Using GIS to Characterize Urban Tree Canopy Values, Change, and Ownership: A Case Study in the City of Winona, MN USA

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Abstract

Cities often capture "gray infrastructure", features such as water mains, sewers, streets, and sidewalks in a GIS to evaluate, manage, and maintain them. However, urban forests or the "green infrastructure" of cities often do not receive similar valuation and management. Urban tree canopy (UTC) cover, a primary indicator used to compare and evaluate urban forests, provides several ecosystem services. CITYgreen® software by American Forests® provides a set of ArcGIS-based tools for mapping, measuring, and quantifying the benefits of UTC. Aerial photo-interpreted (digitized) landcover and UTC data are used within CITYgreen GIS models to reveal landcover composition and UTC derived benefits, including air pollution removal, reduced run-off and contaminant loading, and carbon sequestration and storage. For Winona, MN, aerial photography from 1994 and 2007 were used to characterize past and present UTC coverage and values. The areas and values are compared to understand recent changes. In addition, two scenarios provide insight to the future, one addresses the potential canopy loss due to the emerging threat to ash trees (*Fraxinus spp*.) by the emerald ash borer (EAB) (*Agrilus planipenni*s), and another examines proposed street tree planting affect on UTC values. Landcover and UTC area and its associated values are calculated in a general manufacturing land use study area and in a larger city core area representing several zoning types. The city's present (2007) UTC coverage is further characterized by examining UTC by ownership and zoning classes. Development in specific commercial land use area in the eastern portion of the city between 1994 and 2007 caused a dramatic loss of UTC area and value, while a slight increase in UTC area and value was found in the wider city-core study area. Tree Canopy percentages vary by zoning type whereas UTC percentages by ownership types exhibit less variability. The city and private landowners contribute the vast majority of UTC area. These data can inform the public and assist city planners and urban foresters in understanding status and values of the past, present, recent changes, and future of the city's urban forest. Monetary values herein are estimates only with unknown confidence. The intent of these values is only for comparative purposes. All monetary values referenced are in 2011 dollars.

Introduction

Trees, especially those in urban environments have long been recognized for their aesthetic values. Now, more increasingly, they are evaluated for their biological functions and the associated ecosystem services. These valuable services, once quantified, can be translated into monetary values. Urban forest research reveals a multitude of benefits

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where the urban tree canopy (UTC) is the driving force in the urban forest's ability to produce benefits. UTC is the layer of leaves, branches, and stems of trees that cover the ground when viewed from above (Grove, Oneil-Dunne, Pelletier, Nowak and Walton, 2006). Trees improve air quality (Nowak, 1993), protect water quality (Dwyer, McPherson, Schroeder, and Rowntree, 1992), save energy, and provide wildlife habitat (Coder, 1996; Nowak and Dwyer, 2000; Dimke, 2008). Research also suggests urban forests can increase real estate values (Coder, 1996; Dimke, 2008), extend the life of paved surfaces (McPherson, Simpson, Peper and Ziao, 1999), improve economic sustainability (Coder, 1996), and increase sociological benefits (Prow, 1999; Taylor and Kuo, 2009). McPherson, Nowak, Heisler, Grimmond, Souch, Grant, and Rowntree (1997) conclude by considerable margins, these benefits can outweigh costs of urban forestry programs.

Urbanization of land increases the percentage covered with impermeable surfaces which increases runoff rates. Nowak and Walton (2005) predict the area of urban land in the U.S. will increase from 3.1% in 2000 to 8.1% in 2050. Tree canopies intercept rainfall, reducing flows into storm sewers and waterways, and filter water and air pollutants. The benefits provided by leaf area (UTC) increase as the area of UTC increases (Maaco and McPherson, 2002).

Nowak (2006) suggests urban forests can be developed as a biotechnology to improve environmental quality, and that properly designed and managed urban forests can help meet regulatory requirements for air and water quality. They can help with specific environmental regulatory programs including: (a) State Implementation Plans (SIPS) of the Clean Air Act, (b) Total Maximum Daily Loads (TMDL) and Stormwater Program for Municipal Separate Storm Sewer Systems of the Clean Water Act, and (c) the Kyoto Protocol, aimed at reducing greenhouse gases.

However communities must indentify and comprehensively describe the status and performance of trees and the overall urban tree canopy (UTC) cover in the community (Dwyer and Miller, 1999; Pauleit and Duhme, 2000). This is important to gain support for urban forestry programs in order for them to plant, maintain and replace trees (Dwyer and Miller, 1999) and to preserve and enhance the exiting urban forest (Pauleit and Duhme, 2000).

The intent of this study is to provide baseline information regarding past (1994) and present (2007) UTC and the associated values assigned to the UTC using GIS models in CITYgreen® software (American Forests®). Comparison of canopy coverage between these dates provides indications of change in area and values associated with this UTC. The tree canopy was examined in a specific study area that recently experienced a significant amount of development and in larger study area intended to be representative of the entire city core area. In addition, GIS overlay analysis methods were used to characterize the current UTC area percent canopy by ownership and zoning types. This information is intended to inform the community and city officials of UTC status and value in the study area and to aid in planning and management of the city's forest (both private and public trees).

Study Area

The City of Winona, MN USA, with an estimated population of 25,399 in 1990

(US Census) and 27,592 in 2010 (US Census), was originally built in the historic floodplain of the Mississippi River. Much of the land in the central core of the city has been developed for well over a century. However, an area zoned as general manufacturing recently expanded its development. Part of this development involved dredging a portion of nearby Lake Winona, filling in wetlands and removing trees, including a forested wetland area, to make way for large retail stores, manufacturing facilities, and their associated parking lots and turf areas.

Additionally, a study area was selected to be a representative core area of the city and a subset area of the expanded general manufacturing area noted above was selected to characterize a specific area zoned as general manufacturing. This area recently experienced significant development activity. For the purposes of this study, this relatively newly developed area is referred to as the east-end commercial study area (EEC) covering 231.3 acres (Figure 1). The city-core study area, here after referred to as the half city core (HCC) (Figure 1) covers approximately 1,929 acres and includes several types of land use and zoning designations (Appendix 14). This wider study area represents long-developed areas in the city and most of the HCC area has been urbanized or developed for several decades or even over a century.

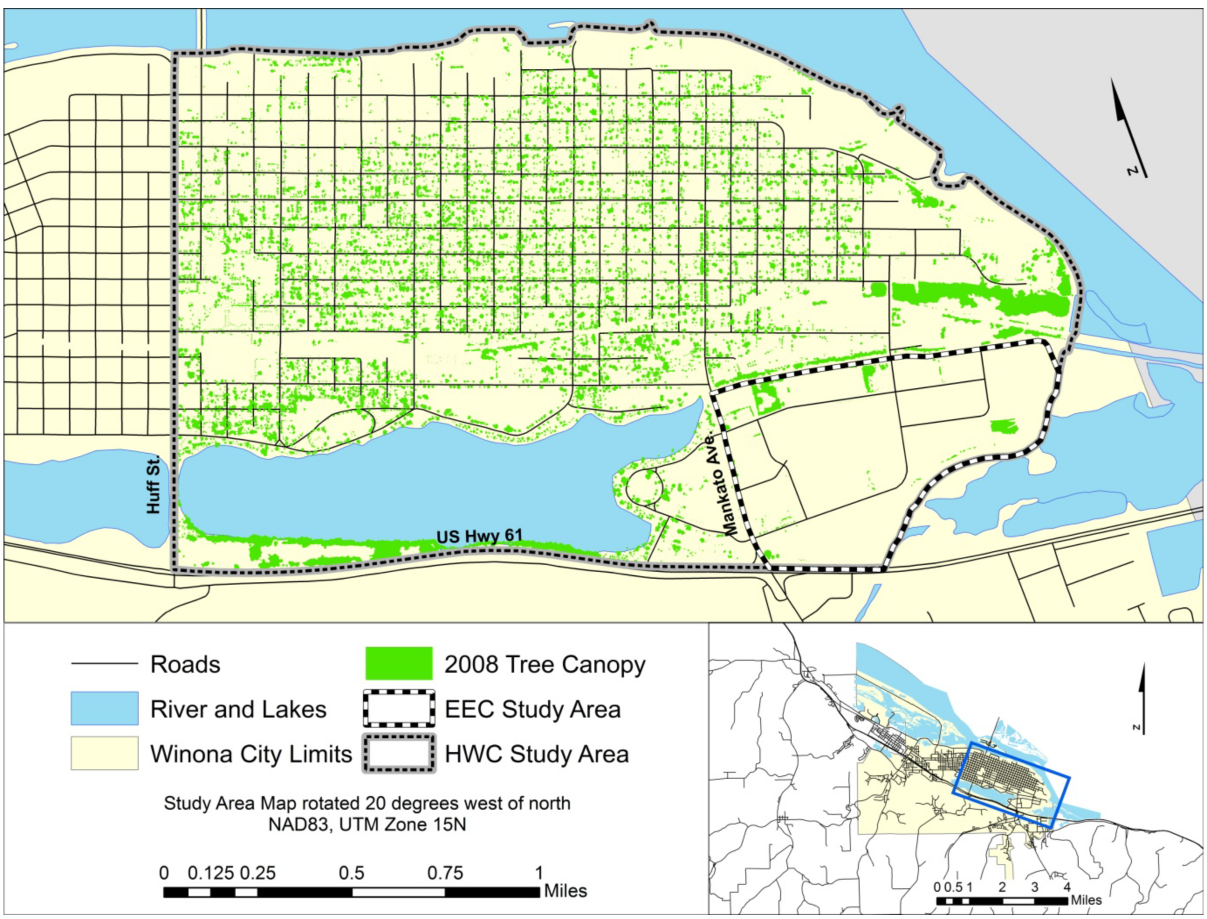

Figure 1. Study areas, east end commercial (EEC) and half-city core (HCC) in relation to the Winona City limits and roads. Note the EEC area resides within the HCC area and that they share a portion of their boundaries.

Methods

Data Acquisition and Development

GIS and tabular data were obtained from the City of Winona, Winona County, USGS Upper Midwest Environmental Sciences Center website and CITYgreen® for ArcGIS software (hereafter CITYgreen). Landcover and UTC data were created through aerial photo-interpretation using onscreen digitizing methods in ArcGIS. Existing National Land Cover Datasets (NLCD) (e.g., 2001 NLCD) were considered too coarse for this project; Nowak and Greenfield (2010) found the NLCD significantly underestimated tree canopy compared with aerial photographic interpretation by an average of 10%. Two separate dates of photography were chosen, 1994 color infrared (CIR) obtained from the USGS Upper Midwest Environmental Sciences Center, and 2007 true-color aerial photo mosaics taken by FEMA for capturing the extent of flood effects during 2007 (36 separate images) obtained from the Winona County, MN Planning Department. GIS data including a digital elevation model (DEM), roads, city boundaries, hydrants, and zoning data were obtained through the City of Winona. Parcel data, containing fields such as owner types and parcel size were obtained from the Winona County Planning Department. Finally, the CITYgreen software contained packaged data used in modeling UTC values according to landcover classifications. These data included soils (GIS data), precipitation, air pollutant, water contaminants, and landcover tables with curve numbers.

Aerial photo interpretation using on-screen digitizing methods in ArcGIS were employed to create the 1994 and 2007 UTC polygon vector data for this project. The data were created in ArcGIS 10.0, primarily using the 'freehand' digitizing tool for tree canopies. The auto-complete polygon digitizing tool was used to digitize other landcover types (e.g., pavement, buildings, turf grass). The following conventions were followed for digitizing tree canopies and other landcover classes: 1) tree canopies were defined as the area of ground by the extension of plant foliage, where vegetation appeared to have a height of at least six feet; 2) A 1:500 scale used to digitize landcover for 2007 photography (Figure 2), 1994 photography (lesser resolution) were digitized at 1:750 scale (Figure 3); 3) shadowed areas were classified as unknown landcover classes.

UTC Coverage and Values – Past and Present

While several different approaches have been used to place a monetary value on individual trees (Dymke, 2008), the CITYgreen software model uses UTC cover (a basic structural component of the urban forest) to calculate tree services. The services valuated by the software include air pollution mitigation and carbon sequestration and storage, stormwater reduction, and reduced water contaminants.

Calculating UTC percent cover and area using 1994 and 2007 photography allowed for a comparison of values, illustrating UTC changes over the 13-year time period. In addition to the tree cover, the CITYgreen GIS model requires other landcover information to produce its UTC percent coverage and associated value outputs. Within the EEC study area, the remaining classification of landcover was completed by aerial photo interpretation from both sets of imagery. This created a detailed landcover dataset containing both UTC and other landcover classes (e.g., parking lots, streets, buildings, turf grass).

Figure 2. Tree canopies (light-green outline) digitized on 2007 true-color aerial photography at 1:500 scale.

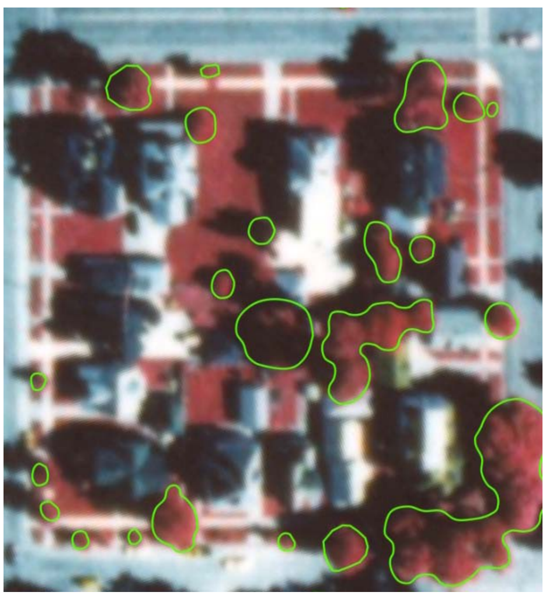

Figure 3. Tree canopies (light green outline) interpreted and digitized on 1994 color infra-red (CIR) aerial photography at a 1:750 scale. Notice the long shadows cast by buildings and trees.

Given the labor-intensive nature of creating such detailed landcover data by aerial interpretation/onscreen digitizing methods, the larger study area (HCC) utilized existing landcover data provided by the City of Winona. These landcover polygon data represented broader landcover classes (e.g., impervious surfaces 50-75%) and overall coarser resolution information (large citywide polygons) than the afore-mentioned photo-interpreted (digitized) landcover classes. Only one landcover vector dataset was available from 2000 and it was used for both 1994 and 2007 CITYgreen analyses in the larger HCC study area including the area represented by the EEC.

This landcover dataset avoided the labor-intensive digitizing of landcover and provided an indication of relative UTC cover and value changes. However, neither of the HCC tree canopy value estimates of 1994 or 2007 are likely to be as accurate as the EEC study area tree canopy cover and values estimates that used detailed landcover classes. The coarse landcover data likely did not precisely represent ground conditions for either of the dates, 1994 or 2007. The landcover classes in the city's landcover dataset were combined with photo-interpreted UTC in the entire HCC study area, whereas a complete landcover dataset was created in the EEC study area using aerial photo-interpretation (digitizing) for both 1994 and 2007 aerial photography. All HCC numbers reported in this study used the combined predefined landcover dataset from the city with the digitized tree canopies and all EEC numbers used a completely digitized landcover dataset for both dates.

This resulted in four separate landcover datasets: two comparable sets for the larger HCC study area and two for the subset EEC study area. These landcover datasets were then cross-walked (translated) to the predefined landcover classes within the CITYgreen software. These landcover classes contain the predetermined curve numbers necessary for the CITYgreen analysis. The landcover class crosswalk for the HCC study area landcover dataset is available in Appendix

1, and the crosswalk for aerial photo-interpreted landcover classes in the EEC study area is available in Appendix 2.

CITYgreen software contained several preferences tabs in which the user selected various parameters for the analyses. The customizable tabs with parameters that affect the final outputs included air pollution, carbon, soils, landcover types, rainfall, and elevation. All customizable parameters were selected once and applied to run all five individual analyses. The five analyses included the HCC in 1994 and 2007, the EEC in 1994 and 2007, and the EEC with a proposed tree-planting scenario.

The software contained GIS models based on peer-reviewed research. First, the software calculated the air pollution-removal value of the study area's UTC based on the Urban Forest Effect model (UFORE) developed by the U.S. Forest Service (USFS). The software then reported amounts (lbs removed per year) of each air pollutant trees naturally filter from the air and the associated dollar value of this removal where dollars were based on avoided externalities. The UFORE model also estimated the amount (tons) of carbon stored in the biomass of trees (i.e., the stems, branches, and roots) making up the UTC. It also provided a calculation of yearly carbon sequestration (tons of C). It also calculated additional carbon removal occurring as a result of trees that make up the UTC growing. Research by Nowak and Rowntree (1991); McPherson, Nowak, and Rowntree (1994) developed calculations to determine carbon storage and sequestration estimates. Since this study (Winona tree canopy) lacks site-specific air pollutant samples and precise forest structure information (e.g. young or mature trees), it utilized an average or unknown age where the weight of stored carbon per unit area of canopy was 96.46 grams per square meter and the annual rate of carbon sequestration per unit area of canopy was 0.751 grams per square meter. Air quality information from 55 cities with prior USFS research (Nowak, 2003) provided the base information for air pollutant avoidance (capture). In this study, Minneapolis, MN was selected for its air pollutant numbers.

The local (Winona) rainfall patterns, soil type, slope, and landcover characteristics were used in the Urban Hydrology for Small Watersheds model (Technical Release 55 or TR-55) (USDA, 1986) by the CITYgreen software. The input values were customizable based on specific study objectives and study site attributes. In the elevation tab, the software was directed to the location of a 10-meter digital elevation model (DEM) of the city (Winona). In the rainfall tab, the software was referenced to a database containing local rainfall amounts based on a two-year, 24-hour storm event and the construction cost, in U.S. dollars per cubic foot of stormwater facility processing to manage the additional peak stormwater runoff volumes that would occur if trees were removed from the study area. For this study, the default value of $2.00 per cu. ft. was chosen for all analyses. The TR-55 runoff model compares two different scenarios on the same site to determine the runoff volumes and associated savings. That is, the runoff and water quality values are calculated by comparing the study area with trees to the study area with impervious surfaces in the place of those trees. In the landcover tab the default landcover is "open space: grass: scattered trees." In cases where landcover was unknown (i.e. shadow areas in the aerial photography) this landcover type was used.

The final model used to create the CITYgreen output for water quality utilized the TR-55 runoff model and the L-THIA spread sheet model developed by Purdue University and the U.S. Environmental Protection Agency (EPA). Working with the TR-55 model, the L-THIA model calculates the amount of contaminant loadings, N, P, suspended solids, Zn, Pb, Cu, Cd, Cr, biological oxygen demand (BOD) and chemical oxygen demand (COD) based on the land use and the associated default values for loadings. Refer to the CITYgreen software manual for a more detailed explanation of the models and a full list of references.

Another indication of change (UTC loss and gain) within the HCC study area was calculated by selecting all UTC polygon features in the 2007 digitized dataset that intersected those in the 1994 digitized dataset. Switching the resulting selection captured the 2007 polygons (tree canopies) that did not intersect the 1994 polygons (tree canopies). This selection was exported to provide an indication of new trees in the 2007 photography. The reverse selection was made to select trees that were in existence in the 1994 photography and were since removed. It is important to note this assumes ground accuracy between datasets was such that polygons representing individual trees were aligned properly. In addition, a source of error existed in this analysis method because not every polygon represented an individual tree; some large polygons represented several individual trees. For example, if a large multi-tree polygon in the 1994 imagery lost one of its larger trees, depending on their location, the remaining trees (2007) may have been erroneously counted as new tree area.

Given a significant loss of UTC in the EEC area from 1994 to 2007, a fully stocked tree canopy will eventually reclaim some of the lost UTC area values (reductions in runoff, contaminants, and increases in carbon sequestration and storage), assuming trees are maintained and replaced after removal. A fully stocked city tree canopy can be considered one where trees are planted in all available planting sites in boulevards along streets and open areas around buildings with enough room to grow to maturity and not conflict with existing infrastructure or land purposes. To address this, a tree planting scenario was created in the EEC study area using points placed at approximately 7.6-m (25-ft) spacing between trees, a minimum of 10 ft from driveways, and a minimum of 25 ft from road intersections and fire hydrants in existing pervious areas (primarily in turf grass or mulch covered boulevards). The points were then converted to polygons where an eight-foot radius or sixteen-foot diameter tree canopy was assumed (representing approximately 10-15 years of growth for typical boulevard tree species in the Midwest).

The aerial photo interpretation process yielded 629 tree-planting sites. These sites were intended to represent a minimum stocking level. Since this only used photo-interpretation methods along with ancillary hydrants location data. On-the-ground data would provide more detailed location information accounting for feature locations such as signage and above and below ground utilities. This scenario proposing an expansion in UTC area in the EEC study area was then run-through the CITYgreen analysis.

Ownership Type

City of Winona 2010 parcel data and 2007 UTC polygon data provided an indication of UTC ownership composition and the UTC cover percentages within a set of grouped ownership classes in the HCC study area. The ArcGIS overlay analysis tool, union, was used to merge the digitized UTC data with the parcel data.

The XTools table function, “calculate area”, created an updated area field for this resulting layer and the tool was used to export the attribute table to Microsoft Excel. A new field of ownership classes created through the interpretation of names in the ownership field of the Winona County parcel data was then added. This provided a means of creating UTC cover percentage and ownership summaries.

Zoning Type

Similar to the parcel data, zoning data were overlaid (intersected) with the digitized UTC polygon data. The resulting polygon areas were re-calculated using Xtools. The zoning data contained a data field called zoning code, which indicated the broad zoning type in a given area of the city. Using Microsoft Excel pivot tables, the data were queried and summarized by zoning type and percent UTC coverage within the entire HCC study area. The total UTC area within each zoning type was divided by the total area of the zoning type clipped to the study boundaries.

Results

UTC Coverage and Values – Past and Present

The HCC study area contained a total UTC coverage of 253.4 acres (13.2% cover) in 1994 and a total of 223.0 acres of UTC in 2007 (11.9% cover). This indicated a net loss of 30.3 acres or a 12% decrease in the total tree canopy area (Table 1). The primary reason for this loss in UTC area was removal of a large floodplain forest area for retail and manufacturing development in the EEC area (a subset of the HCC). Therefore, in excluding the EEC area from the calculation of UTC area change, a net increase in UTC area of 35.7 acres was realized. This meant a 19.7% increase in total canopy area for the HCC without the EEC area (Table 1).

The EEC area experienced a significant reduction (90%) in tree canopy area. In 1994 there was a total of 73.6 acres. In 2007 there was a total of 6.6 acres of tree canopy. Over 70 acres of forested area (primarily remnant woodlands and forested wetlands) was converted to other landcover types, primarily undeveloped grass/shrub landcover classes or to impervious surfaces such as parking lots, buildings, roads, and sidewalks.

Table 1. Urban tree canopy (UTC) area for both study areas (half city core [HCC] and east-end commercial [EEC]) and percent change in area 1994 to 2007.

Year	UTC Area (ac)	% Change
HCC Study Area		
1994	255.1	--
2007	224.7	--
Net Change	-30.4	-11.9
EEC Study Area		
1994	73.6	--
2007	6.6	--
Net Change	-67.0	-89.8
HCC Study Area (Excluding EEC Area)		
1994	181.5	--
2007	217.2	--
Net Change	+35.7	+19.7

Comparison of the 1994 and 2007 landcover data, CITYgreen landcover classes (reclassified from aerial interpreted classes) in the EEC study area illustrated significant alterations of the land surface; approximately 130% increase in the total area of impervious surfaces and a 24% increase in the area of meadow (primarily undeveloped lots) occurred. In addition, a nearly complete loss of remnant, wooded areas occurred. Refer to Appendix 3 for a table displaying these changes.

This loss of tree canopy represents a change in the values placed on the UTC for their functions in air and water quality protection and changes in the estimation of carbon sequestration and storage. The UTC in the EEC study area, during 1994, was estimated by the CITYgreen model to absorb and filter out significant amounts (lbs) of air pollutants. The total assigned value for air pollutant removal, combined removal of CO, O_3, NO_2, and particulate matter (<10 microns) (PM_{10}) was $10,925. The air pollutant-removal values associated with UTC coverage in the EEC study area during 2007 were reduced to a total of $2,394. Refer to Appendix 4 for a table displaying all air quality values of the EEC study area for 1994 and 2007.

The UTC cover in the EEC during 1994 translated into a total of 3,164.4 tons of carbon stored in the existing tree canopy and annually sequestered 24.64 tons of carbon. In 2007, the same area only stored an estimated 285.5 tons and sequestered (annually) 2.23 tons of carbon (Appendix 5). The UTC could provide the area $915,593 in stormwater detention cost savings in 1994. In 2007, the loss of UTC cover and its relationship to the massive increase in the area of impervious surfaces meant the model calculated only $130,477 in total stormwater savings. This represented an 86% loss in potential savings (Appendix 6). Finally, the percent change in the contaminant loadings from 1994 to 2007 decreased by 87% (overall average across all contaminants) (Appendix 7).

The results of the CITYgreen analyses for the larger study area (HCC), which includes the EEC using the combination of existing landcover data and digitized UTC indicate a small reduction in total UTC area, from 253.3 acres in 1994 or 13.1% coverage to 223.0 acres in 2007 or 11.6% coverage. Associated air quality benefits were reduced slightly from $37,639 to $33,130. Carbon storage and sequestration totals also decreased. Total stormwater savings associated with UTC in the HCC study area actually increased slightly (4%) from a total savings of $2.56 million to $2.66 million. Finally, water quality calculated for both 1994 and 2007 were nearly equal. These were contaminant loadings expressed as a percent change in contaminant loadings without trees. That is, with trees the amounts of each contaminant would be reduced by this percentage. The same was true of water quantity (stormwater) savings calculations. Refer to Appendices 3 through 7, for details of 1994 to 2007 HCC landcover change, air quality parameters, carbon storage and sequestration, stormwater savings (water quantity), and contaminant loading (water quality), respectively.

In addition to the CITYgreen analysis, a polygon selection method in ArcGIS provided further characterization of change in UTC cover from 1994 to 2007. According to this selection method, a large area, relative to the total canopy area, changed. This may have been by complete tree gain or loss. Overall, the analysis revealed a larger area of loss than area of gain. As previously noted, a large UTC area was removed within the EEC study are between 1994 and 2007. To further describe the change according to this analysis, both gain and loss area in the HCC study area (with and without the EEC area) were examined (Table 2). Excluding the EEC study area loss and gain acreage, the HCC study area experienced a net loss of 6.4 acres of UTC.

Table 2. Loss and gain of tree canopy polygons (individual trees or overlapping tree canopies) in HCC study area (1994 to 2007).

Category	UTC Area (ac)
Gain	17.3
Loss	28.2
Net Change	-10.9
Gain w/o EEC*	16.7
Loss w/o HCC*	23.0
Net Change w/o EEC*	-6.4

Notes: Gain and loss area was calculated using select by location: do not intersect in ArcGIS, for both 1994 and 2007 polygon datasets. *The EEC study area was excluded for comparison.

Future Scenario

After the identification of 629 potential planting sites, hypothetical trees were planted in boulevards and parking lot islands (virtually, in a GIS). Their growth was simulated approximately 15 years (roughly to year 2022). This meant they grew from 2-inch caliper of dbh (diameter at breast height) trees with insignificant canopy areas in 2007 to trees with canopy diameters of 16 feet in 2022. This analysis did not account for growth or removal of trees already present in the 2007 aerial photography. This created an additional 3.1 acres of tree canopy area. In the 2007 analysis there was a total of 6.6 acres (or 2.9% coverage) of UTC and with the future simulation this increased to 9.7 acres or (4.2% coverage). The total amount of air pollution removal value changed from $987 in 2007 to $1,435 in 2022, a 45.2% increase in savings. This relatively large increase may be due to the trees position near sources of much of the air contaminants (roads and the associated traffic). The carbon storage increased from 285.83 to 415.77 (tons of C), and annual sequestration rates from 2.23 to 3.24 also representing a 45% increase. However, the effects of the increase in tree canopy in the scenario did not influence the estimations of water quantity (stormwater) or water quality (contaminant loadings) according to the analysis.

Ownership Type

Two ownership types accounted for the vast majority (92.4%) of the total UTC area in the HCC study area, “city” and “private”, 47.1% and 45.3%, respectively. The remaining UTC area fell in the following classes: Port Authority (3.2%), University (1.5%), State (1.1%), Hospital (0.6%). All other types categorized from the parcel data (church, HRDA, school, non-profit, and county) accounted for less than one-half of a percent of the total UTC area in the HCC study area.

These ownership types were also summarized by the percentage of UTC by area (Figure 4). This analysis indicated a comparable percentage in the city (Winona), private, port authority, university, and state ownership categories. While, classes such as hospital, church, nonprofit and county contained lower UTC percentages. HRDA showed the highest percentage UTC of any class. These percentages did not identify the ownership of individual trees that make up the digitized UTC, rather only the tree canopies that coincide with the parcel or in the case of city ownership class, the area between parcels. For example, trees in boulevards, which are the city’s responsibility, may have contributed to tree canopy over private or other parcels, or where trees in private or other parcels contribute to city areas. Based on visual examination, it appeared that the latter was more often the case.

Zoning Type

The percent UTC for each of the zoning types within the HCC study area followed

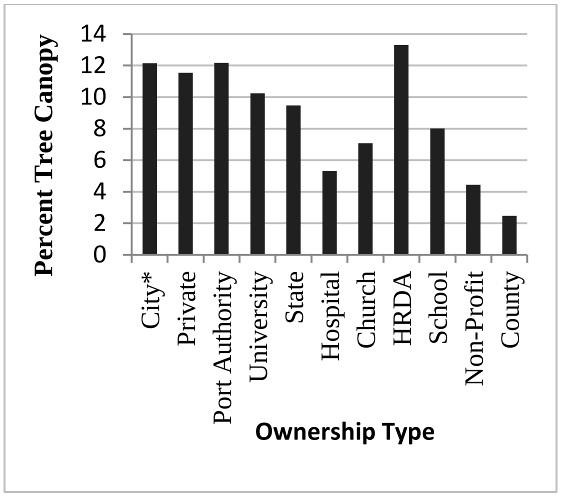

Figure 4. Percentage of urban tree canopy (UTC) cover by ownership type.
* HRDA stands for Housing and Redevelopment Authority. "City" areas included streets, sidewalks, boulevards, and parcels specifically owned by the City of Winona. However, Lake Winona (east portion), a 225acre water body, was subtracted from the "City" area for the percent tree canopy cover calculation.

a logical trend of lower percentages in more developed areas (e.g., mixed use business, manufacturing) and higher percentages for less built-up areas (e.g., residential areas) (Table 3). However, in the area zoned general manufacturing, the UTC percentage was inflated due to large undeveloped areas with unmaintained, remnant-wooded areas. In addition, the east Lake Winona area was contained within the study area. To accurately present tree canopy percentages the lake area was subtracted from the total area in the respective zoning type (R2, Residence 1-Family). Refer to Appendix 14 for a map illustrating the zoning types and 2007 UTC in the HCC study area.

Discussion

The primary source of UTC area loss in the EEC was due to loss in non-planted woodland areas or forested wetland remnants. From visual inspection of the imagery, it is suspected that undeveloped edges along manufacturing areas and along railroads and road right-of-ways may contribute significantly to tree gain and/or loss from 1994 to 2007.

Table 3. Urban tree canopy (UTC) area and percent UTC cover by zoning type for the half city core (HCC) study area in 2007.

Zoning Code	Description	Total Area (ac)	Total Canopy Area (ac)	Percent Tree Canopy
B-1	Neighborhood Business	31.38	4.09	13.06
B-2	Central Business District	50.46	2.06	4.07
B-2.5	Mixed Use Business District	11.50	0.20	1.72
B-3	General Business	72.82	3.45	4.74
M-1	Light Manufacturing	143.17	6.55	4.57
M-2	General Manufacturing	471.13	40.55	8.61
R-1	Residence - 1-Family	485.32	61.39	12.65
R-1 *	Residence - 1-Family	260.32	61.39	23.58
R-2	Residence - 1-4 Family	519.99	87.53	16.83
R-3	Residence - Multi Family	144.72	18.40	12.71
Totals:		2,190.72	224.20	10.23
Totals* (minus lake area):		1,705.40	224.20	13.15

*This represents the exclusion (subtraction) of the east Lake Winona area, 225 acres, in the study area, zoned: residence – 1-family.

These areas often lack active vegetation management for periods of time allowing fast growing trees such as the invasive Siberian elm (*Ulmus pumila*) to cause a quick increase in UTC area. These areas are then periodically cut-back or treated with herbicide to clear right-of-ways or completely removed for development. This can have a significant influence on UTC loss and gain.

The CITYgreen tree benefits analyses in this study all used the same assumption where the values were calculated based on the idea that if the UTC cover in each study area were replaced with impervious surfaces. This replacement assumption results in much higher stormwater savings than if the landcover class replacement was, for example, turf grass. The replacement landcover is complex for areas where tree canopies overlap several different surfaces (e.g., turf grass, buildings, sidewalks, roads, flowerbeds, patios). All of these surfaces have different permeability characteristics and therefore respond differently to the 2 year, 24 storm event that the stormwater savings calculations are based upon. In summary, caution should be used in interpreting the stormwater values created in this study.

Sources of Error

The 1994 CIR aerial photography, collected at a 1:15,000-scale represented an approximate ground resolution of one to 3.3 ft. The sun angle was such that in much of the photography there were considerable shadows. While shadows can aid in interpreting canopy height (i.e. tall trees are more distinguishable from large shrubs of equal width), in some cases they prevent any interpretation/designation of landcover class, thereby presenting a limitation in the data. Sometimes this means missing smaller trees or other features within building or larger tree shadows. The 2007 true-color aerial photography contains very little shadow area and is a much higher resolution, approximately 6- to 12- inch ground resolution. Note that these resolution estimates are not photogrametrically accurate measures of resolution, rather estimates based on visual examination of adjacent objects within the photo scenes.

Another source of error for the analysis results exists in the crosswalk of interpreted landcover classes to the available landcover classes with Curve Numbers (CN) in the CITYgreen software. A curve number is an empirical parameter used to predict the amount of runoff or infiltration from excess rainfall in an area. In some cases, choosing a landcover class in the list of predefined landcover classes in the CITYgreen list was not clear. If the existing landcover dataset contained, for example, “Impervious surfaces 35-75%” as the landcover class, it was not intuitive which CITYgreen landcover classes would be the most appropriate equivalent class. The landcover class “impervious surfaces 35-75 %”, the landcover class “Urban: Residential: 0.125 acre lots size” was selected from the CITYgreen list of options.

Future of the UTC

The emerald ash borer (EAB) (*Agrilus planipennis*), a non-native beetle first discovered in Detroit in 2002, has killed billions of ash tree (*Fraxinus* spp.) across the Midwest, U.S. (Buck and Frappier, 2011). Though it has not been found in Winona to date, “it poses an enormous threat to all of North America’s ash resources” (Buck and Frappier, 2011, pp. 2.1). A 2007 sample inventory of the city’s boulevard revealed the following estimates of tree composition by species: maple 38%, ash 23%, hackberry, 6%, linden 5%, oak 3%, and other species together 25% (Keith Nelson, Assistant City Manager [Winona, MN], pers. comm., July 2011).

If the assumption this boulevard species composition sampling is representative of citywide species composition (including trees on private lands) and given the prediction ash trees have a nearly 100% mortality rate when faced with an EAB infestation, this could represent an enormous loss to UTC cover in the city. In addition, this would represent an in-kind loss of the associated UTC values. The losses could rival the scale of American elm (*Ulmus americana*) tree losses communities faced when Dutch Elm's Disease swept across the U.S. in the 1960s and 1970s.

With large losses of UTC cover in the EEC study area and the primary conversion of this canopy area to a large area of parking lots, the questions of what other ecological costs are associated with these parking lots and how much parking is truly needed is relevant. Davis, Pijanowksi, Robinson, and Engel (2010) found in Tippecanoe County, Indiana the number of parking spaces (excluding those in private driveways or on-street parking) totaled 1.7x the number of registered vehicles, 6.3x the number of households, and 2.2x the number of people living in the county of driving age. Future study would be needed to determine if these statistics would be similar in Winona County, MN.

The tree planting scenario increased UTC in a developed area. The primary change in calculated values were in air quality protection and carbon sequestration, whereas stormwater runoff savings and water contaminant loading remained nearly identical based on the models. It is likely that a more significant area of tree canopy would be needed to realize a significant difference in the amount of stormwater and contaminants reduced by the UTC.

Conclusions

This analysis provides baseline UTC information and describes a software and additional GIS methods used to characterize a city's UTC. A significant investment in time for the project was dedicated to the creation of vector data (UTC and landcover); both imagery dates contain polygon datasets with thousands of features. In the HCC study area, the 1994 UTC data contained 7,934 individual polygons and the 2007 UTC data contained 7,468 polygons; in some cases this represented individual trees, in other cases several trees or even hundreds of trees. Even more time consuming was the creation of full landcover data at this map scale; within the EEC study area, there were 337 polygons in the 1994 landcover data. The photo scene became more complex and higher in resolution in the 2007 data, resulting in 651 individual polygons. The digitizing accounted for over 195 hours of the total project time.

An alternative method to on-screen (heads-up) digitizing for capturing high resolution landcover features was examined during the initiation of the project. Software called Feature Analyst™ was explored. After nearly 30 hours of experimentation to create a UTC layer and to identify impervious surfaces, the use of the software was abandoned. However, while it was found the learning curve for this software was too steep for the scale and scope of this project, this software holds promise for greatly reducing the time investment to digitize features such as buildings, roads, and vegetation.

Further Considerations

The CITYgreen software additionally

allows the user to create tree canopy scenarios where the percent tree canopy is increased or decreased or where the tree canopy is replaced with another type of landcover. These types of scenarios would aid in understanding the future of UTC. For example, with more detailed information about a particular threat to the urban forest, the software could model the effects of such a threat, or if a community planned to increase the tree canopy to a certain effect the software could reveal some of the benefits for a given scenario or set of scenarios.

The CITYgreen analysis portion of this study used water quality methods based upon the TR-55 runoff model and the L-THIA for contaminant loadings, carbon storage and sequestration calculations from methods in Nowak and Crane (1991). However, this project did not include field data specific to the city, instead it used CITYgreen default forest structure and composition parameters and air quality information from research in Minneapolis, MN. Using the field data methods described in the UFORE Model (Nowak and Crane, 2000) would increase the accuracy of estimates by providing site-specific field data on species composition and diversity, diameter distribution, tree density and health, leaf area, leaf biomass, and other structural characteristics. Because the methodology uses randomly located 0.04-ha plots stratified by land use, it could also aid in characterizing a larger study area (i.e. an entire urban forest ecosystem) (Nowak and Crane, 2000).

The USDA Forest Service also created iTree™, a software suite that allows users to analyze and assess urban forests and their values. This freely available software helps community tree programs understand the structure of the urban forest (e.g., UTC cover, species importance rankings, available planting space, species composition, and age distribution). It can also provide information on management concerns such as tree health and potential impacts of pests such as EAB. Like CITYgreen, it provides calculations, in dollar amounts, of annual environmental benefits. Finally, its summary report outputs can be used to brief elected officials, municipal foresters, arborists, etc. to promote informed decision making regarding community tree programs (USFS, 2011).

Indentifying potential tree-planting sites could be a relatively time consuming task either by on-the-ground efforts or by remote sensing and GIS-based methods. In this study, potential tree-planting sites were simply interpreted using aerial photography and collateral GIS data, such as hydrants and parcel data. However, in research examining potential planting sites in Los Angeles, CA, Wu, Xioa, and McPherson (2008) created a computer program which utilized several criteria and iteratively searched, tested, and located potential tree planting sites; they suggest the accuracy of planting site identification is highly dependent on the accuracy of the land cover classification. In this study, the high spatial resolution of the 2007 imagery provides a base for the creation of accurate landcover data. Another consideration is the use of the USFS iTree™ software suite to identify available planting space.

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References

Buck, J.H., and Frappier, S. 2011. Emerald ash borer program manual, *Agrilus planipennis* (fairmaire), ver. 1.2. United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS). Retrieved 6 June 2011 from: http://www.aphis. usda.gov/import_export/plants/manuals/ domestic/downloads/emerald_ash_borer _manual.pdf.

Coder, R.D. 1996. Indentified benefits of community trees and forests. University of Georgia. Retreived 1 July 2011 from: http://www.coloradotrees.org/benefits/Identified%20Benefits%20of%20Community%20Trees.pdf.

Davis, A.Y., Pijanowksi, B.C., Robinson, K., and Engel, B. 2010. The environmental and economic costs of sprawling parking lots in the United States. Journal of Land Use Policy 27. Pp. 255-261.

Dimke, K.C. 2008. Valuation of tree canopy on property values of six communities in Cincinnati, Ohio. Dissertation. Ohio State University, OH.

Dwyer, J.F., McPherson, E.G, Schroeder, H.W., and Rowntree, R.A. 1992 Assessing the benefits and costs of the urban forest. Journal of Arboriculture 18 (5) pp. 227-234.

Dwyer, M.C., and Miller, R.W. 1999. Using GIS to assess urban tree canopy benefits and surrounding greenspace distributions. Journal of Arboriculture 25(2): March 1999.

Grove, J.M, Oneil-Dunne, J., Pelletier, K., Nowak D., and Walton, J. 2006. A report on New York City's present and possible urban tree canopy. U.S. Department of Agriculture, Forest Service. Syracuse, NY.

Maaco, S.E., and McPherson, E.G. 2002. Assessing canopy cover over streets and sidewalks in street tree populations. Journal of Arboriculture 28(6) pp. 270-276.

McPherson, E.G., Nowak, D.J., and Rowntree, R. 1994. Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186. Radnor, PA: U.S. Department of Agriculture, Forest service, Northeastern Forest Experiment Station: 201 p.

McPherson, G.E, Nowak, D., Heisler, G., Grimmond, S., Souch, C., Grant, R., and Rowntree, R. 1997. Quantifying urban forest structure, functions, and value: the Chicago Urban Forest Climate Project. Urban Ecosystems Vol. 1, pp. 49-61.

McPherson, G.E., Simpson, J.R., Peper, P.J., and Xiao, Q. 1999. Tree guidelines for San Joaquin Valley communities. U.S. Department of Agriculture, Forest Service. Western Center for Urban Forest Research and Education.

Maco, S.E., and McPherson, G.E. 2002. Assessing canopy cover over streets and sidewalks in street tree populations. Journal of Arboriculture 28(6). pp.270-275.

Nowak, D.J. 1993. Atmospheric carbon reduction by urban trees. Journal of Environmental Management. 37, pp. 207-217.

Nowak, D.J. 2003. U.S. Forest Service, unpublished, City specific data produced for American Forests.

Nowak, D.J. 2006. Institutionalizing urban forestry as a "biotechnology" to improve environmental quality. Urban Forestry & Urban Greening 5 (2006) pp. 93-100.

Nowak, D.J., and Rownntree, R.A. 1991. Quantifying the role of urban forests in removing atmospheric carbon dioxide. Journal of Arboriculture, 17 (10) p. 269.

Nowak, D.J., and Crane, D.E. 2000. The Urban Forest Effects (UFORE) Model: quantifying urban forest structure and functions, In Hansen, M. and T. Burk

(Eds.) Integrated tools for Natural Resources iInventories in the 21st Centure. Proc. Of the IUFRO Conference. USDA Foest Service General Technical Report NC0212. North Central Research Station, St. Paul, MN. pp. 714-720.

Nowak, D.J., and Dwyer, J.F. 2000. Understanding the benefits and costs of urban forest ecosystems. In Kuser, J (ed.), Urban and Community Forestry in the Northeast. Plenum Publishers, New York, pp. 11-25.

Nowak, D.J., and Walton, J.T. 2005. Projected urban growth (2000 - 2050) and its estimated impact on the US forest resource. Journal of Forestry. December: 383-389.

Nowak, D.J., and Greenfield, E.J. 2010. Evaluating the National Land Cover Database tree canopy and impervious cover estimates across the conterminous United States: a comparison with photo-interpreted estimates. Environmental Management 46, pp. 378-390.

Pauleit, S., and Duhme, F. 2000. GIS assessment of Munich's urban forest structure for urban planning. Journal of Arboriculture 26(03): May 2000.

Prow, T. 1999. The power of trees. The Illinois Steward. Vol. 7, Issue 4. Winter 1999.

Taylor, F., and Kuo, F.E. 2009. Children with attention deficits concentrate better after walk in the park. Journal of Attention Disorders, 12. Pp. 40-409.

U.S. Department of Agriculture (USDA). 1986. Technical Release 55, urban hydrology for small watersheds, Soil Conservation Service, USDA, Washington, D.C., June , 1986.

U.S. Forest Service (USFS). 2011. iTree™, Tools for assessing and managing community forests. Retrieved 1 June 2011 from: http://www.itreetools.org/index.php. Accessed 1 June 2011.

Wu, C., Xioa, Q., and McPherson, E.G. 2008. A method for locating potential tree-planting sites in urban areas: a case study of Los Angeles, USA. Urban Forestry & Urban Greening 7, pp. 65-76.

Appendix 1. Landcover classes translated (cross-walked) into CITYgreen landcover classes for the half city core (HCC) study area for both 1994 and 2007 analyses.

Landcover Class	**CITYgreen Landcover Class (used in analysis)**
Bare Soil	Impervious Surfaces: Unpaved: Dirt
Built - Central Urban	Urban: Commercial/Business
Floodplain Forest	Water Area
Grasses/Forbes - Other	Open Space - Grass/Scattered Trees: Grass Cover >75%
Imp Surf <10%	Urban: Residential: 2.0ac Lots
Imp Surf >90%	Impervious Surfaces: paved: drain to sewer
Imp Surf 10-35%	Urban: Residential: 0.25ac Lots
Imp Surf 35-65%	Urban: Residential: 0.125ac Lots
Imp Surf 69-95%	Urban: Commercial/Business
Lake	Water Area
Marsh	Water Area
Open Water	Water Area
River	Water Area
Road Corridor	Meadow (Continuous grass, generally mowed, not grazed)
Road/Hwy	Impervious Surfaces: paved: drain to sewer
Rock / Mineral	Impervious Surfaces: Unpaved: Gravel
Shrub/scrub	Shrub: Ground cover >75%
*Trees: Unknown	Trees: Grass/turf understory: Ground cover 50% - 75%
*Trees: Litter	Trees: Forest litter understory: No grazing, forest litter and brush adequately cover soil
*Trees: Turf	Trees: Grass/turf understory: Ground cover > 75%
Wetland - Other	Water Area

*Only the “Tree” landcover classes were digitized via aerial photo interpretation/onscreen digitizing methods, all other classes were within the existing landcover dataset provided by the City of Winona.

Appendix 2. Landcover classes (aerial photo-interpretation) translated (cross-walked) to CITYgreen landcover classes in the east end commercial (EEC) study area for both 1994 and 2007.

Landcover Class (aerial photo-interpretation)	**CITYgreen Landcover Class (used in analysis)**
*Bare	Impervious Surfaces: Unpaved: Dirt
Bare Wetland	Water Area
Bare/Grass	Meadow (Continuous grass, generally mowed, not grazed)
*Building	Impervious Surfaces: Buildings/ structures: All other buildings
*Driveway/Sidewalk	Impervious Surfaces: Paved: Drain to sewer
Garden	Meadow (Continuous grass, generally mowed, not grazed)
Grass/Mulch/Shrub	Shrub: Ground cover 50% - 75%
Grass/Small Shrubs	Meadow (Continuous grass, generally mowed, not grazed)
Grass: Small Shrub	Meadow (Continuous grass, generally mowed, not grazed)
*Gravel	Impervious Surfaces: Unpaved: Gravel
Impervious Other	Impervious Surfaces
Mulch	Open Space - Grass/Scattered Trees: Grass cover > 75%
Mulch: Shrub	Shrub: Ground cover < 50%
New Tree	Trees: Grass/turf understory
*Open Water	Water Area
Parking Lot	Impervious Surfaces: Paved: Drain to sewer
Pavement	Impervious Surfaces: Paved: Drain to sewer
Road	Impervious Surfaces: Paved: Drain to sewer
Scrub Shrub	Shrub: Ground cover > 75%
Scrub Shrub/Bare	Shrub: Ground cover < 50%
Shrub	Shrub: Ground cover > 75%
Shrub: Gravel	Shrub: Ground cover < 50%
Shrubs	Shrub: Ground cover > 75%
*Trees: Grass	Trees: Grass/turf understory: Ground cover > 75%
*Trees: Impervious	Trees: Impervious understory
*Trees: Litter	Trees: Forest litter understory: No grazing, forest litter and brush adequately cover soil
*Trees: Unknown	Trees: Grass/turf understory
*Turf Grass	Meadow (Continuous grass, generally mowed, not grazed)
Wetland: Grass	Water Area
*Wetland: Scrub Shrub	Shrub: Ground cover > 75%
*Wetland: Shrub	Shrub: Ground cover > 75%
*Wetland: Grass/Shrub	Meadow (Continuous grass, generally mowed, not grazed)

*Landcover classes interpreted in both dates of imagery, 1994 and 2007, all others landcover classes were interpreted only in the 2007 aerial photography.

Appendix 3. Landcover change by class in the east end commercial (EEC) study area from 1994 to 2007.

Landcover Class	**1994** area (ac)	**1994** %	**2007** area (ac)	**2007** %	**% Change (+/-)**
Impervious Surfaces	1.7	0.7	4.7	2.0	+176.5
Impervious Surfaces: Buildings/ structures: All other buildings	8.6	3.7	24.1	10.4	+180.2
Impervious Surfaces: Paved: Drain to sewer	27.2	11.8	71.2	30.8	+161.8
Impervious Surfaces: Unpaved: Dirt	11.0	4.8	35.0	15.1	+218.2
Impervious Surfaces: Gravel	12.3	5.3	4.3	1.8	-65.0
Meadow (continuous grass, generally mowed, not grazed	56.6	24.5	69.3	29.9	+22.4
Open Space - Grass / Scattered Trees	5.4	2.3	5.3	2.3	-1.9
Shrub: Ground cover <50%	0.0	0.0	0.1	0.0	NA
Shrub: Ground cover >75%	0.0	0.0	7.4	3.2	NA
Shrub: Ground cover 50-75%	0.0	0.0	0.4	0.2	NA
Trees: Forest litter understory: No grazing, forest litter and brush adequately cover soil	69.1	29.9	4.9	2.1	-92.9
Trees: Grass / turf understory: Ground cover >75%	2.3	1.0	0.3	0.1	-87.0
Trees: Impervious understory	0.0	0.0	0.5	0.2	NA
Trees: Grass /turf understory: Ground cover 50-75%	2.2	0.9	0.9	0.4	-59.1
Water Area (includes wetlands)	34.9	15.1	3.1	1.3	-91.1
Totals:	231.3	100.0	231.5	100.0	

Appendix 4. Air quality protection by parameter for 1994 and 2007 associate urban tree canopy (UTC) cover in the east end commercial (EEC) study area.

Air Quality Parameter	**1994** Lbs. Removed/yr	**1994** Value ($)	**2007** Lbs. Removed/yr	**2007** Value ($)	**% Change in Value (+/-)**
Carbon Monoxide (CO):	197	$84	18	$8	-90.5
Ozone (O3):	2,032	$6,242	184	$564	-91.0
Nitrogen Dioxide (NO2):	983	$3,021	89	$273	-91.0
Particulate matter (PM_{10}):	721	$1,479	65	$134	-90.9
Sulfur Dioxide (SO2):	131	$98	12	$9	-90.8
Totals:	4,064	$10,924	368	$988	-91.0

Appendix 5. Carbon storage and sequestration through derived through urban tree canopy (UTC) and leaf area indexes for the east end commercial (EEC) study area in 1994 and 2007.

Carbon storage and Sequestration	1994	2007	% Change (+/-)
Total Stored (tons):	3,164.11	285.83	-91.0
Total Sequestered Annually (tons)	24.63	2.23	-91.0

Appendix 6. Water quantity (runoff) savings associated with urban tree canopy (UTC) in the east end commercial (EEC) study area in 1994 and 2007.

Water Quantity (Runoff)	1994	2007	% Change (+/-)
Curve number reflecting existing conditions:	85	88	NA
Curve number using default replacement cover (Impervious Surfaces: Building other structures):	92	89	NA
Additional stormwater storage volume needed:	457,796	65,238	-85.7
Construction Cost per cu. Ft.:	$2.00	$2.00	NA
Total Stormwater Savings:	$915,593	$130,477	-85.7
Annual Costs (based on payments over 20 years at 6% interest):	$79,826	$11,376	-85.7

Appendix 7. Water quality for the 1994 and 2007 east end commercial (EEC) study area, expressed as the percent change in contaminant loadings by comparing existing conditions (with tree canopy) to landcover conditions where tree canopy is replaced with impervious sufaces: buildings.

Percent Change in Contaminant Loadings	1994	2007	% Change (+/-)
Biological Oxygen Demand:	24.38	3.15	-87.1
Cadmium	28.47	3.63	-87.2
Chromium	32.98	4.13	-87.5
Chemical Oxygen Demand	34.35	4.28	-87.5
Copper	0	0	NA
Lead	11.78	1.6	-86.4
Nitrogen	15.09	2.02	-86.6
Phosphorus	27.09	3.47	-87.2
Suspended Solids	24.15	3.13	-87.0
Zinc	8.8	1.21	-86.3

Appendix 8. Landcover change by class in the half city core (HCC) study area from 1994 to 2007.

CITYgreen Landcover Class	1994 area (ac)	1994 %	2007 area (ac)	2007 %	% Change (+/-)
Impervious Surfaces: Drain to sewer	547.7	28.4	663.4	34.4	+21.1
Impervious Surfaces: Unpaved: Dirt	4.9	0.3	4.9	0.3	0.0
Impervious Surfaces: Gravel	1.3	0.1	1.3	0.1	0.0
Meadow (Continuous grass, generally mowed, not grazed).	12.5	0.6	13.1	0.7	+4.8
Open Space - Grass / Scattered Trees	0.0	0.0	1.1	0.1	NA
Shrub: Ground cover >75%	1.2	0.1	1.5	0.1	+25.0
Trees: Forest litter understory: No grazing, forest litter and brush adequately cover soil	106.0	5.5	46.0	2.4	-56.6
Trees: Grass / turf understory: Ground cover >75%	11.9	0.6	19.6	1.0	+64.7
Trees: Grass/turf understory: Ground cover 50 - 75%	135.4	7.0	157.4	8.2	+16.2
Urban: Commercial/Business	204.5	10.6	202.7	10.5	-0.9
Urban: Residential 0.125 ac Lots	413.3	21.4	409.2	21.2	-1.0
Urban: Residential 0.25 ac Lots	130.4	6.8	128.1	6.6	-1.8
Urban: Residential: 2.0 ac Lots	132.6	6.9	54.6	2.8	-58.8
Water Area (includes wetlands)	227.4	11.8	226.2	11.7	-0.5
Totals:	1,929.1	100.0	1,929.1	100.0	

Appendix 9. Air Quality protection by parameter for 1994 and 2007 associate urban tree canopy (UTC) cover in the half city core (HCC) study area.

Air Quality Parameter	1994 Lbs. Removed/yr	1994 Value ($)	2007 Lbs. Removed/yr	2007 Value ($)	% Change in Value (+/-)
Carbon Monoxide (CO):	677	$289	596	$255	-11.8
Ozone (O3):	7,001	$21,508	6,162	$18,932	-12.0
Nitrogen Dioxide (NO2):	3,387	$10,407	2,982	$9,161	-12.0
Particulate matter (PM_{10}):	2,484	$5,095	2,187	$4,485	-12.0
Sulfur Dioxide (SO2):	452	$339	398	$298	-12.1
Totals:	14,001	$37,638	12,325	$33,131	-12.0

Appendix 10. Carbon storage and sequestration through derived through urban tree canopy (UTC) and leaf area indexes for the half city core (HCC) study area in 1994 and 2007.

Carbon storage and Sequestration	1994	2007	% Change (+/-)
Total Stored (tons):	10,901.80	595.9	-94.5
Total Sequestered Annually (tons)	84.87	74.7	-12.0

Appendix 11. Water quantity (runoff) savings associated with urban tree canopy (UTC) in the half city core (HCC) study area in 1994 and 2007.

Water Quantity (Runoff)	1994	2007	% Change (+/-)
Curve number reflecting existing conditions:	92	93	NA
Curve number using default replacement cover (Impervious Surfaces: Building other structures):	94	95	NA
Additional stormwater storage volume needed:	1,281,685	1,330,538 cu. ft.	+4.0
Construction Cost per cu. Ft.:	$2.00	$2.00	NA
Total Stormwater Savings:	2,2563,370	$2,661,075	+15.2
Annual Costs based on payments over 20 years at 6% interest:	$223,486/yr	$232,005/yr	+3.7

Appendix 12. Water quality for the 1994 and 2007 half city core (HCC) study area, expressed as the percent change in contaminant loadings by comparing existing conditions (with tree canopy) to landcover conditions where tree canopy is replaced with impervious sufaces: buildings.

Percent Change in Contaminant Loadings	1994	2007
Biological Oxygen Demand:	5.6	5.45
Cadmium	6.3	6.14
Chromium	7.09	6.84
Chemical Oxygen Demand	7.31	7.05
Copper	0	0
Lead	3.01	2.97
Nitrogen	3.75	3.68
Phosphorus	6.09	5.91
Suspended Solids	5.56	5.41
Zinc	2.31	2.28

Appendix 13. Proposed tree planting locations for future east end commercial study area.

Appendix 14. Zoning types and 2007 urban tree canopy (UTC) in the half city core (HCC) study area.