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Assessing Urban Forest Effects and Values: Douglas County, Kansas

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Abstract

An analysis of trees in Douglas County, Kansas, reveals that this area has about 14,164,000 trees with tree and shrub canopy that covers 25.2 percent of the county. The most common tree species are American elm, northern hackberry, eastern redcedar, Osage-orange, and honeylocust. Trees in Douglas County currently store about 1.7 million tons of carbon (6.4 million tons CO_2) valued at $124 million. In addition, these trees remove about 82,000 tons of carbon per year (300,000 tons CO_2 per year valued at $5.8 million per year) and about 3,870 tons of air pollution per year ($17.7 million per year). Douglas County's trees are estimated to reduce annual residential energy costs by $2.9 million per year. The compensatory value of the trees is estimated at $6.2 billion. Loss of the current tree cover in the Wakarusa River watershed in Douglas County would increase annual flow by an average of 2.6 percent (88.9 million ft^3). Information on the structure and functions of the regional forest can be used to inform forest management programs and to integrate regional forests within plans to improve environmental quality in Douglas County.

Acknowledgments

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Cover Photo

The City of Lawrence took over the ownership of a Union Pacific Depot, turning it into a Visitor's Center in the northern part of the city. Photo by Kim Bomberger, Kansas Forest Service, used with permission.

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Clinton Lake near Lawrence, Kansas.
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PROJECT OVERVIEW

Forest resources in Kansas occur across several ecoregions and comprise large blocks of forest, urban and community forests and trees, riparian forests, and agroforestry systems.[1] Douglas County resides in the Central Irregular Plains ecosystem, a Level III description by the U.S. Geological Survey.[2] This ecosystem supports vegetation from the tallgrass prairie to an oak-hickory forest. According to the U.S. Forest Service Forest Inventory and Analysis program, the oak-hickory forest that occurs in the eastern part of the State makes up 55 percent of Kansas forest land.[3]

Douglas County is adjacent to the Kansas City metropolitan area and within the Interstate-70 corridor, an area defined as a priority landscape in the Kansas Forest Action Plan.[1] According to the Mid-America Regional Council, growth in the nine-county Kansas City region is expected to increase by half a million people by 2030. Between 2000 and 2010, Douglas County's population increased by 10.9 percent and between 2010 and 2040, the county's population is expected to expand by 37.6 percent.[4] We assessed Douglas County forests because projected growth and land conversion threaten acreage and quality of forest and woodlands. Findings from this project will complement and encourage conservation practices and environmental planning within the county. By demonstrating the value of trees and forests in eastern Kansas, this project supports national priorities of conserving working forest landscapes, protecting forests from harm, and enhancing public benefits associated with trees and forests.

Results of this project will broaden the understanding of what trees and forests contribute to a growing Kansas population, such as the filtering of air pollutants, the reduction of power plant emissions, the sequestration (i.e., annual removal) and storage of carbon dioxide, energy benefits to residential structures, and positive impacts to water quality. Data will quantify the current composition and structure of the trees and forests in Douglas County and inform how this resource could be threatened by current and future insect and disease threats.

The project builds on the findings from the first i-Tree Eco project conducted in the Kansas City region and further strengthens a growing knowledge base that trees and forests are necessary for human health and well-being as the Kansas population grows. This report provides information on the current resource, but also necessary information to help plan for a better future.

The project builds on the findings from the first i-Tree Eco project conducted in the Kansas City region and further strengthens a growing knowledge base that trees and forests are necessary for human health and well-being as the Kansas population grows.

EXECUTIVE SUMMARY

Trees in urban and rural areas contribute significantly to human health and environmental quality by providing various ecosystem services (i.e., the conditions and processes through which natural ecosystems, and the species which make them up, sustain and fulfill human life[5]). To better understand the ecosystem services and values provided by trees, the U.S. Forest Service, Northern Research Station, developed the Urban Forest Effects (UFORE) model, which is now known as i-Tree Eco. Results from i-Tree models are used to advance the understanding of tree and forest resources; improve urban and rural forest policies, planning and management; provide data to support the potential inclusion of trees within environmental regulations; and determine how trees affect the environment and consequently enhance human health and environmental quality in urban and rural areas.

Benefits ascribed to urban trees include:

- **Air pollution removal**
- **Air temperature reduction**
- **Reduced building energy use**
- **Absorption of ultraviolet radiation**
- **Improved water quality**
- **Reduced noise**
- **Improved human comfort**
- **Increased property value**
- **Improved physiological & psychological well-being**
- **Aesthetics**
- **Community cohesion**

The i-Tree Eco model is used to help quantify forest structure, function, and values. Forest structure is a measure of various physical attributes of the vegetation, including tree species composition, number of trees, tree density, tree health, leaf area, biomass, and species diversity. Forest functions, which are determined by forest structure, include a wide range of environmental and ecosystem services such as air pollution removal and cooler air temperatures. Forest values are an estimate of the economic worth of the various forest functions.

To help determine the vegetation structure, functions, and values of trees in Douglas County, Kansas, a vegetation assessment was conducted during summer of 2012. For this assessment, 0.1-acre field plots (74.4 feet diameter circular plots) were sampled and analyzed using the i-Tree Eco model. This report summarizes (Table 1) results and values of:

- Forest structure
- Potential risk to trees from various insects or diseases
- Air pollution removal
- Carbon storage
- Annual carbon removal (sequestration)
- Changes in building energy use

In addition, a tree growth projection model was used to estimate annual tree canopy change based on tree data for Douglas County. Tree growth was based on various tree characteristics including species (growth rate, longevity, height at maturity), current tree size, crown competition, and tree condition. The model was used to consider several different scenarios to estimate the number of trees that need to be established to meet desired canopy goals in the future (Table 2). Ecosystem services under these scenarios are also summarized.

A specialized analysis of the Wakarusa River watershed of eastern Kansas was also completed using the i-Tree Hydro model.[6] i-Tree Hydro is a semi-distributed, physical-based model created to simulate tree effects on stream hydrology using local cover and elevation information, hourly weather data, and hourly stream flow data. This report details the stream flow response to changes in tree and/or impervious cover in the Wakarusa River watershed.

Table 1.—Summary of regional forest features, Douglas County, 2012

Feature	Measure
Number of trees	14,164,000
Tree and shrub canopy cover	25.2%
Tree canopy cover	23.5%
Most common species	American elm, northern hackberry, eastern redcedar, Osage-orange, honeylocust
Trees <6 inches diameter (%)	66.8%
Pollution removal, trees	
Ozone	1,781 tons/year ($3.0 million/year)
Particulate matter (2.5-10μ)	1,269 tons/year ($8.0 million/year)
Nitrogen dioxide	436 tons/year ($149,000/year)
Sulfur dioxide	209 tons/year ($24,000/year)
Particulate matter (<2.5μ)	115 tons/year ($6.5 million/year)
Carbon monoxide	58 tons/year ($77,000/year)
All 6 pollutants	3,868 tons/year ($17.7 million/year)
Carbon storage	1.7 million tons ($124 million)
Carbon sequestration	82,000 tons/year ($5.8 million/year)
Building energy reduction	$2.9 million/year
Reduced carbon emissions	$534,300/year
Structural value	$6.2 billion

Ton – short ton (U.S.) (2,000 lbs)

Table 2.—Number of trees needed to be established to meet cover goals, Douglas County, 2012[a]

		Cover Goal			
Land Use	Current cover (%)	Maintain cover	Increase cover 5%	Increase cover 10%	Increase cover 20%
		trees			
Agriculture	10.5	201,000	325,000	468,000	774,000
Commercial	7.1	3,300	5,300	7,800	13,000
Park/Open	10.6	60,000	84,000	109,000	163,000
Residential	31.4	66,000	84,000	109,000	162,000
Vacant	81.9	86,000	129,000	176,000	262,000
Total	23.5	416,300	627,300	869,800	1,374,000

[a] Estimated number of trees needed to be established annually by land use to achieve various canopy coverage goals in 50 years with 4 percent annual mortality. Most of these trees will likely be established through natural regeneration.

I-TREE ECO MODEL AND FIELD MEASUREMENTS

Urban trees and forests have many functions and values but currently only a few of these attributes can be assessed due to a limited ability to quantify all of these values through standard data analyses. To help assess Douglas County's urban and rural forests, data from 190 field plots located throughout the region (Fig. 1) were analyzed using the U.S. Forest Service's i-Tree Eco model (formerly known as UFORE).[7]

The i-Tree Eco model uses standardized field data from randomly located plots and local hourly air pollution and meteorological data to quantify forest structure and its numerous effects, including:

- Forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass, species diversity, etc.)
- Amount of pollution removed hourly by the forest, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, particulate matter (2.5-10 microns), and particulate matter (<2.5 microns)
- Total carbon stored and net carbon annually sequestered by the forest
- Effects of trees on residential building energy use and consequent effects on carbon dioxide emissions from power sources

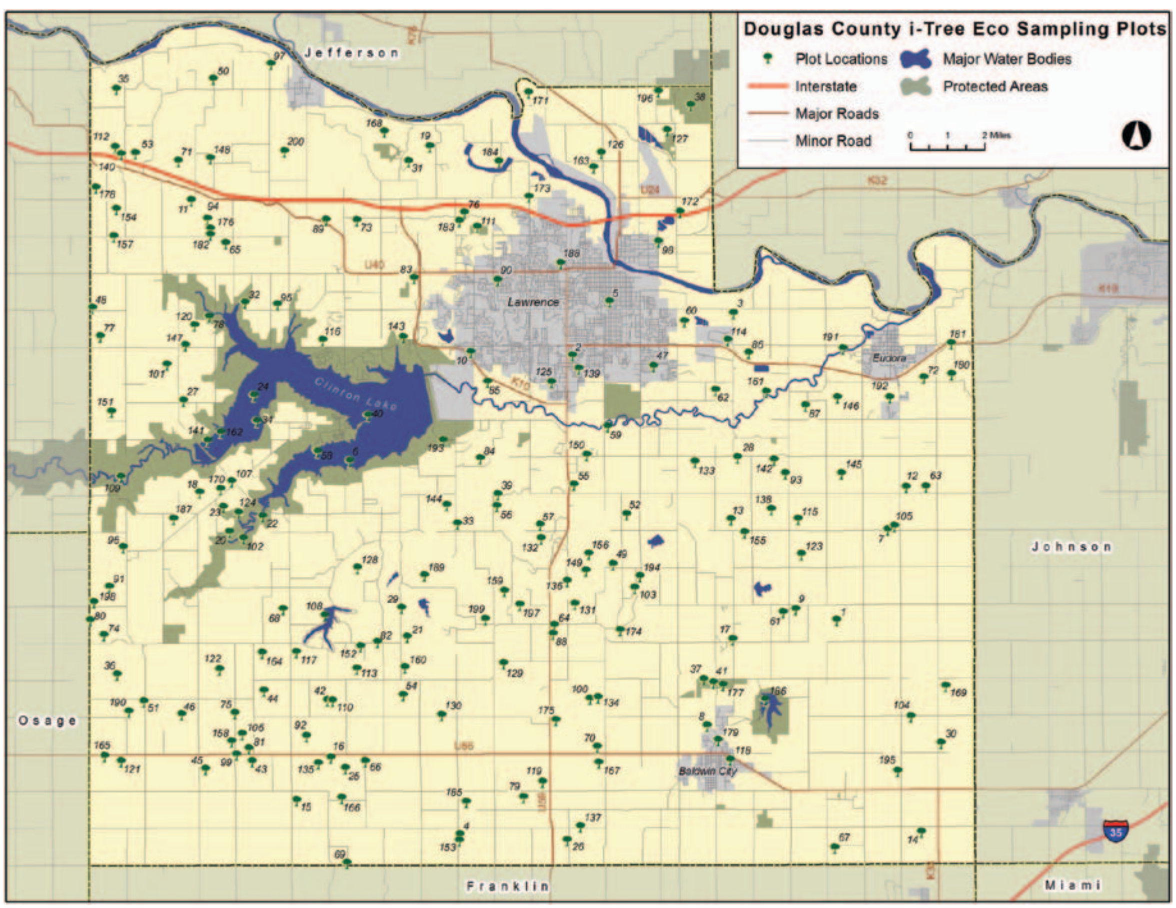


Figure 1.—Map of the study area and field plot distribution, Douglas County, 2012.

Field Survey Data

Plot Information

- **Land use**
- **Percent tree cover**
- **Percent shrub cover**
- **Percent plantable**
- **Percent ground cover types**
- **Shrub species/ dimensions**

Tree parameters

- **Species**
- **Stem diameter**
- **Total height**
- **Height to crown base**
- **Crown width**
- **Percent foliage missing**
- **Percent dieback**
- **Crown light exposure**
- **Distance and direction to buildings from trees**

- Compensatory value of the forest, as well as the value of air pollution removal and carbon storage and sequestration
- Potential impact of infestations by insects and diseases, such as Asian longhorned beetle, oak wilt, thousand cankers disease, gypsy moth, or Dutch elm disease

In the field, 0.1-acre plots were selected based on a randomized grid with an average density of approximately 1 plot for every 1,570 acres. The study is divided into smaller areas based on a land use classification recorded in the field. The plots were divided among the following land uses (Fig. 2): agriculture (124 plots, 71.4 percent of area); vacant (30 plots, 3.1 percent); commercial, including industrial, mixed and utility (12 plots, 1.5 percent); residential, including single and multiple family (11 plots, 10.8 percent); water (8 plots, 3.8 percent); and park/open, including institutional (5 plots, 9.5 percent).

Field data were collected by the Kansas Forest Service. Data collection took place during the leaf-on season to properly assess tree canopies. Within each plot, data collected included land use, ground and tree cover, shrub characteristics, and individual tree attributes of species, stem diameter at breast height (d.b.h.; measured at 4.5 feet, hereafter referred to as stem diameter), tree height, height to base of live crown, crown width, percentage crown canopy missing and dieback, and distance and direction to residential buildings.[8] Trees were recorded as woody plants with a stem diameter greater than or equal to 1 inch. As many species are classified as small tree/ large shrub, the 1-inch minimum stem diameter of all species means that many species commonly considered as shrubs will be included in the species tallies when they meet the minimum diameter requirement.

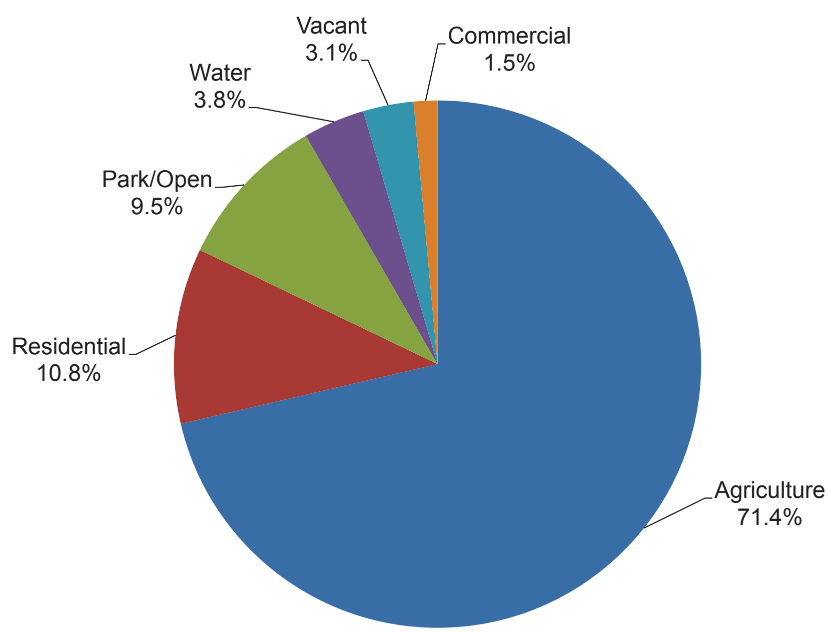


Figure 2.—Land-use distribution, Douglas County, 2012, for inventoried plots.

To estimate current carbon storage, biomass for each tree was calculated using equations from the literature and measured tree data. Open-grown, maintained trees tend to have less biomass than predicted by forest-derived biomass equations.[9] To adjust for this difference, biomass results for open-grown trees are multiplied by 0.8.[9] No adjustment was made for trees found in natural stand conditions. Tree dry-weight biomass was converted to stored carbon by multiplying by 0.5.[9]

Data collector, Grant Thompson, measuring d.b.h.
Photo by Kim Bomberger, Kansas Forest Service, used with permission.

To estimate the gross amount of carbon sequestered annually, average diameter growth from appropriate genera and diameter class and tree condition was added to the existing tree diameter (year *x*) to estimate tree diameter and carbon storage in year *x*+1.

Air pollution removal estimates were calculated for carbon monoxide (CO), ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter greater than 2.5 microns and less than 10 microns ($PM_{2.5\text{-}10}$, and particulate matter less than 2.5 microns ($PM_{2.5}$). Estimates are derived from calculated hourly tree-canopy resistances for O_3, SO_2, and NO_2 based on a hybrid of big-leaf and multi-layer canopy deposition models.[10,11] As the removal of CO and $PM_{2.5\text{-}10}$ by vegetation is not directly related to transpiration, removal rates (deposition velocities) for these pollutants were based on average measured values from the literature[12,13] that were adjusted depending on leaf phenology and leaf area. Removal rates for $PM_{2.5}$ varied with wind speed.[14] Particulate removal incorporated a 50 percent resuspension rate of particles back to the atmosphere for $PM_{2.5\text{-}10}$ and used variable resuspension rates that varied with windspeed for $PM_{2.5}$.[14,15]

Seasonal effects of trees on residential building energy use were calculated based on procedures described in the literature[16] using distance and direction of trees from residential structures, tree height, and tree condition data.

Compensatory values were based on valuation procedures of the Council of Tree and Landscape Appraisers[17], which uses tree species, diameter, condition, and location information.[17] Compensatory values represent compensation to owners for the loss of an individual tree and can be viewed as the value of the trees as a structural asset.

To learn more about i-Tree Eco methods[7,18] refer to: http://nrs.fs.fed.us/tools/ufore/ or www.itreetools.org.

TREE CHARACTERISTICS OF DOUGLAS COUNTY'S FOREST

Tree and shrub cover in Douglas County is estimated at 25.2 percent of the land area.

Douglas County has an estimated 14,164,000 trees with a standard error (SE) of 2,600,000. Tree and shrub cover is estimated from the photo-interpretation of Google Earth imagery of 500 random points (Table 3). Tree and shrub cover in Douglas County is estimated at 25.2 percent of the land area.[19] As it is difficult to differentiate between trees and shrubs from aerial imagery, the plot estimates of tree and shrub cover separately were used to differentiate between tree and shrub cover. Based on the field data in conjunction with photo-interpretation[19], tree cover (without shrubs) in Douglas County is estimated to be 23.5 percent.

The five most common species in the region's urban and rural forest were American elm (20.2 percent), northern hackberry (16.4 percent), eastern redcedar (13.7 percent), Osage-orange (13.3 percent), and honeylocust (6.0 percent). The 10 most common species account for 86.1 percent of all trees; their relative abundance is illustrated in Figure 3. Thirty-nine tree species were sampled in Douglas County; these species and their relative abundance are presented in Appendix I. More information on species distribution by land use is given in Appendix II (Figures 25-32).

Table 3.—Land cover in Douglas County, 2010

Cover type	%	SE
Grass/herbaceous	66.2	2.1
Tree/shrub	25.2	1.9
Water	4.4	0.9
Impervious - building	1.8	0.6
Impervious - other	1.4	0.5
Impervious - road	0.6	0.3
Soil/bare ground	0.4	0.3

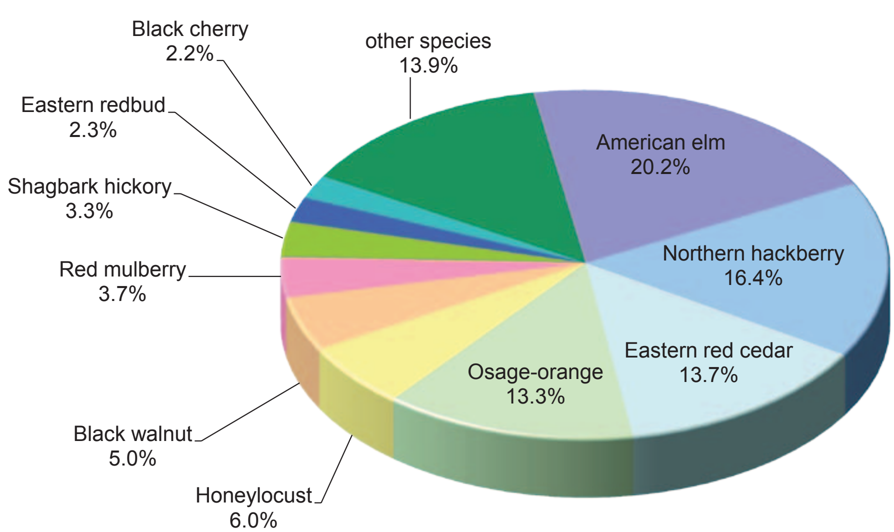


Figure 3.—Tree species composition, Douglas County, 2012.

The overall tree density for Douglas County is 47.5 trees/acre. The highest tree densities occur in vacant areas (328 trees/acre), followed by residential (43 trees/acre), and agriculture land (41 trees/acre) (Fig. 4). Land uses that contain the greatest percentage of the total tree population are agriculture (62.1 percent), followed by vacant (21.4 percent), and residential (9.7 percent). More information on the tree species in each land use and their structure and functions is given in Appendix III.

Leaf area refers to the total one-sided area of a leaf and is typically summed for all leaves within any one classification. In Douglas County, leaf area is highest in agriculture (55.7 percent of total tree leaf area) and vacant (17.3 percent) land use types (Fig. 5). Leaf area index (LAI) is a ratio of the estimated total leaf area divided by land area. As each land use has a different land area, LAI standardizes the canopy extent on an equal area basis. Higher LAIs indicate a greater number of leaves per acre. Land uses that have the highest LAI are vacant (6.8), residential (1.7), and park/open (1.5).

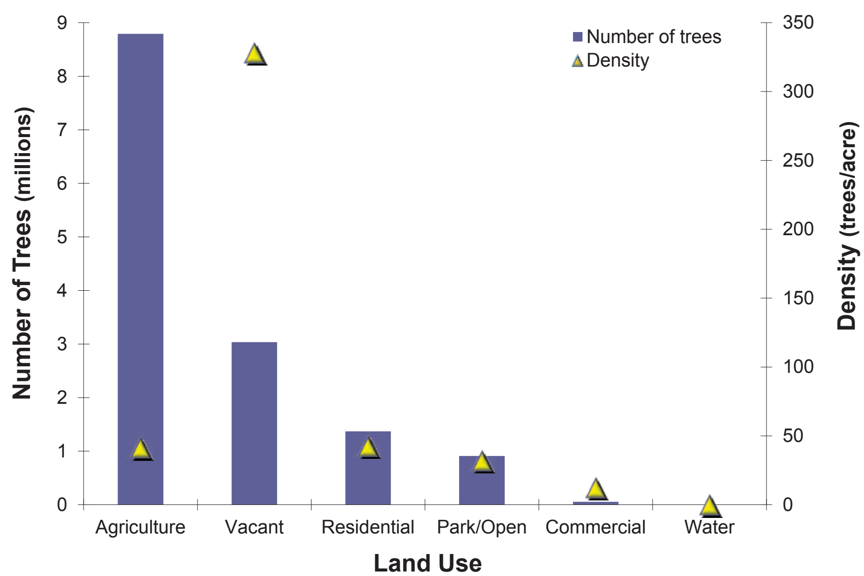


Figure 4.—Number of trees and tree density by land use, Douglas County, 2012.

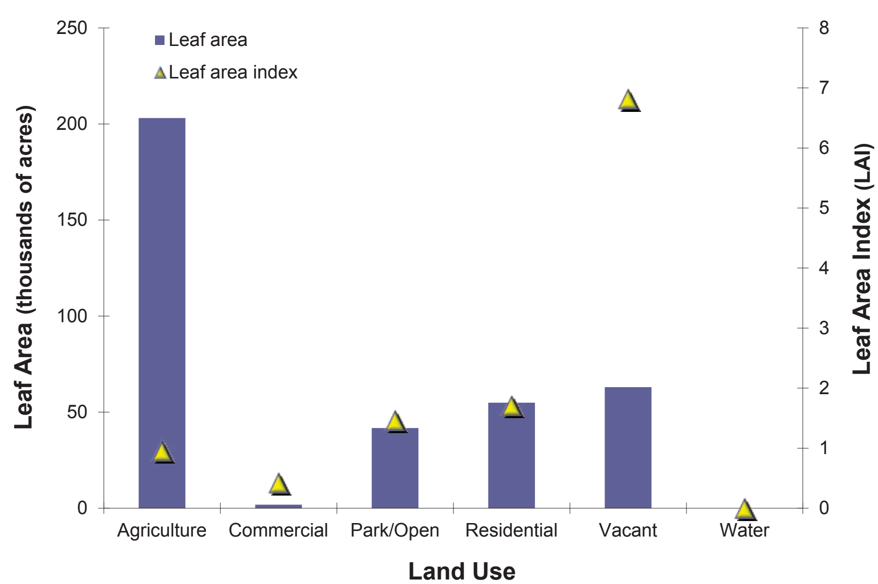


Figure 5.—Total leaf area and leaf area index by land use, Douglas County, 2012.

Trees that have diameters less than 6 inches account for 66.8 percent of the population. This diameter class also contains 21.5 percent of the total leaf area. Trees that have diameters greater than 18 inches account for 4.7 percent of the population and 29.0 percent of the total leaf area. Though these larger trees are a small percentage of the population, they are an important part of the urban and rural forests in Douglas County. Leaf area has a strong correlation with benefits that the trees produce for the ecosystem, such as pollution removal; the percent of abundance and leaf area contributed by each tree diameter class and species are illustrated in Figures 6 and 7.

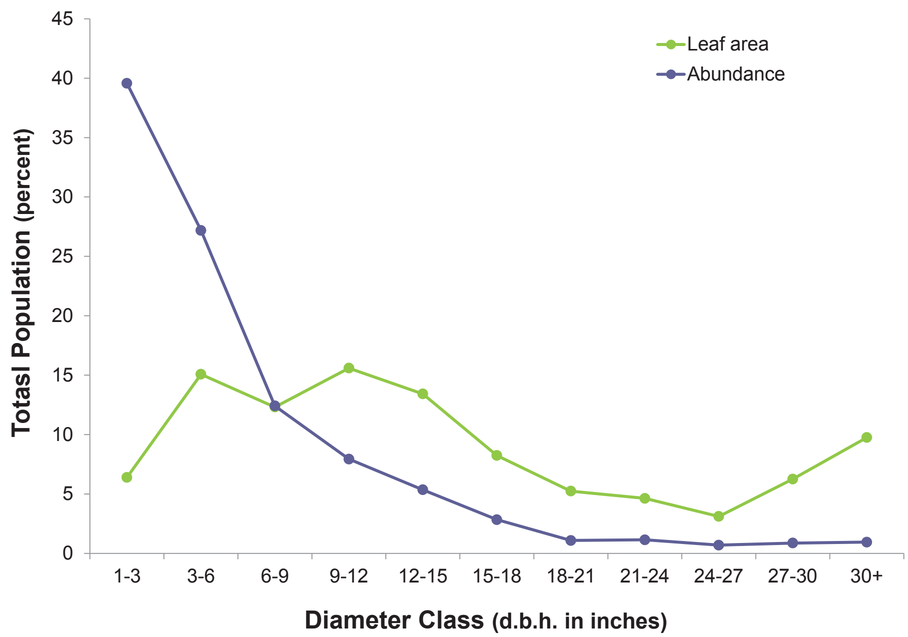


Figure 6.—Percent of total tree population (abundance) and leaf area by tree diameter class, Douglas County, 2012.

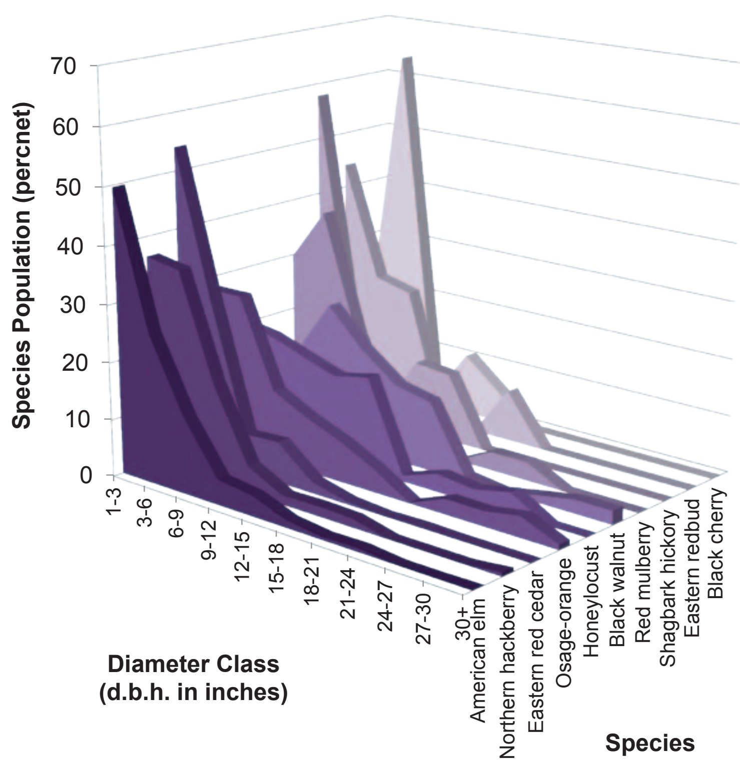
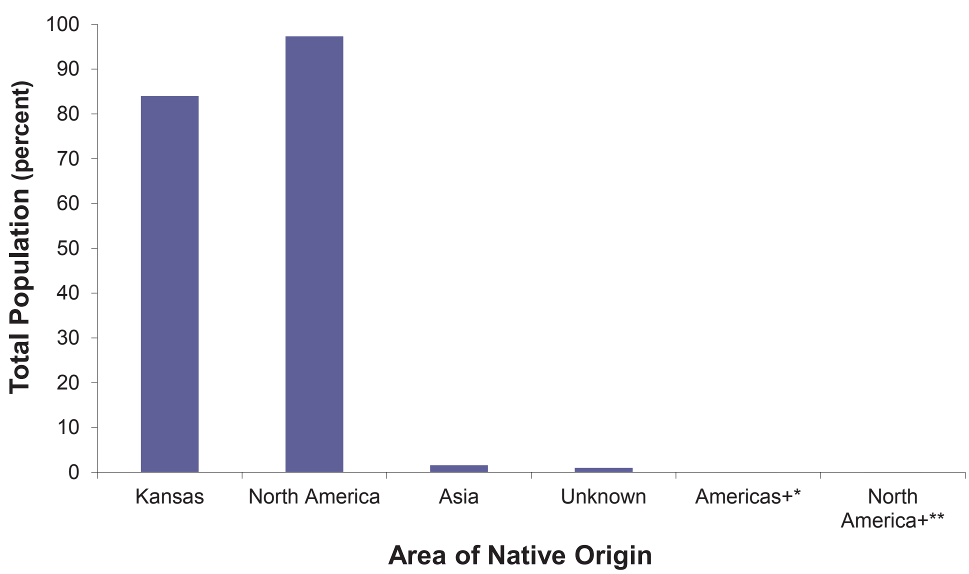


Figure 7.—Percent of species population by diameter class for 10 most common tree species, Douglas County, 2012.

Urban forests are a mix of native tree species that existed prior to development of the area and exotic species that were introduced by residents or other means.

Tree populations vary in diameter class distribution between the small (<3 inches stem diameter) and large trees (>18 inches stem diameter). Most of the small trees tend to be on agriculture and vacant land uses, while most of the large trees tend to be on agriculture and residential land (see Appendix IV). The small tree population tends to be dominated by American elm, northern hackberry, and eastern redcedar, with a distribution that varies among the land use classes (see Appendix IV). Eighteen percent of the small trees are American elms on agriculture lands. A few of the most common large trees demonstrate limited regeneration (i.e., they have a similar or greater number of large trees as they do small trees): black walnut, northern red oak, silver maple, and pin oak. This pattern may indicate poor regeneration or planting rates that may lead to a loss of these large tree populations in the future. Some other common large trees have substantially more small trees than large trees: American elm, northern hackberry, and Osage-orange. This pattern might be due to prolific regeneration and/or a limited ability of these species to reach large diameter classes (e.g., Dutch elm disease limiting the number of mature, large trees). Long-term monitoring can help determine how species populations are changing, and differences in diameter distributions illuminate potential problems with sustaining species populations through time.

Urban forests are a mix of native tree species that existed prior to the development of the area and exotic species that were introduced by residents or other means. Thus, urban forests often have a tree diversity that is higher than surrounding native landscapes. Increased tree diversity can minimize the overall impact or destruction by a species-specific insect or disease, but the increase in the number of exotic plants can also pose a risk to native plants if exotic species are invasive and out-compete and displace native species. In Douglas County, about 84.0 percent of the trees are native to Kansas (Fig. 8). Trees with a native origin outside of North America are predominantly from Asia (1.6 percent of all species).



* native to North America and South America, and one other continent
** native to North America and one other continent, excluding South America

Figure 8.—Percent of total tree population by area of native origin, Douglas County, 2012.

Russian olive.
Photo by Leslie J. Mehrhoff, University of Connecticut, Bugwood.org.

Invasive plant species are often characterized by their vigor, ability to adapt, reproductive capacity, and general lack of natural enemies. These characteristics enable them to displace native plants and threaten the native landscape.[20] One of the tree species sampled in Douglas County, Russian olive, has been identified on the Kansas invasive species list.[21] Though it contributes less than 0.1 percent to the total population of Douglas County, Russian olive is considered to be one of the most invasive plant species in the state of Kansas.

TREE AND FOREST COVER AND LEAF AREA

Trees cover about 23.5 percent of Douglas County; shrubs cover 1.7 percent of the area. Dominant ground-cover types include herbaceous (82.6 percent), water (7.9 percent), and duff/mulch cover (3.3 percent) (Fig. 9).

Many tree benefits are linked directly to the amount of healthy leaf surface area of the plant. In Douglas County, trees that dominate in terms of leaf area are northern hackberry, Osage-orange, and black walnut.

Tree species with relatively large individuals contributing leaf area to the population (species with percentage of leaf area much greater than percentage of total population) are black walnut, chinkapin oak, and Siberian elm. Smaller trees in the population are sandbar willow, American elm, and honeylocust (species with percent of leaf area much less than percent of total population). The species must also have constituted at least 1 percent of the total population to be considered as relatively large or small trees in the population.

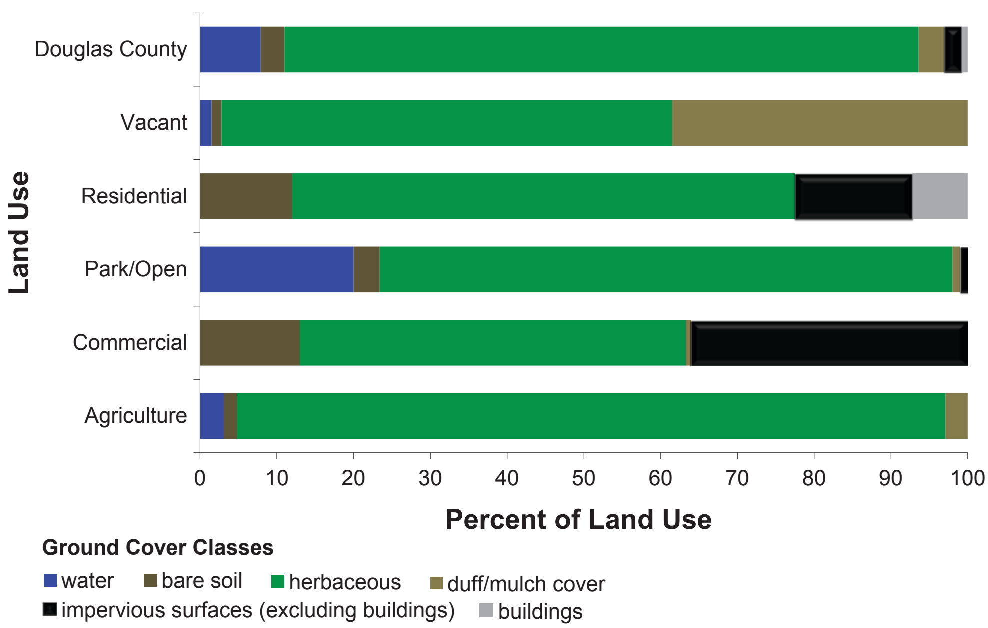


Figure 9.—Percent of the county and land use areas covered by ground-cover classes, Douglas County, 2012.

The importance value (IV) of a species is calculated using a formula that takes into account the relative leaf area and relative abundance (Fig. 10). The most important species in Douglas County, according to calculated IVs, are northern hackberry, Osage-orange, and American elm (Table 4). High importance values do not mean that these trees should necessarily be used in the future, rather that these species currently dominate the urban and rural forest structure.

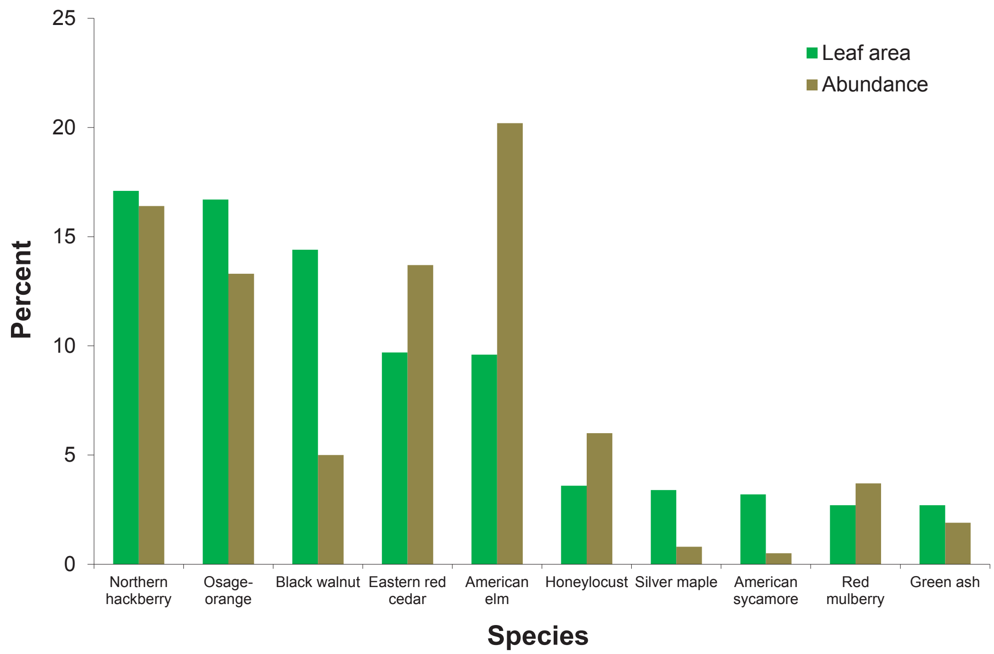


Figure 10.—Percent of total population (abundance) and leaf area for the 10 most common tree species, Douglas County, 2012.

The most important species in Douglas County are northern hackberry, Osage-orange, and American elm.

Table 4.—Percent of total population, percent of total leaf, and importance values of species with the greatest importance values, Douglas County, 2012

Common Name	% Pop[a]	%LA[b]	IV[c]
Northern hackberry	16.4	17.1	33.5
Osage-orange	13.3	16.7	30.0
American elm	20.2	9.6	29.8
Eastern redcedar	13.7	9.7	23.4
Black walnut	5.0	14.4	19.4
Honeylocust	6.0	3.6	9.6
Red mulberry	3.7	2.7	6.4
Shagbark hickory	3.3	2.7	6.0
Green ash	1.9	2.7	4.6
Silver maple	0.8	3.4	4.2

[a] %Pop - percent of total tree population
[b] %LA - percent of total leaf area
[c] Importance Value (IV) = %Pop + %LA

In Douglas County tree and shrub cover combined remove approximately 5,466 tons of pollution per year ($24.0 million/ year).

General urban forest management recommendations to improve air quality are given in Appendix VI.

AIR POLLUTION REMOVAL BY TREES AND FORESTS

Poor air quality is a common problem in many urban areas. It can lead to human health problems, damage to landscape materials and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduce air pollutant emissions from power sources. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation.[22]

The monetary value of pollution removal by trees is estimated using the median externality values (c. 1994) for the United States for carbon monoxide (CO; $870/ton) and particulate matter less than 10 microns (PM_{10}; $4,091/ton).[23] These values have been adjusted to 2010 values (CO = $1,334/ton and PM_{10} = $6,271/ton) based on the producer's price index.[24] The value for PM_{10} was applied to the $PM_{2.5\text{-}10}$ removal (i.e., particles between 2.5 and 10 microns in size). The U.S. EPA's BenMAP program was used to estimate the incidence of adverse health effects (i.e., mortality and morbidity) and associated monetary value that result from changes in NO_2, O_3, $PM_{2.5}$ and SO_2 concentrations due to pollution removal by trees. BenMAP is a Windows-based computer program that uses geographic information system (GIS) data to estimate the health impacts and economic value when populations experience changes in air quality.[25] See Appendix V for more details on the effect of pollution removal on local health.

Pollution removal by trees and shrubs (25.2 percent tree and shrub cover) in Douglas County was estimated using the i-Tree Eco model in conjunction with field data and hourly pollution and weather data for the year 2010. Pollution removal by trees and shrubs (Fig. 11) was greatest for O_3 (2,580 tons), followed by $PM_{2.5\text{-}10}$ (1,725 tons), NO_2 (618 tons), SO_2 (305 tons), $PM_{2.5}$ (150 tons), and CO (88 tons). It is estimated

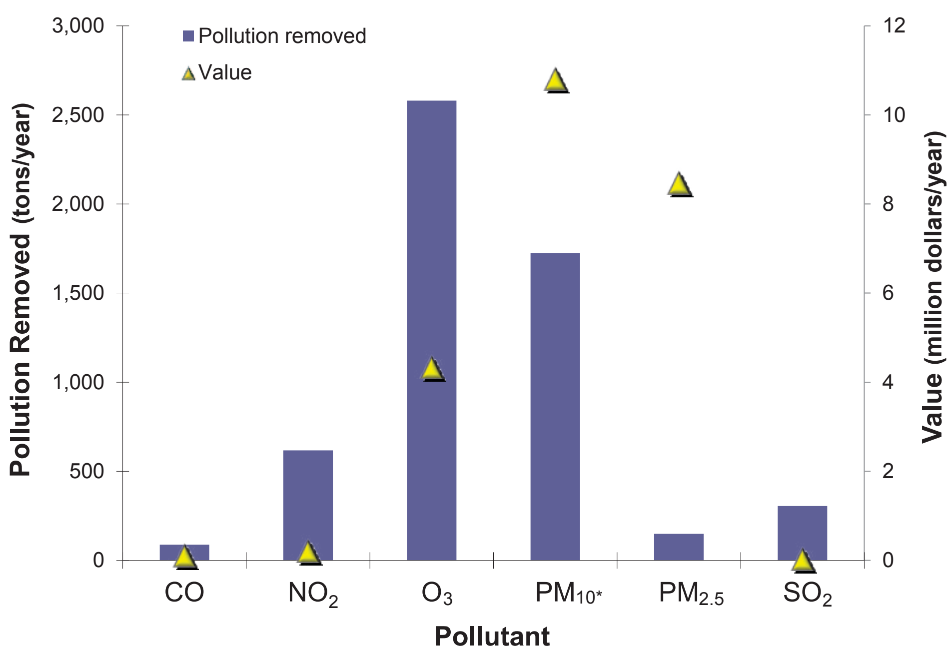


Figure 11.—Annual air pollution removal and value by trees and shrubs, Douglas County, 2012.

that trees remove 3,868 tons of air pollution (CO, NO_2, O_3, $PM_{2.5\text{-}10}$, $PM_{2.5}$, SO_2) per year with an associated value of $17.7 million (Table 5). The effects of shrub cover (Table 6) in Douglas County would remove an additional estimated 1,599 tons/year ($6.3 million/year). Thus, tree and shrub cover combined remove approximately 5,466 tons of pollution per year ($24.0 million/year).

In 2012, trees in Douglas County emitted 682 tons of volatile organic compounds (VOCs) in the forms of isoprene (357 tons) and monoterpenes (325 tons). Land uses with the highest VOC emissions were agriculture, vacant, and residential. Seventy-one percent of Douglas County's VOC emissions were from the *Quercus* (oak) and *Juglans* (walnut) genera. Figure 12 illustrates the annual VOC emissions by genera.

These VOCs are a precursor chemical to O_3 formation. Studies have estimated VOC emission costs. These costs are not included here as it is incorrect to add positive dollar estimates of ozone removal effects with negative dollar values of VOC emission effects to determine whether tree effects are positive or negative in relation to ozone. Estimates of VOC impacts on O_3 formation (e.g., via photochemical models) should be contrasted with ozone removal by trees (i.e., O_3 effects should be directly compared, not dollar estimates). In addition, air temperature reductions by trees have

Table 5.—Annual air pollution removal and value by trees, Douglas County, 2012[a]

Pollutant	Removal (tons)		Value (U.S. $1,000)	
O_3	1,781	(393-2,122)	2,978	(657-3,548)
$PM_{2.5\text{-}10}$[b]	1,269	(2,350-9,420)	7,952	(3,294-11,901)
NO_2	436	(186-518)	149	(64-177)
SO_2	209	(91-319)	24	(11-37)
$PM_{2.5}$	115	(15-263)	6,529	(847-14,951)
CO	58		77	
Total	3,868	(1,268-5,178)	17,710	(4,949-30,691)

[a,b] See explanation below Table 6

Table 6.—Annual air pollution removal and value by shrubs, Douglas County, 2012[a]

Pollutant	Removal (tons)		Value (U.S. $1,000)	
O_3	799	(190-1,061)	1,362	(323-1,808)
$PM_{2.5\text{-}10}$[b]	456	(187-688)	2,861	(1,174-4,313)
NO_2	182	(90-251)	63	(31-88)
SO_2	96	(44-165)	11	(5-20)
$PM_{2.5}$	35	(4-79)	1,951	(252-4,461)
CO	31		41	
Total	1,599	(547-2,275)	6,290	(1,827-10,731)

[a] Estimated tons of pollution removed by trees/shrubs in Douglas County (2009) and associated monetary value (thousands of dollars); numbers in parentheses represent expected range of values (no range determined for carbon monoxide). Monetary value of pollution removal by trees estimated using median externality values[23] or health effect values from BenMAP[14,25] for United States for each pollutant.

[b] Assumes 50 percent resuspension of particles

been shown to significantly reduce O_3 concentrations[26], but are not considered in this analysis. Modeling that integrates tree effects on air temperature, pollution removal, VOC emissions, and emissions from power plants can be used to determine the overall effect of trees on O_3 concentrations. General recommendations for air quality improvement with trees are given in Appendix VI.

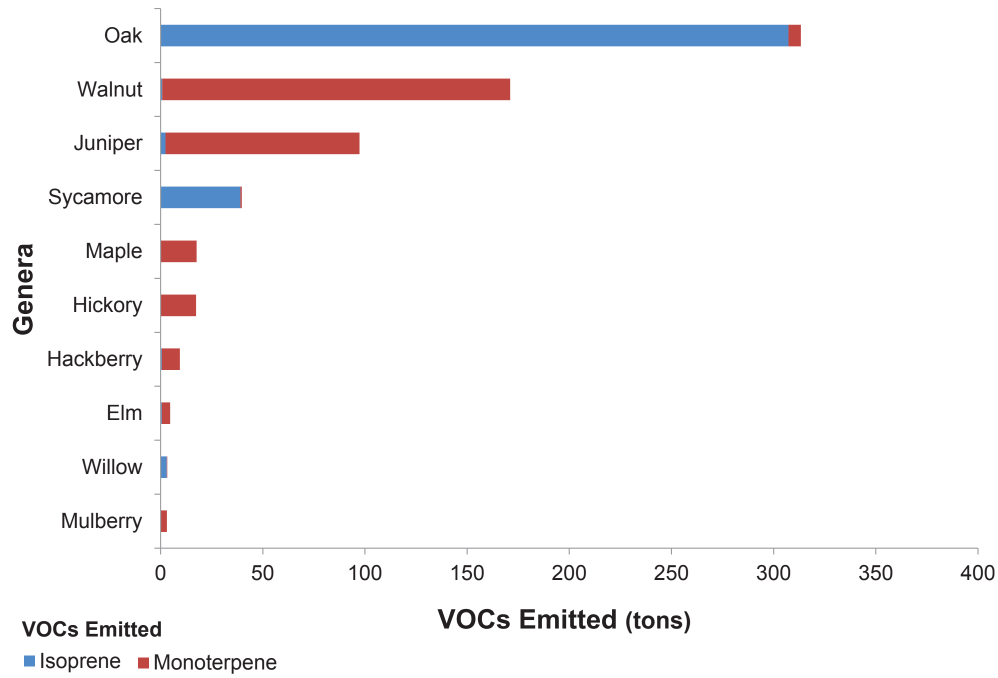


Figure 12.—Annual isoprene and monoterpene volatile organic compound (VOC) emissions by genera with highest total emissions, Douglas County, 2012.

City of Lawrence downtown.
Photo by Kim Bomberger, Kansas Forest Service, used with permission.

Regenerating American elm.
Photo by Kim Bomberger, Kansas Forest Service, used with permission.

CARBON STORAGE AND SEQUESTRATION

Climate change is an issue of global concern to many people. Tree and forest resources can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by reducing energy use in buildings, and consequently reducing carbon dioxide emissions from fossil-fuel and wood-based power sources.[27]

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new tissue growth every year. The amount of carbon annually sequestered is greater for healthier trees and larger diameter trees. Gross sequestration by trees in Douglas County is about 82,000 tons of carbon per year (300,000 tons/year of CO_2) with an associated value of $5.8 million/year (Fig. 13).[28] Net carbon sequestration in Douglas County is estimated at about 73,000 tons/year (266,000 tons/year of CO_2) based on estimated carbon loss due to tree mortality and decomposition.

Carbon storage by trees is another way trees can influence global climate change. As trees grow, they store more carbon by holding it in their accumulated tissue. When trees die and decay, they release much of the stored carbon back to the atmosphere. Thus, carbon storage is an indication of the amount of carbon that could be released if trees are allowed to die and decompose. Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance can contribute to carbon emissions.[29] When trees die, using the wood in long-term wood products or using wood to heat buildings or produce energy will help reduce carbon emissions from wood decomposition or from fossil-fuel or wood-based power sources.

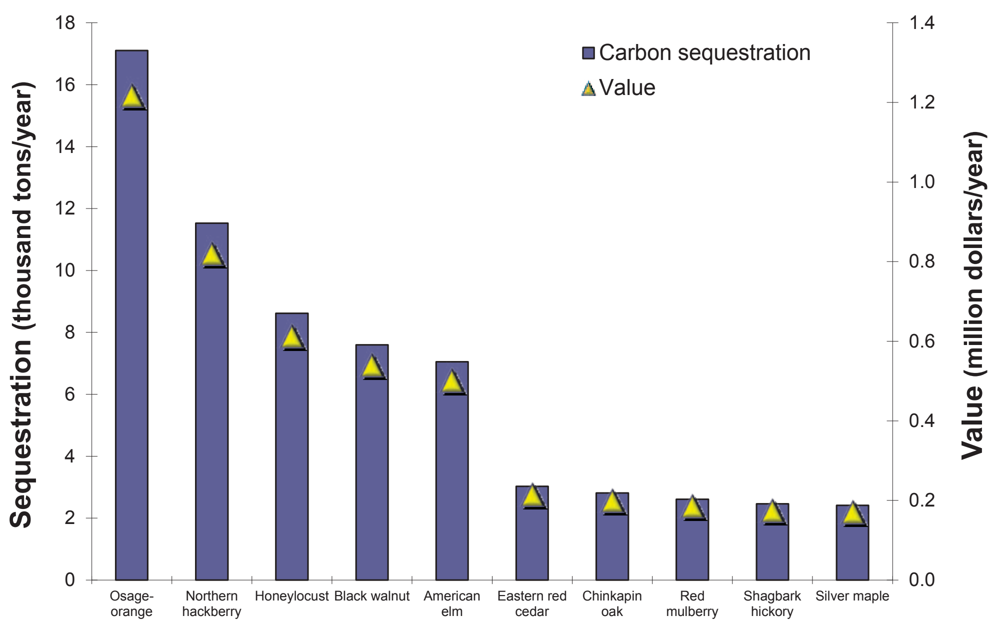


Figure 13.—Annual carbon sequestration and value for the tree species with the greatest total sequestration, Douglas County, 2012.

Live and dead trees in Douglas County store an estimated 1.7 million tons of carbon (6.4 million tons of CO_2) ($124 million). Of all the species sampled, Osage-orange stores the most carbon (approximately 25.2 percent of total carbon stored) and annually sequesters the most carbon (20.9 percent of all sequestered carbon). Total and average carbon storage and sequestration by diameter class are illustrated in Figures 14 and 15.

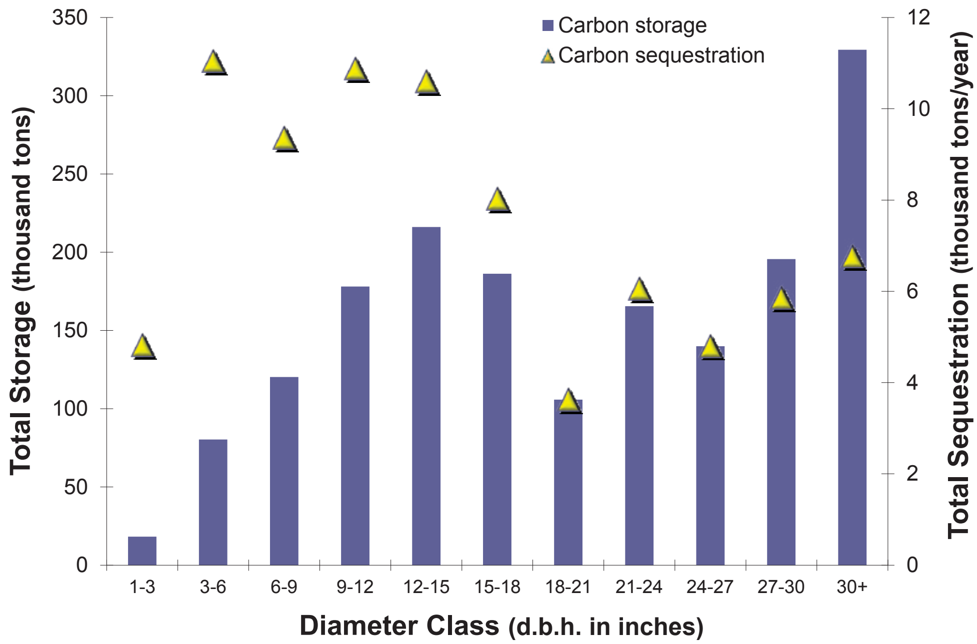


Figure 14.—Total carbon storage and sequestration by diameter class, Douglas County, 2012.

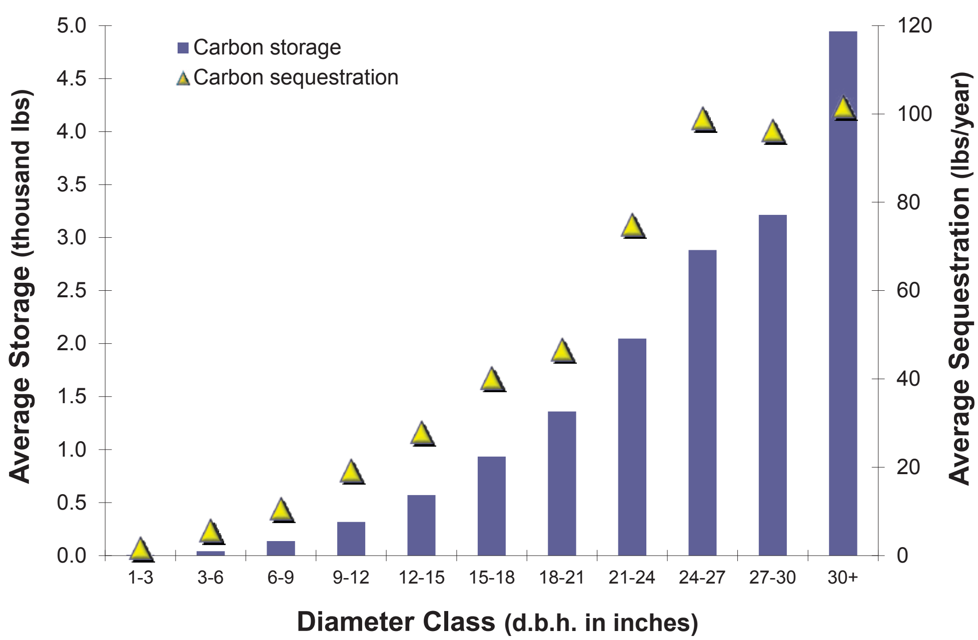


Figure 15.—Average carbon storage and sequestration by diameter class, Douglas County, 2012.

Photo by Kim Bomberger, Kansas Forest Service, used with permission.

TREES AFFECT ENERGY USE IN BUILDINGS

Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Trees tend to reduce building energy consumption in the summer months and can either increase or decrease building energy use in the winter months, depending on the location of trees around the building. To enhance or sustain evaporative cooling by trees in Douglas County, many trees are, or may need to be, irrigated. Estimates of tree effects on energy use are based on field measurements of tree distance and direction to space-conditioned residential buildings.[16]

Based on average energy costs in 2009, trees in Douglas County reduce energy costs from residential buildings by an estimated $2.9 million annually. Trees also provide an additional $534,300 in value per year by reducing amount of carbon released by fossil-fuel based power sources (a reduction of 7,500 tons of carbon emissions or 27,500 tons of carbon dioxide). Energy savings are illustrated in Tables 7 and 8. This study did not attempt to estimate energy conservation benefits associated with commercial or institutional buildings or from urban heat island reduction.

Table 7.—Annual energy savings (MBTUs, MWHs, or tons) due to trees near residential buildings, Douglas County, 2012

	Heating	Cooling	Total
MBTU[a]	-10,600	n/a	-10,600
MWH[b]	-100	29,600	29,500
Carbon avoided (tons)	-200	7,700	7,500

[a] MBTU – Million British thermal units (not used for cooling)
[b] MWH – Megawatt-hour

Table 8.—Annual monetary savings[c] (dollars) in residential energy expenditures during heating and cooling seasons, Douglas County, 2012

	Heating	Cooling	Total
MBTU[a]	-138,600	n/a	-138,600
MWH[b]	-11,300	3,036,200	3,024,900
Carbon avoided	-14,400	548,700	534,300

[a] MBTU – Million British thermal units (not used for cooling)
[b] MWH – Megawatt-hour
[c] Based on 2009 statewide energy costs[30]

Based on average energy costs in 2009, trees in Douglas County reduced energy costs from residential buildings by an estimated $2.9 million annually.

i-Tree

STRUCTURAL AND FUNCTIONAL VALUES

Urban and rural forests have a structural value based on the tree itself, including compensatory value (e.g., the cost of having to replace the tree with a similar tree) and a carbon storage value. The compensatory value[17] of the trees and forests in Douglas County is about $6.2 billion (Fig. 16). The structural value of an urban or rural forest tends to increase with a rise in the number and size of healthy trees.

Urban and rural forests also have functional values (either positive or negative) based on the functions the tree performs. Annual functional values also tend to increase with increased number and size of healthy trees, and are usually on the order of several million dollars per year. There are many other functional values of the tree and forest resource, though they are not quantified here (e.g., reduction in air temperatures and ultraviolet radiation, improvements in water quality, aesthetics, wildlife habitat, etc.). Through proper management, tree and forest values can be increased. However, the values and benefits also can decrease as the amount of healthy tree cover declines.

Structural values:

- Compensatory value: $6.2 billion
- Carbon storage: $124 million

Annual functional values:

- Carbon sequestration: $5.8 million
- Pollution removal: $17.7 million
- Reduced energy costs: $2.9 million

More detailed information on the trees and forests in Douglas County can be found at http://nrs.fs.fed.us/data/urban. Additionally, information on tree statistics by diameter class can be found in Appendix VII and priority planting areas are detailed in Appendix VIII.

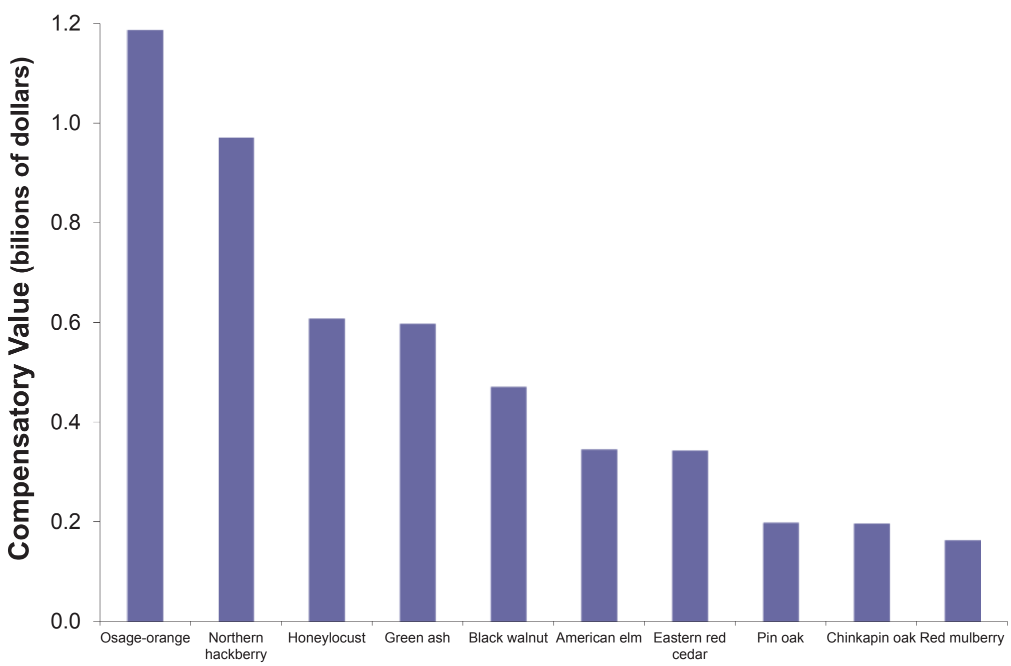


Figure 16.—Tree species with the greatest compensatory value, Douglas County, 2012.

Asian longhorned beetle.
Photo by Kenneth R. Law, USDA APHIS PPQ, www.invasive.org

POTENTIAL INSECT AND DISEASE IMPACTS

Insects and diseases can infest urban and rural forests, potentially killing trees and reducing the health, value, and sustainability of the forest resource. Various pests have different tree hosts, so the potential damage or risk of each pest will differ. Thirty-one exotic insects/diseases were considered for their potential impact using range maps of these pests in the coterminous United States (www.foresthealth.info).[31] For a complete analysis of the 31 exotic insects/diseases, see Appendix IX.

Although there are numerous pests that could impact Douglas County's urban and rural forests, Asian longhorned beetle (ALB), Dutch elm disease (DED), gypsy moth (GM), thousand cankers disease (TCD), and oak wilt (OW) pose the most serious threats based on the number of trees at risk of infestation.

Black walnut recently killed by thousand cankers disease.
Photo by Curtis Utley, CSUE, bugwood.org

Dutch elm disease and OW pose a threat because they currently exist within Douglas County, while ALB, GM, and TCD can be found within 750 miles of the county. Potential loss of trees from ALB is 3.7 million ($1.2 billion in compensatory value), DED is 3.0 million ($434 million), GM is 797,000 ($733 million), TCD is 702,000 ($473 million), and OW is 531,000 ($719 million)(Fig. 17).

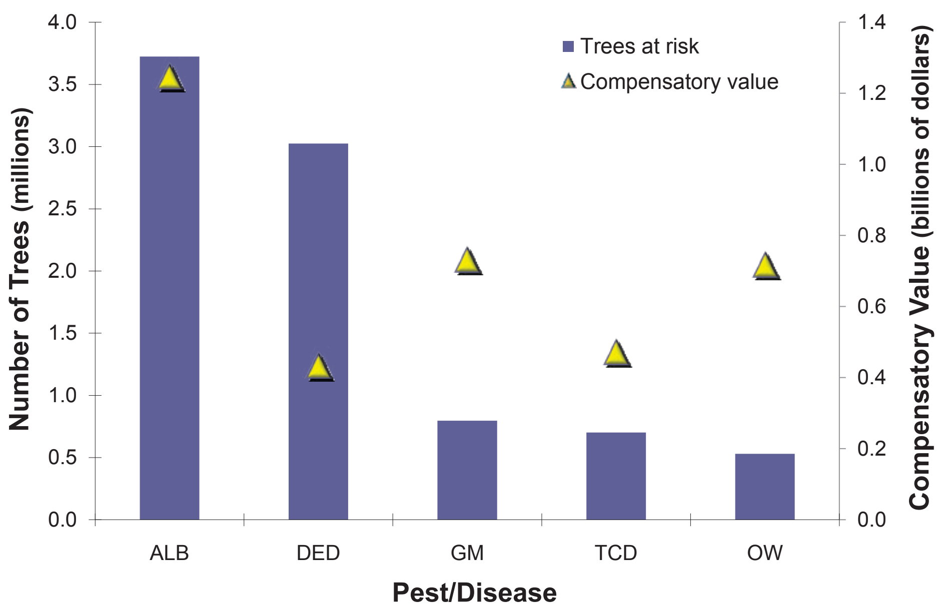


Figure 17.—Number of trees at risk and associated compensatory value for five most threatening insects/diseases, Douglas County, 2012.

TREE CANOPY COVER CHANGE

Tree cover in Douglas County is 23.5 percent, but the canopy will change based on numerous factors, including tree mortality, tree growth, and new tree establishment. A tree population projection model was used to estimate annual tree canopy change based on current tree data for Douglas County. The model was used to consider several different scenarios to show the number of trees that need to be established to meet desired tree canopy goals in the future. For details on methods and results, see Appendix X.

For Douglas County, the population projection model was used to estimate the number of new trees required annually to maintain existing tree canopy cover or to increase canopy cover by 5, 10, or 20 percent over 10, 25, or 50 years. The scenarios below are based on an average tree mortality of 4 percent.

In Appendix X, additional scenarios are detailed that cover results for average mortality rates of 2, 3, and 5 percent. Multiple mortality rates are estimated as the true average mortality rate for the region is unknown and the multiple estimates will illustrate a range of possible values. Long-term monitoring of tree populations can help determine actual average mortality rates for Douglas County.

Two other scenarios are detailed in Appendix X:

1) Annual tree establishment needed to sustain tree cover at the existing level given an emerald ash borer infestation that kills off all ash trees in 10 years
2) Annual tree establishment needed to sustain tree cover at the existing level given a thousand cankers disease outbreak that kills off all black walnut trees in 10 years.

Note that the estimated number of trees required is not the number of trees needed to be planted as many new trees are established annually through natural regeneration, particularly in more rural areas. Human activities in urban areas (development, mowing) often preclude the establishment of tree cover. Decreasing activities such as mowing, as well as sustaining pervious surfaces can facilitate natural regeneration.

Model Scenarios

In modeling tree establishment rates for Douglas County, each land use was modeled separately. Table 9 details the estimated annual tree establishment rates needed (number of trees per year) in each land use to either maintain or increase tree cover 10, 25, or 50 years in the future given an average 4 percent tree mortality rate. It should be noted that increasing canopy cover in too short of a time frame can lead to unsustainable canopy cover levels. Though planting many trees in a short time can reach a canopy goal, canopy cover will surpass the goal through time. Having too many trees in one age class can lead to a significant canopy cover loss in a relatively short time period as many of these trees can die within a relatively short time frame.

Table 9.—Estimated number of trees to be established annually for various cover and year scenarios, Douglas County, 2012. These estimates assume a 4% annual mortality.

Agriculture Land Use
2012 canopy cover: 10.5%

Scenario	10 Years	25 Years	50 Years
Maintain canopy cover	7,600	134,000	201,000
Increase cover by 5%	926,000	411,000	325,000
Increase cover by 10%	1,910,000	716,000	468,000
Increase cover by 20%	4,110,000	1,310,000	774,000

Commercial Land Use
2012 canopy cover: 7.1%

Scenario	10 Years	25 Years	50 Years
Maintain canopy cover	4,800	3,600	3,300
Increase cover by 5%	20,000	8,100	5,300
Increase cover by 10%	42,000	14,000	7,800
Increase cover by 20%	82,000	24,000	13,000

Park/Open Land Use
2012 canopy cover: 10.6%

Scenario	10 Years	25 Years	50 Years
Maintain canopy cover	74,000	62,000	60,000
Increase cover by 5%	209,000	109,000	84,000
Increase cover by 10%	341,000	152,000	109,000
Increase cover by 20%	640,000	256,000	163,000

Residential Land Use
2012 canopy cover: 31.4%

Scenario	10 Years	25 Years	50 Years
Maintain canopy cover	153,000	96,000	66,000
Increase cover by 5%	287,000	134,000	84,000
Increase cover by 10%	431,000	180,000	109,000
Increase cover by 20%	780,000	283,000	162,000

Vacant Land Use
2012 canopy cover: 81.9%

Scenario	10 Years	25 Years	50 Years
Maintain canopy cover	57,000	75,000	86,000
Increase cover by 5%	127,000	129,000	129,000
Increase cover by 10%	215,000	174,000	176,000
Increase cover by 20%	353,000	260,000	262,000

All Land Uses
2012 canopy cover: 23.5%

Scenario	10 Years	25 Years	50 Years
Maintain canopy cover	296,400	370,600	416,300
Increase cover by 5%	1,569,000	791,100	627,300
Increase cover by 10%	2,939,000	1,236,000	869,800
Increase cover by 20%	5,965,000	2,133,000	1,374,000

Also, for shorter time frames, estimated canopy growth can offset the need to establish new trees, thus tree planting estimates will be relatively low. However, if no new trees are established, the population will become unstable in the long run as there will be missing age classes in the future to sustain canopy cover (e.g., if no new trees were ever established, tree cover would be sustained for a while due to canopy growth, but eventually the tree cover would drop to zero). Thus, long-term estimates of establishment (e.g., 50-year estimates) are likely the most reasonable estimates for tree establishment. However, many of the trees to be established in the region will not need to be planted because of likely establishment through natural regeneration.

The projections of annual tree establishment are rough estimates based on average growth and mortality rates. As growth rates increase, the number of trees needed to be established decreases as canopy growth offsets the need for more new trees. Given the existing assumptions about growth and mortality, canopy cover can be sustained for about 10 years with no new trees added as existing growth can compensate for the loss of canopy due to mortality during this period. However, if no new trees are established during this period, the canopy cover will decline more rapidly in the future due to a lack of trees in this age class of trees. Many trees are established due to natural regeneration, but this regeneration varies by land use type.

Ecosystem Services from Increased Tree Cover

Increasing or sustaining tree canopy cover through time will produce environmental benefits for Douglas County. As an example, the benefits provided by the regional forest over the next 25 years were estimated for the model scenario of increasing canopy cover by 10 percent (increasing tree cover from 23.5 to 33.5 percent by establishing about 1.2 million trees per year with an average 4 percent mortality rate). Three ecosystem services/disservices were estimated: air pollution removal, carbon sequestration, and volatile organic compound (VOC) emissions

Air pollution removal was estimated by summing annual air pollution removal effects during the 25-year period. This simulation used the meteorological and pollution conditions of 2010 for all simulation years. Total pollution removal over the 25-year period is estimated at 119,000 tons ($544 million at nondiscounted current value), increasing from 3,868 tons/year ($17.7 million/year) in 2010 to 5,430 tons/year in 25 years ($24.9 million/year).

For carbon sequestration, the estimated tree population and diameter distribution in year 25 was used to estimate future carbon storage. This result was contrasted with the current carbon estimate to determine carbon sequestration over the 25 year period. Total carbon storage of live trees is estimated to increase from 1.49 million tons to 1.54 million tons, for a 25-year sequestration amount of 47,000 tons ($3.4 million).

Annual VOC emissions over the 25 years were summed to estimate the total VOC emissions during the 25-year period. This simulation used the meteorological conditions of 2010 for all simulation years. Total isoprene and monoterpene emissions over the 25-year period are estimated at 20,950 tons, increasing from 682 tons/year in 2010 to 957 tons/year in 25 years. These values will fluctuate annually based on local air temperatures, but assume constant 2010 meteorological conditions over the next 25 years.

All of the projected estimates of new trees required and their associated ecosystem services should be considered rough estimates due to the numerous assumptions needed to attain these estimates. The numbers provided here are first-order estimates and will likely change through time as mortality, growth, and establishment rates in Douglas County differ from projected rates. However, these estimates provide a broad estimate of potential needs and impacts of attaining future canopy goals.

WAKARUSA RIVER WATERSHED ANALYSIS

The Wakarusa River watershed (291,192 acres) in eastern Kansas was analyzed using the i-Tree Hydro model.[6] The i-Tree Hydro model (formerly known as UFORE-Hydro) simulates the stream flow hydrograph using hourly precipitation data, digital elevation data (Fig. 18), and land cover parameters. The model flow is calibrated against actual stream flow values recorded for a 1-year simulation period (see Appendix XI for details on methods). The flow of the Wakarusa watershed at the gauging station is largely controlled by the dam at Clinton Lake, and consequently this led to relatively low model calibration (Appendix XI); the effects illustrated by the model are likely more representative of flow changes in the river above the dam, not at the gauging station (i.e., the flow below the dam is based on water storage and release from the dam).

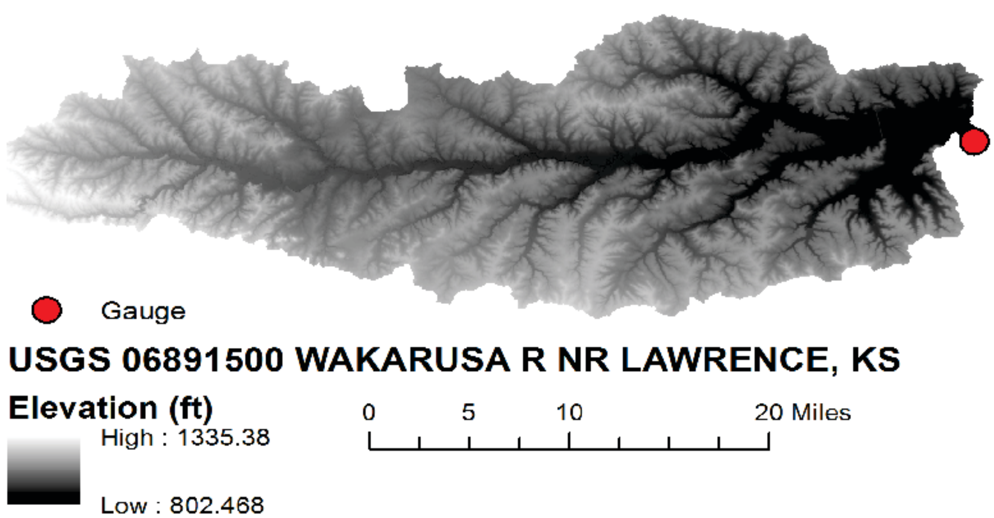


Figure 18.—Wakarusa River watershed.

Tree Cover Effects

Loss of current tree cover in the Wakarusa River watershed results in a 2.6 percent (88.9 million ft^3) increase in estimated total flow for the simulation period. Based on national average costs of storm water control of $0.008936/gallon[32], the current tree cover is valued at $5.9 million. Based on the simulation, increasing canopy cover from 25.2 percent to 30 percent would result in a reduction of overall flow by another 0.5 percent (15.8 million ft^3) during the year (Fig. 19). Increasing tree cover reduces flow mainly from pervious areas (Fig. 20).

Impervious Cover Effects

Removing all impervious cover reduces total flow by an average of 6.7 percent (234 million ft^3) during the simulation period. Increasing impervious cover from 7.3 percent to 10 percent of the watershed increases total flow another 2.8 percent (99 million ft^3) during the period (Fig. 21). Increasing impervious cover in the simulation reduces base flow and pervious runoff while significantly increasing flow from impervious surfaces (Fig. 22).

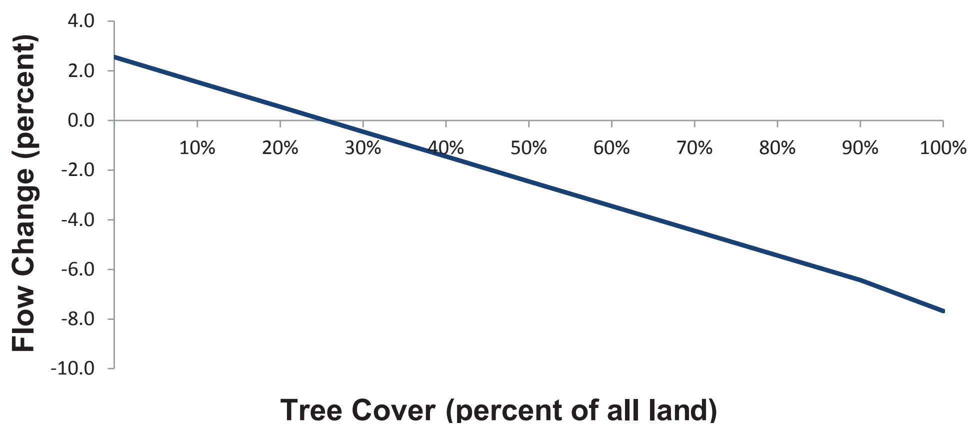


Figure 19.—Percent change in total flow with changes in canopy cover, Wakarusa River watershed.

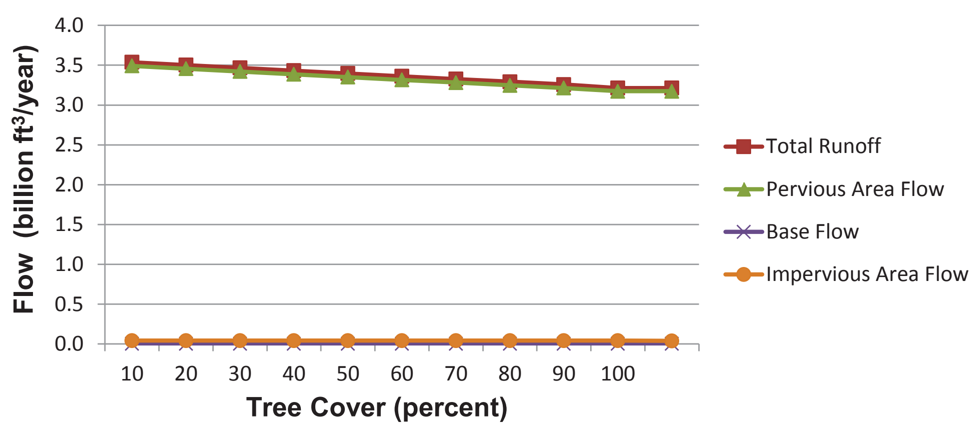


Figure 20.—Changes in total runoff and components of total runoff (pervious area flow, impervious area flow, and base flow) with increases in percent tree cover in the Wakarusa River watershed (impervious cover maintained at 7.3 percent).

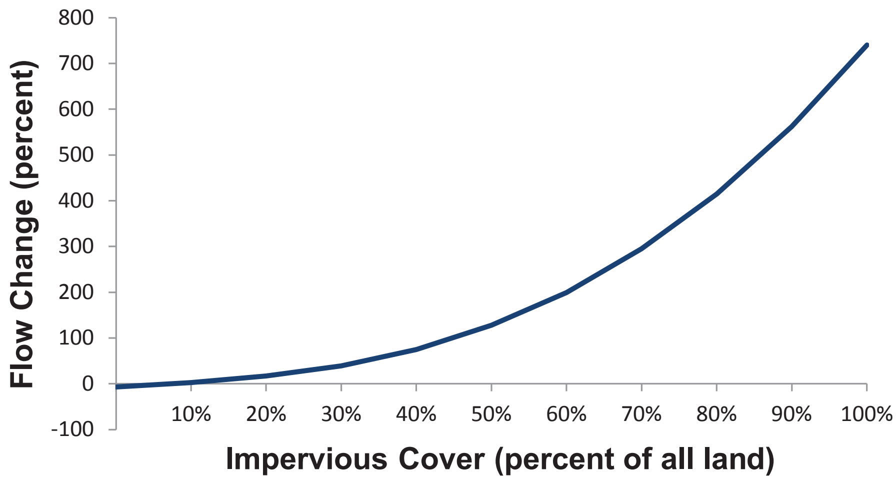


Figure 21.—Percent change in total flow with changes in percent impervious cover, Wakarusa River watershed.

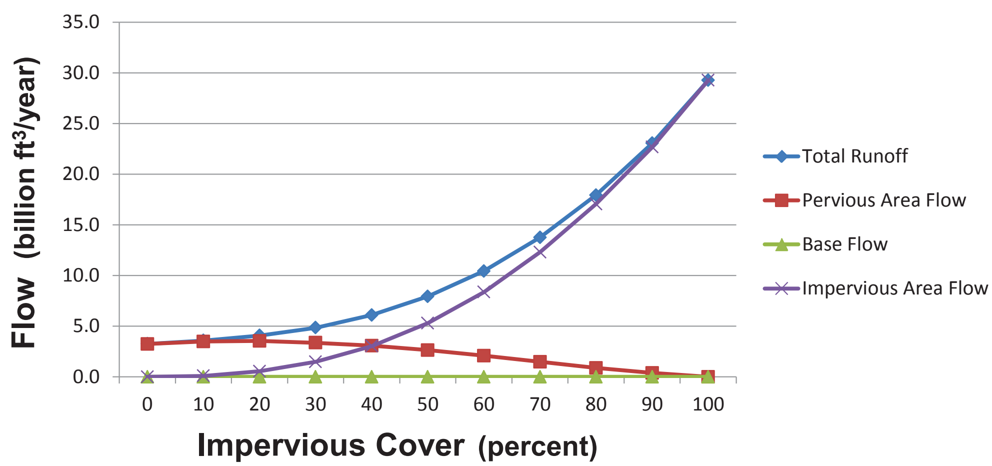


Figure 22.—Changes in total runoff and components of total runoff (pervious area runoff, impervious area runoff and base flow) with changes in percent impervious cover in the Wakarusa River watershed (Tree cover held at 25.2 percent).

Increasing tree cover will reduce stream flow, but the cover type most influencing stream flow is impervious surfaces. Under current cover conditions, the impact of increasing impervious cover on flow is 24 times greater relative to increasing tree cover. Increasing impervious cover by 1 percent averaged a 2.5 percent increase in stream flow, while increasing tree cover by 1 percent averaged only a 0.1 percent decrease in stream flow. The effects of manipulations of both tree and impervious cover are illustrated in Figures 23 (for total flow) and 24 (for changes in percent flow).

During the simulation period, 33.8 inches of rain were “recorded”. Since that amount is assumed to have fallen over the entire 291,192-acre watershed, a total of 35.7 billion ft^3 of rain fell on the watershed during the simulation period. The simulated flow in the Wakarusa River watershed for the base case scenario (no landscape change) was 3.48 billion ft^3. The total flow is made up of surface runoff and baseflow (water that travels underground to the stream). Runoff from pervious surfaces contributes 98.7 percent of total stream flow. Tree canopies intercepted about 10.7 percent of the total

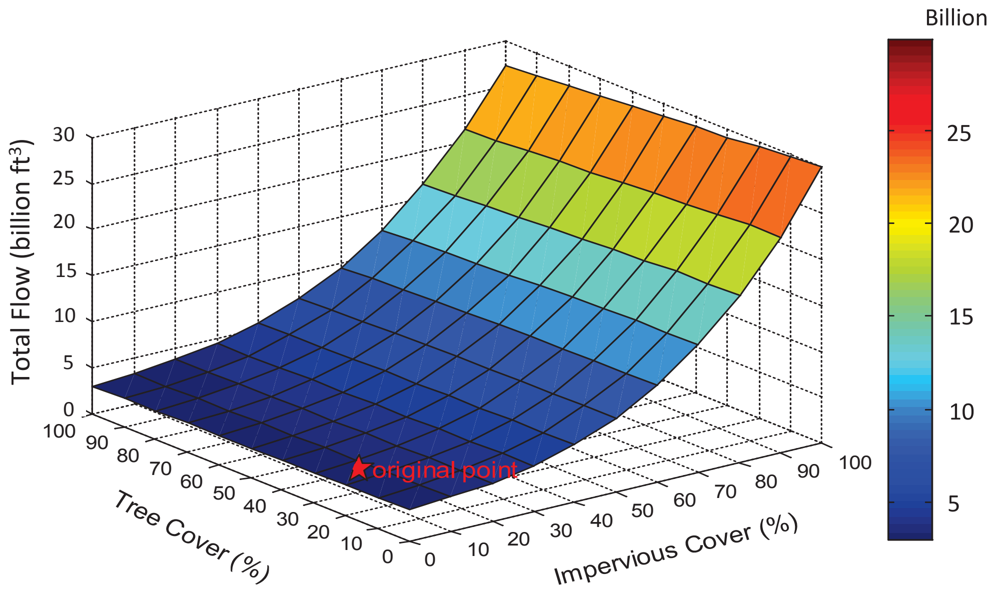


Figure 23.—Changes in total flow during simulation period based on changes in percent impervious and percent tree cover, Wakarusa River watershed. Red star indicates current conditions.

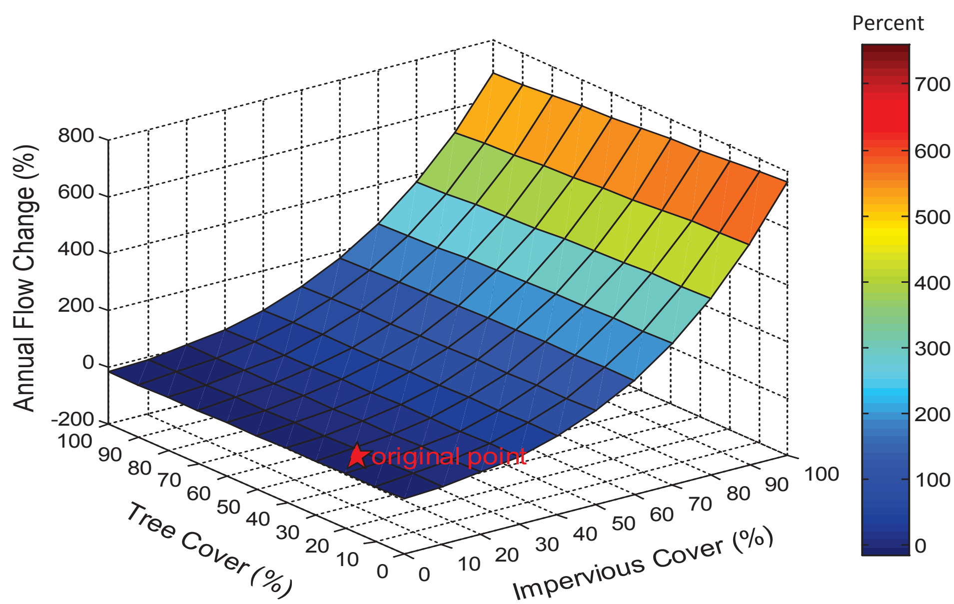


Figure 24.—Percent change in total flow during simulation period based on changes in percent impervious and percent tree cover, Wakarusa River watershed. Red star indicates current conditions.

rainfall, but since only 25.2 percent of the watershed is under tree cover, interception of total precipitation in the watershed by trees was only 2.7 percent (966 million ft^3). Areas of short vegetation, including shrubs, intercepted about 5.4 percent of the total rainfall, but since only 66.8 percent of the watershed is under short vegetation, interception of total precipitation in the watershed by short vegetation was only 3.6 percent (1.3 billion ft^3). About 83.9 percent of total precipitation is estimated to re-enter the atmosphere through evaporation or evapotranspiration before it enters the stream.

Table 10.—Estimated reduction in chemical constituents in Wakarusa River watershed from existing tree cover during simulation period based on median and mean pooled event mean concentration values

	Reduction (tons)	
Constituent	Median	Mean
Total suspended solids	83.3	119.8
Biochemical oxygen demand	17.6	21.5
Chemical oxygen demand	68.3	80.7
Total phosphorus	0.4	0.5
Soluble phosphorus	0.2	0.2
Total Kjeldhal nitrogen[a]	2.2	2.6
Nitrite and nitrate	0.8	1.0
Copper	0.02	0.02

[a] sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+)

Based on these changes in flow rates and national event mean concentration (EMC) values, the current tree cover is estimated to reduce total suspended solids during the simulation period by around 83 to 120 tons. Other chemical constituents are also reduced due to tree cover (Table 10).

CONCLUSION

Data from this report provide the basis for a better understanding of the urban and rural forest resource and the ecosystem services and values provided by this resource. Managers and citizens can use these data to help improve long-term management plans and policies to sustain a healthy tree and forest population and ecosystem services for future generations. Improved planning and management to sustain healthy tree populations can lead to improved environmental quality and quality of life for residents of Douglas County.

More information on trees in Douglas County can be found at: http://nrs.fs.fed.us/data/urban.

Arbor Day planting by local scouts along Burroughs Creek Trail in the City of Lawrence. Photo by Kim Bomberger, Kansas Forest Service, used with permission.

APPENDIX I. SPECIES IN DOUGLAS COUNTY

Table 11.—Tree species sampled in the regional forest, Douglas County, 2012

Genus	Species	Common Name	Number of Trees	Pop %	Leaf Area %	IV[a]	Med Dbh (in)	Ave Dbh (in)	Basal Area (ft^2)	Value ($ millions)
Acer	*negundo*	boxelder	6,160	0.0	0.0	0.0	1.5	1.5	134	0.0
Acer	*rubrum*	red maple	3,620	0.0	0.0	0.0	3.5	3.5	316	1.0
Acer	*saccharinum*	silver maple	117,340	0.8	3.4	4.2	14.7	15.6	237,114	144.9
Acer	*saccharum*	sugar maple	32,800	0.2	0.7	0.9	10.6	10.7	22,593	62.6
Aesculus	*glabra*	Ohio buckeye	3,080	0.0	0.0	0.0	2.5	2.5	151	0.1
Asimina	*triloba*	pawpaw	80,120	0.6	0.1	0.7	1.6	1.8	2,387	1.1
Carya	*cordiformis*	bitternut hickory	124,160	0.9	0.3	1.2	2.8	4.9	33,293	23.8
Carya	*ovata*	shagbark hickory	470,960	3.3	2.7	6.0	2.0	4.8	121,686	156.2
Celtis	*occidentalis*	northern hackberry	2,324,120	16.4	17.1	33.5	4.2	5.2	730,959	972.8
Cercis	*canadensis*	eastern redbud	323,600	2.3	1.4	3.7	3.6	5.1	89,979	125.3
Elaeagnus	*angustifolia*	Russian olive	3,080	0.0	0.0	0.0	2.5	2.5	151	0.0
Fraxinus	*americana*	white ash	36,980	0.3	0.0	0.3	1.7	1.8	1,143	0.7
Fraxinus	*pennsylvanica*	green ash	263,070	1.9	2.7	4.6	6.8	10.4	352,350	600.1
Gleditsia	*triacanthos*	honeylocust	843,740	6.0	3.6	9.6	8.2	8.8	561,140	610.4
Gymnocladus	*dioicus*	Kentucky coffeetree	17,170	0.1	0.0	0.1	1.5	1.5	375	0.7
Juglans	nigra	black walnut	701,860	5.0	14.4	19.4	10.1	10.3	595,109	473.1
Juniperus	*species*	juniper spp	7,250	0.1	0.0	0.1	6.0	6.0	1,680	3.5
Juniperus	*virginiana*	eastern redcedar	1,944,450	13.7	9.7	23.4	2.9	3.9	305,566	346.1
Maclura	*pomifera*	Osage-orange	1,882,360	13.3	16.7	30.0	4.9	8.1	1,388,494	1,188.2
Malus	*tschonoskii*	crabapple	3,620	0.0	0.0	0.0	8.5	8.5	1,601	4.2
Morus	*alba*	white mulberry	56,010	0.4	0.4	0.8	3.5	4.3	8,992	5.2
Morus	*rubra*	red mulberry	519,320	3.7	2.7	6.4	3.9	5.8	181,707	165.7
Ostrya	*virginiana*	eastern hophornbeam	46,230	0.3	0.2	0.5	3.3	3.2	3,614	1.5
Other	*species*	unknown species	3,080	0.0	0.0	0.0	1.5	1.5	67	0.0
Platanus	*occidentalis*	American sycamore	64,510	0.5	3.2	3.7	5.0	10.9	62,932	101.6
Populus	*deltoides*	eastern cottonwood	90,600	0.6	0.1	0.7	1.5	1.9	4,750	1.9
Prunus	*americana*	American plum	106,110	0.7	0.0	0.7	1.5	1.5	2,315	1.9
Prunus	*serotina*	black cherry	317,240	2.2	1.9	4.1	4.4	5.1	71,195	49.0
Quercus	*alba*	white oak	18,490	0.1	0.1	0.2	10.0	10.0	13,766	6.2
Quercus	*macrocarpa*	bur oak	128,680	0.9	1.3	2.2	4.1	9.0	129,400	158.2
Quercus	*muehlenbergii*	chinkapin oak	215,030	1.5	2.6	4.1	9.7	10.0	186,261	199.4
Quercus	*palustris*	pin oak	32,800	0.2	1.1	1.3	22.6	23.1	99,667	201.3
Quercus	*rubra*	northern red oak	135,710	1.0	1.5	2.5	14.0	10.8	133,969	153.9
Salix	*interior*	sandbar willow	145,870	1.0	0.1	1.1	2.5	2.5	7,479	2.5
Salix	*nigra*	black willow	36,980	0.3	0.0	0.3	1.8	3.1	3,681	1.3
Tilia	americana	American basswood	33,900	0.2	0.2	0.4	3.5	5.0	9,833	4.9
Ulmus	*americana*	American elm	2,854,730	20.2	9.6	29.8	3.0	4.5	637,222	348.1
Ulmus	*pumila*	Siberian elm	166,550	1.2	1.9	3.1	4.3	8.6	166,154	85.9
Ulmus	*rubra*	slippery elm	3,080	0.0	0.1	0.1	4.5	4.5	420	0.2

[a] IV = importance value (% population + % leaf area)

Table 12.—Shrub species[a] by land use, Douglas County, 2012

Land Use[b]	Genus	Species	Common Name	Per Unit Area: Leaf Area (ft²/ac)	Per Unit Area: Leaf Biomass (lb/ac)	County Total: Leaf Area (ac)	County Total: Leaf Biomass (tons)
Agriculture	*Symphoricarpos*	*orbiculatus*	coralberry	6,728.64	76.99	32,891.48	8,194.54
	Cornus	*drummondii*	roughleaf dogwood	3,510.22	41.92	17,158.62	4,462.62
	Juniperus	*virginiana*	eastern redcedar	1,193.61	67.90	5,834.03	7,227.80
	Rubus	*occidentalis*	black raspberry	1,015.80	7.76	4,964.24	826.29
	Ribes	*missouriense*	Missouri gooseberry	286.46	4.39	1,401.06	467.61
	Lonicera	*maackii*	amur honeysuckle	276.74	2.79	1,351.64	297.19
	Rubus	*ostryifolius*	highbush blackberry	213.36	1.63	1,042.76	173.53
	Prunus	*americana*	American plum	200.86	3.19	980.99	338.82
	Zanthoxylum	*americanum*	common prickly ash	112.08	1.72	548.56	182.95
	Maclura	*pomifera*	Osage-orange	109.38	2.25	533.74	239.70
	Ulmus	*americana*	American elm	89.56	1.34	437.37	141.97
	Rosa	*multiflora*	multiflora rose	55.02	0.85	269.34	89.84
	Gleditsia	*triacanthos*	honeylocust	17.60	0.37	86.49	40.16
	Celtis	*occidentalis*	northern hackberry	15.55	0.17	76.60	17.64
	Morus	*rubra*	red mulberry	9.54	0.20	46.95	20.61
	Carya	*cordiformis*	bitternut hickory	3.01	0.04	14.83	4.13
Total, Agriculture				13,837.43	213.51	67,638.68	22,725.38
Commercial	*Symphoricarpos*	*orbiculatus*	coralberry	2,433.92	27.85	242.16	60.52
	Cornus	*drummondii*	roughleaf dogwood	1,997.31	23.86	200.15	51.85
	Morus	*rubra*	red mulberry	1,452.89	29.56	145.79	64.22
	Juniperus	*virginiana*	eastern redcedar	744.89	42.38	74.13	92.09
	Lonicera	*tatarica*	Tartarian honeysuckle	333.50	3.36	32.12	7.32
	Syringa	*vulgaris*	common lilac	193.24	3.82	19.77	8.30
	Maclura	*pomifera*	Osage-orange	107.38	2.21	9.88	4.80
	Gleditsia	*triacanthos*	honeylocust	16.38	0.35	2.47	0.76
Total, Commercial				7,279.51	133.38	726.47	289.87
Park/Open	*Cornus*	*drummondii*	roughleaf dogwood	13,405.61	160.12	8,767.11	2,280.26
	Carya	*ovata*	shagbark hickory	2,830.76	42.46	1,850.78	604.68
	Morus	*rubra*	red mulberry	1,311.92	26.69	857.44	380.05
	Quercus	*muehlenbergii*	chinkapin oak	1,309.18	26.46	857.44	376.84
	Aesculus	*glabra*	Ohio buckeye	593.56	8.90	387.95	126.69
Total, Park/Open				19,451.08	264.62	12,720.71	3,768.50
Residential	*Cornus*	*drummondii*	roughleaf dogwood	9,009.62	107.62	6,637.11	1,726.27
	Rhus	*glabra*	smooth sumac	1,255.47	14.18	924.15	227.44
	Symphoricarpos	*orbiculatus*	coralberry	227.69	2.61	168.03	41.79
	Ribes	*missouriense*	Missouri gooseberry	154.86	2.37	113.67	38.10
Total, Residential				10,647.64	126.77	7,842.95	2,033.61

Table 12.—continued

Land Use[b]	Genus	Species	Common Name	Per Unit Area: Leaf Area (ft²/ac)	Per Unit Area: Leaf Biomass (lb/ac)	County Total: Leaf Area (ac)	County Total: Leaf Biomass (tons)
Vacant	*Symphoricarpos*	*orbiculatus*	coralberry	48,747.44	557.78	10,346.08	2,577.64
	Cornus	*drummondii*	roughleaf dogwood	31,816.97	380.04	6,753.24	1,756.25
	Juniperus	*virginiana*	eastern redcedar	10,409.84	592.24	2,209.07	2,736.95
	Ribes	*missouriense*	Missouri gooseberry	7,570.45	116.10	1,606.15	536.54
	Asimina	*triloba*	pawpaw	1,681.67	57.78	355.82	267.03
	Rubus	*occidentalis*	black raspberry	1,326.56	10.14	281.69	46.85
	Rosa	*multiflora*	multiflora rose	1,207.42	18.51	256.98	85.57
	Carya	*ovata*	shagbark hickory	931.51	13.97	197.68	64.57
	Lonicera	*maackii*	amur honeysuckle	799.21	8.07	170.50	37.27
	Cercis	*canadensis*	eastern redbud	509.36	6.68	108.72	30.88
	Rubus	*ostryifolius*	highbush blackberry	357.94	2.74	76.60	12.64
	Zanthoxylum	*americanum*	common prickly ash	331.45	5.09	69.19	23.49
	Aesculus	glabra	Ohio buckeye	287.94	4.32	61.78	19.95
	Fraxinus	*americana*	white ash	245.55	2.86	51.89	13.20
	Salix	*nigra*	black willow	231.48	3.01	49.42	13.89
	Juglans	*nigra*	black walnut	225.04	3.69	46.95	17.07
	Quercus	*muehlenbergii*	chinkapin oak	203.95	4.12	44.48	19.05
	Ulmus	*americana*	American elm	195.76	2.92	42.01	13.48
	Rhus	*glabra*	smooth sumac	177.42	2.01	37.07	9.26
	Quercus	*rubra*	northern red oak	173.50	2.83	37.07	13.09
	Morus	*rubra*	red mulberry	172.50	3.51	37.07	16.22
	Gleditsia	*triacanthos*	honeylocust	148.54	3.19	32.12	14.72
	Celtis	*occidentalis*	northern hackberry	36.46	0.39	7.41	1.80
	Fraxinus	*pennsylvanica*	green ash	25.27	0.34	4.94	1.55
Total, Vacant				107,813.16	1,802.29	22,881.46	8,328.93
Douglas County Total				16,324.32	249.06	111,812.75	37,146.28

[a] Shrubs are defined as woody plants with stem diameter at 4.5 feet less than 1 inch.
[b] Water land use did not have any shrubs.

APPENDIX II. TREE SPECIES DISTRIBUTION

Species distributions for each land use are illustrated (Figs. 25-32) for up to 20 most common species in each land use category. More detailed information on species by land use can be found at: http://nrs.fs.fed.us/data/urban.

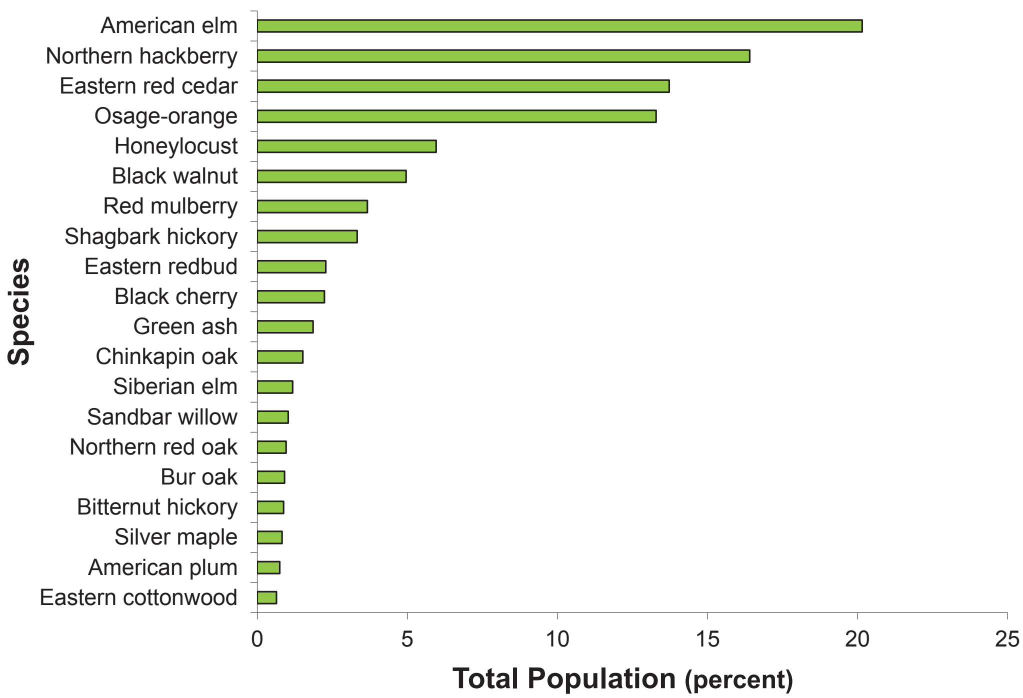


Figure 25.—The 20 most common tree species as a percent of the total tree population, Douglas County, 2012.

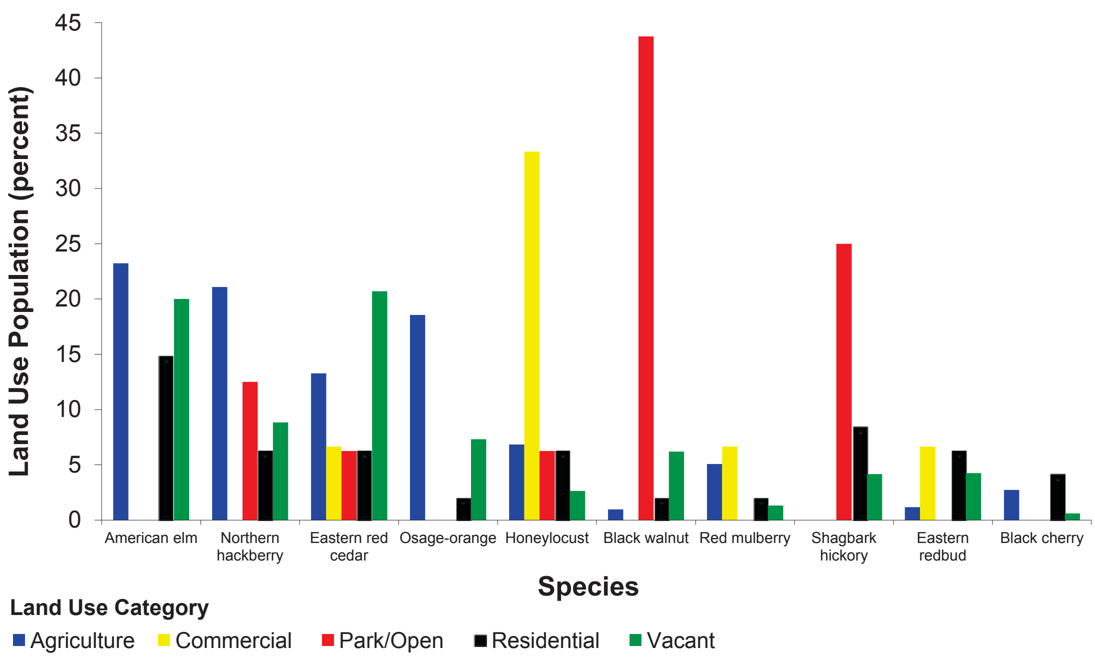


Figure 26.—The percent land use population occupied by the 10 most common tree species, Douglas County, 2012. For example, American elm comprises 23.2 percent of the tree population on agriculture land.

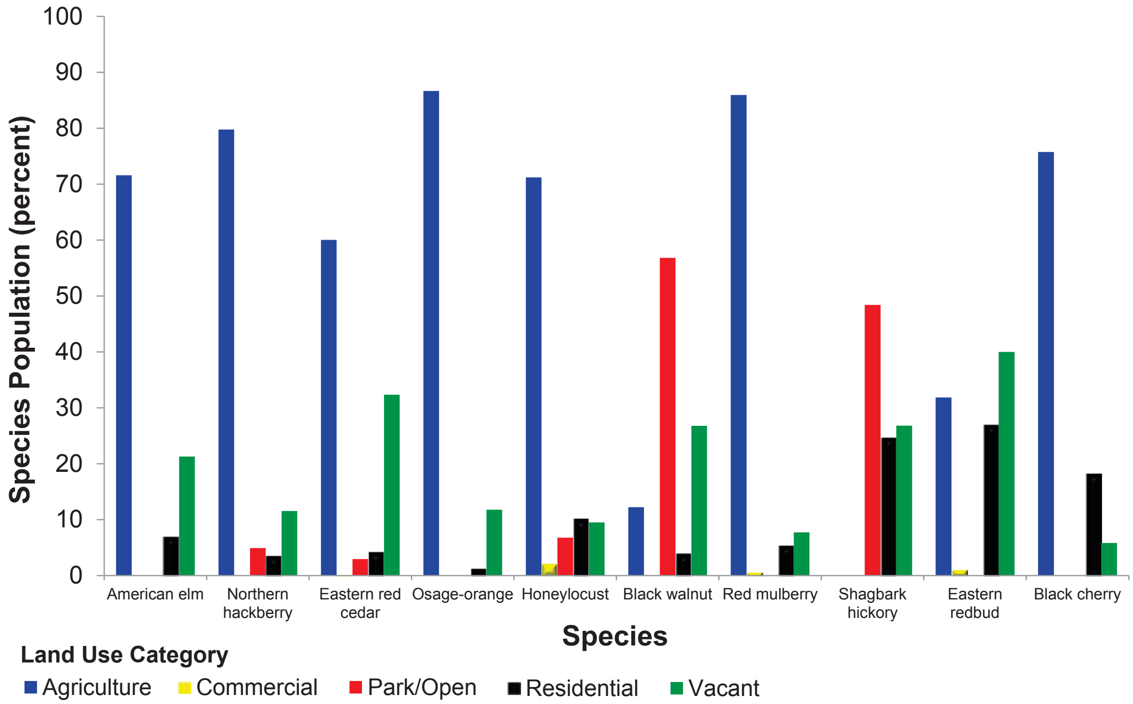


Figure 27.—The percent species population occupied by the 10 most common tree species, Douglas County, 2012. For example, 71.6 percent of American elm are found on agriculture land.

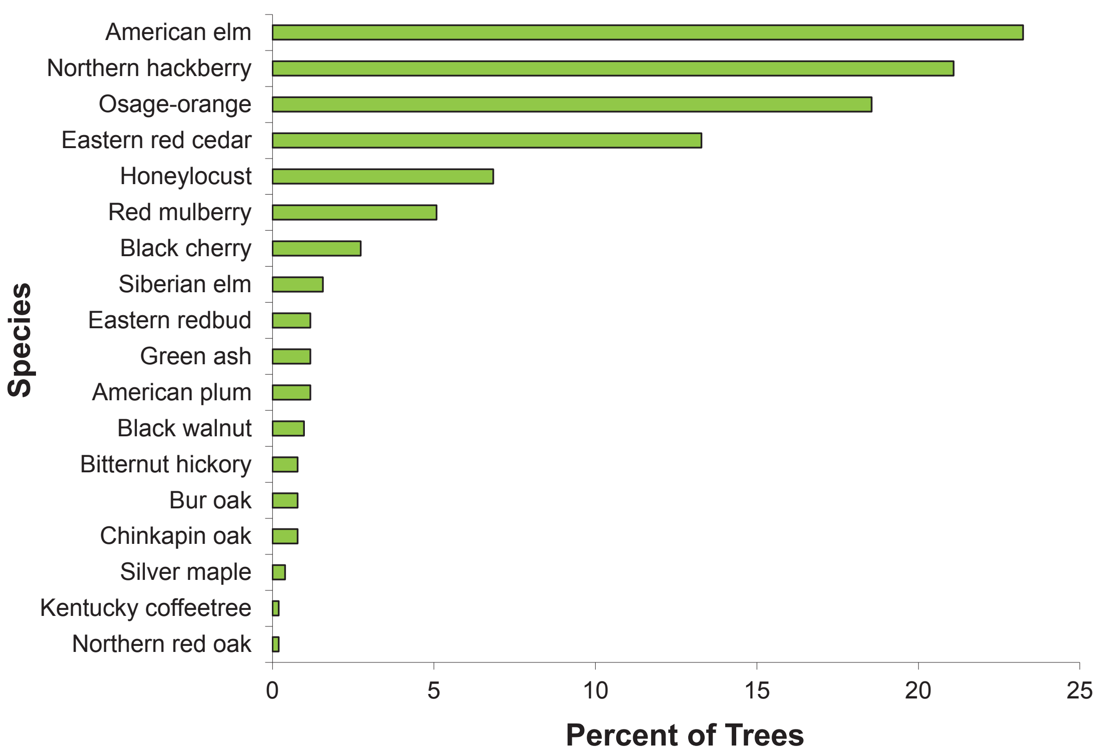


Figure 28.—Percent of trees in agriculture land use category, Douglas County, 2012.

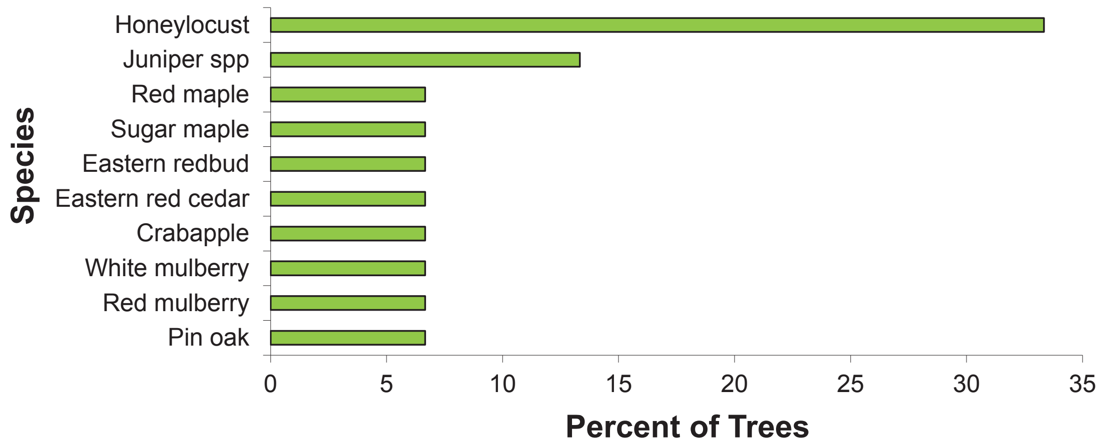


Figure 29.—Percent of trees in commercial land use category, Douglas County, 2012.

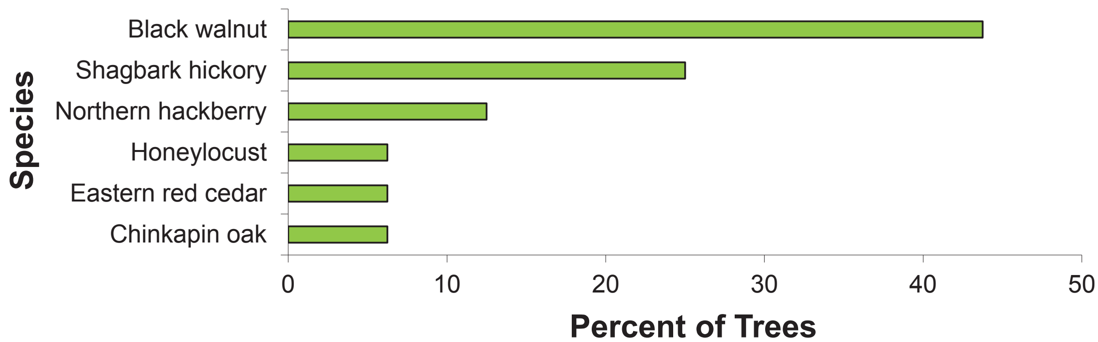


Figure 30.—Percent of trees in park/open land use category, Douglas County, 2012.

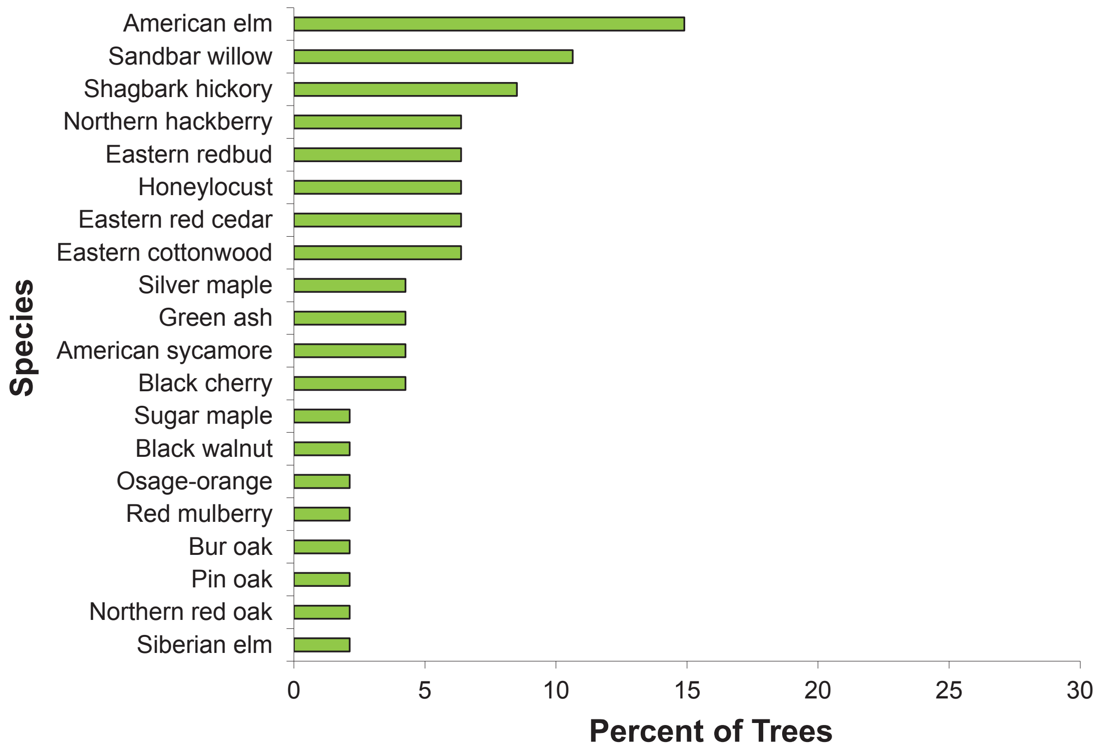


Figure 31.—Percent of trees in residential land use category, Douglas County, 2012.

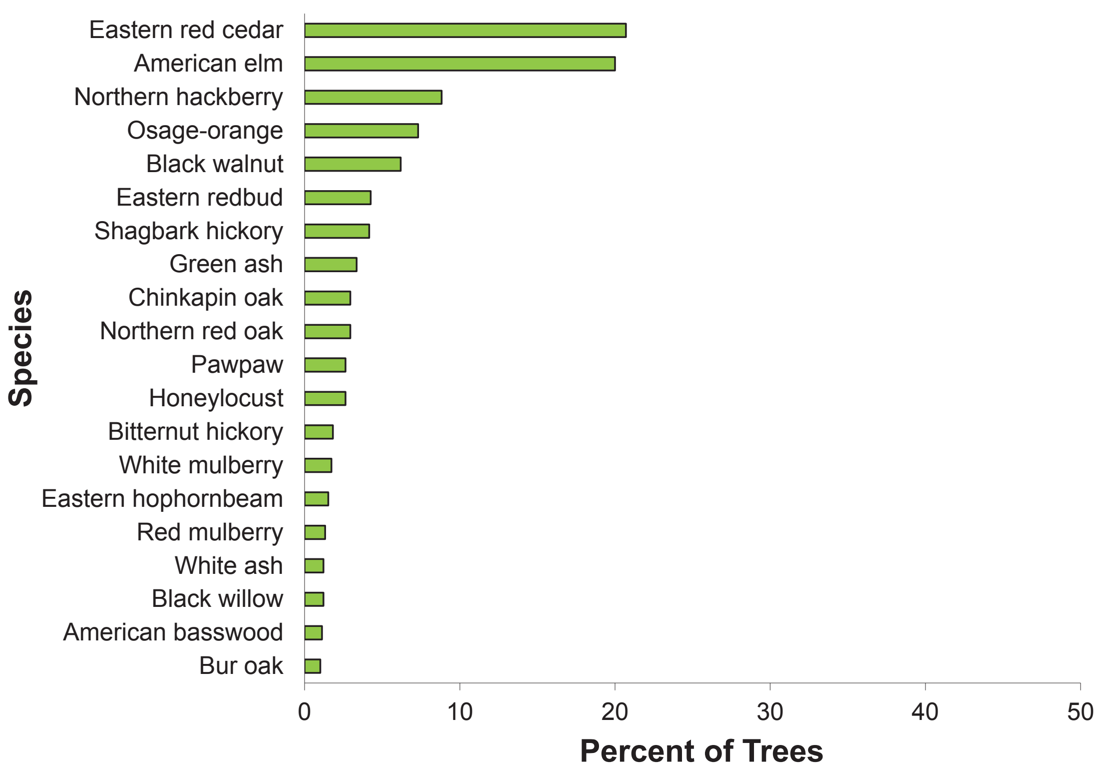


Figure 32.—Percent of trees in vacant category of land use category, Douglas County, 2012.

APPENDIX III. TREE STRUCTURE AND FUNCTIONS BY LAND USE

This appendix provides details of various structural and functional values for each species by land use class and overall values for each land use class. More information can be found at: http://nrs.fs.fed.us/data/urban.

Table 13.—Tree structure and functions by land use, Douglas County, 2012

Common Name	Number of Trees	Carbon Storage (tons)	Carbon Sequestration (tons/year)	Net Carbon Sequestration (tons/year)	Leaf Area (acres)	Leaf Biomass (tons)	Structural Value ($US)
-----Agriculture-----							
American elm	2,043,422	93,725	4,916	2,768	22,597	7,331	267,763,181
Northern hackberry	1,854,534	182,189	9,020	8,708	49,344	11,453	809,088,248
Osage-orange	1,631,303	367,163	14,367	13,232	52,266	23,438	1,006,907,390
Eastern redcedar	1,167,670	22,594	1,633	1,597	18,689	23,158	178,718,001
Honeylocust	601,006	72,302	4,260	3,880	6,716	3,137	275,469,382
Red mulberry	446,462	46,139	2,516	2,348	9,221	4,085	162,621,043
Black cherry	240,403	16,301	1,484	1,448	6,811	2,356	46,548,331
Siberian elm	137,373	3,818	420	413	1,344	408	12,529,091
Eastern redbud	103,030	2,067	291	286	765	219	15,355,265
Green ash	103,030	4,622	327	316	2,610	759	38,101,177
American plum	103,030	179	99	98	157	54	1,912,918
Black walnut	85,858	77,685	2,557	2,503	19,489	6,967	162,893,096
Bitternut hickory	68,686	5,035	406	402	337	94	17,458,665
Kentucky coffeetree	17,172	29	16	16	34	11	686,865
Northern red oak	17,172	9,961	463	455	1,347	479	41,023,412
Total	8,791,866	989,116	46,105	41,739	203,076	88,593	3,334,144,427
-----Commercial-----							
Honeylocust	18,115	2,635	224	213	265	124	11,236,437
Juniper spp	7,246	191	32	31	40	50	3,519,031
Red maple	3,623	61	22	22	33	10	988,332
Sugar maple	3,623	1,053	86	82	398	107	8,456,213
Eastern redbud	3,623	238	38	37	27	8	3,385,275
Eastern redcedar	3,623	800	43	40	201	249	6,740,515
Crabapple	3,623	334	47	45	113	44	4,229,126
White mulberry	3, 623	83	25	24	75	24	801,370
Red mulberry	3,623	5	4	4	8	4	101,999
Pin oak	3,623	6,880	283	256	694	280	27,655,549
Total	54,344	12,281	803	754	1,856	899	67,113,846
-----Park/Open-----							
Black walnut	398,846	63,636	3,541	2,265	21,557	7,707	259,184,242
Shagbark hickory	227,912	26,445	2,117	2,054	8,400	2,744	148,243,054
Northern hackberry	113,956	7,580	812	794	4,665	1,083	85,255,860
Honeylocust	56,978	17,531	1,016	975	2,712	1,267	106,497,731
Eastern redcedar	56,978	7,189	341	324	4,321	5,354	86,131,204
Chinkapin oak	56,978	49	37	36	74	32	3,328,940
Total	911,648	122,431	7,864	6,448	41,729	18,187	688,641,032

continued

Table 13.—continued

Common Name	Number of Trees	Carbon Storage (tons)	Carbon Sequestration (tons/year)	Net Carbon Sequestration (tons/year)	Leaf Area (acres)	Leaf Biomass (tons)	Structural Value ($US)
---Residential---							
American elm	204,215	2,688	666	653	2,260	733	30,125,011
Sandbar willow	145,868	817	289	241	364	103	2,456,978
Shagbark hickory	116,695	167	143	141	460	150	3,255,778
Eastern redbud	87,521	17,073	1,338	1,268	3,163	903	102,184,443
Northern hackberry	87,521	1,808	548	539	2,186	507	24,120,629
Honeylocust	87,521	46,569	2,499	2,464	2,296	1,072	188,905,309
Eastern redcedar	87,521	504	103	100	577	715	5,718,690
Eastern cottonwood	87,521	155	68	52	102	33	875,209
Silver maple	58,347	49,747	1,956	1,764	9,938	2,333	126,362,056
Green ash	58,347	45,093	1,435	1,262	5,285	1,538	543,886,102
American sycamore	58,347	19,545	1,243	1,165	11,234	2,428	100,618,637
Black cherry	58,347	690	141	32	81	28	1,935,524
Sugar maple	29,174	6,436	666	639	2,195	590	54,132,190
Black walnut	29,174	543	176	173	540	193	3,851,947
Osage-orange	29,174	40,881	1,718	1,689	2,921	1,310	140,939,365
Red mulberry	29,174	30	30	30	105	47	1,232,025
Bur oak	29,174	162	0	-45	0	0	0
Pin oak	29,174	32,334	1,579	1,452	3,230	1,304	173,664,116
Northern red oak	29,174	14,241	930	873	2,511	892	91,407,525
Siberian elm	29,174	45,207	1,666	1,238	5,489	1,668	73,405,479
Total	1,371,161	324,690	17,195	15,731	54,935	16,547	1,669,077,013
---Vacant---							
Eastern redcedar	628,660	23,588	909	876	11,744	14,553	68,801,291
American elm	607,088	35,021	1,469	1,144	10,143	3,291	50,215,874
Northern hackberry	268,105	24,506	1,146	1,059	6,300	1,462	54,372,956
Osage-orange	221,880	28,378	1,024	870	5,588	2,506	40,381,096
Black walnut	187,982	45,162	1,322	1,047	10,873	3,887	47,174,487
Eastern redbud	129,430	1,829	184	168	1,266	362	4,384,641
Shagbark hickory	126,348	1,954	206	203	997	326	4,702,297
Green ash	101,695	6,941	300	278	1,854	539	18,066,607
Chinkapin oak	89,368	37,120	1,111	943	3,653	1,608	56,223,765
Northern red oak	89,368	23,717	396	-85	1,722	612	21,481,070
Pawpaw	80,123	256	49	45	303	227	1,058,265
Honeylocust	80,123	24,868	620	450	1,133	530	28,323,960
Bitternut hickory	55,470	4,540	224	221	837	235	6,361,669
White mulberry	52,388	1,950	142	138	1,230	401	4,400,071
Eastern hophornbeam	46,225	483	71	70	686	200	1,510,036
Red mulberry	40,062	1,424	61	40	417	185	1,708,613
White ash	36,980	120	31	30	161	41	716,547

continued

Table 13.—continued

Common Name	Number of Trees	Carbon Storage (tons)	Carbon Sequestration (tons/year)	Net Carbon Sequestration (tons/year)	Leaf Area (acres)	Leaf Biomass (tons)	Structural Value ($US)
Black willow	36,980	723	35	20	77	22	1,309,541
American basswood	33,898	1,991	79	75	901	117	4,939,245
Bur oak	30,817	9,172	274	267	956	421	16,678,312
Silver maple	24,653	6,166	97	37	677	159	2,748,680
Black cherry	18,490	691	20	9	71	25	550,931
White oak	18,490	4,929	118	-8	378	123	6,205,963
Boxelder	6,163	13	2	2	8	3	14,638
American sycamore	6,163	407	27	27	500	108	1,019,265
Ohio buckeye	3,082	19	4	4	20	7	62,394
Russian olive	3,082	12	3	3	27	9	43,984
Unknown species	3,082	5	2	2	18	6	41,211
Eastern cottonwood	3,082	685	29	29	154	50	976,520
American plum	3,082	5	2	2	1	0	25,270
Slippery elm	3,082	76	8	8	320	64	161,410
Total	3,035,442	286,752	9,966	7,973	63,018	32,077	444,660,609
------Water------							
Total	0	0	0	0	0	0	0
Douglas County Total	14,164,460	1,735,269	81,933	72,645	364,613	156,303	6,203,636,926

Table 14.—Summary of tree structure and functions by land use, Douglas County, 2012

	Trees		Carbon Storage (tons)		Carbon Seq (tons/yr)		Net Carbon Seq (tons/yr)		Leaf Area (acres)		Leaf Biomass (tons)		Tree Value ($US billion)	
Land Use	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Agriculture	8,791,866	62.1	989,116	57.0	46,105	56.3	41,739	57.5	203,076	55.7	88,593	56.7	3.33	53.7
Commercial	54,344	0.4	12,281	0.7	803	1.0	754	1.0	1,856	0.5	899	0.6	0.07	1.1
Park/Open	911,648	6.4	122,431	7.1	7,864	9.6	6,448	8.9	41,729	11.4	18,187	11.6	0.69	11.1
Residential	1,371,161	9.7	324,690	18.7	17,195	21.0	15,731	21.7	54,935	15.1	16,547	10.6	1.67	26.9
Vacant	3,035,442	21.4	286,752	16.5	9,966	12.2	7,973	11.0	63,018	17.3	32,077	20.5	0.44	7.2
Water	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0.00	0.0
Total	14,164,460		1,735,269		81,933		72,645		364,613		156,303		6.20	

APPENDIX IV. POPULATION INFORMATION BY STEM DIAMETER CLASS

This appendix details how trees in each diameter class are distributed among land uses (Fig. 33); whether the most common species in the diameter classes less than 3 inches or greater than 18 inches are gaining or losing prominence (Figs. 34 and 35); and how trees less than 3 inches in diameter are distributed by land use (Fig. 36).

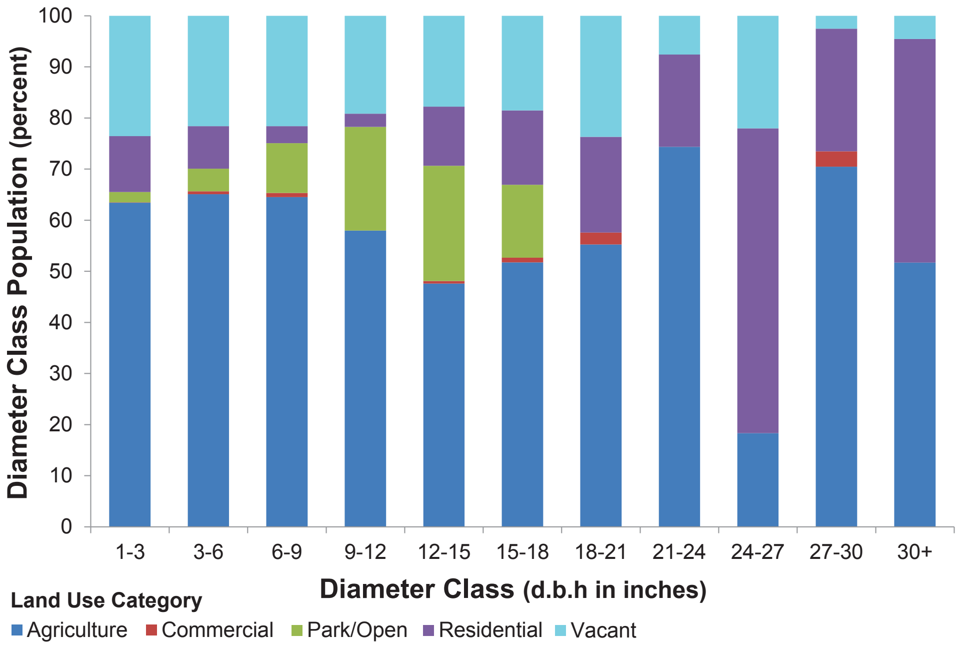


Figure 33.—Percent of tree population by diameter class and land use category, Douglas County, 2012. For example, of the trees that have diameters between 27 and 30 inches, 70 percent are found in agriculture land uses and 24 percent are found in residential areas.

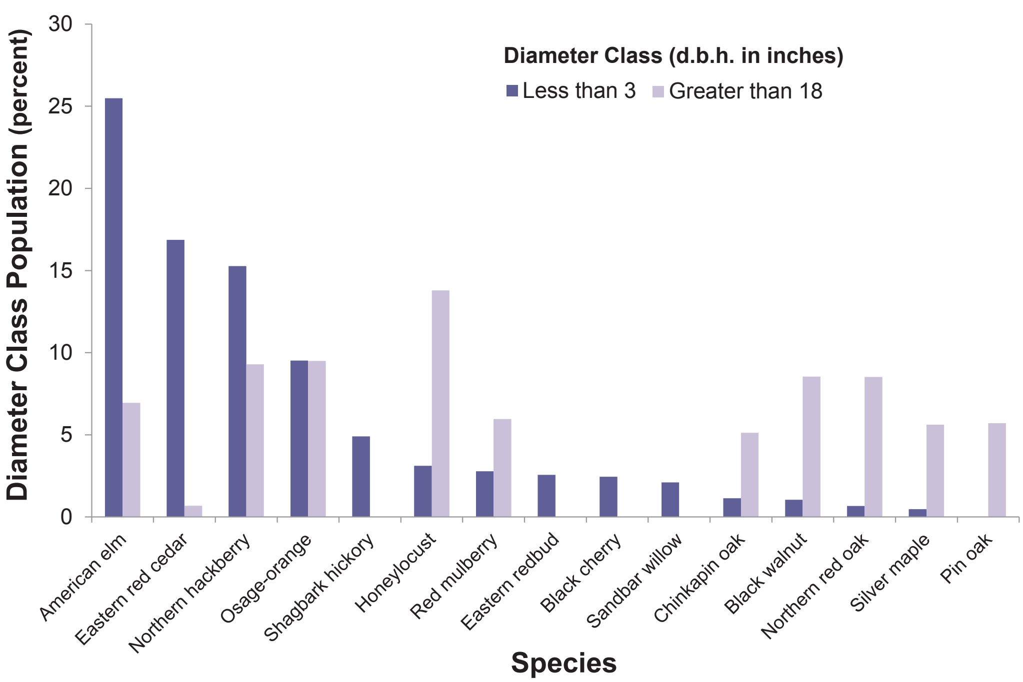


Figure 34.—Percent of smallest and largest diameter classes (less than 3 inches and greater than 18 inches) by species for the most common tree species in those classes, Douglas County, 2012.

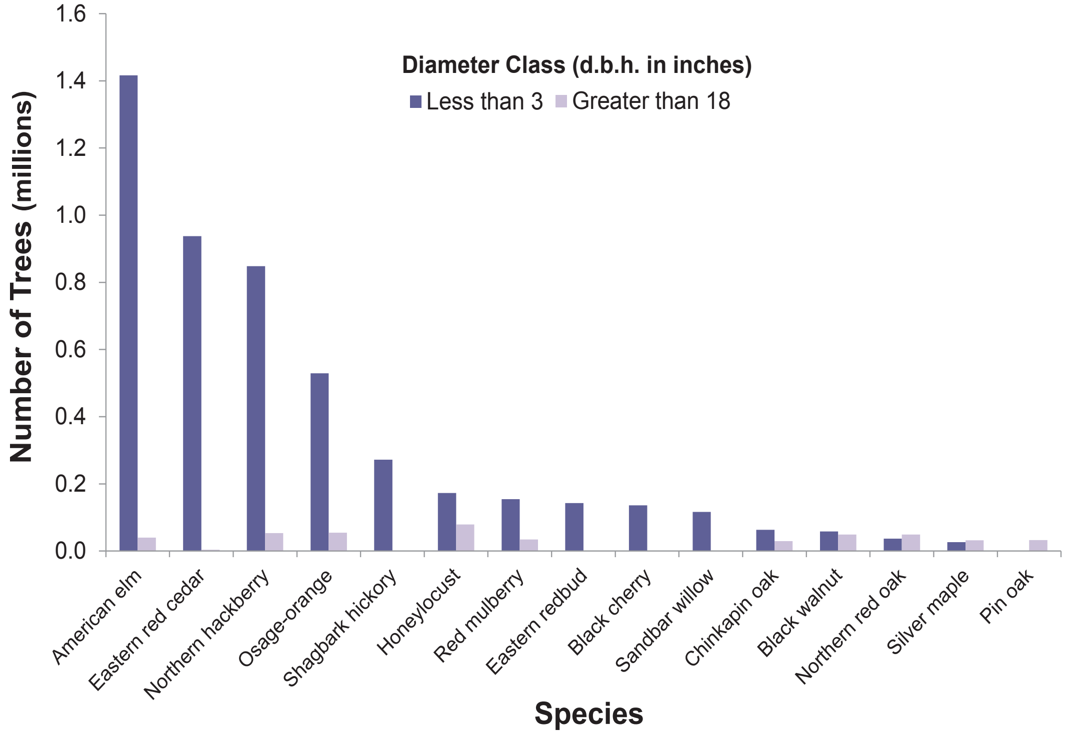


Figure 35.—Number of trees in smallest and largest diameter classes for the most common tree species in those classes, Douglas County, 2012.

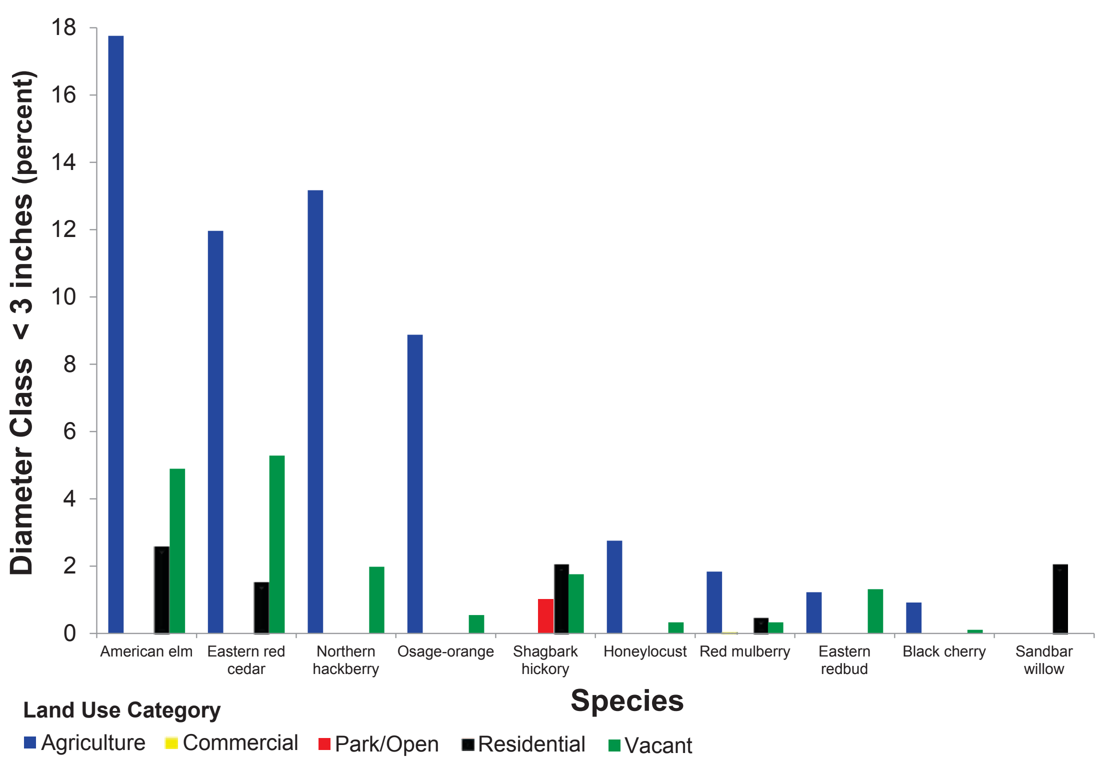


Figure 36.—Percent of trees in less than 3 inch diameter class for the most common species in that diameter class, by land use category, Douglas County, 2012. For example, 17.8 percent of the trees less than 3 inches in diameter are American elm within agriculture land uses.

APPENDIX V. EFFECTS OF POLLUTION REMOVAL ON LOCAL HEALTH

Air pollution is a common problem in many urban areas and can have far-reaching effects, impacting human health, ecosystem health, and landscape materials. To calculate the effects of pollution removal on local health in Douglas County, we used the U.S. Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program (BenMAP)[25] along with 2010 population statistics from the U.S. Census Bureau.[33] The model estimates the incidence of adverse health effects and associated monetary value that result from changes in pollution concentrations due to pollution removal by trees and shrubs.

The number of adverse health effects and associated economic value is calculated for ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter <2.5 microns ($PM_{2.5}$) in Douglas County (Table 15 and 16).

Table 15.—Number of incidences of avoided health effects from pollutants, Douglas County, 2012[a]

Health Effect	NO_2	SO_2	O_3	$PM_{2.5}$
----------Trees only----------				
Hospital admissions	2.1	0.6	1.0	
Emergency room visits	1.0	0.5	0.5	0.4
Asthma exacerbation	834.3	84.9		284.8
Acute respiratory symptoms	54.9	9.2	1181.2	525.3
Mortality			0.4	0.8
School loss days			295.8	
Acute bronchitis				0.6
Acute myocardial infarction				0.4
Chronic bronchitis				0.3
Hospital admissions (cardiovascular)				0.1
Hospital admissions (respiratory)				0.1
Lower respiratory symptoms				7.3
Upper respiratory symptoms				5.8
Work loss days				91.0
----------Shrubs only----------				
Hospital admissions	0.9	0.3	0.5	
Emergency room visits	0.4	0.2	0.3	0.1
Asthma exacerbation	354.8	39.4		85.2
Acute respiratory symptoms	23.3	4.2	543.8	157.1
Mortality			0.2	0.2
School loss days			136.0	
Acute bronchitis				0.2
Acute myocardial infarction				0.1
Chronic bronchitis				0.1
Hospital admissions (cardiovascular)				0.03
Hospital admissions (respiratory)				0.03
Lower respiratory symptoms				2.2
Upper respiratory symptoms				1.7
Work loss days				27.2

[a] The same health effects are not analyzed for each pollutant. Blank cells indicate that the incidence is not estimated for that pollutant and health effect.

Table 16.—Associated value ($) of avoided health effects from pollutants, Douglas County, 2012[a]

Health Effect	NO_2	SO_2	O_3	$PM_{2.5}$
---Trees, only---				
Hospital admissions	73,300	17,200	24,800	
Emergency room visits	400	200	200	200
Asthma exacerbation	73,700	6,700		23,200
Acute respiratory symptoms	1,700	300	101,000	51,500
Mortality			2,823,000	6,314,800
School loss days			29,000	
Acute bronchitis				50
Acute myocardial infarction				32,900
Chronic bronchitis				84,200
Hospital admissions (cardiovascular)				4,000
Hospital admissions (respiratory)				3,000
Lower respiratory symptoms				400
Upper respiratory symptoms				300
Work loss days				14,500
Total value (trees)	149,200	24,400	2,978,000	6,529,000
---Shrubs, only---				
Hospital admissions	31,100	8,100	11,300	
Emergency room visits	200	100	100	50
Asthma exacerbation	31,300	3,100		6,900
Acute respiratory symptoms	700	100	46,500	15,400
Mortality			1,290,400	1,887,400
School loss days			13,400	
Acute bronchitis				20
Acute myocardial infarction				9,800
Chronic bronchitis				25,200
Hospital admissions (cardiovascular)				1,200
Hospital admissions (respiratory)				900
Lower respiratory symptoms				100
Upper respiratory symptoms				80
Work loss days				4,300
Total value (shrubs)	63,400	11,500	1,361,600	1,951,400
Total (trees and shrubs)	212,600	35,800	4,339,600	8,480,400

[a] The same health effects are not analyzed for each pollutant. Blank cells indicate that the value is not estimated for that pollutant and health effect.

APPENDIX VI. GENERAL RECOMMENDATIONS FOR AIR QUALITY IMPROVEMENT

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

Temperature reduction and other microclimatic effects
Removal of air pollutants
Emission of volatile organic compounds (VOC) and tree maintenance emissions
Energy conservation on buildings and consequent power plant emissions

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

Urban forest management strategies to help improve air quality include:

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

APPENDIX VII. RELATIVE TREE EFFECTS

The tree and forest resource in Douglas County provides benefits that include carbon storage and sequestration and air pollutant removal. These benefits vary by stem diameter class (Table 17). To estimate a relative value of these benefits, tree benefits were compared to estimates of average carbon emissions in the region[34], average passenger automobile emissions[35], and average household emissions.[36]

General tree information:

Average tree stem diameter = 6.1 in.
Median tree stem diameter = 4.0 in.
Number of trees sampled = 1,387
Number of species sampled = 39

Table 17.—Average tree effects by stem diameter class (d.b.h.), Douglas County, 2012

D.b.h.	Carbon storage			Carbon sequestration			Pollution removal	
(inches)[a]	(lbs)	($)	(miles)[b]	(lbs/yr)	($/yr)	(miles)[b]	(lbs)	($)
1-3	6	0.23	20	1.7	0.06	6	0.09	0.20
3-6	42	1.48	150	5.7	0.20	21	0.3	0.69
6-9	137	4.88	500	10.7	0.38	39	0.5	1.24
9-12	316	11.27	1,160	19.4	0.69	71	1.1	2.45
12-15	570	20.30	2,090	28.0	1.00	103	1.4	3.13
15-18	934	33.25	3,420	40.3	1.43	147	1.6	3.66
18-21	1,359	48.40	4,980	46.7	1.66	171	2.6	5.96
21-24	2,047	72.89	7,500	75.0	2.67	275	2.2	5.07
24-27	2,882	102.66	10,560	99.1	3.53	363	2.5	5.67
27-30	3,215	114.50	11,770	96.3	3.43	353	4.0	9.10
30+	4,945	176.14	18,110	101.7	3.62	373	5.7	12.96

[a] lower limit of the diameter class (d.b.h.) is greater than displayed (e.g., 3-6 is actually 3.01 to 6 inches)
[b] miles = number of automobile miles driven that produces emissions equivalent to tree effect

The trees in Douglas County provide:

Carbon storage equivalent to:
Amount of carbon (C) emitted in region in 943 days or
annual carbon emissions from 1,041,000 automobiles or
annual C emissions from 522,900 single family houses

Carbon monoxide removal equivalent to:
Annual carbon monoxide emissions from 351 automobiles or
annual carbon monoxide emissions from 1,500 family houses

Nitrogen dioxide removal equivalent to:
Annual nitrogen dioxide emissions from 39,000 automobiles or
annual nitrogen dioxide emissions from 26,000 single family houses

Sulfur dioxide removal equivalent to:
Annual sulfur dioxide emissions from 445,900 automobiles or
annual sulfur dioxide emissions from 7,500 single family houses

Particulate matter less than 10 micron (PM_{10}) removal equivalent to:
Annual PM_{10} emissions from 4,994,400 automobiles or
annual PM_{10} emissions 482,100 single family houses

Annual C sequestration equivalent to:
Amount of C emitted in region in 45 days or
annual C emissions from 49,200 automobiles or
annual C emissions from 24,700 single family homes

APPENDIX VIII. TREE PLANTING INDEX MAP

To determine the best locations to plant trees, tree canopy and impervious cover maps from National Land Cover Data[37] were used in conjunction with 2010 U.S. Census Bureau data to produce an index of priority planting areas for Douglas County. Index values were produced for each census block group; the higher the index value for an area, the higher the priority for tree planting. This index is a type of "environmental equity" index with areas with higher human population density and lower tree cover tending to get the higher index value. The criteria for the index were:

- Population density: the greater the population density, the greater the priority for tree planting
- Tree stocking levels: the lower the tree stocking level (the percent of available greenspace [tree, grass, and soil cover areas] that is occupied by tree canopies), the greater the priority for tree planting
- Tree cover per capita: the lower the amount of tree cover per capita (m^2/capita), the greater the priority for tree planting

Each criteria was standardized[38] on a scale of 0 to 1 with 1 representing the census block group with the highest value in relation to priority of tree planting (i.e., the census block group with highest population density, lowest stocking density or lowest tree cover per capita were standardized to a rating of 1).

Individual scores were combined and standardized based on the following formula to produce an overall priority planting index (PPI) value between 0 and 100:

$$PPI = (PD * 40) + (TS * 30) + (TPC * 30)$$

Where PPI = index value, PD is standardized population density, TS is standardized tree stocking, and TPC is standardized tree cover per capita.

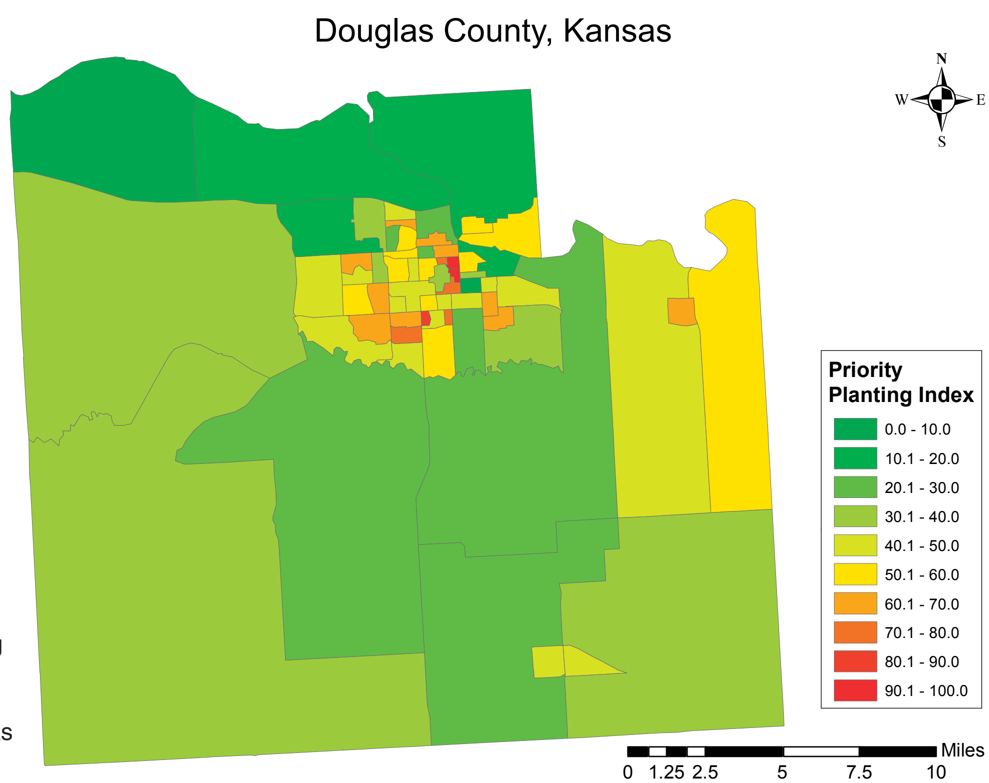


Figure 37.—Priority planting areas, Douglas County, 2012. Higher index scores indicate higher priority areas for planting.

APPENDIX IX. POTENTIAL INSECT AND DISEASE IMPACTS

The following insects and diseases were analyzed to quantify their potential impact on Douglas County's rural and urban forests:

- Aspen leafminer (AL)—An insect that causes damage primarily to trembling or small tooth aspen by larval feeding of leaf tissue. While outbreaks of the aspen leafminer have been recorded throughout parts of Alaska, Canada, and the western United States, the pest is relatively uncommon in eastern North America.[39]
- Asian longhorned beetle (ALB)—A beetle[40] that bores into and kills a wide range of hardwood species. This beetle was discovered in 1996 in Brooklyn, NY, and has subsequently spread to Long Island, Queens, and Manhattan. In 1998, the beetle was discovered in the suburbs of Chicago, IL, and successfully declared eradicated in 2006. Beetles have also been found in Jersey City, NY (2002), Toronto/Vaughan, Ontario (2003), and Middlesex/Union counties, NJ (2004). In 2007, the beetle was found on Staten and Prall's Islands, NY. Most recently, beetles were detected in Worcester, MA (2008) and Bethel, OH (2011). In addition to the eradication in Chicago, successful eradication has since occurred in Hudson County, NJ (2008) and Islip, NY (2011).
- Beech bark disease (BBD)—An insect- disease complex that primarily impacts American beech. It is caused by the infestation of several different species. First, the insect, *Cryptococcus fagisuga,* feeds on the sap of the beech trees. These affected trees can become hosts to the nectria fungi. The two primary species of nectria fungi in North America are *N. coccinea* var. *faginata* and *N. gallifena*.[41]
- Butternut canker (BC)—Caused by a fungus that infects butternut trees. The disease was first discovered in 1967 in Wisconsin and has since caused significant declines in butternut populations in the United States.[42]
- Chestnut blight (CB)—The most common hosts of the fungus that cause chestnut blight are American and European chestnut. This disease causes canker formation in host trees resulting in dead limbs, brown or yellowing leaves, or mortality.[43]
- Dogwood anthracnose (DA)—A disease that affects dogwood species, specifically flowering and Pacific dogwood. It is caused by a fungus that produces leaf spots and necrotic blotches and canker formation on twigs, branches, and the main stem of infected trees.[44]
- Dutch elm disease (DED)—American elm, one of the most important street trees in the 20th century, has been devastated by the Dutch elm disease. Since first reported in the 1930s, it has killed more than 50 percent of the native elm population in the United States.[45]
- Douglas-fir beetle (DFB)—A bark beetle that infests Douglas-fir trees. Infestations of the Douglas-fir beetle have been seen throughout the western United States, British Columbia, and Mexico often resulting in tree mortality.[46]
- Emerald ash borer (EAB)—Since being discovered in Detroit in 2002, emerald ash borer[47] has killed millions of ash trees in Connecticut, Illinois, Indiana, Iowa, Kansas, Kentucky, Massachusetts, Maryland, Michigan, Minnesota, Missouri, New York, Ohio, Ontario, Pennsylvania, Quebec, Virginia, Tennessee, West Virginia, and Wisconsin. With the recent detection of emerald ash borer in Wyandotte County, Kansas in 2012, millions of ash trees in Kansas are now at a greater risk of infestation, including the 300,000 ash trees in Douglas County.

- Fir Engraver (FE)—One common pest of white fir, grand fir, and red fir trees is the fir engraver. This bark beetle is distributed primarily in the western United States.[48]
- Fusiform rust (FR)—A fungal disease that is distributed in the southern United States. It is particularly damaging to slash pine and loblolly pine because it infects the living tissue of the host's stems and branches. Pine trees affected by the fungus can develop fatal galls and cankers.[49]
- Goldspotted oak borer (GSOB)—Infestations of the goldspotted oak borer have been a growing problem in southern California. This forest pest is native to southeastern Arizona and Mexico and believed to have been transported to California by the movement of firewood. The three known host species for GOB are coast live oaks, California black oaks, and canyon live oaks.[50]
- Gypsy moth (GM)—The larvae of the gypsy moth[51] feed on the leaves of many species causing widespread defoliation and tree death if outbreak conditions last several years.
- Hemlock woolly adelgid (HWA)—As one of the most damaging pests to eastern hemlock and Carolina hemlock, hemlock woolly adelgid has played a large role in hemlock mortality in the United States. Since the pest was first discovered in 1951, infestations have expanded to cover about half of the range of hemlock in the eastern United States.[52]
- Jeffrey pine beetle (JPB)—Native to North America, the beetle is distributed across California, Nevada, and Oregon where its only host, Jeffrey pine, also occurs. [53]
- Large aspen tortrix(LAT)—Quaking aspen is a principal host for the defoliator, large aspen tortrix. The insect has been found across much of the northeastern, north central, and western United States, as well as Alaska and Canada. Large aspen tortrix can reach outbreak levels where quaking aspen are abundant and will potentially strip hosts of all of their foliage.[54]
- Laurel wilt disease (LWD)—A fungus-caused disease that is introduced to host trees by the redbay ambrosia beetle. Redbay, as well as other tree species in the Laurel family, are common hosts for laurel wilt disease which has been observed in North Carolina, South Carolina, Georgia, Alabama, Mississippi, and Florida.[55]
- Mountain pine beetle (MPB)—This bark beetle primarily attacks pine species in the western United States. The major host species of the mountain pine beetle, lodgepole pine, ponderosa pine, western white pine, sugar pine, limber pine, and whitebark pine, have a similar distribution as this pest.[56]
- Northern spruce engraver (NSE)—This insect has had a significant impact on the boreal and sub-boreal forests of North America where the pest's distribution overlaps with the range of its major hosts, white spruce, Englemann spruce, and Lutz's spruce. This forest pest has been found in Alaska, Maine, Michigan, Minnesota, and Montana within the United States and in most of the provinces of Canada.[57]
- Oak wilt (OW)—Caused by a fungus and is a prominent disease among oak trees producing leaf wilting and discoloration, heavy defoliation, or fungal mats beneath the bark. The disease has been found in 21 states throughout most of the midwestern United States and it is still unknown whether any species of oak are immune to it.[58]
- Port-Orford-cedar root disease (POCRD)—Caused by a fungus and is most damaging to Port-Orford cedar and Pacific yew species.[59]

- Pine shoot beetle (PSB)—A wood borer that attacks various pine species, though Scotch pine is the preferred host in North America. The beetle has an international geographic distribution. In the United States it has been discovered in Illinois, Indiana, Maine, Maryland, Michigan, New Hampshire, New York, Ohio, Pennsylvania, Vermont, West Virginia, and Wisconsin, as well as in Ontario and Quebec in Canada.[60]
- Spruce beetle (SB)—All species of spruce that fall within the spruce beetle's range are suitable hosts for attack. This bark beetle causes significant mortality and covers large areas of Alaska, Canada, and the northern United States, as well as some patches through the Rocky Mountain range.[61]
- Spruce budworm (SBW)—An insect that causes severe damage to balsam fir. During the larval stage of the budworm's life, it feeds primarily on the needles or expanding buds of its hosts. Years of heavy defoliation can ultimately lead to tree mortality. Other hosts for the spruce budworm include white, red, and black spruce.[62]
- Sudden oak death (SOD)—A fungus-caused disease most common in British Columbia, Washington, Oregon, and California. It impacts many different species including, southern red oak, California black oak, northern red oak, pacific madrone, tanoak, and coastal live oak.[63]
- Southern pine beetle (SPB)—Although the southern pine beetle will attack most pine species, its preferred hosts are loblolly, Virginia, pond, spruce, shortleaf, and sand pines. The range of this particular bark beetle covers much of the southeastern United States.[64]
- Sirex woodwasp (SW)—A wood borer that primarily attacks pine species. It is not native to the United States, but is known to cause high amounts of tree mortality among North American species that have been planted in countries of the southern hemisphere.[65]
- Thousand cankers disease (TCD)—An insect-disease complex that kills several species of walnuts, including black walnut. It is known to occur primarily in the western states of Washington, Oregon, California, Idaho, Utah, Arizona, New Mexico, and Colorado. Tennessee was the first state in the east where thousand cankers disease was been found. Tree mortality is the result of attacks by the walnut twig beetle and subsequent canker development caused by associated fungi.[66] Black walnut, the most important commercially-harvested tree in Kansas, constitutes 5% of the tree population in Douglas County.
- Western pine beetle (WPB)—This beetle aggressively attacks ponderosa and Coulter pines and has caused significant swaths of damage in California, Oregon, Washington, Idaho, British Columbia, Montana, Nevada, Utah, Colorado, Arizona, New Mexico, Texas, and parts of northern Mexico.[67]
- White pine blister rust (WPBR)—Since its introduction to the United States in 1900, white pine blister rust has had a detrimental effect on white pines, particularly in the Lake States.[68]
- Western spruce budworm (WSB)—An insect that causes defoliation in western conifers. It has been found in Arizona, New Mexico, Colorado, Utah, Wyoming, Montana, Idaho, Oregon, and Washington in the United States and British Columbia and Alberta in Canada. The western spruce budworm feeds on new foliage of its hosts. Common host species include Douglas-fir, grand fir, white fir, subalpine fir, corkbark fir, blue spruce, Engelmann spruce, white spruce, and western larch.[69]

As each insect/disease is likely to attack different host tree species, the implications for Douglas County will vary. The number of trees at risk reflects only the known host species that could experience mortality (Table 18). The species host lists used for these insects/diseases can be found at http://nrs.fs.fed.us/data/urban.

Table 18.—Potential risk to trees by insect or disease, Douglas County, 2012

Code	Scientific Name	Common Name	Trees at Risk #	Compensatory Value ($ millions)
AL	*Phyllocnistis populiella*	Aspen leafminer	182,848	3.8
ALB	*Anoplophora glabripennis*	Asian longhorned beetle	3,723,887	1,248
BBD	*Cryptococcus fagisuga*	Beech bark disease	-	-
BC	*Sirococcus clavigignenti-juglandacearum*	Butternut canker	-	-
CB	*Cryphonectria parasitica*	Chestnut blight	-	-
DA	*Discula destructive*	Dogwood anthracnose	-	-
DED	*Ophiostoma novo-ulmi*	Dutch elm disease	3,024,355	434
DFB	*Dendroctonus pseudotsugae*	Douglas-fir beetle	-	-
EAB	*Agrilus planipennis*	Emerald ash borer	300,052	601
FE	*Scotylus ventralis*	Fir engraver	-	-
FR	*Cronartium fusiforme*	Fusiform rust	-	-
GSOB	*Agrilus auroguttatus*	Goldspotted oak borer	-	-
GM	*Lymantria dispar*	Gypsy moth	797,305	733
HWA	*Adelges tsugae*	Hemlock woolly adelgid	-	-
JPB	*Dendroctonus jeffreyi*	Jeffrey pine beetle	-	-
LAT	*Choristoneura conflictana*	Large aspen tortrix	182,848	3.8
LWD	*Raffaelea lauricola*	Laurel wilt disease	-	-
MPB	*Dendroctonus ponderosae*	Mountain pine beetle	-	-
NSE	*Ips perturbatus*	Northern spruce engraver	-	-
OW	*Ceratocystis fagacearum*	Oak wilt	530,711	719
POCRD	*Phytophthora lateralis*	Port-Orford-cedar root disease	-	-
PSB	*Tomicus piniperda*	Pine shoot beetle	-	-
SB	*Dendroctonus rufipennis*	Spruce beetle	-	-
SBW	*Choristoneura fumiferana*	Spruce budworm	-	-
SOD	*Phytophthora ramorum*	Sudden oak death	168,511	355
SPB	*Dendroctonus frontalis*	Southern pine beetle	-	-
SW	*Sirex noctilio*	Sirex woodwasp	-	-
TCD	*Pityophthorus juglandis & Geosmithia spp.*	Thousand canker disease	701,859	473
WPB	*Dendroctonus brevicomis*	Western pine beetle	-	-
WPBR	*Cronartium ribicola*	White pine blister rust	-	-
WSB	*Choristoneura occidentalis*	Western spruce budworm	-	-

Pest range maps from the Forest Health Technology Enterprise Team (FHTET)[27] were used to determine the proximity of each pest to the county. For Douglas County, proximity was classified as whether the insect/disease occurs within the county, is within 250 miles of the county edge, is between 250 and 750 miles away, or is greater than 750 miles away (Fig. 38). FHTET did not have pest range maps for Dutch elm disease and chestnut blight. The range of these pests was based on known occurrence and the host range, respectively. [31]

For more information on these pests and to access pest range maps, please visit www.foresthealth.info.

Based on the host tree species for each pest and the current range of the pest, it is possible to determine what the risk is that each tree species sampled in Douglas County could be attacked by an insect or disease. In Table 19, species risk is designated as one of the following:

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

Species that were sampled in Douglas County, but that are not listed in this matrix, are not known to be hosts to any of the 31 exotic insects/diseases analyzed. Tree species at the greatest risk to existing pest infestations in Douglas County are oaks and elms.

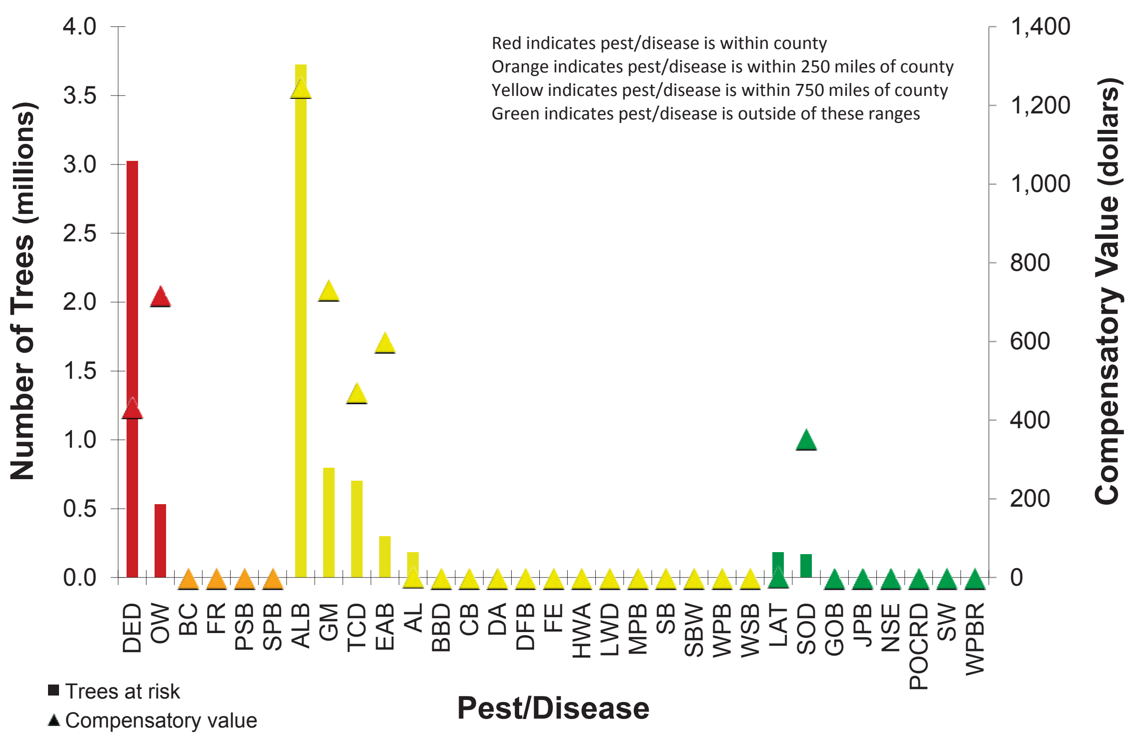


Figure 38.—Number of trees at risk and associated compensatory value of insect/disease effects, Douglas County, 2012.

Table 19.—Potential insect and disease risk for tree species, Douglas County, 2012

			Pest[c]																														
Spp. Risk[a]	Risk weight[b]	Common Name	DED	OW	EAB	BC	FR	PSB	SPB	ALB	GM	TCD	AL	BBD	CB	DA	DFB	FE	HWA	LWD	MPB	SB	SBW	WPB	WSB	LAT	SOD	GOB	JPB	NSE	POCRD	SW	WPBR
Red	7	Northern red oak		Red							Yellow																				Green						
Red	7	Pin oak		Red							Yellow																				Green						
Red	6	American elm	Red							Yellow																								
Red	6	Chinkapin oak		Red							Yellow																							
Red	6	Siberian elm	Red							Yellow																								
Red	6	Bur oak		Red							Yellow																							
Red	6	White oak		Red							Yellow																							
Red	6	Slippery elm	Red							Yellow																								
Orange	5	Green ash			Orange					Yellow																								
Orange	3	White ash			Orange																													
Yellow	7	Sandbar willow								Yellow	Yellow		Yellow													Green							
Yellow	7	Black willow								Yellow	Yellow		Yellow													Green							
Yellow	2	Black walnut										Yellow																					
Yellow	2	Silver maple								Yellow																							
Yellow	2	Eastern cottonwood								Yellow																							
Yellow	2	Eastern hophornbeam									Yellow																						
Yellow	2	American basswood									Yellow																						
Yellow	2	Sugar maple								Yellow																							
Yellow	2	Boxelder								Yellow																							
Yellow	2	Red maple								Yellow																							
Yellow	2	Crabapple									Yellow																						
Yellow	2	Ohio buckeye								Yellow																							

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

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

[c]Pest Color Codes
Red indicates pest is within Douglas County
Orange indicates pest is within 250 miles of Douglas County
Yellow indicates pest is within 750 miles of Douglas County
Green indicates pest is outside of these ranges

APPENDIX X. i-TREE FORECAST PROTOTYPE MODEL METHODS AND RESULTS

The i-Tree Forecast Prototype Model was built to simulate future forest structure (e.g., number of trees and sizes) and various ecosystem services based on annual projections from the current forest structure data. There are three main components of the model:

1) Tree growth—projects annual growth for tree diameter, crown size, and leaf area for each tree
2) Tree mortality—projects annual mortality based on user defined mortality rates
3) Tree establishment—projects new trees; can be used to illustrate the effect of the new trees or determine how many new trees need to be added annually to sustain a certain level of tree cover or benefits.

Tree Growth

Annual tree diameter growth is estimated for the region based on: 1) the length of growing season; 2) species average growth rates; 3) tree competition; 4) tree condition; and 5) current tree height relative to maximum tree height.

Length of growing season - To determine a base growth rate based on length of growing season, growth measurement for urban street trees, park trees, and forest trees were standardized to growth rates for 153 frost-free days based on: Standardized growth = measured growth x (number of frost-free days of measurement/153).[7] Growth rates of trees of the same species or genera were also compared to determine the average difference between standardized street tree growth and standardized park tree and forest tree growth rates. Park growth was 1.78 times less than street trees, on average, and forest growth was 2.26 times less than street tree growth.

Species growth rates - Based on these data, average standardized growth rates for open-grown trees were set at 0.26 in/yr for slow growing species, 0.39 in/yr for moderate growing species and 0.52 in/yr for fast growing species. There are limited measured data on urban tree growth for slow, moderate or fast-growing tree species, so the growth rates used are estimates. These growth rates, by species growth-rate class, were estimated such that the entire population's average growth rate was comparable to the measured growth rates for trees standardized to the number of frost-free days.

Tree competition - Crown light exposure (CLE) measurements were used to represent tree competition the CLE of 0-1 representing forest conditions; 2-3 for park conditions; and 4-5 for open-grown conditions. Thus, for: CLE 0-1: Base growth = Standardized growth (SG) / 2.26; CLE 2-3: Base growth = SG / 1.78; and CLE 4-5: Base growth = SG. However, as the canopy cover increased or decreased, the CLE factors were adjusted proportionally to the amount of available greenspace (i.e., as tree cover decreased and available greenspace increased, the CLE adjustment factor decreased; as tree cover increased and available greenspace decreased, the CLE adjustment factor increased).

Tree condition - Base growth rates are also adjusted depending on tree condition. These adjustment factors are based on percent crown dieback and the assumption that less than 25 percent crown dieback had a limited effect on diameter growth rates. For trees in fair to excellent condition (less than 25 percent dieback), base growth rates are multiplied by 1 (no adjustment), trees in poor condition (crown dieback of 26 to 50 percent) by 0.76, critical trees (crown dieback of 51 to 75 percent) by 0.42, dying trees (crown dieback of 76 to 99 percent) by 0.15, and dead trees (crown dieback of 100 percent) by 0.

Tree height - As trees approach maximum height, growth rates decrease. Thus the species growth rates as described above were adjusted based on the ratio between the current height of the tree and the average height at maturity for the species. When a tree's height is more than 80 percent of its average height at maturity, the annual diameter growth is proportionally reduced from full growth at 80 percent of height to one-half growth rate at height at maturity. The growth rate is maintained at one-half growth until the tree is 125 percent of maximum height, when the growth rate is then reduced to 0.

Tree height, crown width, crown height, and leaf area are then estimated based on tree diameter for each year. Height, crown height, and crown width are calculated using species, genus, order, and family specific equations that were derived from measurements from urban tree data (unpublished equations). If there is no equation for a particular species, then the genus equation is used, followed by the family and order equations, if necessary. If no order equation is available, we use an equation for all trees to estimate these parameters. Leaf area is calculated from the crown height, tree height, and crown width estimates based on i-Tree methods.[7]

Total canopy cover is calculated by summing the two-dimensional crown area of each tree in the population. This estimate of crown area was adjusted to attain the actual tree cover of the study area based on photo-interpretation. Trees often have overlapping crowns, so the sum of the crown areas will often over estimate total tree cover as determined by aerial estimates. Thus the crown overlap can be determined by comparing the two estimates:

% crown overlap = (sum of crown area – actual tree cover area) / sum of crown area

When projections predict an increase in percent tree cover, the percent crown overlap is held constant. However, when 100 percent tree cover is attained, all new canopy added is considered as overlapping canopy. When there is a projected decrease in percent tree cover, the percent crown overlap decreases in proportion to the increase in the amount of available greenspace (i.e., as tree cover decreases and available greenspace increases—the crown overlap decreases).

Tree Mortality Rate

Canopy dieback is the first determinant for tree mortality. Trees with 50 to 75 percent crown dieback have an annual mortality rate of 13.1 percent; trees with 76 to 99 percent dieback have a 50 percent annual mortality rate, and trees with 100 percent dieback have a 100 percent annual mortality rate.[70] Trees with less than 50 percent dieback have a user-defined mortality rate that is adjusted based on the tree size class and diameter.

Trees are assigned to species size classes: small trees have an average height at maturity of less than or equal to 40 ft (maximum diameter class = 20+ inches); medium trees have mature tree height of 41to 60 ft (maximum diameter = 30+ inches); large trees have a mature height of greater than 60 ft (maximum diameter = 40+ inches). Each size class has a unique set of seven diameter ranges to which base mortality rates are assigned based on measured tree mortality by diameter class (Fig. 39).[70] The same distribution of mortality by diameter class was used for all tree size classes, but the diameter range of the classes differed by size class. The actual mortality rate for each diameter class was adjusted so that the overall average mortality rate for the base population equaled the mortality rates assigned by the user. That is, the relative curve of mortality stayed the same among diameter classes, but the actual values would change based on the user-defined overall average rate.

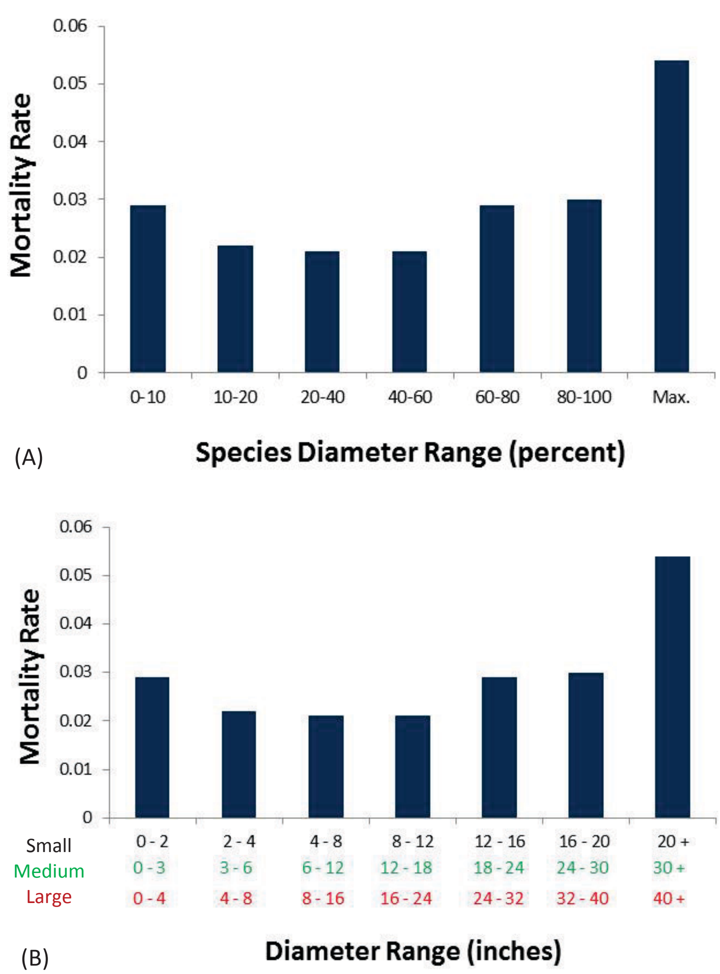


Figure 39.—A) Mortality rate distribution by diameter class (d.b.h.) with d.b.h. range classified by the percent of maximum d.b.h. for the species; and B) for actual d.b.h. classes for small, medium, and large tree species.

Tree Establishment

Based on the desired level of tree cover and the number of years desired to reach that canopy goal, the model calculates the number of trees needing to be established annually to reach that goal given the model growth and mortality rate. In simulating the addition of new trees to the model each year, the species composition of new trees was assumed to be proportional to the current species composition. Crown light exposure of newly established trees was also assumed to be proportional to the current growth structure of the canopy. Newly established trees were given a starting stem diameter of 1 inch.

Model Scenarios

Numerous model scenarios were run for Douglas County. All scenarios were run with 2, 3, 4, or 5 percent average annual mortality rates for projections 10, 25, and 50 years in the future. All model scenarios were run by land use class with land use tree cover based on field data estimates.

For cases seeking to maintain current tree cover, two additional scenarios were run taking into account:

1) Ash mortality: the entire ash population dies in 10 years. The mortality rate is 10 percent of the initial population per year.
2) Black walnut mortality: the entire black walnut population dies in 10 years. The mortality rate is 10 percent of the initial population per year.

Land Use—Agriculture

Current Conditions

Area: 212,935 ac
Current Canopy Cover: 10.5%
Tree-size Classes (height)
Small Trees – 21.5%
Medium Trees – 14.7%
Large Trees – 63.8%

Scenarios

The following tables illustrate the number of trees that must be established annually to attain the desired canopy cover goal within the 10-, 25-, and 50-year periods.

Maintain existing agriculture canopy cover of 10.5 percent

	Number of Trees								
	no additional mortality			ash kill in 10 years			black walnut kill in 10 years		
Mortality (%)	10 yrs	25 yrs	50 yrs	10 yrs	25 yrs	50 yrs	10 yrs	25 yrs	50 yrs
2	0	0	0	0	0	0	0	0	0
3	0	0	63,000	0	0	75,000	0	0	73,000
4	7600	134,000	201,000	52,000	151,000	210,000	95,000	170,000	210,000
5	321,000	378,000	340,000	373,000	373,000	347,000	439,000	392,000	346,000

Increase agriculture canopy cover by 5 to 15.5 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	225,000	0	15,000
3	667,000	164,000	155,000
4	926,000	411,000	325,000
5	1,440,000	680,000	519,000

Increase agriculture canopy cover by 10 to 20.5 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	1,080,000	157,000	78,000
3	1,450,000	416,000	261,000
4	1,910,000	716,000	468,000
5	2,500,000	1,000,000	689,000

Increase agriculture canopy cover by 20 to 30.5 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	2,930,000	590,000	235,000
3	3,480,000	930,000	483,000
4	4,110,000	1,310,000	774,000
5	4,720,000	1,760,000	1,133,000

Land Use—Commercial

Current Conditions

Area: 4,347 ac

Current Canopy Cover: 7.1%

Tree Size Classes (height)

- Small Trees – 20.0%
- Medium Trees – 20.0%
- Large Trees – 60.0%

Scenarios

The following tables illustrate the number of trees that must be established annually to attain the desired canopy cover goal within the 10-, 25-, and 50-year periods.

Maintain existing commercial canopy cover of 7.1 percent
(Note: there were no ash or walnut trees in this land use category)

	Number of Trees No Additional Mortality		
Mortality (%)	10 years	25 years	50 years
2	0	0	600
3	1,200	1,500	2,000
4	4,800	3,600	3,300
5	8,500	5,700	4,900

Increase commercial canopy cover by 5 to 12.1 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	11,000	3,000	1,800
3	16,000	5,300	3,400
4	20,000	8,100	5,300
5	26,000	12,000	8,000

Increase commercial canopy cover by 10 to 17.1 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	27,000	6,300	3,000
3	33,000	9,300	5,200
4	42,000	14,000	7,800
5	47,000	17,000	11,300

Increase commercial canopy cover by 20 to 27.1 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	59,000	14,000	5,900
3	70,000	19,400	9,200
4	82,000	24,000	13,000
5	87,000	33,000	19,000

Land Use—Park/Open

Current Conditions

Area: 28,489 ac

Current Canopy Cover: 10.6%

Tree Size Classes (height)

Small Trees – 0.0%

Medium Trees – 7.1%

Large Trees – 92.9%

Scenarios

The following tables illustrate the number of trees that must be established annually to attain the desired canopy cover goal within the 10-, 25-, and 50-year periods.

Maintain existing park/open canopy cover of 10.6 percent (Note: there were no ash trees in this land use category)

	Number of Trees					
	no additional mortality			black walnut kill in 10 years		
Mortality (%)	10 yrs	25 yrs	50 yrs	10 yrs	25 yrs	50 yrs
2	0	0	7,800	292,000	69,000	32,000
3	3,900	24,000	34,000	344,000	99,000	54,000
4	74,000	62,000	60,000	394,000	134,000	82,000
5	112,000	99,000	90,000	443,000	180,000	120,000

Increase park/open canopy cover by 5 to 15.6 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	73,000	19,000	19,000
3	135,000	64,000	48,000
4	209,000	109,000	84,000
5	176,000	159,000	129,000

Increase park/open canopy cover by 10 to 20.6 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	195,000	50,000	29,000
3	269,000	96,000	65,000
4	341,000	152,000	109,000
5	412,000	215,000	161,000

Increase park/open canopy cover by 20 to 30.6 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	429,000	117,000	55,000
3	513,000	179,000	102,000
4	640,000	256,000	163,000
5	711,000	337,000	243,000

Land Use—Residential

Current Conditions

Area: 32,092 ac

Current Canopy Cover: 31.4%

Tree Size Classes (height)

Small Trees – 9.3%

Medium Trees – 16.3%

Large Trees – 74.4%

Scenarios

The following tables illustrate the number of trees that must be established annually to attain the desired canopy cover goal within the 10-, 25-, and 50-year periods.

Maintain existing residential canopy cover of 31.4 percent

	Number of Trees								
	no additional mortality			ash kill in 10 years			black walnut kill in 10 years		
Mortality (%)	10 yrs	25 yrs	50 yrs	10 yrs	25 yrs	50 yrs	10 yrs	25 yrs	50 yrs
2	0	0	8,800	80,000	14,000	12,000	0	4,000	10,000
3	78,000	48,000	37,000	152,000	61,000	39,000	95,000	52,000	38,000
4	153,000	96,000	66,000	237,000	105,000	68,000	178,000	98,000	68,000
5	265,000	152,000	101,000	325,000	159,000	103,000	264,000	154,000	104,000

Increase residential canopy cover by 5 to 36.4 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	95,000	32,000	20,000
3	194,000	82,000	50,000
4	287,000	134,000	84,000
5	398,000	194,000	125,000

Increase residential canopy cover by 10 to 41.4 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	225,000	58,000	30,000
3	336,000	117,000	67,000
4	431,000	180,000	109,000
5	559,000	248,000	155,000

Increase residential canopy cover by 20 to 51.4 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	490,000	128,000	56,000
3	620,000	203,000	105,000
4	780,000	283,000	162,000
5	890,000	374,000	232,000

Land Use—Vacant

Current Conditions

Area: 9,244 ac

Current Canopy Cover: 81.9%

Tree Size Classes (height)

- Small Trees – 13.3%
- Medium Trees – 26.5%
- Large Trees – 60.2%

Scenarios

The following tables illustrate the number of trees that must be established annually the desired canopy cover goal within the 10-, 25-, and 50-year periods.

Maintain existing vacant canopy cover of 81.9 percent

	Number of Trees								
	no additional mortality			ash kill in 10 years			black walnut kill in 10 years		
Mortality (%)	10 yrs	25 yrs	50 yrs	10 yrs	25 yrs	50 yrs	10 yrs	25 yrs	50 yrs
2	0	0	0	0	0	0	0	0	0
3	0	4,800	39,000	9,100	16,000	42,000	108,000	33,000	47,000
4	57,000	75,000	86,000	109,000	89,000	101,000	203,000	105,000	96,000
5	170,000	150,000	141,000	225,000	167,000	150,000	326,000	185,000	153,000

Increase vacant canopy cover by 5 to 86.9 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	0	0	0
3	9,700	34,000	65,000
4	127,000	129,000	129,000
5	245,000	215,000	212,000

Increase vacant canopy cover by 10 to 91.9 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	0	0	0
3	73,000	60,000	85,000
4	215,000	174,000	176,000
5	358,000	292,000	278,000

Increase vacant canopy cover by 20 to 100.0 percent

	Number of Trees		
Mortality (%)	10 years	25 years	50 years
2	60,000	0	18,000
3	193,000	121,000	131,000
4	353,000	260,000	262,000
5	509,000	415,000	410,000

A "0" in several columns of these tables illustrate that at low mortality rates, the projected tree growth more than compensates for the loss of tree cover due to mortality. This result may be an artifact of mortality rates that are too low relative to actual mortality rates, or that growth rates are too high. However, even though tree cover can be sustained without new trees, the total tree population will decline through time and eventually the tree cover of the area will decline rapidly. With very low mortality rates, which are unreasonable (e.g., 0%), no new trees would ever need to be established and tree cover would increase to 100 percent as no trees would die and existing trees would continue to grow.

These population projections are estimates that are based on the assumptions that drive canopy cover and tree population estimates (i.e., tree growth and mortality rates). Some information is known on urban tree and forest growth rates, but very little is known on actual tree mortality rates. Long-term urban forest monitoring studies are needed to help determine actual urban tree mortality rates and factors that influence these rates.

APPENDIX XI. i-TREE HYDRO MODEL METHODS AND CALIBRATION GRAPHS

Data and Model Calibration

The hourly weather data were derived from a local weather station in Lawrence, KS (WBAN: 724508). Tree and impervious cover parameters (Table 20) were derived for the watershed from photo-interpretation of Google Earth imagery (2013) using 301 randomly located points.

Table 20.—Cover estimates for the Wakarusa River watershed, 2013

	Percent Cover			
Area	Impervious	Tree	Grass/shrub	Bare Soil
Wakarusa River Watershed	7.3%	25.2%	66.8%	0.7%

The model was calibrated using hourly stream flow data collected at the "Wakarusa River near Lawrence, KS" gauging station (USGS 06891500) from Jan. 1, 2005 to Jan. 1, 2006. Model results were calibrated against measured stream flow to yield the best fit between modeled and measured stream flow results. Calibration coefficients (-1 to +1 with +1.0 = perfect fit) were calculated for peak flow, base flow, and balance flow (peak and base) (Table 21). A coefficient of +1 indicates a perfect fit, 0 indicates the model predicts the same as using the mean value, and negative values indicate using the mean is a better predictor than the model.[71] Differences between measured and estimated flow can be substantially different, particularly for peak flows, due to mismatching of stream flow and weather data as the weather stations are often outside of the watershed area. For example, it may be raining at the weather station and not in the watershed or vice versa.

Tree canopy leaf area index (LAI) was estimated at 5 based on various field studies; the percent of impervious cover directly connected to the stream varied with percent impervious (2 percent connected at 7.3 percent impervious). The percentage of directly connected impervious cover represents the portion of impervious cover that drains directly to the modeled stream or any of its tributaries. The phrase "drains directly" describes a situation where precipitation that falls on a portion of the watersheds impervious cover is conveyed, overland or through a storm sewer network, directly into the stream or its tributaries.

Table 21.—Calibration coefficients for model estimates and gauging station data

	Calibration Coefficients		
Watershed	Peak Flow	Base Flow	Balanced Flow
Wakarusa River	-0.52	0.25	0.20

Model calibration procedures adjust several model parameters (mostly related to soils) to find the best fit between the observed flow and the model flow on an hourly basis. However, there are often mismatches between the precipitation data, which are often collected outside of the watershed, and the actual precipitation that occurs in the watershed. Even if the precipitation measurements are within the watershed, local variations in precipitation intensity can lead to differing amounts of precipitation than observed at the measurement station. These differences in precipitation can lead to poorer fits between the observed and predicted estimates of flow as the precipitation is a main driver of the stream flow. As can be seen in Figure 40, the observed and simulated results can diverge, which is often an artifact of the precipitation data. For example, observed flow will rise sharply, but

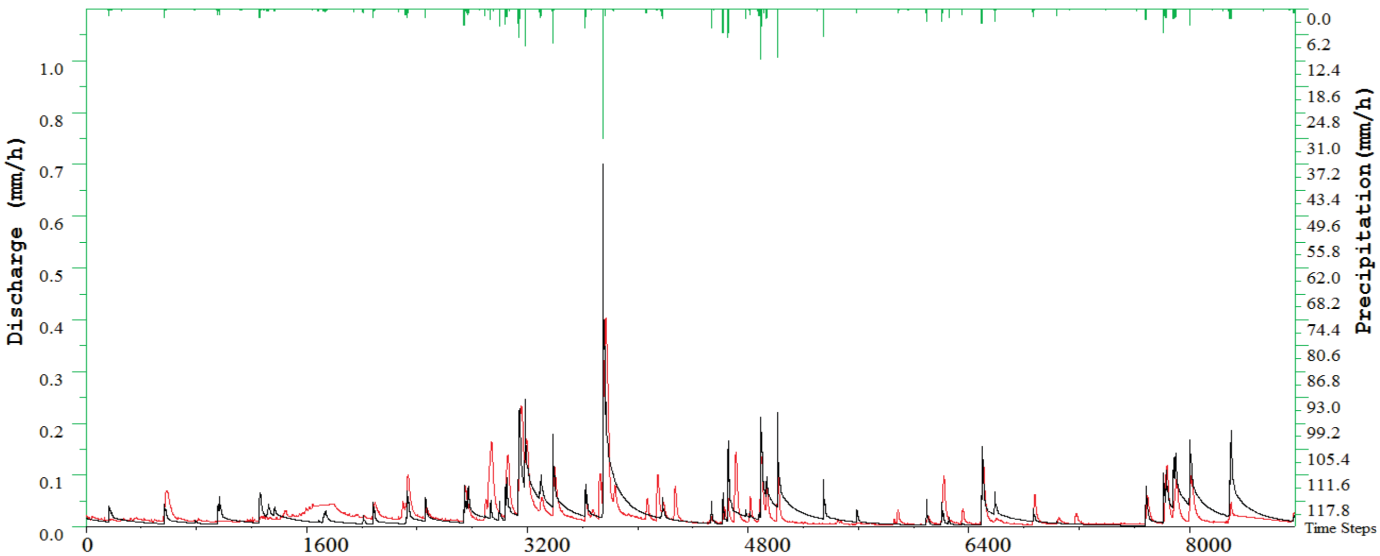


Figure 40.—Comparison of simulated model flow (black) vs. observed flow (red) in Wakarusa River watershed.

predicted flow does not, which is an indication of rain in the watershed, but not at the precipitation measurement station. Conversely, the simulated flow may rise, but the observed flow does not, which is an indication of rain at the precipitation station, but not in the watershed.

As the flow of the Wakarusa watershed at the gauging station is largely controlled by the dam at Clinton Lake, which led to relatively low model calibration, the effects illustrated by the model are likely more representative of flow changes in the river above the dam, not at the gauging station (i.e., the flow below the dam is based on water storage and release from the dam).

Since the model simulations are comparisons between the base simulation flows and another simulated flow with changed surface cover (e.g., increase or decrease in tree cover), both model runs are using the same simulation parameters. This means that the effects of changes in cover types are comparable, but may not exactly match the flow of the stream. Stated in another way, the estimates of the changes in flow are reasonable (e.g., the relative amount of increase or decrease in flow is sound as both are using the same model parameters and precipitation data), but the absolute estimate of flow may be incorrect. Thus the model results can be used to assess the relative differences in flow due to changes in cover parameters, but should not be used to predict the actual effects on stream flow due to precipitation and calibration imperfections. The model can be used to compare the changes in flow (e.g., increased tree cover leads to an X% change in stream flow), but will likely not exactly match the flow observed in the stream. The model is more diagnostic of cover change effects than predictive of actual stream flow due to imperfections of models and data used in the model. Due in part to the dam, the model had a difficult time matching the flow, but did a reasonable job in simulating flow (Fig. 41).

Model Scenarios

After calibration, the model was used under various conditions to determine stream flow response given varying tree and impervious cover values for the watershed area. For tree cover simulations, impervious cover was held constant at the original value with tree cover varying between 0 and 100 percent. Increasing tree cover was assumed to fill grass and shrub covered areas first, followed by bare

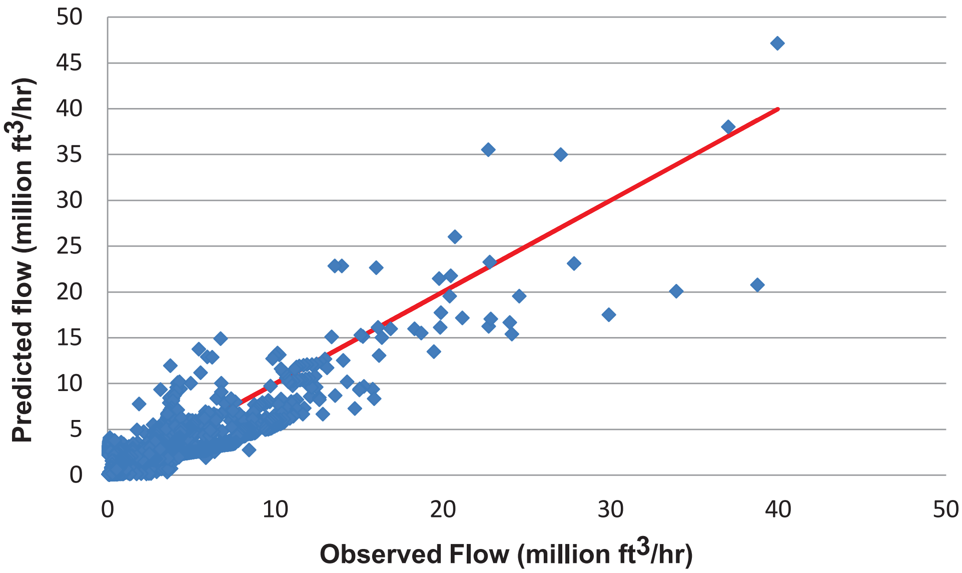


Figure 41.—Comparison observed vs. simulated flow, Wakarusa River watershed.

soil spaces next, and then finally impervious covered land. At 100 percent tree cover, all impervious land is covered by trees. This assumption is unreasonable as all buildings, roads, and parking lots would be covered by trees, but the results illustrate the potential impact. Tree cover reductions assumed that trees were replaced with grass and shrub cover.

For impervious cover simulations, tree cover was held constant with impervious cover varying between 0 and 100 percent. Increasing impervious cover was assumed to fill grass and shrub covered areas first, followed by bare soil spaces, and then under tree canopies. The assumption of 100 percent impervious cover is unreasonable, but the results illustrate the potential impact. In addition, as impervious increased from the current conditions, so did the percent of the impervious cover directly connected to the stream, following equations by Sutherland[72], such that at 100 percent impervious cover, all impervious cover is connected to the stream. Reductions in impervious cover were assumed to be filled with grass and shrub cover.

Water Quality Effects—Event Mean Concentration to Calculate Pollution Load

Event mean concentration (EMC) data is used for estimating pollutant loading into watersheds. EMC is a statistical parameter representing the flow-proportional average concentration of a given parameter during a storm event and is defined as the total constituent mass divided by the total runoff volume. EMC estimates are usually obtained from a flow-weighted composite of concentration samples taken during a storm. Mathematically[73,74]:

$$EMC = \bar{C} = \frac{M}{V} = \frac{\int C(t)\,Q(t)dt}{\int Q(t)dt} \approx \frac{\sum C(t)\,Q(t)\Delta t}{\sum Q(t)\Delta t} \qquad (1)$$

where $C(t)$ and $Q(t)$ are the time-variable concentration and flow measured during the runoff event, and M and V are pollutant mass and runoff volume as defined in Equation 1. It is clear that the EMC results from a flow-weighted average, not simply a time average of the concentration. EMCs are reported as a mass of pollutant per unit volume of water (usually mg/L).

The pollution load (L) calculation from the EMC method is

$$L = EMC * Q = EMC * d_r * A \qquad (2)$$

Where EMC is event mean concentration (mg/l, mg/m^3, lbs/ft^3,…), Q is runoff of a time period associated with EMC (l/h, m^3 /day, ft^3/day, …), d_r is runoff depth of unit area (mm/h, in/h, …), A is the land area (m^2, ft^2…), which is catchment area in i-Tree Hydro.

Thus, when the EMC is multiplied by the runoff volume, an estimate of the pollution loading to the receiving water is provided. The instantaneous concentration during a storm can be higher or lower than the EMC, but the use of the EMC as an event characterization replaces the actual time variation of C versus *t* in a storm with a pulse of constant concentration having equal mass and duration as the actual event. This process ensures that mass loadings from storms will be correctly represented. EMCs represent the concentration of a specific pollutant contained in stormwater runoff coming from a particular land use type or from the whole watershed. Under most circumstances, the EMC provides the most useful means for quantifying the level of pollution resulting from a runoff event.[75] Figure 42 illustrates the inter-storm variation of pollutographs and EMC.

Since collecting the data necessary for calculating site-specific EMCs can be cost prohibitive, researchers or regulators will often use values that are already available in the literature. If site-specific numbers are not available, regional or national averages can be used, although the accuracy of using these numbers is questionable. Due to the specific climatological and physiographic characteristics of individual watersheds, agricultural and urban land uses can exhibit a wide range of variability in nutrient export.[76]

To understand and control urban runoff pollution, the U.S. Congress included the establishment of the Nationwide Urban Runoff Program (NURP) in the 1977 amendments to the Clean Water Act (PL 95-217). The U.S. Environmental Protection Agency developed the NURP to expand the state knowledge of urban runoff pollution by applying research projects and instituting data collection in selected urban areas throughout the country.

In 1983, the U.S. Environmental Protection Agency[77] published the results of the NURP, which nationally characterizes urban runoff for 10 standard water quality pollutants, based on data from 2,300 station-storms at 81 urban sites in 28 metropolitan areas.

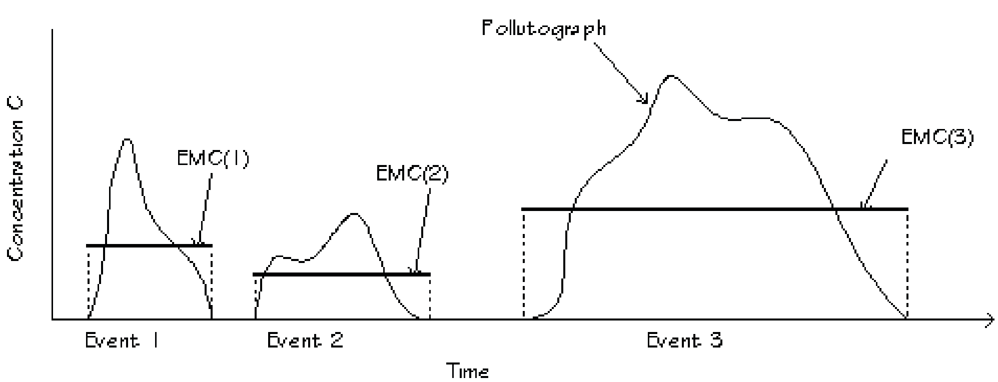


Figure 42.—Inter-storm variation of pollutographs and event mean concentrations (EMC).

Subsequently, the U.S. Geological Survey (USGS) created another urban stormwater runoff base[78], based on data measured through mid-1980s for more than 1,100 stations at 97 urban sites located in 21 metropolitan areas. Additionally, many major cities in the United States collect urban runoff quality data as part of the application requirements for stormwater discharge permits under the National Pollutant Discharge Elimination System (NPDES). The NPDES data are from over 30 cities and more than 800 station-storms for more than 150 paramaters.[72]

The data from the three sources (NURP, USGS, and NPDES) were used to compute new estimates of EMC population means and medians for the 10 pollutants with many more degrees of freedom than were available to the NURP investigators.[79] A "pooled" mean was calculated representing the mean of the total population of sample data. The NURP and pooled mean EMCs for the 10 pollutants or constituents are listed in Table 22.[79] NURP or pooled mean EMCs were selected because they are based on field data collected from thousands of storm events. However, these estimates are based on nationwide data, so they do not account for regional variation in soil types, climate, and other factors.

Table 22.—National pooled EMCs and NURP EMCs

Pollutant/Constituent (Abbrevation)	Data Source	EMCs (mg/l) Mean	EMCs (mg/l) Median	No. of Events
Total suspended solids (TSS)	Pooled	78.4	54.5	3047
	NURP	17.4	113	2000
Biochemical oxygen demand (BOD5)	Pooled	14.1	11.5	1035
	NURP	10.4	8.39	474
Chemical oxygen demand (COD)	Pooled	52.8	44.7	2639
	NURP	66.1	55	1538
Total phosphorus (TP)	Pooled	0.315	0.259	3094
	NURP	0.337	0.266	1902
Soluble phosphorus (Soluble P)	Pooled	0.129	0.103	1091
	NURP	0.1	0.078	767
Total Kjeldhal nitrogen (TKN)	Pooled	1.73	1.47	2693
	NURP	1.67	1.41	1601
Nitrite and nitrate (NO2 and NO3)	Pooled	0.658	0.533	2016
	NURP	0.837	0.666	1234
Copper (Cu)	Pooled	0.0135	0.0111	1657
	NURP	0.0666	0.0548	849
Lead (Pb)	Pooled	0.0675	0.0507	2713
	NURP	0.175	0.131	1579
Zinc (Zn)	Pooled	0.162	0.129	2234
	NURP	0.176	0.140	1281

Note:
(1) No BOD5 data available in the USGS dataset - pooled data includes NURP+NPDES
(2) No TSP data available in NPDES dataset - pooled data includes NURP+USGS

For i-Tree Hydro, the pooled median and mean EMC value for each pollutant were applied to the runoff regenerated from pervious and impervious surface flow, not the base flow values, to estimate effects on pollutant load across the entire modeling period. All rain events are treated equally using the EMC value, which mean some events may be overestimated and others underestimated. In addition, local management actions (e.g., street sweeping) can affect these values. However, across the entire season, if the EMC value is representative of the watershed, the estimate of cumulative effects on water quality should be relatively accurate. Accuracy of pollution estimates will be increased by using locally derived coefficients. It is not known how well the national EMC values represent local conditions.

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Nowak, David J.; Bodine, Allison R.; Hoehn, Robert E., III; Ellis, Alexis; Bomberger, Kim; Crane, Daniel E.; Endreny, Theodore A.; Taggert, Thomas; Stephan, Emily. 2014. **Assessing urban forest effects and values: Douglas County, Kansas.** Resour. Bull. NRS-91. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 76 p.

An analysis of trees in Douglas County, Kansas, reveals that this area has about 14,164,000 trees with tree and shrub canopy that covers 25.2 percent of the county. The most common tree species are American elm, northern hackberry, eastern redcedar, Osage-orange, and honeylocust. Trees in Douglas County currently store about 1.7 million tons of carbon (6.4 million tons CO_2) valued at $124 million. In addition, these trees remove about 82,000 tons of carbon per year (300,000 tons CO_2 per year valued at $5.8 million per year) and about 3,870 tons of air pollution per year ($17.7 million per year). Douglas County's trees are estimated to reduce annual residential energy costs by $2.9 million per year. The compensatory value of the trees is estimated at $6.2 billion. Loss of the current tree cover in the Wakarusa River watershed in Douglas County would increase annual flow by an average of 2.6 percent (88.9 million ft^3). Information on the structure and functions of the regional forest can be used to inform forest management programs and to integrate regional forests within plans to improve environmental quality in Douglas County.

KEY WORDS: urban forestry; ecosystem services; air pollution removal; carbon sequestration; tree value

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