175	1.74	2,535,905.54
Norway maple	*Acer platanoides*	3,119	1.71	9,647,851.37
black walnut	*Juglans nigra*	2,816	1.54	8,475,753.84
thornless honeylocust	*Gleditsia triacanthos inermis*	2,796	1.53	9,546,590.78
ash species	*Fraxinus species*	2,389	1.31	7,443,175.39
hawthorn species	*Crataegus species*	2,245	1.23	2,412,929.09
black locust	*Robinia pseudocacia*	2,220	1.21	7,267,306.60
boxelder	*Acer negundo*	2,197	1.20	7,063,249.72
black cherry	*Prunus serotina*	2,108	1.15	7,001,723.86
American elm	*Ulmus americana*	1,976	1.08	5,273,613.12
sweetgum	*Liquidambar styraciflua*	1,915	1.05	6,581,540.75
tulip tree	*Liriodendron tulipifera*	1,890	1.03	6,607,118.15
American sycamore	*Platanus occidentalis*	1,882	1.03	8,636,641.89
eastern cottonwood	*Populus deltoides*	1,867	1.02	11,551,426.18
other street trees	~215 species of varying genera	36,695	20.07	84,214,478.19
ROW Total	92 genera and ~249 species on the ROW	182,801	100.00	536,321,425

Carbon Sequestration Benefits

Trees absorb CO_2 and sequester some during growth (Nowak et al. 2013). This prevents CO_2 from reaching the upper atmosphere, where it can react with other compounds and form harmful gases like ozone, which adversely affects air quality. i-Tree Streets calculates how much CO_2 is sequestered annually.

The i-Tree Streets calculation also takes into account the carbon emissions that are *not* released from power stations due to the heating and cooling effect of trees (i.e., conserved energy in buildings and homes). It calculates emissions released during tree care and maintenance, such as driving to the site and operating equipment. The net CO_2 benefit was approximately $149,446 per year.

The city's street trees sequester 30,001,892 pounds of CO_2 per year. Through avoidance, 3,323,126 pounds of CO_2 are removed each year. Northern red oak comprises 2% of the total tree population and sequesters an annual average per tree of $2.22 worth of carbon. Flowering crabapple comprises 3% of the total tree population and only sequesters an annual average per tree of $0.45 worth of carbon.

Energy Benefits

Public trees conserve energy by shading structures and surfaces, which reduces electricity use for air conditioning in the summer. Trees divert wind in the winter to reduce natural gas use. Based on the inventoried trees, the annual electric and natural gas savings are equivalent to 10,656 MWh of electricity and 241,199 therms of natural gas, which accounts for an annual savings of $1,311,515 in energy consumption.

Large leafy canopies are valuable because they provide shade, which reduces energy usage. Silver maple, *Platanus occidentalis* (American sycamore), and *Populus deltoides* (eastern cottonwood) all have annual per-tree values exceeding $12.70. Smaller species such as flowering crabapple, *Cercis canadensis* (eastern redbud), and *Prunus* species (plum) all have annual per-tree values between $2.20 and $4.45.

***Malus* species (flowering crabapple)**	***Acer saccharinum* (silver maple)**	***Platanus occidentalis* (American sycamore)**	***Populus deltoides* (eastern cottonwood)**
3% of ROW	8% of ROW	1% of ROW	1% of ROW
219MWh Electricity	1,379MWh Electricity	196MWh Electricity	192MWh Electricity
7,890thm Natural Gas	42,596thm Natural Gas	6,150thm Natural Gas	6,789thm Natural Gas
$4.45 Average $/tree	$12.71 Average $/tree	$13.26 Average $/tree	$13.25 Average $/tree

Importance Value (IV)

Understanding the importance of a tree species to the community is based on its presence on the ROW, but also its ability to provide environmental and economic benefits to the community. The IV calculated by the street computer model takes into account the total number of trees of a species, its percentage in the population, and its total leaf area and canopy cover. The IV can range from 0 to 100, with an IV of 100 suggesting total reliance on one species. If IV values are greater or less than the percentage of a species on the ROW, it indicates that the loss of that species may be more important or less important than its population percentage implies.

The i-Tree Streets assessment found that silver maple has the greatest IV in the ROW population at 12.16, even though it comprises only 8% of the ROW. This indicates that the loss of the silver maple population would be more economically detrimental than its percentage of the population leads us to believe. The second highest IV was for sugar maple (5.95), followed by northern hackberry (5.91) and white mulberry (5.84). The abundance of northern hackberry on the ROW is not as great as white mulberry, but northern hackberry's IV is greater than white mulberry. Because they are large-growing, the size and canopy of broadleaf species naturally provide more environmental benefits to the community, which all factor into assigning IV. The IV for northern hackberry is more than its percentage of the population, indicating that if northern hackberry was lost, its economic impact would be more significant.

Benefit-Cost Ratio

According to the benefits presented in this section, trees provide significant value; but are the collective benefits worth the costs of management? In other words, are trees a good investment for Indianapolis? To answer that question, we must compare the benefit public trees provide to the cost of their management.

Applying a benefit-cost ratio (BCR) is another useful way to evaluate the investment in public trees. A BCR is an indicator used to summarize the overall value compared to the costs of a given project. Specifically in this analysis, BCR is the ratio of the cumulative benefits provided by the city's street trees, expressed in monetary terms, compared to the costs associated with their management, also expressed in monetary terms. When Indianapolis' annual expenditures of $2,522,830 are considered, the net annual benefit (benefits minus costs) returned by public trees to the city is $7,447,205. Indianapolis receives $3.95 in benefits for every $1 spent on its municipal forestry program.

Discussion/Recommendations

The i-Tree Streets analysis found that street trees provide environmental and economic benefits to the community by virtue of their mere presence on the streets. Currently, aesthetics and other tangible and intangible benefits provided by street trees were rated as having the greatest value to the community. In addition to providing aesthetic benefit, trees manage stormwater by mitigating and slowing the flow of runoff, provide shade and windbreaks to reduce energy usage, remove pollutants from the air, and sequester CO_2. Even though these benefits were not found to be as great as the aesthetic benefits, they are noteworthy.

i-Tree Streets analysis found that sugar maple is the most influential tree along Indianapolis' ROW. If this species was lost to Asian longhorned beetle or other threats, its loss would be felt more than the community may realize.

To further increase the benefits the public tree provides, Indianapolis should plant young, large-statured tree species that are low emitters of BVOCs wherever possible. Leafy, large-stature trees consistently created the most environmental and economic benefits. The following list of tree species is used for improving air quality (ICLEI 2006):

- *Betula* spp. (birch)
- *Celtis* spp. (hackberry)
- *Fagus* spp. (beech)
- *Metasequoia glyptostroboides* (dawn redwood)
- *Tilia* spp. (linden)
- *Ulmus* spp. (elm)

SECTION 3: TREE MANAGEMENT PROGRAM

This tree management program was developed to uphold Indianapolis' comprehensive vision for preserving its urban forest. This five-year program is based on the tree inventory data; the program was designed to reduce risk through prioritized tree removal and pruning, and to improve tree health and structure through proactive pruning cycles. Tree planting to mitigate removals and increase canopy cover and public outreach are important parts of the program as well.

While implementing a tree care program is an ongoing process, tree work must always be prioritized to reduce public safety risks. Davey Resource Group recommends completing the work identified during the inventory based on the assigned risk rating; however, it is also essential to routinely monitor the tree population to identify other Extreme or High Risk trees so that they may be systematically addressed. While regular pruning cycles and tree planting is important, priority work (especially for Extreme or High Risk trees) must sometimes take precedence to ensure that risk is expediently managed.

Priority and Proactive Maintenance

In this plan, the recommended tree maintenance work was divided into either priority or proactive maintenance. Priority maintenance includes tree removals and pruning of trees with an assessed risk rating of Moderate, High, and Extreme Risk. Proactive tree maintenance includes pruning of trees with an assessed risk of Low Risk and trees that are young. Tree planting, inspections, and community outreach are also considered proactive maintenance.

Tree and Stump Removal

Extreme Risk
- Perform tree maintenance immediately to reduce hazards
- Includes tree removal and pruning
- Mostly high-use areas

High Risk
- Perform tree maintenance immediately to reduce hazards and improve tree health
- Includes tree removal and pruning
- Generally high-use areas

Moderate Risk
- Perform tree maintenance as soon as possible to improve tree health
- Includes tree removal and pruning
- May be high- or low-use areas

Low Risk
- Perform tree maintenance when convenient to improve aesthetics and eliminate nuisance trees and stumps
- Includes tree removals and pruning
- Mostly low-use areas but may be high-use areas as well

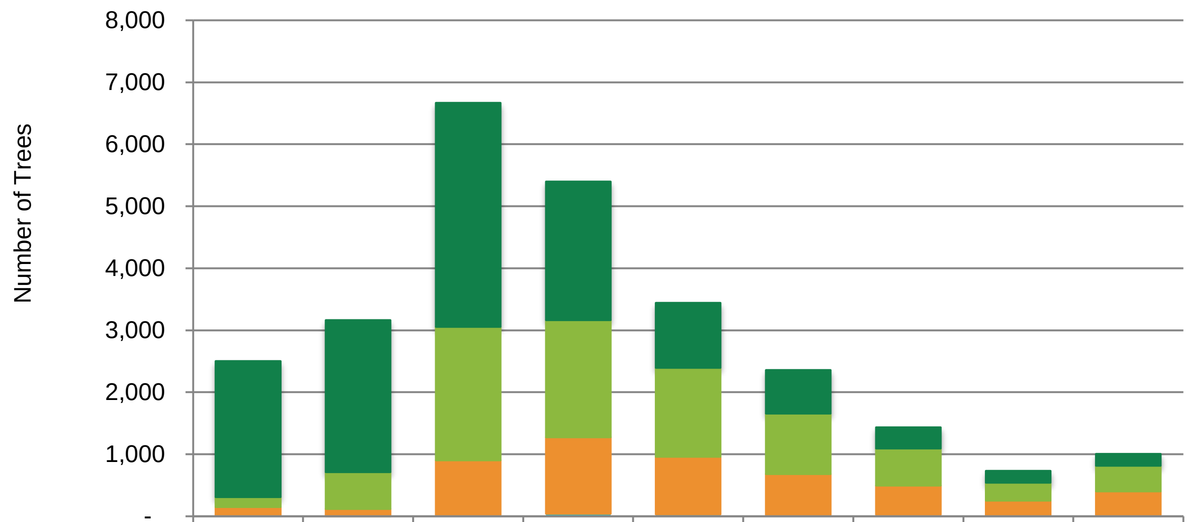
Routine Pruning
- Perform tree maintenance when convenient to improve aesthetics and eliminate nuisance trees

Training Prune
- Perform corrective pruning to young trees to increase structural integrity and develop a strong architecture of branches before serious problems develop

Although tree removal is usually considered a last resort and may sometimes create a reaction from the community, there are circumstances in which removal is necessary. Trees fail from natural causes, such as diseases, insects, and weather conditions, and from physical injury due to vehicles, vandalism, and root disturbances. Davey Resource Group recommends that trees be removed when corrective pruning will not adequately eliminate the hazard or when correcting problems would be cost-prohibitive. Trees that cause obstructions or interfere with power lines or other infrastructure should be removed when their defects cannot be corrected through pruning or other maintenance practices. Diseased and nuisance trees also warrant removal.

Even though large short-term expenditures may be required, it is important to secure the funding needed to complete priority tree removals. Expedient removal reduces risk and promotes public safety.

Figure 9 presents tree removals by risk rating and diameter size class. The following sections briefly summarize the recommended removals identified during the inventory.



	1″–3″	4″–6″	7″–12″	13″–18″	19″–24″	25″–30″	31″–36″	37″–42″	≥43″
Low Risk	2,193	2,452	3,614	2,237	1,051	706	343	189	195
Moderate Riak	156	595	2,153	1,890	1,432	973	597	288	408
High Risk	147	116	881	1,232	932	662	471	244	383
Extreme Risk	4	-	22	41	28	19	25	9	21

Diameter Size Class

Figure 9. Tree removals by risk rating and diameter size class.

Findings

The inventory identified 169 Extreme Risk trees, 5,068 High Risk trees, 8,492 Moderate Risk trees, and 12,980 Low Risk trees that are recommended for removal.

Tree in diameter size classes for Extreme Risk were primarily between 7–12 inches diameter at breast height (DBH) and 31–36 inches DBH. High Risk trees ranged primarily between 7–12 inches DBH and 25–30 inches DBH. These trees should be removed immediately based on their assigned risk. Extreme Risk trees should be removed before High Risk trees; however, Extreme and High Risk removals can be performed concurrently.

Most Moderate Risk trees ranged between 7–12 DBH and 19–24 inches DBH. These trees should be removed as soon as possible after all Extreme and High Risk removals have been completed.

Low Risk removals pose little threat; these trees are generally small, dead, invasive, or poorly-formed trees that need to be removed. Eliminating these trees will reduce breeding site locations for insects and diseases and will increase the aesthetic value of the area. Healthy trees growing in poor locations or undesirable species are also included in this category. All Low Risk trees should be removed when convenient and after all Extreme, High, and Moderate Risk removals have been completed.

The inventory identified 9,911 ash trees recommended for removal.

The inventory identified 8,041 stumps recommended for removal. Almost all of these stumps were between 12–18 inches DBH and 19–24 inches DBH. Stump removals should occur when convenient.

Discussion/Recommendations

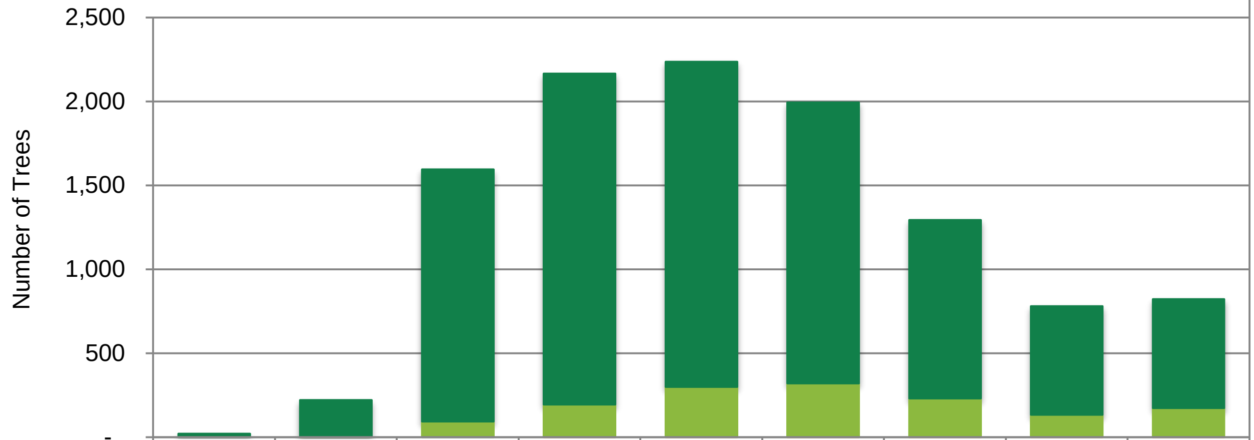
Trees noted as having cavity or decay (9,821 trees) or poor structure (6,138 trees) should be inspected on a regular basis. Recommended removals accounted for 4,766 trees with cavity or decay observed and 1,270 trees with poor structure. Corrective action should be taken when warranted for the remaining 5,055 trees with cavity or decay and 4,868 trees with poor structure. If their condition worsens, tree removal may be required. Proactive tree maintenance that actively mitigates elevated-risk situations will promote public safety.

Updating the tree inventory data can streamline work load management and lend insight into setting accurate budgets and staffing levels. Inventory updates should be made electronically and can be implemented using *TreeKeeper*® 7 or similar computer software.

Tree Pruning

Extreme, High, and Moderate Risk pruning generally require cleaning the canopy of both small and large trees to remove defects such as dead and/or broken branches that may be present even when the rest of the tree is sound. In these cases, pruning the branch or branches can correct the problem and reduce risk associated with the tree.

Figure 10 presents the number of Extreme, High, and Moderate Risk trees recommended for pruning by size class. The following sections briefly summarize the recommended pruning maintenance identified during the inventory.



	1″–3″	4″–6"	7″– 12″	13″–18″	19″– 24″	25″–30″	31″– 36″	37″– 42″	≥43″
Moderate Risk	21	216	1,501	1,970	1,936	1,673	1,062	648	650
High Risk	-	5	94	194	297	316	227	130	171
Extreme Risk	-	-	-	1	3	4	4	3	2

Diameter Size Class (inches)

Figure 10. Extreme, High, and Moderate Risk pruning by diameter size class.

Findings

The inventory identified 17 Extreme Risk trees, 1,434 High Risk trees, and 9,677 Moderate Risk trees recommended for pruning.

Extreme Risk trees ranged in diameter size classes from 13–18 inches DBH to greater than 43 inches DBH. Majority of High Risk trees ranged in diameter size classes from 19–24 inches DBH to 31–36 inches DBH. The majority of Moderate Risk trees ranged in diameter size classes from 7–12 inches DBH to 31–36 inches DBH. This pruning should be performed immediately based on assigned risk and may be performed concurrently with other Extreme, High, or Moderate Risk removal. Low Risk trees recommended for pruning should be included in a proactive, routine pruning cycle after all the higher risk trees are addressed.

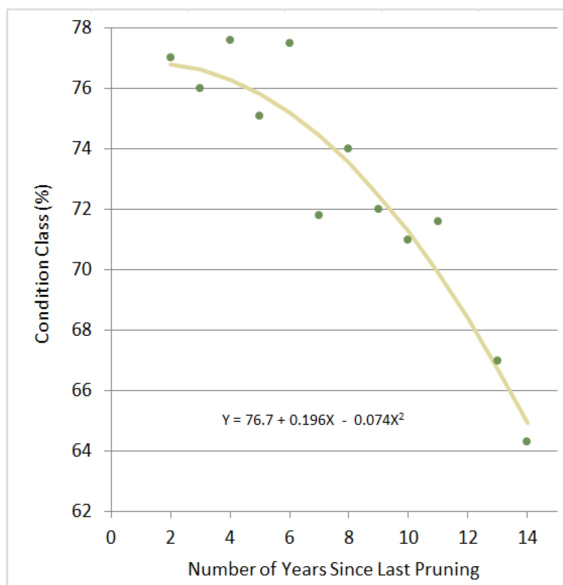


Figure 11. Relationship between average tree condition class and the number of years since the most recent pruning (adapted from Miller and Sylvester 1981).

Pruning Cycles

The goals of pruning cycles are to visit, assess, and prune trees on a regular schedule to improve health and reduce risk. Davey Resource Group recommends that pruning cycles begin after all Extreme, High, and Moderate Risk trees are corrected through pruning. However, due to the long-term benefits of pruning cycles, Davey Resource Group recommends that the cycles be implemented as soon as possible. To ensure that all trees receive the type of pruning they need to mature with better structure and lower associated risk, two pruning cycles are recommended: the young tree training cycle (YTT Cycle) and the routine pruning cycle (RP Cycle). The cycles differ in the type of pruning, the general age of the target tree, and length.

The recommended number of trees in the pruning cycles will need to be modified to reflect changes in the tree population as trees are planted, age, and die. Newly planted trees will enter the YTT Cycle once they become established. As young trees reach maturity, they will be shifted from the YTT Cycle into the RP Cycle. When a tree reaches the end of its useful life, it should be removed and eliminated from the RP Cycle.

For many communities, a proactive tree management program is considered unfeasible. An on-demand response to urgent situations is the norm. Research has shown that a proactive program that includes a routine pruning cycle will improve the overall health of a tree population (Miller and Sylvester 1981). Proactive tree maintenance has many advantages over on-demand maintenance, the most significant of which is reduced risk. In a proactive program, trees are regularly assessed and pruned, which helps detect and eliminate most defects before they escalate to a hazardous situation with an unacceptable level of risk. Other advantages of a proactive program include: increased environmental and economic benefits from trees, more predictable budgets and projectable workloads, and reduced long-term tree maintenance costs.

Why Prune Trees on a Cycle?

Miller and Sylvester (1981) examined the frequency of pruning for 40,000 street and boulevard trees in Milwaukee, Wisconsin. They documented a decline in tree health as the length of the pruning cycle increased. When pruning was not completed for more than 10 years, the average tree condition was rated 10% lower than when trees had been pruned within the last several years. Miller and Sylvester suggested that a pruning cycle of five years is optimal for urban trees.

Young Tree Training Cycle

Trees included in the YTT Cycle are generally less than 8 inches DBH. These younger trees sometimes have branch structures that can lead to potential problems as the tree ages. Potential structural problems include codominant leaders, multiple limbs attaching at the same point on the trunk, or crossing/interfering limbs. If these problems are not corrected, they may worsen as the tree grows, increasing risk and creating potential liability.

YTT pruning is performed to improve tree form or structure; the recommended length of a YTT Cycle is three years because young trees tend to grow at faster rates (on average) than more mature trees.

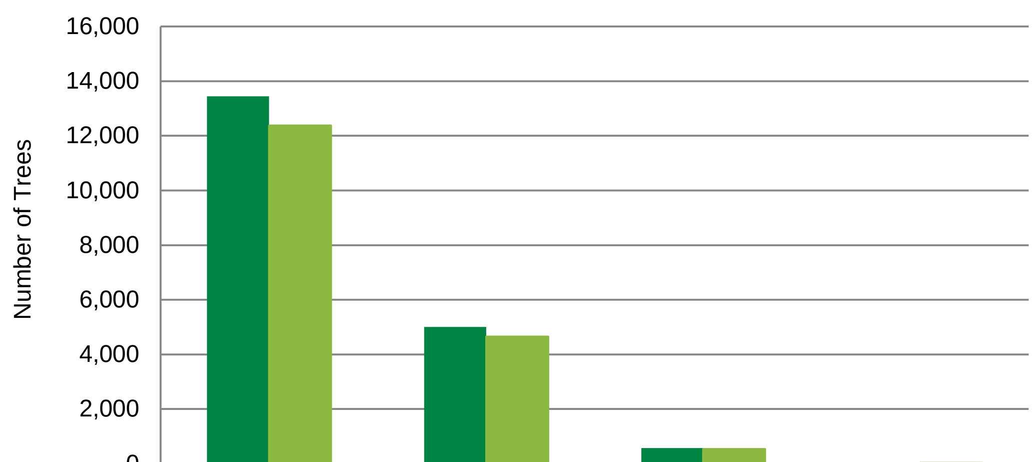
The YTT Cycle differs from the RP Cycle in that these trees generally can be pruned from the ground with a pole pruner or pruning shear. The objective is to increase structural integrity by pruning for one dominant leader. YTT Pruning is species-specific, since many trees such as *Betula nigra* (river birch) may naturally have more than one leader. For such trees, YTT pruning is performed to develop a strong structural architecture of branches so that future growth will lead to a healthy, structurally sound tree.

<u>Recommendations</u>

Davey Resource Group recommends that Indianapolis implement a three-year YTT Cycle to begin as soon as possible. The YTT Cycle will include existing young trees. During the inventory, 19,077 trees smaller than 13 inches DBH were inventoried and recommended for young tree training. The benefit of beginning the YTT Cycle is substantial. Davey Resource Group recommends that an average of 6,359 trees be structurally pruned each year over three years, beginning in Year One of the management program.

If trees are planted, they will need to enter the YTT Cycle after establishment, typically a few years after planting.

In future years, the number of trees in the YTT Cycle will be based on tree planting efforts and growth rates of young trees. The city should strive to prune approximately one-third of its young trees each year.



	1″–3″	4″–6"	7″– 12″	> 13″
Young Tree Training Entire Inventory	13,450	5,009	579	39
Young Tree Training Maintained Areas Only	12,384	4,649	544	39

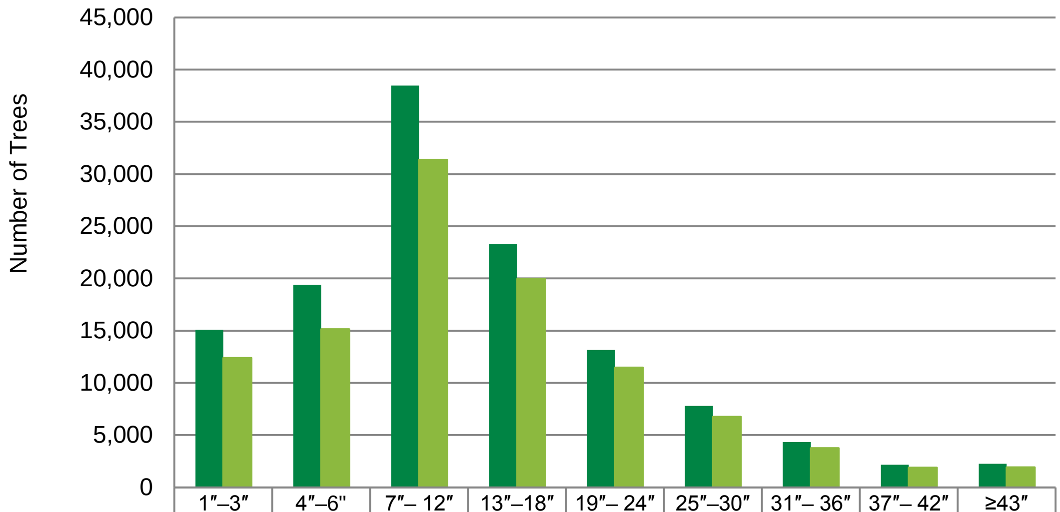
Diameter Size Class (inches)

Figure 12. Trees recommended for the YTT Cycle by diameter size class.

Routine Pruning Cycle

The RP Cycle includes established, maturing, and mature trees (mostly greater than 8 inches DBH) that need cleaning, crown raising, and reducing to remove deadwood and improve structure. Over time, routine pruning can reduce reactive maintenance, minimize instances of elevated risk, and provide the basis for a more defensible risk management program. Included in this cycle are Low Risk trees that require pruning and pose some risk but have a smaller size of defect and/or less potential for target impact. The defects found within these trees can usually be remediated during the RP Cycle.

The length of the RP Cycle is based on the size of the tree population and what was assumed to be a reasonable number of trees for a program to prune per year. Generally, the RP Cycle recommended for a tree population is five years but may extend to additional years if the population is large.



	1″–3″	4″–6"	7″– 12″	13″–18″	19″– 24″	25″–30″	31″– 36″	37″– 42″	≥43″
Routine Prune Entire Inventory	15,070	19,386	38,451	23,285	13,146	7,794	4,330	2,177	2,248
Routine Prune Maintained Areas Only	12,388	15,136	31,381	19,993	11,469	6,753	3,774	1,892	1,924

Diameter Size Class (inches)

Figure 13. Trees recommended for the RP Cycle by diameter size class.

Recommendations

Davey Resource Group recommends that the city establish a nine-year RP Cycle in which approximately one-ninth of the tree population is to be pruned each year. The 2016 tree inventory identified approximately 125,887 trees that should be pruned over a nine-year RP Cycle. An average of 13,987 trees should be pruned each year over the course of the cycle. Davey Resource Group recommends that the RP Cycle begin in Year Two of this five-year plan, after all Extreme, High, and Moderate Risk trees are pruned.

The inventory found that most trees (75%) on the street ROW needed routine pruning. Figure 12 shows that a variety of tree sizes will require pruning; however, most of the trees that require routine pruning were 7–12 inches DBH and 13–18 inches DBH.

Maintenance Schedule

Utilizing data from the 2016 City of Indianapolis tree inventory, an annual maintenance schedule was developed that details the number and type of tasks recommended for completion each year. Davey Resource Group made budget projections using industry knowledge and public bid tabulations. Actual costs were specified by Indianapolis. A complete table of estimated costs for Indianapolis' five-year tree management program is presented on the following page.

The schedule provides a framework for completing the inventory maintenance recommendations over the next five years. Following this schedule can shift tree care activities from an on-demand system to a more proactive tree care program.

To implement the maintenance schedule, the city's tree maintenance budget should be no less than $8,980,593 for the first year of implementation, no less than $8,164,632 for the second year, no less than $8,057,343 for the third year, $7,365,389 for the fourth year, and $7,532,753 for the fifth year of the maintenance schedule. Annual budget funds are needed to ensure that Extreme, High, and Moderate Risk trees are remediated and that crucial YTT and RP Cycles can begin. With proper professional tree care, the safety, health, and beauty of the urban forest will improve.

If routing efficiencies and/or contract specifications allow for the completion of more tree work, or if the schedule requires modification to meet budgetary or other needs, then the schedule should be modified accordingly. Unforeseen situations such as severe weather events may arise and change the maintenance needs of trees. Should conditions or maintenance needs change, budgets and equipment will need to be adjusted to meet the new demands.

Table 8. Estimated Costs for Five-Year Urban Forestry Management Program

Maintenance Priority and DBH Size Class		2017		2018		2019		2020		2021		Five-Year Cost
Activity	Diameter	# of Trees	Total Cost	# of Trees	Total Cost	# of Trees	Total Cost	# of Trees	Total Cost	# of Trees	Total Cost	
Extreme, High, Moderate Risk Removal	1-3"	0	$0	1	$46	0	$0	141	$6,486	0	$0	$6,532
	4-6"	0	$0	134	$6,164	0	$0	577	$26,542	0	$0	$32,706
	7-12"	0	$0	857	$84,380	2,180	$210,900	0	$0	0	$0	$295,280
	13-18"	0	$0	1,320	$264,264	1,956	$393,744	0	$0	0	$0	$658,008
	19-24"	1,029	$382,571	0	$0	1,462	$542,685	0	$0	0	$0	$925,256
	25-30"	766	$419,140	0	$0	940	$513,880	0	$0	0	$0	$933,020
	31-36"	522	$441,446	600	$504,243	0	$0	0	$0	0	$0	$945,688
	37-42"	267	$314,730	288	$340,170	0	$0	0	$0	0	$0	$654,900
	43"+	341	$663,098	348	$701,278	0	$0	0	$0	0	$0	$1,364,377
Activity Total(s)		**2,925**	**$2,220,985**	**3,548**	**$1,900,545**	**6,538**	**$1,661,209**	**718**	**$33,028**	**0**	**$0**	**$5,815,766**
Low Risk Removal	1-3"	0	$0	0	$0	0	$0	0	$0	2,261	$104,006	$104,006
	4-6"	0	$0	0	$0	0	$0	0	$0	2,401	$110,446	$110,446
	7-12"	0	$0	0	$0	0	$0	0	$0	3,622	$337,020	$337,020
	13-18"	0	$0	0	$0	0	$0	0	$0	2,245	$442,468	$442,468
	19-24"	0	$0	0	$0	0	$0	0	$0	1,051	$389,419	$389,419
	25-30"	0	$0	0	$0	0	$0	681	$371,520	0	$0	$371,520
	31-36"	0	$0	0	$0	0	$0	343	$287,774	0	$0	$287,774
	37-42"	0	$0	0	$0	0	$0	189	$223,500	0	$0	$223,500
	43"+	0	$0	0	$0	0	$0	187	$416,104	0	$0	$416,104
Activity Total(s)		**0**	**$0**	**0**	**$0**	**0**	**$0**	**1,400**	**$1,298,898**	**11,580**	**$1,383,359**	**$2,682,257**
Stump Removal	1-3"	361	$3,249	1	$9	0	$0	141	$1,269	2,261	$20,349	$24,876
	4-6"	854	$7,686	134	$1,206	0	$0	577	$5,193	2,401	$21,609	$35,694
	7-12"	2,018	$57,975	857	$25,314	2,180	$63,270	0	$0	3,622	$101,106	$247,665
	13-18"	1,649	$75,906	1,320	$60,984	1,956	$90,864	0	$0	2,245	$102,108	$329,862
	19-24"	1,211	$84,338	1,029	$72,079	1,462	$102,245	0	$0	1,051	$73,369	$332,030
	25-30"	799	$82,080	766	$78,589	940	$96,353	681	$69,660	0	$0	$326,681
	31-36"	550	$75,841	522	$72,554	600	$82,876	343	$47,298	0	$0	$278,569
	37-42"	338	$56,512	267	$44,587	288	$48,191	189	$31,663	0	$0	$180,952
	43"+	261	$25,678	341	$77,912	348	$81,483	187	$47,527	0	$0	$232,600
Activity Total(s)		**8,041**	**$469,265**	**5,237**	**$433,233**	**7,774**	**$565,281**	**2,118**	**$202,609**	**11,580**	**$318,541**	**$1,988,929**
Extreme, High, Moderate Risk Pruning	1-3"	21	$609	0	$0	0	$0	0	$0	0	$0	$609
	4-6"	221	$6,409	0	$0	0	$0	0	$0	0	$0	$6,409
	7-12"	1,595	$83,801	0	$0	0	$0	0	$0	0	$0	$83,801
	13-18"	2,165	$211,656	0	$0	0	$0	0	$0	0	$0	$211,656
	19-24"	2,236	$320,670	0	$0	0	$0	0	$0	0	$0	$320,670
	25-30"	1,993	$331,950	0	$0	0	$0	0	$0	0	$0	$331,950
	31-36"	1,293	$237,199	0	$0	0	$0	0	$0	0	$0	$237,199
	37-42"	781	$183,762	0	$0	0	$0	0	$0	0	$0	$183,762
	43"+	823	$234,627	0	$0	0	$0	0	$0	0	$0	$234,627
Activity Total(s)		**11,128**	**$1,610,682**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**0**	**$0**	**$1,610,682**

Maintenance Priority and DBH Size Class		2017		2018		2019		2020		2021		Five-Year Cost
Activity	Diameter	# of Trees	Total Cost	# of Trees	Total Cost	# of Trees	Total Cost	# of Trees	Total Cost	# of Trees	Total Cost	
Routine Pruning	1-3"	0	$0	1,674	$48,559	1,674	$48,559	1,674	$48,559	1,674	$48,559	$194,236
	4-6"	0	$0	2,154	$62,466	2,154	$62,466	2,154	$62,466	2,154	$62,466	$249,864
	7-12"	0	$0	4,272	$211,339	4,272	$211,339	4,272	$211,339	4,272	$211,339	$845,357
	13-18"	0	$0	2,587	$246,425	2,587	$246,425	2,587	$246,425	2,587	$246,425	$985,700
	19-24"	0	$0	1,461	$208,100	1,461	$208,100	1,461	$208,100	1,461	$208,100	$832,400
	25-30"	0	$0	866	$143,966	866	$143,966	866	$143,966	866	$143,966	$575,864
	31-36"	0	$0	481	$87,998	481	$87,998	481	$87,998	481	$87,998	$351,993
	37-42"	0	$0	242	$56,961	242	$56,961	242	$56,961	242	$56,961	$227,843
	43"+	0	$0	250	$85,378	250	$85,378	250	$85,378	250	$85,378	$341,512
Activity Total(s)		**0**	**$0**	**13,987**	**$1,151,192**	**13,987**	**$1,151,192**	**13,987**	**$1,151,192**	**13,987**	**$1,151,192**	**$4,604,768**
Young Tree Training Pruning	1-3"	4,483	$130,017	4,483	$130,017	4,483	$130,017	4,483	$130,017	4,483	$130,017	$650,083
	4-6"	1,670	$48,420	1,670	$48,420	1,670	$48,420	1,670	$48,420	1,670	$48,420	$242,102
	7-12"	193	$8,293	193	$8,293	193	$8,293	193	$8,293	193	$8,293	$41,466
	>12"	13	$1,347	13	$1,347	13	$1,347	13	$1,347	13	$1,347	$6,733
Activity Total(s)		**6,359**	**$186,730**	**6,359**	**$186,730**	**6,359**	**$186,730**	**6,359**	**$186,730**	**6,359**	**$186,730**	**$933,651**
Tree Planting	Purchasing	3,475	$382,250	3,475	$382,250	3,475	$382,250	3,475	$382,250	3,475	$382,250	$1,911,250
	Planting	3,475	$382,250	3,475	$382,250	3,475	$382,250	3,475	$382,250	3,475	$382,250	$1,911,250
Activity Total(s)		**6,950**	**$764,500**	**6,950**	**$764,500**	**6,950**	**$764,500**	**6,950**	**$764,500**	**6,950**	**$764,500**	**$3,822,500**
Annual Mortality (1%) Removals	Average Tree	1,560	$3,044,870	1,560	$3,044,870	1,560	$3,044,870	1,560	$3,044,870	1,560	$3,044,870	$15,224,352
Activity Total(s)		**8,510**	**$3,044,870**	**8,510**	**$3,044,870**	**8,510**	**$3,044,870**	**8,510**	**$3,044,870**	**8,510**	**$3,044,870**	**$15,224,352**
Annual Mortality (1%) Stump Removals	Average Stump	1,560	$340,361	1,560	$340,361	1,560	$340,361	1,560	$340,361	1,560	$340,361	$1,701,804
Activity Total(s)		**3,120**	**$343,200**	**3,120**	**$343,200**	**3,120**	**$343,200**	**3,120**	**$343,200**	**3,120**	**$343,200**	**$1,716,000**
Annual Mortality (1%) Planting	Average Tree	1,560	$343,200	1,560	$343,200	1,560	$343,200	1,560	$343,200	1,560	$343,200	$1,716,000
Activity Total(s)		**1,560**	**$340,361**	**1,560**	**$340,361**	**1,560**	**$340,361**	**1,560**	**$340,361**	**1,560**	**$340,361**	**$1,701,804**
Activity Grand Total		**45,473**		**46,151**		**51,678**		**41,602**		**60,526**		**245,430**
Cost Grand Total			**$8,980,593**		**$8,164,632**		**$8,057,343**		**$7,365,389**		**$7,532,753**	**$40,100,710**

Community Outreach

The data collected and analyzed to develop this plan contribute significant information about the tree population and can be utilized to guide the proactive management of that resource. These data can also be utilized to promote the value of the urban forest and the tree management program in the following ways:

- Tree inventory data can be used to justify necessary priority and proactive tree maintenance activities as well as tree planting and preservation initiatives.
- Species data can be used to guide tree species selection for planting projects with the goals of improving species diversity and limiting the introduction of invasive pests and diseases.
- Information in this plan can be used to advise citizens about threats to urban trees (such as looper complex, forest tent caterpillar, and ALB).

There are various avenues for outreach. Maps can be created and posted on websites, in parks, or in business areas. Public service announcements can be developed. Articles can be written and programs about trees and the benefits they provide can be developed. Arbor Day and Earth Day celebrations can become community traditions. Signs can be hung from trees to highlight the contributions trees make to the community. Contests can even be created to increase awareness of the importance of trees. Trees provide oxygen we need to breathe, shade to cool our neighborhoods, and canopies to stand under when it rains.

Indianapolis' data are instrumental in helping to provide tangible and meaningful outreach about the urban forest.

Inspections

Inspections are essential to uncovering potential problems with trees. They should be performed by a qualified arborist who is trained in the art and science of planting, caring for, and maintaining individual trees. Arborists are knowledgeable about the needs of trees and are trained and equipped to provide proper care.

Trees along the street ROW should be regularly inspected and attended to as needed based on the inspection findings. When trees need additional or new work, they should be added to the maintenance schedule and budgeted as appropriate. Use appropriate computer management software such as *TreeKeeper*® 7 to update inventory data and work records. In addition to locating potential new hazards, inspections are an opportunity to look for signs and symptoms of pests and diseases. Indianapolis has a large population of trees that are susceptible to pests and diseases, such as maple, ash, and oak.

Inventory and Plan Updates

Davey Resource Group recommends that the inventory and management plan be updated using an appropriate computer software program so that the city can sustain its program and accurately project future program and budget needs:

- Conduct inspections of trees after all severe weather events. Record changes in tree condition, maintenance needs, and risk rating in the inventory database. Update the tree maintenance schedule and acquire the funds needed to promote public safety. Schedule and prioritize work based on risk.

- Perform routine inspections of public trees as needed. Windshield surveys (inspections performed from a vehicle) in line with *ANSI A300 (Part 9)* (ANSI 2011) will help city staff stay apprised of changing conditions. Update the tree maintenance schedule and the budget as needed so that identified tree work may be efficiently performed. Schedule and prioritize work based on risk.
- If the recommended work cannot be completed as suggested in this plan, modify maintenance schedules and budgets accordingly.
- Update the inventory database using appropriate computer management software such as *TreeKeeper®* 7 as work is performed. Add new tree work to the schedule when work is identified through inspections or a citizen call process.
- Re-inventory the street ROW, and update all data fields in five years, or a portion of the population (1/9) every year over the course of nine years.
- Revise the *Tree Management Plan* after five years or when the re-inventory has been completed.

CONCLUSIONS

Every hour of every day, public trees in Indianapolis are supporting and improving the quality of life. The city's trees provide an annual benefit of $9,970,035. Indianapolis' return on investment is $3.95 for every $1 spent on managing and maintaining the public trees. When properly maintained, trees provide numerous environmental, economic, and social benefits that far exceed the time and money invested in planting, pruning, protection, and removal.

Managing trees in urban areas is often complicated. Navigating the recommendations of experts, the needs of residents, the pressures of local economics and politics, concerns for public safety and liability, physical components of trees, forces of nature and severe weather events, and the expectation that these issues are resolved all at once is a considerable challenge.

The city must carefully consider these challenges to fully understand the needs of maintaining an urban forest. With the knowledge and wherewithal to address the needs of the city's trees, Indianapolis is well positioned to thrive. If the management program is successfully implemented, the health and safety of Indianapolis' trees and citizens will be maintained for years to come.

GLOSSARY

address number (data field): The address number was recorded based on the visual observation by the Davey Resource Group arborist at the time of the inventory of the actual address number posted on a building at the inventoried site. In instances where there was no posted address number on a building or sites were located by vacant lots with no GIS parcel addressing data available, the address number assigned was matched as closely as possible to opposite or adjacent addresses by the arborist(s) and an "X" was added to the number in the database to indicate that the address number was assigned.

Aesthetic/Other Report: The i-Tree Streets Aesthetic/Other Report presents the tangible and intangible benefits of trees reflected by increases in property values in dollars ($).

Air Quality Report: The i-Tree Streets Air Quality Report quantifies the air pollutants (ozone [O_3], nitrogen dioxide [NO_2], sulfur dioxide [SO_2], coarse particulate matter less than 10 micrometers in diameter [PM_{10}]) deposited on tree surfaces and reduced emissions from power plants (NO_2, PM_{10}, Volatile Oxygen Compounds [VOCs], SO_2) due to reduced electricity use measured in pounds (lbs.). Also reported are the potential negative effects of trees on air quality due to Biogenic Volatile Organic Compounds (BVOC) emissions.

American National Standards Institute (ANSI): ANSI is a private, nonprofit organization that facilitates the standardization work of its members in the United States. ANSI's goals are to promote and facilitate voluntary consensus standards and conformity assessment systems, and to maintain their integrity.

ANSI A300**:** Tree care performance parameters established by ANSI that can be used to develop specifications for tree maintenance.

arboriculture: The art, science, technology, and business of commercial, public, and utility tree care.

Benefit-Cost Ratio (BCR): The i-Tree Streets (BCR) is the ratio of the cumulative benefits provided by the landscape trees, expressed in monetary terms, compared to the costs associated with their management, also expressed in monetary terms.

biogenic volatile organic compounds (BVOC): Gases emitted from trees, like pine trees, which create the distinct smell of a pine forest. When exposed to sunlight in the air, BVOCs react to form tropospheric ozone, a harmful gas that pollutes the air and damages vegetation.

canopy: Branches and foliage that make up a tree's crown.

canopy cover: As seen from above, it is the area of land surface that is covered by tree canopy.

Carbon Dioxide Report: The i-Tree Streets Carbon Dioxide Report presents annual reductions in atmospheric CO_2 due to sequestration by trees and reduced emissions from power plants due to reduced energy use in pounds. The model accounts for CO_2 released as trees die and decompose and CO_2 released during the care and maintenance of trees.

cell number (data field): All sites at an address are assigned a *cell number*. Sites numbers are not unique; they are sequential to the side of the address only.

community forest: see **urban forest**.

comments (data field): When conditions with a specific tree warrant recognition, it was described in this data field. Observations include EAB infested, construction damage, vehicular damage, vandalism/abuse, wind damage, mower damage, multi-stem, lighting damage, completely topped, partially topped, utility pruned, adventitious/epicromic growth, girdling roots, sight distance, excessive deadwood, and trees in series.

condition (data field): The general condition of each tree rated during the inventory according to the following categories: Good (No Apparent Problems), Fair (Minor Problems), Poor (Major Problems), Dead (Extreme Problems).

cycle: Planned length of time between vegetation maintenance activities.

defect: See **structural defect**.

diameter: See **tree size**.

diameter at breast height (DBH): See **tree size**.

Energy Report: The i-Tree Streets Energy Report presents the contribution of the urban forest toward conserving energy in terms of reduced natural gas use in winter measured in therms (th) and reduced electricity use for air conditioning in summer measured in megawatt-hours (MWh).

Extreme Risk tree: Applies in situations where tree failure is imminent, there is a high likelihood of impacting the target, and the consequences of the failure are "severe." In some cases, this may mean immediate restriction of access to the target zone area in order to prevent injury.

failure: In terms of tree management, failure is the breakage of stem or branches, or loss of mechanical support of the tree's root system.

Hazard inspect (data field): Notes that a specific tree may require an annual inspection for several years to make certain of its maintenance needs. A healthy tree obviously impacted by recent construction serves as a prime example. This tree will need annual evaluations to assess the impact of construction on its root system. Another example would be a tree with a defect requiring additional equipment for investigation.

genus: A taxonomic category ranking below a family and above a species and generally consisting of a group of species exhibiting similar characteristics. In taxonomic nomenclature, the genus name is used, either alone or followed by a Latin adjective or epithet, to form the name of a species.

geographic information system (GIS): A technology that is used to view and analyze data from a geographic perspective. The technology is a piece of an organization's overall information system framework. GIS links location to information (such as people to addresses, buildings to parcels, or streets within a network) and layers that information to provide a better understanding of how it all interrelates.

global positioning system (GPS): GPS is a system of earth-orbiting satellites that make it possible for people with ground receivers to pinpoint their geographic location.

hardscape damage (data field): Indicates trees damaged by hardscape or hardscape damaged by trees (for example, damage to curbs, cracking, lifting of sidewalk pavement 1 inch or more).

High Risk tree: The High Risk category applies when consequences are "significant" and likelihood is "very likely" or "likely," or consequences are "severe" and likelihood is "likely." In a population of trees, the priority of High Risk trees is second only to Extreme Risk trees.

importance value (IV): A calculation in i-Tree Streets displayed in table form for all species that make up more than 1% of the population. The i-Tree Streets IV is the mean of three relative values (percentage of total trees, percentage of total leaf area, and percentage of canopy cover) and can range from 0 to 100, with an IV of 100 suggesting total reliance on one species. IVs offer valuable information about a community's reliance on certain species to provide functional benefits. For example, a species might represent 10% of a population, but have an IV of 25% because of its great size, indicating that the loss of those trees due to pests or disease would be more significant than their numbers suggest.

invasive, exotic tree: A tree species that is out of its original biological community. Its introduction into an area causes or is likely to cause economic or environmental harm, or harm to human health. An invasive, exotic tree has the ability to thrive and spread aggressively outside its natural range. An invasive species that colonizes a new area may gain an ecological edge since the insects, diseases, and foraging animals that naturally keep its growth in check in its native range are not present in its new habitat.

inventory: See **tree inventory**.

i-Tree Streets: i-Tree Streets is a street tree management and analysis tool that uses tree inventory data to quantify the dollar value of annual environmental and aesthetic benefits: energy conservation, air quality improvement, CO_2 reduction, stormwater control, and property value increase.

i-Tree Tools: State-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban forestry analysis and benefits assessment tools. The i-Tree Tools help communities of all sizes to strengthen their urban forest management and advocacy efforts by quantifying the structure of community trees and the environmental services that trees provide.

Land use (data field): A description of the type of area where the tree is growing, including single-family residential, multi-family residential, industrial/large commercial, and park/vacant/other.

Large Tree Clean (Primary Maintenance Need): Based on *ANSI A300 Standards*, these trees require selective removal of dead, dying, broken, and/or diseased wood to minimize potential risk. All trees greater than 20 foot no matter the species will fall into the is category.

location (data fields): A collection of data fields collected during the inventory to aid in finding trees, including address number, street name, site number, side, and block side.

Low Risk tree: The Low Risk category applies when consequences are "negligible" and likelihood is "unlikely"; or consequences are "minor" and likelihood is "somewhat likely." Some trees with this level of risk may benefit from mitigation or maintenance measures, but immediate action is not usually required.

Management Costs: Used in i-Tree Streets, they are the expenditures associated with street tree management presented in total dollars, dollars per tree, and dollars per capita.

mapping coordinate (data field): Helps to locate a tree; X and Y coordinates were generated for each tree using GPS.

Moderate Risk tree: The Moderate Risk category applies when consequences are "minor" and likelihood is "very likely" or "likely"; or likelihood is "somewhat likely" and consequences are "significant" or "severe." In populations of trees, Moderate Risk trees represent a lower priority than High or Extreme Risk trees.

monoculture: A population dominated by one single species or very few species.

multi-stems (Comment): Identifies trees with multiple stems or trunks splitting less than 4 feet above ground level. The sum of DBH for each stem was recorded.

Net Annual Benefits: Specific data field for i-Tree Streets. Citywide benefits and costs are calculated according to category and summed. Net benefits are calculated as benefits minus costs.

Nitrogen Dioxide (NO_2): Nitrogen dioxide is a compound typically created during the combustion processes and is a major contributor to smog formation and acid deposition.

ordinance: See **tree ordinance**.

overhead utilities (data field): The presence of overhead utility lines above a tree or planting site.

Ozone (O_3): A strong-smelling, pale blue, reactive toxic chemical gas with molecules of three oxygen atoms. It is a product of the photochemical process involving the Sun's energy. Ozone exists in the upper layer of the atmosphere as well as at the Earth's surface. Ozone at the Earth's surface can cause numerous adverse human health effects. It is a major component of smog.

Particulate Matter (PM_{10}): A major class of air pollutants consisting of tiny solid or liquid particles of soot, dust, smoke, fumes, and mists.

Plant Tree (Primary and Secondary Maintenance Need): If collected during an inventory, this data field identifies planting sites as small, medium, or large (indicating the ultimate size that the tree will attain), depending on the growspace available and the presence of overhead wires.

Primary Maintenance Need (data field): The type of tree work needed to reduce immediate risk.

pruning: The selective removal of plant parts to meet specific goals and objectives.

Raise (Secondary Maintenance Need): Signifies a maintenance need for a tree. Raising the crown is characterized by pruning to remove low branches that interfere with sight and/or traffic. It is based on *ANSI A300 (Part 1).*

Reduce (Secondary Maintenance Need): Signifies a maintenance need for a tree. Reducing the crown is characterized by selective pruning to decrease height and/or spread of the crown in order to provide clearance for electric utilities and lighting.

Removal (Primary Maintenance Need): Data field collected during the inventory identifying the need to remove a tree. Trees designated for removal have defects that cannot be cost-effectively or practically treated. Most of the trees in this category have a large percentage of dead crown.

Restore (Secondary Maintenance Need): Signifies a maintenance need for a tree. Restoring is selective pruning to improve the structure, form, and appearance of trees that have been severely headed, vandalized, or damaged.

right-of-way (ROW): See **street right-of-way**.

risk: Combination of the probability of an event occurring and its consequence.

risk assessment (data fields): A Level 2 qualitative risk assessment will be performed based on the ANSI A300 (Part 9) and the companion publication Best Management Practices: Tree Risk Assessment, published by the International Society of Arboriculture (2011). Trees can have multiple failure modes with various risk ratings. During the inventory, one risk rating will be assigned per tree. The failure mode having the greatest risk will serve as the overall tree risk rating. The specified time period for the risk assessment is one year.

-OR-

The risk assessment is a point-based assessment of each tree by an arborist using a protocol based on the U.S. Forest Service Community Tree Risk Rating System. In the field, the probability of tree or tree part failure is assigned 1–4 points (identifies the most likely failure and rates the likelihood that the structural defect(s) will result in failure based on observed, current conditions), the size of the defective tree part is assigned 1–3 points (rates the size of the part most likely to fail), the probability of target impact by the tree or tree part is assigned 1–3 points (rates the use and occupancy of the area that would be struck by the defective part), and other risk factors are assigned 0–2 points (used if professional judgment suggests the need to increase the risk rating). The data from the risk assessment is used to calculate the risk rating that is ultimately assigned to the tree.

risk rating: The overall risk rating of the tree determined based on risk assessment.

Secondary Maintenance Need (data field): Recommended maintenance for a tree, which may be risk oriented, such as raising the crown for clearance, but generally was geared toward improving the structure of the tree and enhancing aesthetics.

site type (data field): Best identifies the type of location where a tree is growing. During the inventory, grow space types were categorized as front yard, median, other maintained locations other unmaintained locations, side yard, planting strip, back yard, wooded edge, or cutout/pit.

Small Tree Clean (Primary Maintenance Need): Based on *ANSI A300 Standards*, these trees require selective removal of dead, dying, broken, and/or diseased wood to minimize potential risk. All trees equal to or less than 20 foot which do not require young tree training will fall into the is category.

species: Fundamental category of taxonomic classification, ranking below a genus or subgenus, and consisting of related organisms capable of interbreeding.

stem: A woody structure bearing buds and foliage, and giving rise to other stems.

Stored Carbon Report: While the i-Tree Streets Carbon Dioxide Report quantifies annual CO_2 reductions, the i-Tree Streets Stored Carbon Report tallies all of the Carbon (C) stored in the urban forest over the life of the trees as a result of sequestration measured in pounds as the CO_2 equivalent.

Stormwater Report: A report generated by i-Tree Streets that presents the reductions in annual stormwater runoff due to rainfall interception by trees measured in gallons (gals.).

street name (data field): The name of a street right-of-way or road identified using posted signage or parcel information.

street right-of-way (ROW): A strip of land generally owned by a public entity over which facilities, such as highways, railroads, or power lines, are built.

street tree: A street tree is defined as a tree within the right-of-way.

structural defect: A feature, condition, or deformity of a tree or tree part that indicates weak structure and contributes to the likelihood of failure.

Stump Removal (Primary Maintenance Need): Indicates a stump that should be removed.

Sulfur Dioxide (SO_2): A strong-smelling, colorless gas that is formed by the combustion of fossil fuels. Sulfur oxides contribute to the problem of acid rain.

Summary Report: A report generated by i-Tree Streets that presents the annual total of energy, stormwater, air quality, carbon dioxide, and aesthetic/other benefits. Values are reflected in dollars per tree or total dollars.

Thin (Secondary Maintenance Need): Signifies a maintenance need for a tree. Thinning the crown is the selective removal of water sprouts, epicormic branches, and live branches to reduce density.

topping: Characterized by reducing tree size using internodal cuts without regard to tree health or structural integrity; this is not an acceptable pruning practice.

tree: A tree is defined as a perennial woody plant that may grow more than 20 feet tall. Characteristically, it has one main stem, although many species may grow as multi-stemmed forms.

tree benefit: An economic, environmental, or social improvement that benefits the community and results mainly from the presence of a tree. The benefit received has real or intrinsic value associated with it.

tree height (data field): If collected during the inventory, the height of the tree is estimated by the arborist and recorded in 10-foot increments.

tree inventory: Comprehensive database containing information or records about individual trees typically collected by an arborist.

tree ordinance: Tree ordinances are policy tools used by communities striving to attain a healthy, vigorous, and well-managed urban forest. Tree ordinances simply provide the authorization and standards for management activities.

tree size (data field): A tree's diameter measured to the nearest inch in 1-inch size classes at 4.5 feet above ground, also known as diameter at breast height (DBH) or diameter.

urban forest: All of the trees within a municipality or a community. This can include the trees along streets or rights-of-way, in parks and greenspaces, in forests, and on private property.

Utility (Secondary Maintenance Need): Selective pruning to prevent the loss of service, comply with mandated clearance laws, prevent damage to equipment, avoid access impairment, and uphold the intended usage of the facility/utility space.

Volatile Organic Compounds (VOCs): Hydrocarbon compounds that exist in the ambient air and are by-products of energy used to heat and cool buildings. Volatile organic compounds contribute to the formation of smog and/or are toxic. Examples of VOCs are gasoline, alcohol, and solvents used in paints.

Young Tree Train (Primary Maintenance Need): Data field based on *ANSI A300* standards, this maintenance activity is characterized by pruning of young trees to correct or eliminate weak, interfering, or objectionable branches to improve structure. These trees can be up to 20 feet tall and can be worked with a pole pruner by a person standing on the ground.

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APPENDIX A
DATA COLLECTED AND SITE LOCATION METHODS

Equipment and Base Maps

Inventory arborists use CF-19 Panasonic Toughbook® unit(s) and Trimble® GPS Pathfinder® ProXH™ receiver(s).

Base map layers were loaded onto these unit(s) to help locate sites during the inventory. Table 1 lists the base map layers, utilized along with source and format information for each layer.

Table 1. Base Map Layers Utilized for Inventory

Imagery/Data Source	Date	Projection
City of Indianapolis/Marion County, Indiana http://data1.indygis.opendata.arcgis.com/	2013 - 2016	NAD 1983 StatePlane Indiana, East; USFeet

Street ROW Site Location

Individual street ROW sites (trees, stumps, or vacant planting sites) were located using a methodology that identifies sites by *address number*, *street name, and cell number*. This methodology was requested of Davey Resource Group by the City to help ensure consistent assignment of location.

Address Number and Street Name

The *address number* was recorded based on visual observation by the arborist at the time of the inventory (the address number was posted on a building at the inventoried site). Where there was no posted address number on a building or where the site was located by a vacant lot with no GIS parcel addressing data available, the assigned address number was matched as closely as possible to opposite or adjacent addresses by the arborist.

Sites in medians or islands were assigned an address number using the address on the right side of the street in the direction of collection closest to the site. If there were multiple sites within one median, each site was assigned an address immediately adjacent to the site location.

The *street name* assigned to a site was determined by street ROW parcel information and posted street name signage.

Cell Number

All sites at an address are assigned a *cell number*. Cell numbers are not unique; they are based on the location of the tree along the side of the address. The only unique number is the tree identification number assigned to each site. A separate cell number sequence is used for each side value of the address (front, side, median, or rear). For example, trees at the front of an address may have cell numbers from 1 through 7, trees at the side of an address may have cell numbers from 8 through 13 or 24 through 19, trees at the rear of an address may have cell numbers from 13 through 19, and trees in a median adjacent to the front, side, or rear of an address may have cell numbers from 25 through 52.

Cell Location Example

Back of Property										
		45	44	43	42	41	40	39		
		s	t	r	e	e	t			
46	s	19	18	17	16	15	14	13	s	38
47	t	20	65	64	63	62	61	12	t	37
48	r	21	66	75	74	73	60	11	r	36
49	e	22	67	76	77	72	59	10	e	35
50	e	23	68	69	70	71	58	9	e	34
51	t	24	53	54	55	56	57	8	t	33
52		1	2	3	4	5	6	7		32
		s	t	r	e	e	t			
		25	26	27	28	29	30	31		
Front of Property										

APPENDIX B
RECOMMENDED SPECIES FOR FUTURE PLANTING

Proper landscaping and tree planting are critical components of the atmosphere, livability, and ecological quality of a community's urban forest. The tree species listed below have been evaluated for factors such as size, disease and pest resistance, seed or fruit set, and availability. The following list is offered to assist all relevant campus personnel in selecting appropriate tree species. These trees have been selected because of their aesthetic and functional characteristics and their ability to thrive in the majority of soil and climate conditions (USDA Hardiness Zone 5) found in Indianapolis, Indiana.

Deciduous Trees

Large Trees: Greater than 45 Feet in Height at Maturity

Scientific Name	Common Name	Cultivar
Acer rubrum	red maple	Red Sunset®
Acer nigrum	black maple	
Acer saccharum	sugar maple	'Legacy'
*Aesculus flava**	yellow buckeye	
Betula nigra	river birch	Heritage®
Carpinus betulus	European hornbeam	'Franz Fontaine'
*Castanea mollissima**	Chinese chestnut	
Celtis occidentalis	common hackberry	'Prairie Pride'
Cercidiphyllum japonicum	katsuratree	'Aureum'
*Diospyros virginiana**	common persimmon	
*Fagus grandifolia**	American beech	
*Fagus sylvatica**	European beech	(numerous exist)
Ginkgo biloba	ginkgo	(male trees only)
Gleditsia triacanthos inermis	thornless honeylocust	'Shademaster'
Gymnocladus dioica	Kentucky coffeetree	Prairie Titan®
*Juglans regia**	English walnut	'Hansen'
*Larix decidua**	European larch	
Liquidambar styraciflua	American sweetgum	Cherokee™
Liriodendron tulipifera	tuliptree	'Fastigiatum'
Maclura pomifera	osage-orange	'White Shield','Witchita'
*Magnolia acuminata**	cucumbertree magnolia	(numerous exist)
*Magnolia macrophylla**	bigleaf magnolia	
Metasequoia glyptostroboides	dawn redwood	'Emerald Feathers'
Nyssa sylvatica	black tupelo	
Platanus × acerifolia	London planetree	'Yarwood'
*Platanus occidentalis**	American sycamore	
Quercus alba	white oak	
Quercus bicolor	swamp white oak	
Quercus coccinea	scarlet oak	
Quercus ellipsoidalis	northern pin oak	

Large Trees: Greater than 45 Feet in Height at Maturity (continued)

Scientific Name	Common Name	Cultivar
Quercus frainetto	Hungarian oak	
Quercus imbricaria	shingle oak	
Quercus lyrata	overcup oak	
Quercus macrocarpa	bur oak	
Quercus montana	chestnut oak	
Quercus muehlenbergii	chinkapin oak	
Quercus phellos	willow oak	
Quercus robur	English oak	Heritage®
Quercus rubra	northern red oak	'Splendens'
Quercus shumardii	Shumard oak	
Quercus texana	Texas oak	
Styphnolobium japonicum	Japanese pagodatree	'Regent'
Taxodium distichum	common baldcypress	'Shawnee Brave'
Tilia americana	American linden	'Redmond'
Tilia cordata	littleleaf linden	'Greenspire'
Tilia tomentosa	silver linden	'Sterling'
Ulmus parvifolia	Chinese elm	Allée®
Zelkova serrata	Japanese zelkova	'Green Vase'

Medium Trees: 31 to 45 Feet in Height at Maturity

Scientific Name	Common Name	Cultivar
Aesculus × carnea	red horsechestnut	
Cladrastis kentukea	American yellowwood	'Rosea'
Eucommia ulmoides	hardy rubbertree	
Koelreuteria paniculata	goldenraintree	
Ostrya virginiana	eastern hophornbeam	
Parrotia persica	Persian parrotia	'Vanessa'
Phellodendron amurense	amur corktree	'Macho'
Prunus maackii	amur chokecherry	'Amber Beauty'
Prunus sargentii	Sargent cherry	
Quercus acutissima	sawtooth oak	
Quercus cerris	European turkey oak	
Sorbus alnifolia	Korean mountainash	'Redbird'

Small Trees: 15 to 30 Feet in Height at Maturity

Scientific Name	Common Name	Cultivar
Acer buergerianum	trident maple	Streetwise®
Acer campestre	hedge maple	Queen Elizabeth™
Acer cappadocicum	coliseum maple	'Aureum'
Acer ginnala	amur maple	Red Rhapsody™
Acer griseum	paperbark maple	
*Acer pensylvanicum**	striped maple	
Acer truncatum	Shantung maple	
*Aesculus pavia**	red buckeye	
Amelanchier arborea	downy serviceberry	(numerous exist)
Amelanchier laevis	Allegheny serviceberry	
Carpinus caroliniana	American hornbeam	
Cercis canadensis	eastern redbud	'Forest Pansy'
Chionanthus virginicus	white fringetree	
Cornus kousa	Kousa dogwood	(numerous exist)
*Cornus mas**	corneliancherry dogwood	'Spring Sun'
Corylus avellana	European filbert	'Contorta'
*Cotinus coggygria**	common smoketree	'Flame'
*Cotinus obovata**	American smoketree	
Crataegus phaenopyrum	Washington hawthorn	Princeton Sentry™
Crataegus viridis	green hawthorn	'Winter King'
*Franklinia alatamaha**	Franklinia	
Halesia tetraptera	Carolina silverbell	'Arnold Pink'
*Magnolia × soulangiana**	saucer magnolia	'Alexandrina'
*Magnolia stellata**	star magnolia	'Centennial'
*Magnolia tripetala**	umbrella magnolia	
*Magnolia virginiana**	sweetbay magnolia	Moonglow®
Malus spp.	flowering crabapple	(disease resistant only)
Oxydendrum arboreum	sourwood	'Mt. Charm'
Prunus subhirtella	Higan cherry	pendula
Prunus virginiana	common chokecherry	'Schubert'
Styrax japonicus	Japanese snowbell	'Emerald Pagoda'
Syringa reticulata	Japanese tree lilac	'Ivory Silk'

Note: * denotes species **not** recommended for use as street trees.

Coniferous and Evergreen Trees

Large Trees: Greater than 45 Feet in Height at Maturity

Scientific Name	Common Name	Cultivar
Abies balsamea	balsam fir	
Abies concolor	white fir	'Violacea'
Chamaecyparis nootkatensis	Nootka falsecypress	'Pendula'
Cryptomeria japonica	Japanese cryptomeria	'Sekkan-sugi'
Ilex opaca	American holly	
Picea omorika	Serbian spruce	
Picea orientalis	Oriental spruce	
Pinus densiflora	Japanese red pine	
Pinus strobus	eastern white pine	
Pinus sylvestris	Scotch pine	
Psedotsuga menziesii	Douglasfir	
Thuja plicata	western arborvitae	(numerous exist)
Tsuga canadensis	eastern hemlock	

Medium Trees: 31 to 45 Feet in Height at Maturity

Scientific Name	Common Name	Cultivar
Chamaecyparis thyoides	Atlantic whitecedar	(numerous exist)
Juniperus virginiana	eastern redcedar	
Pinus bungeana	lacebark pine	
Pinus flexilis	limber pine	
Thuja occidentalis	eastern arborvitae	(numerous exist)

Small Trees: 15 to 30 Feet in Height at Maturity

Scientific Name	Common Name	Cultivar
Ilex × attenuata	Foster's holly	
Pinus aristata	bristlecone pine	
Pinus mugo mugo	mugo pine	

This suggested species list was compiled using the excellent references *Dirr's Hardy Trees and Shrubs* (Dirr 2003) and *Manual of Woody Landscape Plants (5th Edition)* (Dirr 1998). Cultivar selections are only recommendations and are based on Davey Resource Group's experience and tree availability in the nursery trade.

APPENDIX C
INVASIVE PESTS AND DISEASES THAT AFFECT TREES

In today's worldwide marketplace, the volume of international trade brings increased potential for pests and diseases to invade our country. Many of these pests and diseases have seriously harmed rural and urban landscapes and have caused billions of dollars in lost revenue and millions of dollars in clean-up costs. Keeping these pests and diseases out of the country is the number one priority of the United States Department of Agriculture's (USDA) Animal and Plant Inspection Service (APHIS).

Although some invasive species enter the United States naturally via wind, ocean currents, and other means, most enter with some help from human activities. Their introduction to our country is a byproduct of cultivation, commerce, tourism, and travel. Many species enter the United States each year in baggage, cargo, contaminants of commodities, or mail.

Once they arrive, hungry pests grow and spread rapidly because controls, such as native predators, are lacking. Invasive pests disrupt the landscape by pushing out native species, reducing biological diversity, killing trees, altering wildfire intensity and frequency, and damaging crops. Some pests may even push species to extinction. The following sections include key pests and diseases that adversely affect trees in America at the time of this plan's development. This list is not comprehensive and may not include all threats.

It is critical to the management of community trees to routinely check APHIS, USDA Forest Service, and other websites for updates about invasive species and diseases in your area and in our country so you can be prepared to combat their attack.

APHIS, Plant Health, Plant Pest Program Information
- www.aphis.usda.gov/plant_health/plant_pest_info

The University of Georgia, Center for Invasive Species and Ecosystem Health
- www.bugwood.org

USDA National Agricultural Library
- www.invasivespeciesinfo.gov/microbes

USDA Northeastern Areas Forest Service, Forest Health Protection
- www.na.fs.fed.us/fhp

Asian Longhorned Beetle

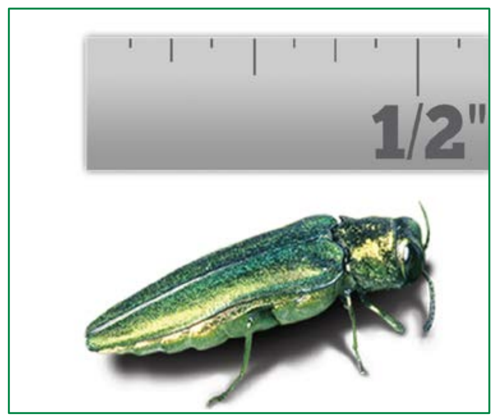
Adult Asian longhorned beetle

Photograph courtesy of New Bedford Guide 2011

The Asian longhorned beetle (ALB, *Anoplophora glabripennis*) is an exotic pest that threatens a wide variety of hardwood trees in North America. The beetle was introduced in Chicago, New Jersey, and New York City, and is believed to have been introduced in the United States from wood pallets and other wood-packing material accompanying cargo shipments from Asia. ALB is a serious threat to America's hardwood tree species.

Adults are large (3/4- to 1/2-inch long) with very long, black and white banded antennae. The body is glossy black with irregular white spots. Adults can be seen from late spring to fall depending on the climate. ALB has a long list of host species; however, the beetle prefers hardwoods, including several maple species. Examples include: *Acer negundo* (box elder); *A. platanoides* (Norway maple); *A. rubrum* (red maple); *A. saccharinum* (silver maple); *A. saccharum* (sugar maple); *Aesculus glabra* (buckeye); *A. hippocastanum* (horsechestnut), *Betula* (birch), *Platanus × acerifolia* (London planetree), *Salix* (willow), and *Ulmus* (elm).

Emerald Ash Borer



Close-up of the emerald ash borer

Photograph courtesy of APHIS (2011)

Emerald ash borer *(EAB) (Agrilus planipennis*) is responsible for the death or decline of tens of millions of ash trees in 14 states in the American Midwest and Northeast. Native to Asia, EAB has been found in China, Japan, Korea, Mongolia, eastern Russia, and Taiwan. It likely arrived in the United States hidden in wood-packing materials commonly used to ship consumer goods, auto parts, and other products. The first official United States identification of EAB was in southeastern Michigan in 2002.

Adult beetles are slender and 1/2-inch long. Males are smaller than females. Color varies but adults are usually bronze or golden green overall with metallic, emerald-green wing covers. The top of the abdomen under the wings is metallic, purplish-red and can be seen when the wings are spread.

The EAB-preferred host tree species are in the genus *Fraxinus* (ash).

Forest Tent Caterpillar

Forest tent caterpillar (*Malacosoma disstria*) is possibly the most damaging tent caterpillar in the United States. It attacks ash, various fruit trees, poplar, willow, and many other deciduous trees. The name may be slightly misleading as the larvae do not make a silken tent between the trunk and branches of trees as other tent caterpillars do. Instead, this larva makes a mat on the trunk for masses of caterpillars to rest on. The larval caterpillar is distinctive in the bright blue coloration along its sides with a white "keyhole"-shaped pattern running along its back.

Forest Tent Caterpillar larva with blue stripe and white "keyhole" pattern running down its back.

Photograph courtesy Greg Hume CC-BY-SA-3.0 (2006).

Gypsy Moth

The gypsy moth (GM) *(Lymantria dispar*) is native to Europe and first arrived in the United States in Massachusetts in 1869. This moth is a significant pest because its caterpillars have voracious appetites for more than 300 species of trees and shrubs. GM caterpillars defoliate trees, which makes them vulnerable to diseases and other pests that can eventually kill the tree.

Male GMs are brown with a darker brown pattern on their wings and have a 1/2-inch wingspan. Females are slightly larger with a 2-inch wingspan and are nearly white with dark, saw-toothed patterns on their wings. Although they have wings, the female GM cannot fly.

The GMs prefer approximately 150 primary hosts but feed on more than 300 species of trees and shrubs. Some trees are found in these common genera: *Betula* (birch), *Juniperus* (cedar), *Larix* (larch), *Populus* (aspen, cottonwood, poplar), *Quercus* (oak), and *Salix* (willow).

Close-up of male (darker brown) and female (whitish color) European gypsy moths

Photograph courtesy of APHIS (2011b)

Oak Wilt

Oak wilt was first identified in 1944 and is caused by the fungus *Ceratocystis fagacearum*. While considered an invasive and aggressive disease, its status as an exotic pest is debated since the fungus has not been reported in any other part of the world. This disease affects the oak genus and is most devastating to those in the red oak subgenus, such as *Quercus coccinea* (scarlet oak), *Q. imbricaria* (shingle oak), *Q. palustris* (pin oak), *Q. phellos* (willow oak), and *Q. rubra* (red oak). It also attacks trees in the white oak subgenus, although it is not as prevalent and spreads at a much slower pace in these trees.

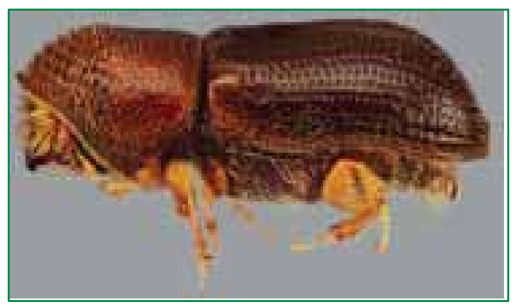
Oak wilt symptoms on red and white oak leaves

Photograph courtesy of USDA Forest Service (2011a)

Just as with DED, oak wilt disease is caused by a fungus that clogs the vascular system of oaks and results in decline and death of the tree. The fungus is carried from tree to tree by several borers common to oaks, but the disease is more commonly spread through root grafts. Oak species within the same subgenus (red or white) will form root colonies with grafted roots that allow the disease to move readily from one tree to another.

Thousand Cankers Disease

A complex disease referred to as Thousand Cankers disease (TCD) was first observed in Colorado in 2008 and is now thought to have existed in Colorado as early as 2003. TCD is considered to be native to the United States and is attributed to numerous cankers developing in association with insect galleries.



Walnut twig beetle, side view

Photograph courtesy of USDA Forest Service (2011b)

TCD results from the combined activity of the *Geosmithia morbida* fungus and the walnut twig beetle (WTB, *Pityophthorus juglandis*). The WTB has expanded both its geographical and host range over the past two decades, and coupled with the *Geosmithia morbida* fungus, *Juglans* (walnut) mortality has manifested in Arizona, California, Colorado, Idaho, New Mexico, Oregon, Utah, and Washington. In July 2010, TCD was reported in Knoxville, Tennessee. The infestation is believed to be at least 10 years old and was previously attributed to drought stress. This is the first report east of the 100th meridian, raising concerns that large native populations of *J. nigra* (black walnut) in the eastern United States may suffer severe decline and mortality.

The tree species preferred as hosts for TCD are walnuts.

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