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# Urban Ecological Analysis, January 1996

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# City of Tampa
# Urban Ecological Analysis

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# Executive Summary

Although the majority of the State of Florida's fifteen million residents live in urban environments, most ecological studies focus on rural and somewhat pristine ecosystems. The city is a human dominated ecosystem and very little is known about it. Consequently, it is very difficult for policymakers to make decisions concerning this resource in our backyard of which so little is known. The Florida Center for Community Design and Research at the University of South Florida conducted an Urban Ecological Analysis of the City of Tampa from January 1996-June 1999. The study involved researchers and graduate students from several disciplines as well as volunteers and City of Tampa Parks Department Staff. The Florida Department of Agriculture and Consumer Affairs funded the study.

The Urban Ecological Analysis is a method established by American Forests for mapping, measuring, and analyzing the ecological and economic benefits of trees in urban environments. Aside from the obvious aesthetic benefits provided by trees in an urban environment, there are several quantifiable ecological and environmental benefits provided by trees. For example, trees intercept incoming rainfall and reduce the amount of stormwater runoff, resulting in potential reductions in stormwater infrastructure and lowered demand on existing stormwater systems. Trees also play a role in energy savings, pollution attenuation, and as habitat and food for wildlife. In effect, trees may be able to mitigate some of the costs of built infrastructure such as stormwater ponds, energy generated from power plants, and air pollution control programs.

The Urban Ecological Analysis methodology makes use of satellite imagery, GIS (Geographic Information Systems) mapping, Digital Aerial Photography and other technical tools combined with a rapid field survey to quickly assess the urban forest and then model potential benefits. Although the methods for this type of study are still being refined (including refinements made in this study), we feel the information provided to local policymakers will prove to be very valuable. The study provides indicators concerning the health of the forest, as well as the economic services it provides. This comprehensive approach allows trees to be compared to other types of infrastructure. Using the Urban Ecological Analysis methodology, we estimated the percentage of the city covered by tree canopy, the total number of trees, average tree age and health, and species diversity of the forest. Models established by the USDA Forest Service and Lawrence Berkley Labs were then employed to quantify economic benefits provided by the trees. These benefit models include: direct energy savings due to shading of buildings, reduced stormwater runoff from interception of precipitation, carbon sequestration and storage, and improved air quality from air pollutant interception and attenuation.

Specifically, the goals of the project were: (1) Quantify the change in overall canopy coverage in Tampa from 1975-1996, (2) Estimate key statistics concerning the health of Tampa's forest, (3) Estimate and model economic benefits provided by this tree canopy, and (4) Estimate potential benefits and/or costs under different future scenarios.

## Key Results of this Study

### Change in Overall Canopy Coverage from 1975-1996

The change in overall canopy cover was estimated from satellite imagery using a widely accepted technique known as the Normalized Difference Vegetation Index (NDVI). Key findings from this analysis include:

- Citywide canopy cover decreased in the time period 1975-1985 from 23% to 14%

- Citywide canopy cover increased in the time period of 1986-1996 from 14% to 19%
- A net decrease in canopy cover occurred in the time period of 1975-1996 of approximately 4%
- Canopy cover in rapidly developing "New Tampa" decreased by 20% from 1975-1996, but canopy cover in that region is still double the citywide average presumably due to existing agricultural land in the area

## The Health and Diversity of the Forest

- 46% of the tree species sampled were native species and native trees were the predominant individuals encountered including: live oak, laurel oak, and cabbage palm
- Seven out of the fifty species sampled were identified by the Florida Exotic Pest Plant Council as species that have shown a potential to disrupt native plant communities
- The diversity of trees in Tampa is relatively low with approximately 3.6 species per acre
- Canopy coverage in Light Commercial and Light Industrial study sites were extremely low at 4.7% and .8% respectively
- The age of trees in Tampa is mature and health is slightly above average
- The second most dominant tree encountered was the relatively short-lived Laurel Oak (*Quercus laurifolia*) which has a relatively short life span.  Mortality of these older trees may serve to further reduce canopy coverage in the city.
- Tree density (~15 trees / acre) in the city is less than 8% of the least dense stand of natural hardwood hammock ecosystem (202 trees /acre) and is slightly less than 50% as dense as other cities like Chicago (28 trees / acre) and Marlborough (20 trees / acre)

## Economic Benefits of the Current Urban Forest

- Total annual benefits of Tampa's trees are approximately $16 million annually or a per capita benefit of $55
- The forest reduces household energy consumption in the city by over 28 million kWh which saves approximately $2.4 million annually in reduced energy bills.
- Tampa's trees reduce 8.7 million gallons (65 million cubic feet) of runoff annually saving the City an estimated $10 million annually
- Trees sequester 1,541 tons of carbon and store 336,211 tons with an economic value of $35,443 annually
- Tampa's trees remove 4.7 million pounds of air pollutants per year with an economic value of $3.4 million annually

## Future Scenarios

- In twenty years, the current tree planting initiative started by the Mayor of Tampa (5,000 trees in five years) will result in a net return on investment of approximately $20 million, a benefit that will continue to increase each year that these trees survive.
- Including the costs of planting, maintenance, and replacement due to mortality, the cost of each planted tree will be recovered in approximately fifteen years.
- If existing agricultural and vacant land is converted to residential or mixed-use developments and tree preservation efforts are not increased, the citywide tree canopy in Tampa could decrease from 19% to 14%, possibly negating any benefits of future tree planting.

# Introduction

As urban areas expand, it is becoming increasingly important to study "urban ecosystems". The majority of the United States' and Florida's population now resides in areas that are classified as urban. In addition, Florida's population already at 15,307,457 is forecasted to grow at about 1% per year for the next 20 years. To compound the problem, the majority of Florida's urban centers are in coastal watersheds that are particularly sensitive to pollution and runoff. These estuarine systems provide billions of dollars statewide in economic impact through tourism, commercial fishing, and sport fishing activities (TBNEP 1996). This impact is highly dependent on ecosystem function, which in turn is dependent on the management of the watershed. Understanding the role of canopy cover, impervious surface, and development patterns in stormwater management and overall environmental quality is an important factor in the management of this valuable resource (Chester L. Arnold and Gibbons 1996; Schueler 1996). This study seeks to begin the research needed for a holistic model of the effects of development on natural systems and overall quality of life in urban areas.

The technology now exists through remote sensing, GIS (Geographic Information Systems), and field surveys to determine the composition, structure, function, and economic benefits of urban vegetation. Tree canopy coverage in many U.S. cities is declining as removal rates exceed replanting rates (Forests 1997c). Along with this decline is a decrease in the environmental benefits provided by trees. These benefits include, but are not limited to: the creation of cooler microclimates (Mcpherson 1994) and the reduction of energy use for cooling (Akbari et al. 1992), cleaner water through stormwater interception (McPherson 1994), and reduced air pollution through interception (Nowak 1994a) and carbon sequestration (Nowak 1994b).

The City of Tampa, approximately 110 sq. miles, is the largest city on the west coast of Florida. The current population is estimated at 289,337 persons (THCVA 1999). The city is located at approximately 28° N and 82° W in Hillsborough County (Figure 1). The population of Hillsborough County has grown by nearly 363% since 1940. Tampa's climate is considered subtropical with an annual average temperature of 72°F. The city has two distinct seasons'related to annual precipitation, wet (June-October) and dry (November-May) that can be punctuated by periods of wet weather during December-February.



Figure 1. Location of City of Tampa

Historically, the natural plant communities of the Tampa Bay region included pine flatwoods, cypress domes, hardwood hammocks, high pine forests, freshwater marshes, and mangrove forests. Most of the natural old-growth forests were eliminated in the late 1800's and early 1900's when logging activities were widespread. Following the logging, residential development boomed, as did agriculture, and additional areas of natural vegetation were eliminated . Currently, the city is predominantly covered by hardwood hammock species such as Live Oak (*Quercus virginiana*), Laurel Oak (*Quercus laurifolia*), Magnolia (*Magnolia grandiflora*), and Cabbage Palm (*Sabal palmetto*).

In Tampa, as in many cities of the Sunbelt, population is increasing (BEBR 1996). Along with population, comes an increase in what's commonly known as "suburban sprawl". This expansion

of urban / suburban land-use is increasing the boundary of the urban forest and decreasing the amount of natural forest coverage.  It is therefore imperative that municipalities inventory these urban resources and manage them appropriately.

For these reasons, The Florida Center for Community Design and Research at the University of South Florida conducted an Urban Ecological Analysis of the City of Tampa.  The goals of the project were to quantify overall vegetation change in the city from 1975-1996; characterize the age, species diversity, and distribution of Tampa's canopy; provide data about the overall economic and environmental benefits of trees in Tampa; and model the potential benefits resulting from current planting initiatives.

# Project Objectives

(1) Quantify the change in overall canopy coverage in Tampa from 1975-1995
(2) Estimate, citywide, key statistics concerning the overall health (i.e. age, diversity, etc.) of the forest by land-use type
(3) Estimate and model economic benefits provided by the current canopy using established models
(4) Estimate potential benefits and/or costs under scenarios for the future.

# Methods

## *Regional Analysis*

The use of satellite imagery in the analysis of tree canopy coverage is an efficient and effective method to quantify canopy coverage at the regional scale (Wiegand et al. 1973), (Ormsby, Choudhury, and Owe 1987). Using the method of Normalized Difference Vegetation Index (NDVI), multi-spectral scanner (MSS) and thematic mapper (TM) satellite images were analyzed in order to quantify the overall change in canopy coverage within the City of Tampa since 1975.

## Satellite Image Selection

Satellite data were analyzed over a period of 21 years (1975-1996) to determine temporal change in forest canopy cover in the city of Tampa. Several criteria were established for satellite image "scene" selection to ensure temporal, spatial and spectral compatibility. Images were selected based upon the following criteria: (1) forest cover phenological stability (leaf-out conditions), (2) lowest percent cloud cover, (3) minimal differences between precipitation, and (4) spectral compatibility. Leaf-out conditions in central Florida are approximately April – November. Cloud cover is lowest during the dry spring months March – May. Therefore, it was determined that late spring (April) provided the best atmospheric and meteorological conditions for analysis. Because of constraints with data availability and spectral compatibility a total of six images were required for the analysis. Table 1 details the imagery that was selected and the date of acquisition. Two MSS images were selected (1975 and 1985) and four TM scenes were selected (1986 and 1996) for complete coverage of the study site analysis.

Table 1. Satellite Imagery Used in Analysis

| Path / Row | Scene ID | Satellite | Acq. Date | Upper Left (UTM) | Lower Right (UTM) |
|---|---|---|---|---|---|
| 18/40 | LM2018040007511890 | Landsat 2 MSS | 4/28/75 | 833517.25W,294114.92N | 815736.45W,274137.20N |
| 17/41 | LM5017041008511290 | Landsat 5 MSS | 4/22/85 | 835734.09W,0282734.40N | 821845.62W,262333.99N |
| 17 / 41 | LT5017041008611510 | Landsat 5 TM | 4/25/86 | 840434.13W,282338.61N | 822418.30W,262922.29N |
| 17 / 40 | LT5017040008611510 | Landsat 5 TM | 4/25/86 | 834449.96W,294635.6N | 820115.7W,275824.0N |
| 17 / 41 | LT5017040009611110 | Landsat 5 TM | 4/20/96 | 835942.39W,281935.28N | 821722.74W, 263129.96N |
| 17 / 40 | LT5017041009611110 | Landsat 5 TM | 4/20/96 | 833550.62W,294941.46N | 815539.69W,275325.97N |

## Preprocessing of Imagery

The software packages EASI/PACE Image Pro (PCI 1997) was used to analyze the satellite data. The procedures followed for image processing and quality control were established by the U.S. Geological Survey for classifying imagery in coastal wetlands in West Central Florida (Raabe and Stumpf 1997). Once the imagery was selected the images were registered to the UTM (Universal Transverse Mercator) coordinate system using GPS (Global Positioning System) ground control points and GCPworks software module of PCI. Radiometric and solar atmospheric calibration were performed.

## NDVI Classification

The index used to classify the imagery was the NDVI (Normalized Difference Vegetation Index). The NDVI calculation for the MSS and TM data is as follows: NDVI = NIR-R/(NIR+R)*100, where

NIR=near infrared band, and R=red band. The images were classified on NDVI using the EASI ISOCLUS (PCI 1997) program module of PCI. TIFF images and color maps were then exported from PCI and converted to Arc/Info GRID's (ESRI 1999).

## Data Integration

Arc/Info GRID data was then overlaid with a modified version of the City of Tampa's municipal boundary that was held constant throughout the study in spite of recent and past annexations. The coverage was modified to remove areas of the city that were open water such as Tampa Bay, Garrison Channel, and other large bodies of water (see Figure 2). Percent canopy areas were then calculated using Arcview's Spatial Analyst.

## *Local Analysis*

The CITYgreen 2.0 extension of the ArcView software package (Forests 1997a) was used to model the benefits of the urban tree canopy based on field data collected on individual study sites in the City of Tampa. CITYgreen uses currently accepted models to estimate the benefit of the urban tree canopy with regards to household energy savings, stormwater reduction, and pollution sequestration using GIS data imported into ArcView and data collected during field sampling.

## GIS Data Collection and Integration

In order to utilize the CITYgreen extension, GIS data was acquired from several sources. ArcInfo NT was used to convert and project data into a UTM (Universal Transverse Mercator) projection, NAD83 Datum. Data used in the analysis are listed in Table 2.

Table 2. GIS Data Used in the Local Analysis

| Name | Description | Source |
|---|---|---|
| Orthophotoquads | Digital Orthophotography with one-meter resolution. | (USGS 1995) |
| Census Blocks | Census block GIS database and attribute data. | (Census 1996) |
| Parcels | Hillsborough County Parcel GIS database and attribute information exported in 1997. | (Halvorsen 1997a) |
| Roads | Detailed road layer. | (Halvorsen 1997b) |
| Land-use | City of Tampa Existing Land-use | (Commission 1998a) |
| Soils | Detailed soils from the Natural Resources Conservation Service soil survey maps. | (N.R.C.S. 1989) |

## Study Site Selection

Each study site for the local analysis was defined as a census block (Census 1996). Individual parcels were identified using ArcView GIS within each census block according to the Hillsborough County Property Appraiser (Halvorsen 1997b) and then classified by land-use according to the Hillsborough County-City Planning Commission (Robe 1997). Fourteen land-use categories (plus "unknown") were identified within the City of Tampa: single family residential, vacant, light commercial, public institutional, two family (duplex) residential, light industrial, commercial, multi-family residential, mobile home park / parking lot, public utilities, industrial, natural, agriculture, and water. The five most abundant land-use categories, representing over 70% of the total land area, were chosen for inclusion in this study: single family residential, light commercial, public institutional, light industrial, and multi-family residential.

Only 36% of census blocks within the City of Tampa were homogeneous with regards to land-use category. Most blocks, similar to many urban areas, were composed of mixed residential (e.g. single-family residential and multi-family residential located on the same block) or mixed residential-commercial land-use categories. Blocks were considered as a single land-use type if at least 80% of the land area within the block was composed of parcels classified as that land-use. Study sites for the local analysis were then randomly selected within the City of Tampa. A total of eighteen study sites were chosen: six within the single-family residential land-use category and three within each of the remaining four land-use categories. Additional single-family residential study sites were sampled in order to increase the accuracy of results in this land-use. Figure 2 indicates the location and land-use classification of sample sites within the City of Tampa.
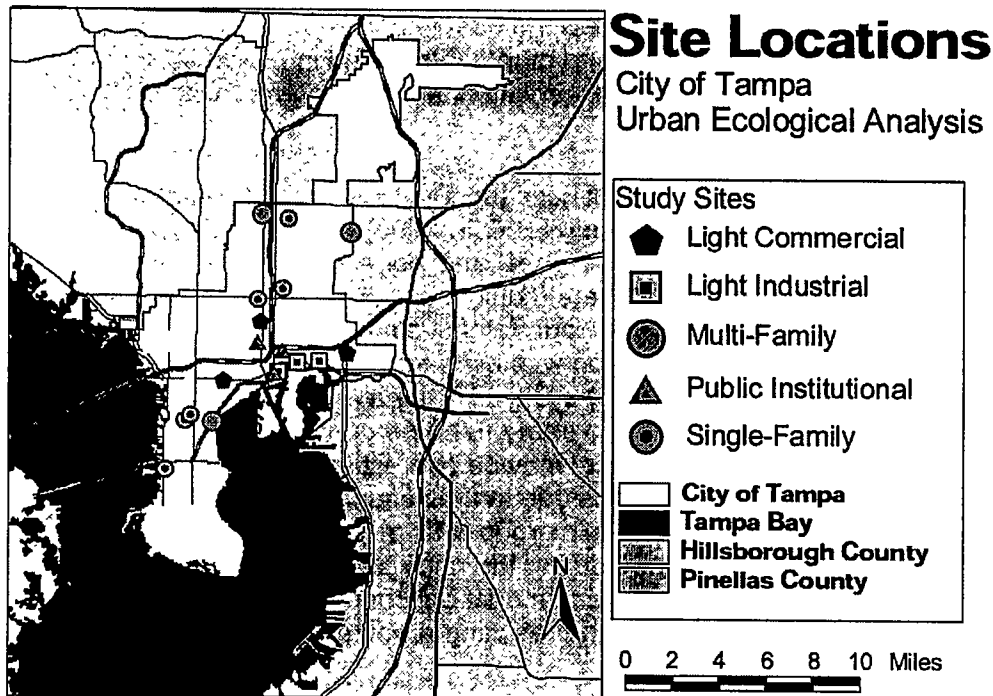


Figure 2. Location of Local Analysis Study Sites

## Sampling Protocol

After selection of each study site (i.e. census block), digital orthophotographs (USGS 1995) were imported into the ArcView CITYgreen extension and study site boundaries were digitized. Within each study site, land cover was then digitized as tree canopy, buildings, impervious surfaces, grasslands and other pervious surfaces, and water. Digitized areas (polygons) within each study site were given a unique identifier and then color maps of each study site were printed for use during field sampling. Unique identifiers for each tree, building, and other land cover category were included on each map so that field sampling teams could easily identify each feature (see Appendix A: Example of Field Survey Map).

Field sampling teams composed of trained botanists/arborists, architects, and volunteers visited each study site between April and August of 1998. At each study site, detailed data were collected about buildings, pervious and impervious surfaces, and trees with a trunk diameter greater than 2.5 inches at 4½ ft above ground (dbh). Detailed data collected included: tree species identity, dbh within 2 inches, height class (<15', 15-35', or >35'), whether or not the tree has been topped (e.g.

to prevent powerline interference), overall health of the tree (dead/dying, poor, fair, good, or excellent), and the location of all air conditioners and windows. In addition to the detailed information recorded about each tree, digitized land cover polygons were ground truthed and adjusted when necessary according to field observations at each site. Many of the building outlines originally digitized from orthophotography were inaccurate, especially when underneath a tree canopy, and had to be corrected. In addition, the position of many smaller trees and shrubs located underneath a larger tree canopy were added to the maps. See Appendix B for an example of the field survey form used at each study site.

## CITYgreen Analyses

CITYgreen is an ArcView GIS extension designed to model the benefits of the tree canopy using accepted models from USDA, Lawrence Berkeley Lab, and others. Included in the software package are tools to model stormwater runoff, energy conservation, air pollution removal, carbon storage and sequestration, and wildlife benefits.

Stormwater Modeling. The CITYgreen stormwater model uses the TR-55 hydrologic model developed by the Natural Resource Conservation Service (N.R.C.S. 1986). This model uses precipitation data, land cover percentages, hydrologic soil types, and slope to calculate runoff (inches), time of concentration (hours), and peak runoff rate (cubic feet per second) for each site. Precipitation amount included in the analysis was the average rainfall during a two-year period for a 24 hour storm event. A value of four inches precipitation was used for all study sites (Ratliff 1998). Due to the very limited elevation changes within the City of Tampa and limitations of the Citygreen software, the minimum slope allowed in the program of one percent slope was used for all study sites. Since actual slopes are much less, velocity may be overestimated. The soils within all study sites were assigned to two hydrologic soil groups due to the seasonally high water table. Soils within the City of Tampa were classified as hydrologic group B/D; moderate runoff potential when drained and high runoff potential when undrained during the rainy season (N.R.C.S. 1989). Since the CITYgreen model for stormwater was designed to model only one hydrologic group, both models (Group B and then Group D) were run and then the resulting runoff and concentration values were averaged for the B model and the D model.

Air Pollution Removal Modeling. The model used to calculate air pollution removal was based on a methodology developed by the United States Forest Service (McPherson, Nowak, and Rowntree 1994). The model uses average yearly pollutant flux (grams of pollutants per square centimeter per second) based on studies conducted in Chicago, Austin, Baltimore, and Milwaukee in order to determine total pollutant removal. Because rate of uptake may differ between these four cities and the City of Tampa, pollutant removal statistics should be viewed as estimates only.

Carbon Storage and Sequestration Modeling. Trees process carbon dioxide and produce oxygen. As part of this process, trees store carbon throughout their lives. Rapidly growing, young trees, store carbon faster than older, slower growing trees. Carbon storage and sequestration rates for each study site were calculated based on total area of the tree canopy at the site multiplied by a carbon storage (or sequestration) constant based on the age of the entire tree population at the site (Nowak and Rowntree 1993).

Energy Conservation Modeling. The energy conservation model included in the CITYgreen application estimated the kilowatt-hour savings resulting from direct shading of buildings, air conditioners and windows by trees (Forests 1997b). Energy ratings were assigned (by the model) to each tree and then multiplied by an energy savings constant developed based on results of two

recent studies of the urban forest ecosystem (McPherson, Nowak, and Rowntree 1994) and (McPherson, Sacamano, and Wensman 1993). Included in the model was an estimate of the average cooling costs for residential homes in the City of Tampa, $640/year (Wiggins 1998).

Information collected during field sampling was entered into the ArcView CITYgreen extension, including the detailed tree information and all land cover polygon corrections and additions (i.e. trees, buildings, air conditioners and windows, grasslands, and impervious surface). In order for all CITYgreen analyses to function properly, all land cover polygons (including trees) could not extend beyond the study site boundary polygon and were appropriately cropped. After all data was entered, CITYgreen was used to calculate general statistics related to percent coverage of land cover types, tree species diversity, and tree health and population information for each study site. Finally, CITYgreen analyses were used to determine carbon storage and sequestration rates, annual pollution (Ozone ($O_3$), Sulfur Dioxide ($SO_2$), Nitrogen Dioxide ($NO_2$), Particulate Matter (PM10), and Carbon Monoxide (CO)) removal rates, and stormwater reduction benefits for each study site. Because the energy savings models included in the CITYgreen application are based on single story residential homes (Forests 1997b), energy savings resulting from tree canopy shading were calculated for single-family residential study sites only.

## Statistical Analyses

All data resulting from CITYgreen statistical summaries and models were analyzed using Microsoft Excel (Microsoft 1997) and SPSS (SPSS 1995). A Kruskal-Wallis Test for differences between means of independent samples was used to test whether there was a significant difference in land cover, tree species diversity and health, carbon storage and sequestration rates, annual removal rates, or stormwater reduction between land-use categories. This non-parametric test was used because the distribution of values for most of the variables was shown to be non-normal with heterogeneous variation (Zar 1996). Results were extrapolated using simple averages or weighted averages (weighted by land-use category) to obtain estimated land cover, pollution reduction, and other values for the City of Tampa.

# Results

## *Regional Analysis*

Temporal Change in Tree Canopy Coverage

The results of the regional analysis of canopy cover are illustrated in Figure 4 (1975), Figure 5 (1985), Figure 6 (1986), and Figure 7 (1996) and summarized in Table 3. Analyzing the change in canopy coverage between 1975-1985, we found a net decrease of 8.5%. Figure 3 illustrates the areas within the City of Tampa that had a decrease in canopy coverage between 1975-1985. From this imagery, it was also apparent that a large decrease occurred in the region known as New Tampa, which is north of Fletcher Avenue. In addition, a large decrease occurred on the interbay peninsula at MacDill Air Force Base. We isolated the New Tampa Region and found a net decrease in canopy coverage of 23%.

Table 3. Canopy Coverage Results for City of Tampa

| Year | Citywide Canopy Area (acres) | Citywide Canopy Area (%) | New Tampa Canopy Area (acres) | New Tampa Canopy Area (%) | Cloud Cover |
|------|------|------|------|------|------|
| 1975 | 15,815 | 23% | 9,130 | 67% | 2.9% |
| 1985 | 9,845 | 14% | 6,026 | 44% | 8.0% |
| 1986 | 9,911 | 14% | 6,406 | 47% | 0.0% |
| 1996 | 13,586 | 19% | 6,404 | 47% | 0.0% |

The thematic mapper analysis provided spectrally compatible data for the period 1986-1996. Figure 6 (1986) and Figure 7 (1996) illustrate pixels that were classified as canopy from the NDVI algorithm. The results of change detection are shown in Table 3. We found that canopy cover citywide had increased from 14.1% to 19.4% for a net gain of 5.3%.



LEGEND

■ Net Decrease in Tree Canopy
☐ Hillsborough County
Tampa Bay

2  0  2  4  6  Miles

N
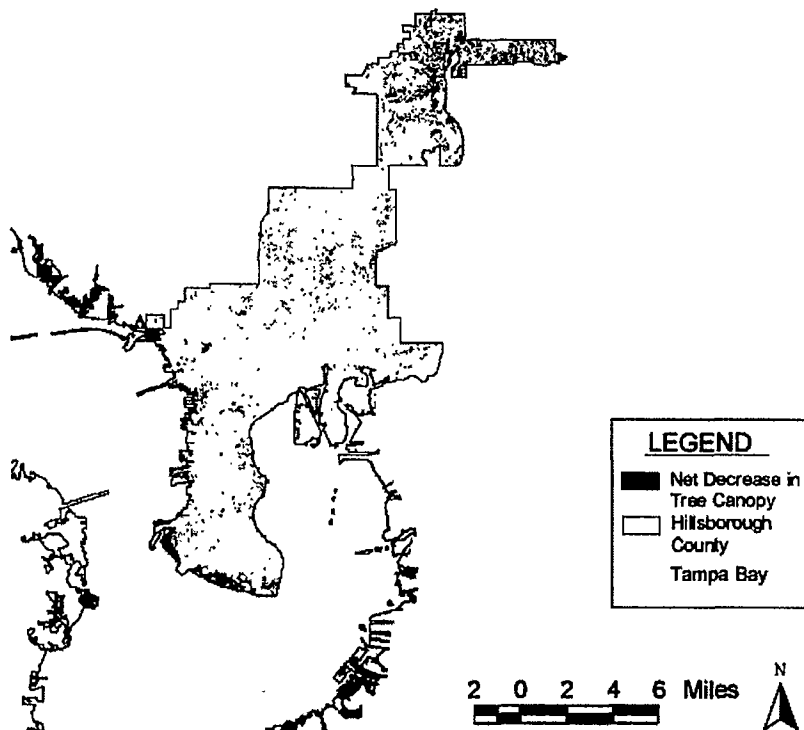
Figure 3. Net Decrease in Tree Canopy between 1975 and 1985
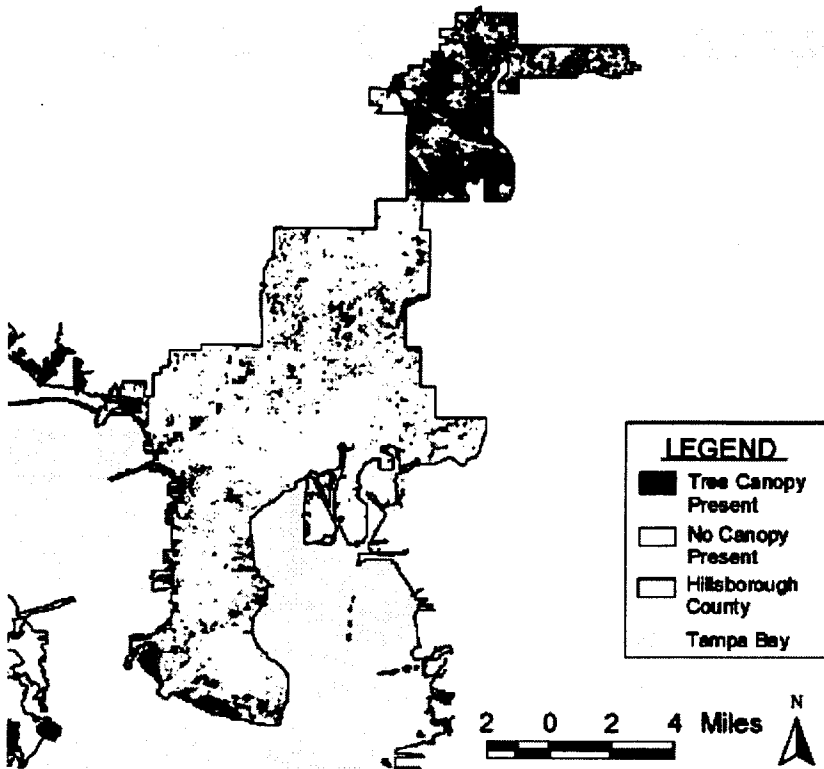
Figure 4. NDVI Results from 1975 Satellite Image

LEGEND
- Tree Canopy Present
- No Canopy Present
- Hillsborough County
- Tampa Bay

2  0  2  4  Miles

N
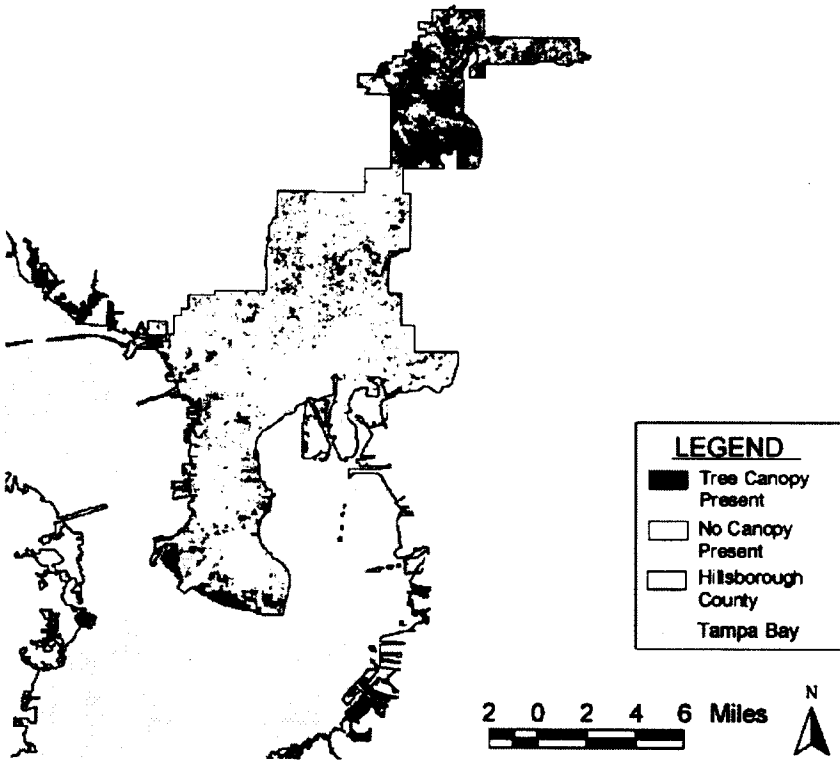


Figure 5. NDVI Results from 1985 Satellite Image

LEGEND
- Tree Canopy Present
- No Canopy Present
- Hillsborough County
- Tampa Bay

2  0  2  4  6  Miles

N

LEGEND

■ Tree Canopy Present

☐ No Canopy Present

☐ Hillsborough County

Tampa Bay

2 0 2 4 6 Miles

N
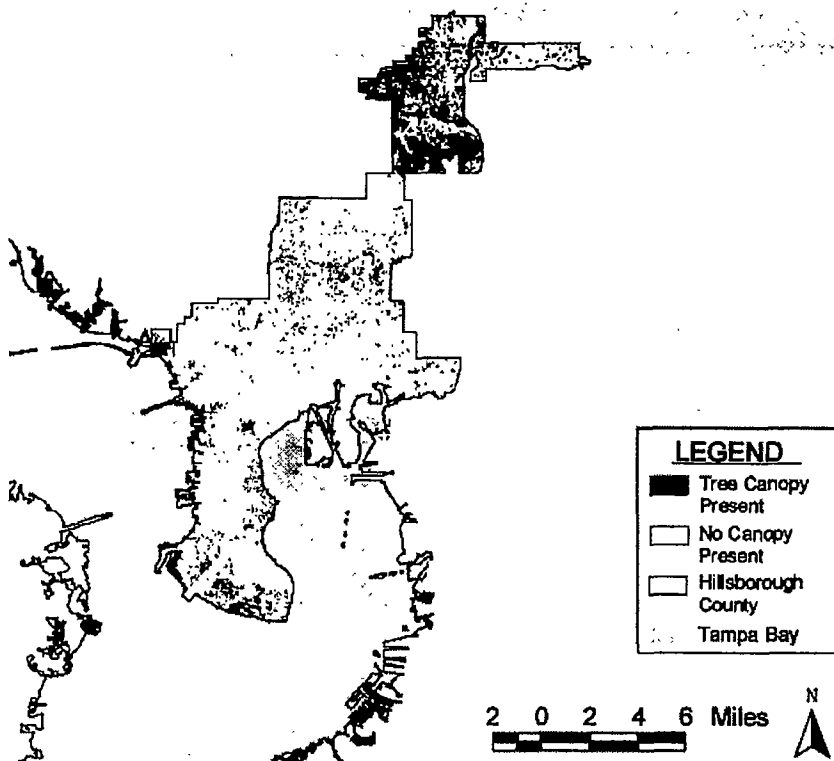
Figure 6.  NDVI Results from 1986 Satellite Image



LEGEND

■ Tree Canopy Present

☐ No Canopy Present

☐ Hillsborough County

Tampa Bay

2 0 2 4 6 Miles

N
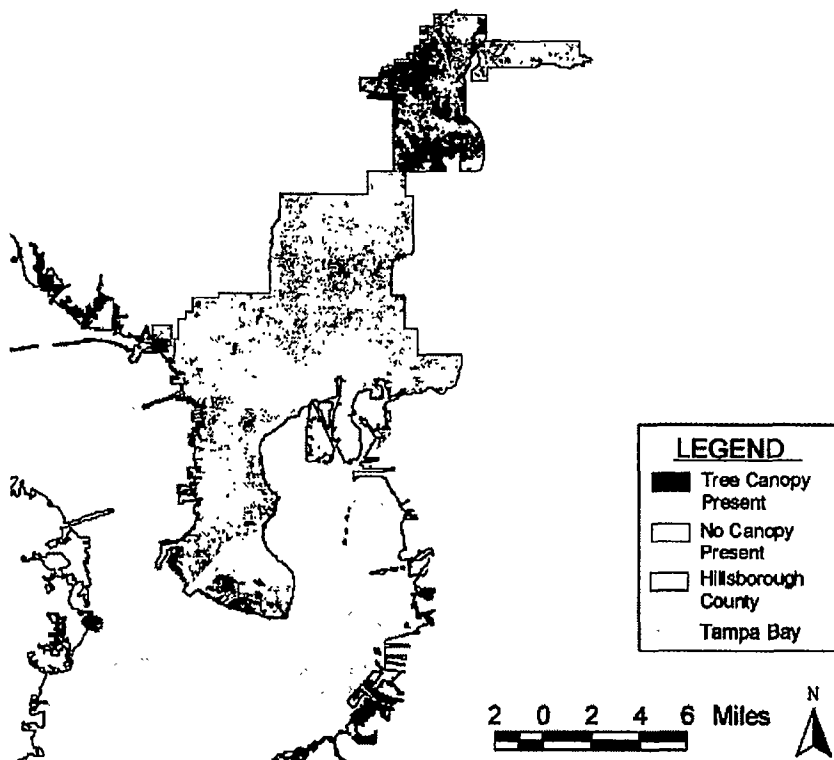
Figure 7.  NDVI Results from 1996 Satellite Image

## 1996 Canopy Coverage Differences between Land Use Categories

The 1996 NDVI classified image was used to determine the total canopy coverage within each land-use category. Parcels within each land-use category were used to clip the NDVI image and then the resulting image was analyzed in order to determine the total canopy coverage and total area within each category. Percentages of each land-use category covered by forest canopy are shown in Table 4. Not surprisingly, canopy coverage was greatest in the agricultural (61.8%), vacant (41.9%), and natural (36%) land-use categories. The lowest canopy coverage occurred in the commercial (1.7%), industrial (2.2%), and mobile home park (5.8%) land-use categories.

Table 4. Canopy Coverage by Land-use Category Based on Satellite Analysis

| Land-use Category | % of Land Area in the City | Canopy Coverage |
|---|---|---|
| Agriculture | 6% | 61.8% |
| Vacant | 11% | 41.9% |
| Natural | 1% | 36.0% |
| Public Utilities | 1% | 23.5% |
| Public Institutional | 25% | 17.3% |
| Single Family | 22% | 15.3% |
| Multi-Family | 2% | 9.9% |
| Other (right-of-way) | 20% | 9.9% |
| Two Family (Duplex) | 1% | 9.5% |
| Unknown | 1% | 8.2% |
| Light Commercial | 6% | 7.5% |
| Mobile Home Park / Parking Lot | 1% | 5.8% |
| Light Industrial | 3% | 2.5% |
| Industrial | 1% | 2.2% |
| Commercial | 1% | 1.7% |
| Total for City of Tampa | 100% | 19.3% |

## Local Analysis

### Land Cover

A total of 56.4 acres was sampled from eighteen study sites in five land-use categories within the City of Tampa, including: light commercial (LC), light industrial (LI), multi-family residential (MF), public/institutional (PI), and single-family residential (SF). The size of each study site ranged from 0.8 acres to 5.5 acres, and averaged 3.1 acres (Table 5). Results from the analysis of land cover values indicate that average canopy coverage, grassland coverage, and impervious surface area coverage differed significantly between land-use categories. Table 5 summarizes total study area and land coverage values for each study site, average values for each land-use category, and Kruskal-Wallis test results. Average canopy coverage ranged from 0.8% (light industrial) to 28.5% (single-family residential), while average impervious surface coverage ranged from 19.1% (single-family residential) to 64.8% (light commercial), and grassland coverage ranged from 8.2% (public-institutional) to 62.4% (single-family residential). Building coverage and water coverage were not significantly different between land-use categories. Building coverage ranged from 14.1% (single-family residential) to 39.2% (light industrial), and water coverage ranged from 0% (light commercial and light industrial) to 4.8% (multi-family residential).

Table 5. Summary of Percent Coverage for Each Study Site

| Land Use | Site ID | Study Area (acres) | Percent Coverage of Total Study Area | | | | |
|---|---|---|---|---|---|---|---|
| | | | Canopy | Building | Impervious Surface | Grass | Water |
| LC | 29_103 | 0.8 | 0.8% | 9.1% | 74.8% | 9.8% | 0.0% |
| LC | 37_436 | 4.6 | 6.2% | 26.6% | 54.9% | 13.2% | 0.0% |
| LC | 57_102 | 2.0 | 7.1% | 16.1% | 64.7% | 15.7% | 0.0% |
| | LC Average | 2.5 | 4.7% ± 1.9%se | 17.3% | 64.8% | 12.9% | 0.0% |
| LI | 38_322 | 2.7 | 0.9% | 27.9% | 35.5% | 33.9% | 0.0% |
| LI | 39_312 | 1.8 | 0.2% | 39.6% | 41.9% | 14.8% | 0.0% |
| LI | 53_112 | 5.1 | 1.4% | 50.1% | 39.9% | 5.2% | 0.0% |
| | LI Average | 3.2 | 0.8% ± 0.4%se | 39.2% | 39.1% | 18.0% | 0.0% |
| MF | 1_238 | 2.7 | 17.4% | 12.2% | 30.5% | 38.7% | 14.5% |
| MF | 4_145 | 3.3 | 10.0% | 29.7% | 39.0% | 28.1% | 0.0% |
| MF | 61_702 | 0.9 | 4.4% | 19.9% | 50.0% | 36.2% | 0.0% |
| | MF Average | 2.3 | 10.6% ± 3.8%se | 20.6% | 39.8% | 34.4% | 4.8% |
| PI | 29_324 | 2.5 | 3.1% | 28.2% | 52.9% | 11.5% | 0.0% |
| PI | 39_714 | 2.7 | 10.3% | 19.6% | 2.7% | 1.5% | 0.5% |
| PI | 51_318 | 2.1 | 2.5% | 0.0% | 84.9% | 11.5% | 0.0% |
| | PI Average | 2.5 | 5.3% ± 2.5%se | 15.9% | 46.8% | 8.2% | 0.2% |
| SF | 17_402 | 5.2 | 29.7% | 13.6% | 16.9% | 64.7% | 0.0% |
| SF | 2_307 | 1.5 | 16.3% | 13.2% | 14.0% | 66.1% | 0.0% |
| SF | 23_105 | 5.3 | 37.9% | 14.2% | 14.4% | 66.6% | 0.0% |
| SF | 63_105 | 3.8 | 30.2% | 17.0% | 25.8% | 52.0% | 0.0% |
| SF | 71_319 | 5.6 | 16.8% | 10.4% | 13.5% | 73.2% | 0.5% |
| SF | 63_710 | 3.7 | 39.9% | 16.0% | 30.1% | 51.8% | 0.0% |
| | SF Average | 4.2 | 28.5% ± 4.1%se | 14.1% | 19.1% | 62.4% | 0.1% |
| | Grand Average | 3.1 | 13.1% | 20.2% | 38.1% | 33.0% | 0.9% |
| | Kruskal-Wallis test | | $X^2$=13.3, 4 df, P=0.01 | $X^2$=7.2, 4 df, P=0.13 | $X^2$=10.2, 4 df, P=0.04 | $X^2$=14.3, 4 df, P=0.01 | $X^2$=2.3, 4 df, P=0.68 |

* se = standard error about the mean

## Tree statistics

A total of 719 individual trees representing 50 species were inventoried from the 18 study sites within the City of Tampa. The three most common tree species inventoried included Live Oak (*Quercus virginiana*), Laurel Oak (*Quercus laurifolia*), and Cabbage Palm (*Sabal palmetto*). Table 6 summarizes the tree statistics for each study site and average values for each land-use category. The average number of individual trees per acre, species diversity (tree species per acre), and average height class of trees differed significantly between land-use categories. The average number of individual trees ranged from 1.6 (LI) to 18.1 (MF) trees per acre, and tree species diversity ranged from 0.7 (LI) to 5.2 (MF) tree species per acre. The average height class (See Appendix B for definition) ranged from 1.0 (LI) to 2.2 (SF). Canopy area per tree (within the drip-line), average DBH, and average health class were not significantly different between land-use categories. The size of the area within the drip-line of a single tree ranged from 59 ft$^2$ to 1486 ft$^2$, averaging 430 ft$^2$ for all study sites. Average diameter-at-breast-height (DBH) ranged from 7" to 24", and averaged 15" for all study sites. The average health class (see Appendix B for definitions) ranged from 2.8 to 4.5, and averaged 3.7 for all study sites. The diameter class distribution (relative age) of trees indicated that the overall tree age was young at five sites, average at one site, and mature at twelve sites.

### Table 6. Summary of Tree Statistics for Each Study Site

| Land Use | Site ID | # Trees/ Acre | Canopy Area (ft$^2$)/ Tree | Diam. Class Distribution | Avg. DBH (in) | Avg. Height Class | Avg. Health Class | # Species/ Acre |
|---|---|---|---|---|---|---|---|---|
| LC | 29_103 | 6.1 | 59 | young | 8 | 1.0 | 3.4 | 6.1 |
| LC | 37_436 | 10.7 | 253 | young | 10 | 1.3 | 3.8 | 1.1 |
| LC | 57_102 | 10.2 | 305 | young | 10 | 1.5 | 3.4 | 3.1 |
| | LC Average | 9.0 | 206 | | 9 | 1.3 | 3.5 | 3.4 |
| LI | 38_322 | 1.8 | 211 | mature | 16 | 1.0 | 4.0 | 0.7 |
| LI | 39_312 | 0.6 | 151 | mature | 12 | 1.0 | 4.0 | 0.6 |
| LI | 53_112 | 2.4 | 262 | mature | 12 | 1.1 | 3.8 | 0.8 |
| | LI Average | 1.6 | 208 | | 13 | 1.0 | 3.9 | 0.7 |
| MF | 1_238 | 25.9 | 292 | mature | 14 | 2.0 | 3.7 | 5.5 |
| MF | 4_145 | 17.4 | 251 | mature | 15 | 1.6 | 4.0 | 3.4 |
| MF | 61_702 | 11.0 | 172 | mature | 16 | 1.5 | 3.3 | 6.6 |
| | MF Average | 18.1 | 239 | | 15 | 1.7 | 3.7 | 5.2 |
| PI | 29_324 | 3.1 | 433 | mature | 24 | 2.3 | 3.4 | 2.4 |
| PI | 39_714 | 20.8 | 216 | young | 12 | 1.1 | 4.5 | 1.9 |
| PI | 51_318 | 17.5 | 63 | young | 7 | 1.3 | 2.8 | 2.8 |
| | PI Average | 13.8 | 237 | | 14 | 1.6 | 3.6 | 2.4 |
| SF | 17_402 | 10.3 | 1249 | mature | 21 | 2.8 | 3.5 | 2.3 |
| SF | 2_307 | 15.3 | 465 | average | 17 | 1.8 | 3.3 | 11.3 |
| SF | 23_105 | 11.1 | 1486 | mature | 24 | 2.8 | 3.5 | 2.3 |
| SF | 63_105 | 22.7 | 580 | mature | 15 | 2.0 | 3.6 | 4.9 |
| SF | 71_319 | 15.1 | 485 | mature | 15 | 1.9 | 3.9 | 3.8 |
| SF | 63_710 | 21.7 | 799 | mature | 15 | 2.0 | 4.1 | 5.6 |
| | SF Average | 16.0 | 844 | | 18 | 2.2 | 3.7 | 5.0 |
| Grand Average | | 12.4 | 430 | | 15 | 1.7 | 3.7 | 3.6 |
| Kruskal-Wallis test | | X$^2$=10.26, 4 df, P=0.04 | X$^2$=11.47, 4 df, P=0.02 | | X$^2$=7.99, 4 df, P=0.09 | X$^2$=11.5, 4 df, P=0.02 | X$^2$=2.83, 4 df, P=0.59 | X$^2$=9.72, 4 df, P=0.04 |

## Carbon and Pollutant Statistics

Carbon sequestration and storage was not significantly different between land-use categories (Table 7). The average carbon storage capacity of the trees in this study was 4.8 tons/acre/year, and ranged from 0.1 tons per acre to 17.6 tons per acre. The average carbon sequestration rate found in this study was 0.02 tons of carbon per year per acre. Pollutant sequestration was significantly different between land-use categories for $O_3$, $SO_2$, $NO_2$, PM10 and CO. In all cases, pollutant sequestration was greatest in the single-family land-use category and lowest in the light commercial land-use category. The average sequestration rate as a result of the trees in the single-family residential land-use category was 46.2 lbs./yr./acre for $O_3$, 11.5 lbs./yr./acre for $SO_2$, 19.1 lbs./yr./acre for $NO_2$, 38.5 lbs./yr./acre for PM10, and 21 lbs./yr./acre for CO (Table 7).

Table 7. Summary Carbon and Pollutant Statistics for Each Study Site

| Land Use | Site ID | Carbon Storage (tons/acre) | Carbon Sequestration Rate (tons/yr/acre) | $O_3$ (lbs/yr/ acre) | $SO_2$ (lbs/yr/ acre) | $NO_2$ (lbs/yr/ acre) | PM10 (lbs/yr/ acre) | CO (lbs/yr/ acre) |
|---|---|---|---|---|---|---|---|---|
| LC | 29_103 | 0.3 | 0.006 | 0.2 | 0.1 | 0.1 | 0.2 | 0.0 |
| LC | 37_436 | 2.0 | 0.045 | 10.7 | 2.7 | 4.4 | 9.0 | 1.1 |
| LC | 57_102 | 2.3 | 0.052 | 5.2 | 1.3 | 2.2 | 4.4 | 0.6 |
| LC Average | | 1.5 | 0.034 | 5.4 | 1.4 | 2.2 | 4.5 | 0.6 |
| | | | | | | | | |
| LI | 38_322 | 0.4 | 0.001 | 0.8 | 0.2 | 0.4 | 0.7 | 0.1 |
| LI | 39_312 | 0.1 | 0.000 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 |
| LI | 53_112 | 0.6 | 0.001 | 8.3 | 0.5 | 3.4 | 7.3 | 0.1 |
| LI Average | | 0.4 | 0.001 | 3.1 | 0.2 | 1.3 | 2.7 | 0.1 |
| | | | | | | | | |
| MF | 1_238 | 7.7 | 0.014 | 17.9 | 4.4 | 7.4 | 14.9 | 1.8 |
| MF | 4_145 | 4.4 | 0.008 | 12.4 | 3.0 | 5.1 | 10.3 | 1.3 |
| MF | 61_702 | 1.9 | 0.003 | 1.5 | 0.4 | 0.6 | 1.2 | 0.1 |
| MF Average | | 4.7 | 0.008 | 10.6 | 2.6 | 4.4 | 8.8 | 1.1 |
| | | | | | | | | |
| PI | 29_324 | 1.4 | 0.002 | 3.0 | 0.7 | 1.2 | 2.5 | 0.4 |
| PI | 39_714 | 3.3 | 0.075 | 10.4 | 2.5 | 4.2 | 8.7 | 1.1 |
| PI | 51_318 | 0.8 | 0.018 | 2.1 | 0.5 | 0.8 | 1.7 | 0.2 |
| PI Average | | 1.8 | 0.032 | 5.2 | 1.3 | 2.1 | 4.3 | 0.6 |
| | | | | | | | | |
| SF | 17_402 | 13.1 | 0.023 | 58.2 | 14.4 | 24.0 | 48.5 | 6.1 |
| SF | 2_307 | 7.0 | 0.054 | 9.2 | 2.3 | 3.8 | 7.6 | 98.2 |
| SF | 23_105 | 16.8 | 0.029 | 75.6 | 18.7 | 31.2 | 63.0 | 7.9 |
| SF | 63_105 | 0.1 | 0.023 | 43.5 | 10.8 | 17.9 | 36.2 | 4.5 |
| SF | 71_319 | 7.4 | 0.013 | 35.2 | 8.7 | 14.5 | 29.1 | 3.6 |
| SF | 63_710 | 17.6 | 0.031 | 55.8 | 13.8 | 23.0 | 46.5 | 5.8 |
| SF Average | | 10.3 | 0.029 | 46.2 | 11.5 | 19.1 | 38.5 | 21.0 |
| | | | | | | | | |
| Grand Average | | 4.8 | 0.022 | 19.5 | 4.7 | 8.0 | 16.2 | 7.4 |
| Kruskal-Wallis test | | $X^2$=9.46, 4 df, P=0.05 | $X^2$=7.64, 4 df, P=0.11 | $X^2$=10.68, 4 df, P=0.03 | $X^2$=11.15, 4 df, P=0.03 | $X^2$=10.68, 4 df, P=0.03 | $X^2$=10.68, 4 df, P=0.03 | $X^2$=13.39, 4 df, P=0.01 |

## Stormwater Reduction Statistics

CityGreen uses the T.R. 55 model developed by the U.S. Natural Resources Conservation Service to estimate the affects of trees on runoff volume and peak flow by comparing each site with existing trees to the same site with the trees removed from the model. The volume of runoff reduced, reduction in peak flow, increase in time of concentration, and storage volume required to mitigate the affects of the trees were each significantly different between land-use categories. Volume of runoff reduced ranged from 0.5% (light industrial) to 17.6% (single-family residential), resulting in an average 60 ft³/acre reduction on the light industrial study sites and an average 1,629 ft³/acre reduction on the single-family residential study sites. Peak flow was reduced by an average 0.9% on light industrial sites and 26.5% on single-family residential study sites. In addition, time of concentration was reduced by an average 0.8% on light industrial sites and 20.4% on single-family residential study sites (Table 8).

Table 8.  Summary Stormwater Statistics for Each Study Site

| Land Use | | Volume of Runoff Reduced by (%) | Volume of Runoff Reduced ( ft³) | Peak Flow Reduced by (%) | Time of Concentration Increased by (%) | Storage Volume Required to Mitigate (ft³/acre) |
|---|---|---|---|---|---|---|
| LC | 29_103 | 0.5% | 49 | 0.8% | 0.8% | 59 |
| LC | 37_436 | 3.6% | 2019 | 6.4% | 5.7% | 441 |
| LC | 57_102 | 4.2% | 995 | 7.1% | 6.6% | 507 |
| LC Average | | 2.8% | 1021 | 4.8% | 4.3% | 336 |
| | | | | | | |
| LI | 38_322 | 0.6% | 159 | 0.9% | 0.7% | 58 |
| LI | 39_312 | 0.1% | 24 | 0.2% | 0.2% | 13 |
| LI | 53_112 | 0.9% | 552 | 1.6% | 1.5% | 108 |
| LI Average | | 0.5% | 245 | 0.9% | 0.8% | 60 |
| | | | | | | |
| MF | 1_238 | 11.0% | 2831 | 16.9% | 12.3% | 1,034 |
| MF | 4_145 | 6.0% | 2200 | 9.8% | 8.3% | 671 |
| MF | 61_702 | 2.7% | 266 | 4.2% | 3.5% | 293 |
| MF Average | | 6.5% | 1766 | 10.3% | 8.0% | 666 |
| | | | | | | |
| PI | 29_324 | 1.9% | 564 | 3.2% | 2.9% | 222 |
| PI | 39_714 | 2.0% | 2482 | 6.3% | 9.2% | 921 |
| PI | 51_318 | 1.5% | 390 | 2.6% | 2.4% | 184 |
| PI Average | | 1.8% | 1145 | 4.0% | 4.8% | 442 |
| | | | | | | |
| SF | 17_402 | 18.7% | 8670 | 28.9% | 20.4% | 1,661 |
| SF | 2_307 | 11.1% | 1348 | 16.4% | 10.5% | 896 |
| SF | 23_105 | 23.3% | 11182 | 34.6% | 26.6% | 2,105 |
| SF | 63_105 | 18.2% | 6880 | 27.5% | 22.4% | 1,793 |
| SF | 71_319 | 11.5% | 5018 | 17.7% | 10.6% | 904 |
| SF | 63_710 | 22.9% | 9001 | 34.1% | 31.7% | 2,415 |
| SF Average | | 17.6% | 7017 | 26.5% | 20.4% | 1,629 |
| | | | | | | |
| Grand Average | | 7.8% | 3035 | 12.2% | 9.8% | 794 |
| Kruskal-Wallis test | | $X^2$=14.05, 4 df, P=0.01 | | $X^2$=13.95, 4 df, P=0.01 | $X^2$=12.83, 4 df, P=0.01 | $X^2$=12.55, 4 df, P=0.01 |

## Cooling-cost Energy Savings Statistics

Energy savings benefits resulting from direct shading by trees of windows and air conditioning units were analyzed for single-family residential study sites. These results indicate that the yearly reduction in electrical energy used for cooling ranged from 134 KwH to 740 KwH per home, and averaged 371 KwH per home for all study sites. Based on a cost of $0.08 per KwH in the City of Tampa (Company 1998), the average dollar savings attributed to this reduction was $32 per home (Table 9).

Table 9. Summary Energy Savings Statistics for Each Single-family Residential Study Site

| Land Use | | # Homes | Energy Savings per year | | | |
|---|---|---|---|---|---|---|
| | | | Total KwH Saved | Total $ Saved | KwH Saved per Home | $ Saved per Home |
| SF | 17_402 | 18 | 4,937 | $ 420 | 274 | $ 23 |
| SF | 2_307 | 6 | 1,772 | $ 151 | 295 | $ 25 |
| SF | 23_105 | 25 | 9,365 | $ 796 | 375 | $ 32 |
| SF | 63_105 | 13 | 9,619 | $ 817 | 740 | $ 63 |
| SF | 71_319 | 9 | 3,669 | $ 312 | 408 | $ 35 |
| SF | 63_710 | 17 | 2,278 | $ 194 | 134 | $ 11 |
| SF Average | | 14.7 | 5,273 | $ 448 | 371 | $ 32 |

## Citywide Projections

The City of Tampa encompassed approximately 70,046 acres of land at the time when this study was performed (the City has since annexed more land area). Each study site (census block) encompassed a portion of the right-of-way directly bordering the block. Therefore, the portion of total citywide right-of-way bordering each land use type was calculated and included in the land area for that land use type (see "% of City with R/W" in Table 10). Using the land areas including right-of-way, a total of 72% of citywide land area was represented by the five land-use categories sampled during this study: light commercial, light industrial, multi-family residential, public/institutional, and single-family residential (Table 10). Many of the analyses indicated a significant difference in results between land-use categories. Therefore, rather than use a simple average of all study sites, weighted averages were calculated in order to improve the accuracy of citywide extrapolations for all statistics that were significantly different between land-use categories. These calculations were weighted in terms of the total land area within each land-use category.

### Land-cover

As was previously mentioned, not all land-use categories were sampled and thus only 72% of the City of Tampa land area was represented by the sampled study sites. In order to increase the accuracy of our citywide land-cover estimates, we decided to sample one additional land-use category, vacant land. A total of 14% of the City of Tampa is categorized as vacant. By including this land-use category in the estimate of citywide land coverage, fully 86% of the land area within the city will be represented by the sampled sites. Land cover was estimated from five randomly selecting vacant parcels within the City of Tampa. Results from this sampling indicate that 29% of vacant land was canopy coverage, 41% was grassland coverage, 23% was impervious surface area coverage, 4% was building coverage and 0% was water coverage.

Using the results from the five originally sampled land use categories in addition to the vacant land-use category, weighted averages (coverage per land-use multiplied by land area within land-use)

**Table 10. Percentage of Total City Land Area Represented by Land-use Categories**

| Sampled Land-use Categories | % of City with R/W | % of City without R/W |
|---|---|---|
| Single Family | 31.4% | 22.1% |
| Public Institutional | 28.3% | 24.8% |
| Light Commercial | 7.1% | 5.6% |
| Light Industrial | 3.5% | 2.8% |
| Multi-Family | 1.8% | 1.8% |
| *Total Area Represented by Sampling* | *72.2%* | *57.1%* |
| **Non-Sampled Land-use Categories** | | |
| Vacant | 13.6% | 11.4% |
| Agriculture | 5.8% | 5.5% |
| Natural | 1.2% | 0.9% |
| Public Utilities | 1.5% | 1.2% |
| Commercial | 1.5% | 1.2% |
| Two Family (Duplex) | 1.2% | 0.8% |
| Mobile Home Park / Parking Lot | 1.1% | 0.8% |
| Industrial | 1.1% | 0.9% |
| Unknown | 0.9% | 0.7% |
| Water | 0.0% | 0.0% |
| Right of Way | NA* | 19.5% |
| *Total Area Not Represented by Sampling* | *27.8%* | *42.9%* |
| Total Area in City of Tampa | 70,046 Acres | |
| *\* see discussion of methods left* | | |

**Table 11. Estimated Total Land-cover**

| Land Cover | Land Area (Acres) | % of Total Land Area |
|---|---|---|
| Buildings | 10,223 | 15±4% (se) |
| Grasslands | 24,178 | 35±4% (se) |
| Impervious Surfaces | 23,808 | 34±11% (se) |
| Tree Canopy | 12,220 | 17±5% (se) |
| Water | 164 | 0.2±0% (se) |
| Total Area* | 70,594 | 101% |
| *\* numbers do not add to 100% due to rounding* | | |

were calculated in order to estimate the citywide land coverage. The percentage of the City of Tampa covered by grasslands was 35 ± 4% standard error (se), and the percentage covered by impervious surface was 34 ± 11%. The tree canopy coverage totaled 17 ± 5% of the land area, building coverage totaled 15 ± 4%, and water covered only 0.2% of the land area (Table 11).

## Citywide Benefits

Benefits resulting from Tampa's urban tree canopy were extrapolated across the entire city for stormwater reduction, carbon storage and sequestration, air pollution sequestration, and energy savings. Weighted averages were used where data indicated a significant difference between land-use categories, such as stormwater reduction and air pollution sequestration. Carbon sequestration was calculated using the overall average of all study sites extrapolated for the total land area within the City. Energy savings were estimated using the average energy savings per single-family residential house extrapolated for the total number of single-family houses (77,171) in the City of Tampa (Halvorsen 1997b). These results indicate that Tampa's tree canopy helps to reduce stormwater runoff by over 65 million cubic feet of water during the average two-year storm event. In addition, over 336,000 tons of carbon is currently stored in these trees and over 1,500 tons of additional carbon is sequestered each year. Tampa's urban tree canopy stores almost 4.7 million pounds of combined air pollutants, including carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, and particulate matter smaller than ten microns. Finally, the urban tree canopy associated with the single-family residential land-use result in total estimated energy savings of 28.1 million KWh per year (Table 12).

Table 12. City of Tampa Citywide Projections

| | Value per unit area | Total Value Citywide |
|---|---|---|
| Stormwater | | |
| Percent reduction in stormwater runoff during one 2yr storm event due to tree canopy* | 8.8 % | 8.8 % |
| Volume of stormwater runoff reduced during one 2yr storm event due to tree canopy* | 934 ft³/acre | 65,453,051 ft³ |
| | | |
| Carbon | | |
| Carbon sequestration rate due to trees** | 44 lbs/yr/acre | 1,541 tons/yr |
| Total carbon stored in trees** | 4.8 tons/acre | 336,221 tons |
| Air Pollutants | | |
| CO sequestration rate due to trees* | 9 lbs/yr/acre | 661,222 lbs/yr |
| NO² sequestration rate due to trees* | 10 lbs/yr/acre | 665,718 lbs/yr |
| O³ sequestration rate due to trees* | 23 lbs/yr/acre | 1,616,306 lbs/yr |
| PM10 sequestration rate due to trees* | 19 lbs/yr/acre | 1,347,231 lbs/yr |
| SO² sequestration rate due to trees* | 6 lbs/yr/acre | 398,152 lbs/yr |
| Combined Sequestration rate for Air Pollutants | 67 lbs/yr/acre | 4,688,628 lbs/yr |
| Energy Conservation | | |
| Yearly energy savings for single-family residential homes due to trees*** | 370 KWh/home/yr | 28,626,582 KWh/yr |

* Calculation uses average value per acre in sampled land-use categories multiplied by total acreage in each land-use category in the City of Tampa (weighted average).
** Calculation uses average value per acre for all sample sites multiplied by total City of Tampa acreage.
*** Calculation uses average value per home for all sampled sites multiplied by # of homes in City of Tampa.

## Economic Benefits

Economic benefits of Tampa's tree canopy are summarized in Table 13. These benefits were calculated using several assumptions regarding dollar values per benefit. Although actual dollar values per benefit are based upon the best available information, quantifying these benefits is at best a very rough estimate and should be interpreted with caution. The avoided cost of constructing stormwater retention facilities to handle the reduction in stormwater runoff resulting from the tree canopy was estimated by calculating the construction costs to add additional capacity to existing stormwater infrastructure. Stormwater pond construction costs of 10¢ per cubic foot (land and maintenance costs excluded) were based on the average wet pond design in the City of Tampa (Wade, Janicki, and Pribble 1997), (Burwell 1999). Given a typical municipal bond used for large-scale capital improvement projects of twenty years (5% interest), this represents an annual benefit of $549,000 per year. If land value and operation and maintenance are included then the cost of stormwater storage rises to approximately $1.95 per cubic foot. This would result in an annual benefit of $10 million calculated as above for typical capital improvement projects. Please refer to the stormwater section in the discussion for further explanation. To calculate the dollar value of the urban tree canopy as it relates to pollutants, economists multiply the number of tons of pollutants by an "externality cost", such as the cost to society in terms of rising health care or in emission control methods. Based on a 1990 California study of emission control costs only, the externality costs of nitrogen dioxide is $4,412/ton, ozone is $490/ton, sulphur dioxide is $1,634/ton, carbon monoxide is $920/ton and particulate matter smaller than 10 microns is $1,307/ton (Nowak 1994a).

In the City of Tampa, the existing tree canopy removes almost 4.7 million pounds of pollutants per year, a benefit valued at over $3 million per year. The economic value of carbon sequestration was calculated based on the externality cost of $23 per ton, for a total annual benefit of $35,443. Energy savings were calculated based on electric costs of $0.08/KWh in the City of Tampa at the time of this study (Company 1998). Yearly energy savings for all single-family residential homes in the City of Tampa totaled $2.4 million. In total, the tree canopy results in an estimated savings of $16 million per year, or over $55 per year for every man, woman, and child in the City of Tampa, based on an estimated population of 289,337 (THCVA 1999).

Table 13. Estimated Economic Benefits of Trees in City of Tampa

|  | Total Dollar Savings Citywide |
|---|---|
| Avoided retention costs due to reduction in stormwater runoff (based on $1.95/ft³ stormwater retention costs) | $ 10,232,913 /yr |
| Economic value of Carbon sequestration | $ 35,443 /yr |
| Economic value of reduction in air pollutants | $ 3,374,436 /yr |
| Yearly energy savings for single-family residential homes due to trees (based on $0.07/KWh) | $ 2,432,533 /yr |
|  |  |
| Total Economic Value of Tampa's Urban Forest | $ 16,075,325 /yr |

## Estimated Benefits per Tree

Although Citywide tree canopy information is useful for many policy decisions, urban forestry professionals and developers often make decisions that affect individual trees. The following preliminary estimates were calculated in order to provide the information necessary when making these decisions. Stormwater, carbon, and pollution benefits provided by the individual tree were estimated by dividing the citywide benefits by the estimated number of individual trees within the

City of Tampa (967,167 ± 232,812 standard-error). Energy savings benefits were calculated by dividing the total citywide savings for single-family residential homes by the citywide estimated number of individual trees within the single-family residential land-use category (352,368 ± 148,358 standard-error). Table 14 lists the estimated economic benefits of the average tree in the City of Tampa. The economic value of the average tree in the City of Tampa was estimated to be $20 per year.

Table 14. Estimated Annual Benefits of the Average Tree

|  | Dollar Savings per Tree per Year |
| --- | --- |
| Volume of stormwater runoff reduced | $10 / yr |
| Total reduction in air pollutants | $ 3 / yr |
| Energy savings for single-family homes | $ 7 / yr |
|  |  |
| Total economic value of the average tree | $ 20 / yr |

## Example Benefits from Future Planting Efforts

The Mayor of the City of Tampa has authorized an initiative to plant 5,000 trees during the next five years (in addition to the trees and shrubs normally planted per year by the City of Tampa). A thorough cost/benefit analysis is beyond the scope of this study. However, we estimated the impact of the Mayor's tree planting initiative on citywide canopy coverage and economic benefits based on the average growth patterns, mortality, and maintenance costs of planting 5,000 of the ubiquitous Live Oak (*Quercus virginiana*). The average thirty gallon Live Oak tree when planted is approximately 8-10 ft tall and has a canopy area of 10 $ft^2$ (Graham 1999). After five years this tree typically grows to 18-20 ft tall with a canopy area of 95 $ft^2$, after 10 years to 26 ft tall with a canopy are of 227 $ft^2$, and after 20 years the tree may reach 30-35 ft tall with a canopy area of 594 $ft^2$. The additional canopy coverage in the City is estimated to increase by 2% within twenty years as a result of planting these 5,000 trees. In Tampa, street trees are monitored and maintained for at least five years after planting. During this five-year time period, mortality is estimated at 5% of newly planted oaks. Using these growth and mortality estimates, the impact on citywide canopy coverage as a result of planting 5,000 trees was determined and a linear regression was used to estimate the equation relating canopy coverage to stormwater reduction, carbon and pollution sequestration. The additional benefit provided in terms of energy savings were not modeled because energy savings were not found to be correlated with canopy coverage.
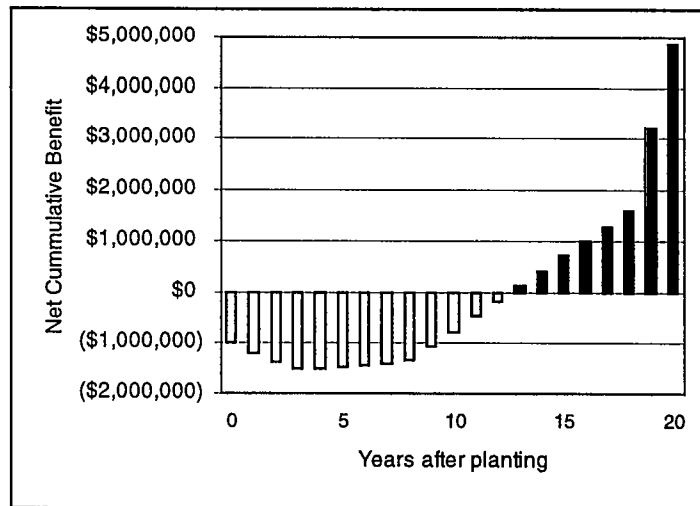


Figure 8. Net Cumulative Economic Benefit of Planting 5,000 Oak Trees

In order to estimate the *net economic benefit* of this tree planting initiative, the following costs were subtracted from the economic benefits resulting from the additional trees: the cost of planting 5,000

tree ($150), the cost of replacing those that die within five years (@250 trees at $150 each), and the cost of maintenance of these trees ($50/tree in year one decreasing to $5 per tree in year six and every year afterward). The estimated net cumulative benefits resulting from the planting of 5,000 trees will total almost $5 million in twenty years (Figure 8). According to these same estimates, there will be *positive net benefit* within 14 years. Although this cost-benefit model is only preliminary, it illustrates that the financial investment required for tree planting efforts can result in a net positive benefit to a community.

## Citywide Tree Species Diversity

Both the number of individual trees per acre and the number of tree species per acre differed significantly between land-use categories (see Results: Tree statistics). As a result, a weighted average of tree species abundance was used to determine the top nine dominant tree species within the City of Tampa. Not surprisingly, Live Oak and Laurel Oak were the two most dominant tree species, comprising roughly 20% of the estimated number of trees within the City or Tampa (Table 15). Crape Myrtle, Cabbage Palm, Slash Pine, Queen Palm, Cherry Laurel, Drake Elm, and Citrus comprised the remaining nine most dominant tree species in Tampa. The total number of individual trees represented by these nine species was estimated to be 57% of the total number of trees within the City of Tampa. Other dominant tree species within the City of Tampa included: Southern Waxmyrtle, Red Maple, Longleaf Pine, Cedar, Goldenrain Tree, Bottlebrush, Southern Magnolia, and Water Oak.

Table 15. Summary of the Nine Most Dominant Tree Species in All Study Sites

| Species Name | Estimated # of trees in City | Individuals Sampled |
|---|---|---|
| Live Oak | 110,139 | 130 |
| Laurel Oak | 89,947 | 116 |
| Crape Myrtle | 76,359 | 40 |
| Cabbage Palm | 74,053 | 91 |
| Slash Pine | 53,316 | 28 |
| Queen Palm | 42,461 | 28 |
| Cherry Laurel | 37,796 | 43 |
| Drake Elm | 24,908 | 24 |
| Citrus | 24,621 | 25 |
| | | |
| Total Individuals of all 50 sampled species | 967,167 | 719 |

# Discussion

Geographic Information Systems software and remote sensing techniques were used to characterize the urban ecosystem and model the economic benefits of trees in Tampa, Florida. The results of these analyses indicate that the urban forest in the City of Tampa currently provides some quantifiable economic benefits to the citizens of the city, as well as some ecological benefits to the Tampa Bay area. Because of the many different issues considered in the study, the following discussion of our results is organized by topic.

## *Land Cover*

### Citywide Canopy Change

Satellite imagery was used to analyze the citywide change in canopy coverage between 1975-1985 and then 1986-1996. Results indicated that canopy coverage totaled 23% in 1975, 14% in both 1985 and 1986, and then 19% in 1996. Although satellite images were selected in part because they had low cloud cover, there was a small amount of cloud cover in the 1975 (2.9%) and 1985 (8%) MSS images. Because the canopy coverage was the same (14%) between the 1985 image with 8% clouds and the 1986 images with no clouds, it is suggested that the effect of cloud cover in the detection of tree canopy was minimal if any.

Tampa had a net loss of forest cover between 1975-1996 of 4%. The majority of this loss occurred during the decade of 1975-1985, during which time our results suggest the canopy cover decreased from 23% to 14%. This was a period of rapid growth for the region and limited environmental protection regulations. The original City of Tampa Tree Ordinance (enacted in 1972) was limited in terms of its replacement requirements for trees that were removed during development. During the period of 1986-1996 canopy coverage increase from 14% to 19% citywide. One possible contributing factor to this increase in canopy coverage was the adoption of a new City of Tampa Tree Ordinance in 1986. The ordinance adopted in 1986 increased protection of canopy trees because it prevented a percentage of existing trees from being cut down during development, required greater replacement size for those trees that were cut down, and required permits for removing trees greater that five-inch diameter (Graham 1999).

### Comparison between Citywide Extrapolations and Satellite Imagery Analysis

The results of citywide extrapolations agree with the results from the satellite data analysis for only two out of the six land-use categories sampled and also for the total citywide canopy coverage (Table 16). Canopy coverage in Tampa in 1998 was estimated by sampling at 17±5%, which does not differ significantly with results from the 1996 satellite imagery that indicated total citywide canopy coverage was approximately 19%. In addition, canopy coverage results were not significantly different within the vacant and multi-family land use categories. However, large differences in results did occur within the public institutional,

Table 16. Comparison of Canopy Coverage Results between Local Analysis and Regional Analysis

| | Canopy Coverage | |
| --- | --- | --- |
| Land-use Category | Local Analysis Results | Regional Analysis Results |
| Vacant | 29±16.4% | 41.9% |
| Public Institutional | 5.3±2.5% | 17.3% |
| Single Family | 28.5±4.1% | 15.3% |
| Multi-Family | 10.6±3.8% | 9.9% |
| Light Commercial | 4.7±2.0% | 7.5% |
| Light Industrial | 0.8±0.4% | 2.5% |
| Total for City of Tampa | 17±5% | 19.3% |

single family, light commercial and light industrial areas. There are several possible reasons for these differences in results, including: (1) a two-year difference in sampling time between methods, 1996 versus 1998, (2) possible inadequate number of sample sites to compensate for the large variation between sites, and (3) limited resolution of the satellite images (30 meters or 150 ft per pixel), and perhaps most importantly with regards to single family land-use, (4) the absence of any recently constructed single family land-use blocks from the randomly selected study sites. With regard to the large difference apparent in the public institutional land-use category, the discrepancy was probably a result of the lack of parks included in the study. Canopy coverage is typically very high in Tampa's parks (included in the public institutional land use) but our random selection of study sites did not result in the inclusion of a park in this study. From this we conclude that the sampling protocol may prove to be more effective if land use types are subsampled based on appropriate categories (e.g. Public Institutional Parks versus non-parks) and/or based on the age of development (e.g. single family). We suspect there is a strong correlation between age of development (year built) and canopy cover of a neighborhood (regardless of land use type). As is the case in any scientific study, a more robust sampling protocol is expected to result in more accurate results.

## Citywide Land-use Comparisons

Regionally, the rapidly developing portion of the city's suburban fringe referred to as New Tampa experienced a 20% loss of canopy between 1975 and 1985. However, the total canopy coverage in this area has remained the same since 1985 at 47%, double the citywide average. Land-use within the areas of New Tampa that showed high canopy coverage in 1996 was primarily classified as agricultural and vacant land. Future land use in this area according to the City of Tampa's Comprehensive Plan is designated as suburban mixed use with a maximum residential housing density of six units per acre (Commission 1998b).

By definition, new development typically occurs on land classified as agricultural land, vacant land, and or natural land, whereas redevelopment occurs on land classified as residential, commercial, or some other "developed" land use. Within the City of Tampa, canopy coverage differed widely between land-use categories, ranging from 61.8% in agricultural areas to 1.7% in (heavy) commercial areas. Not surprisingly, canopy coverage was greatest in natural, agricultural, and vacant areas. These same areas are often subjected to extreme pressure to develop into a residential, mixed use, or other "developed" area. Based on results of the NDVI analysis, we estimated that if all of the land currently classified as agricultural or vacant was developed into single family residential with the resulting average canopy coverage of 15.3% (Table 4), the citywide canopy coverage would decrease from 19.3% to 13.7%. Possible implications of this change include increased stormwater runoff, decreased carbon and pollution reduction, decreased energy savings, and reduced wildlife habitat. An interesting extension of this research would be to model the difference in *regional* urban forest benefits between additional high-density development within the City of Tampa versus additional development in the surrounding rural and suburban areas, assuming one precludes the other. Efforts to preserve existing canopy cover in new Tampa should be attempted to avoid this loss since it takes over ten years to regenerate any significant canopy cover through planting efforts.

## *Urban Forest Structure*

Citywide tree density is estimated at approximately 14-16 trees / acre (~1 tree per 3000 sq. ft.) which is lower compared to other cities such as Marlborough, Massachussets which found 20 trees per acre (1997d), and much lower than Chicago which found approximately 28 trees per

(McPherson, Nowak, and Rowntree 1994). However, overall canopy coverage is higher suggesting the age and size of the trees sampled in our study is different. In fact, the average dbh value for all study sites in Marlborough were 10.3 inches and in our study we found 15.3 inches dbh. For comparison, in natural hammock ecosystems (which the city most closely approximates under anthropogenic conditions) tree density ranged from 202 – 536 trees per acre (1 tree per 215 sq. ft. – 1 tree per 81 sq. ft.)(Vince, Humphrey, and Simons 1989). While it is not realistic to assume that cities can maintain tree populations on this order of magnitude, increasing tree density is supported by public preference studies which found optimal densities in parks to be 51 trees per acre (125 trees / ha) (Schroeder and Green 1985).

We found approximately 50 species of trees throughout the study but total diversity is likely much higher and some species remained unidentified because of limited access to private property. Of the 50 species identified, 46% of the species were native and 54% were exotic. Seven of the tree species found in the study were identified by the Florida Exotic Pest Plant Council as species that are invading and disrupting native plant communities in Florida or have shown a potential to disrupt native plant communities (EPPC 1999). Of the natives, only one species was found that was threatened, the Paurotis Palm (*Acoelorraphe wrightii*), which is not native to the Tampa region but is occasionally cultivated. Table 15 shows the top nine tree species in the study area. The second most abundant tree species encountered during sampling was the relatively short-lived Laurel Oak (*Quercus laurifolia*). Because this species was also found to be predominantly in the mature age class distribution, much of the city's current canopy could be reduced from tree mortality. Overall, diversity varied significantly among blocks with multifamily and single family residential sites having 5.2 and 5.0 species per acre. Public institutional land-use was surprisingly low in diversity at 2.4 species per acre. This is likely explained by the heterogeneous nature of sites that are classified as public-institutional as expressed in our SE for the land-use category. For example, in our study one of the sites classified as PI was a parking lot in downtown while others were schools (site 51_318). Unfortunately, public parks were not randomly selected as explained above. Additional samples would be required to determine the true diversity of this land-use type.


## Energy Savings

Energy models included in the CITYgreen application are at this point in the early phase of development and can be considered estimates only. The model used in this analysis calculated energy savings for single-family residential homes resulting from direct shading of windows and air conditioners by the tree canopy. Although direct shading does indeed contribute to energy savings, recent research suggests that the air supply to air conditioning units comes from a much larger area than could be shaded by a single canopy tree (Parker, S. F. Barkaszi, and Sonne 1996). It might be discovered that overall canopy coverage might prove to be a better indicator of energy savings.

With these caveats in mind, the most heavily canopied residential site that was modeled saved approximately $63 per year and saved over 740 kWh per home. Average energy savings for all study sites equaled 371 kWh or $32 per home. Citywide, by multiplying the average savings per home by the total number of homes (approximately 77,171), the potential energy savings could reach almost $2.5 million dollars per year. In addition to these direct savings, the reduction in energy usage, especially peak energy usage, could decrease air pollution from power plants and reduce the need to build new power generation facilities.

Compared to other cities where data are available, the tree canopy in Tampa results in greater savings per home than in Dade County where savings are valued at $17 per home (Forests

1996a), Ft. Lauderdale at $20 per home (Forests 1996b), and Marlborough, Massachusetts at $7 per home (Forests 1997d). Although it is unknown why these differences occurred between the cities in Florida given the similarity in climatic conditions and energy costs, the difference between energy savings in Tampa versus Marlborough was probably a result on the increased overall cooling costs in Florida.

## Stormwater Management

In economic terms, a valuable contribution of urban trees in reducing infrastructure costs may be the ability to capture incoming rainfall and as consequence reduce the negative ecological effects of stormwater runoff. We have shown that the existing citywide canopy is providing a valuable service to the city. Our results suggest that even modest canopy cover reduces the overall stormwater runoff in cities. In fact, the beneficial effects of trees are particularly pronounced in wet subtropical climates such as Tampa's. Our results suggest volume of runoff reduced ranged from 0.5% (light industrial) to 17.6% (single-family residential), resulting in an average runoff reduction of 8.8% citywide, or 934 cubic feet of water per acre. These results were similar to results of studies in Dade County (1,000 $ft^3$ per acre) and Tallahassee (1,178 $ft^3$ per acre) (Forests 1996a) and (Forests 1999). This translates to a reduction of over 65 million $ft^3$ during a two year, 24 hour design storm for Tampa. We estimate a conservative economic value for this reduction in runoff at approximately $500,000 annually and if land acquisition costs and maintenance costs were figured in the value would be ten million dollars annually. While trees will never completely compensate for the amount of runoff generated by urban and suburban development, they may provide additional capacity to the overall stormwater management system. This may prove extremely valuable in formulating public policy with regard to stormwater infrastructure. In our opinion, further studies should focus on modeling the relationship between canopy coverage and runoff reductions in future development scenarios. Perhaps a beneficial approach would be pursued in the form of (stormwater) runoff coefficient credits for preservation of natural areas and existing canopy. Thus reduced cost in stormwater management systems could be translated into additional tree planting and preservation.

Overall, additional citywide canopy coverage may prove to be extremely valuable for coastal cities like Tampa because stormwater carries such a large proportion of the total pollutants that enter surface water, such as, streams, bays and rivers. In fact, in the Tampa Bay watershed the total nitrogen loading entering the bay from urban stormwater is estimated at 45% and selected heavy metals may be as high as 60% (TBNEP 1996). Reducing stormwater runoff through preservation and maintenance of the tree canopy may prove to be a valuable tool for managing the watershed.

## Air Pollution Benefits

Overall air quality in the Tampa area is typically well above national standards (DARM 1997). This is largely due to the geography and meteorological conditions in the area that tend to favor good dispersion of air pollution. Despite the overall good air quality in the area, temperature inversions and large point source polluters often result in temporary high concentrations of ozone, sulfur dioxide, and particulate matter. Of major concern is the level of ozone pollution measured within the City of Tampa; the area is nearly in non-compliance for meeting ozone standards under the Clean Air Act (DARM 1999).

The tree canopy in Tampa was estimated to reduce 2,344 tons of pollutants per year (combined O3, SO2, NO2, PM10 and CO). As a comparison, total point source pollution emissions in Hillsborough County of carbon monoxide, sulfur dioxide, nitrogen oxides and particulate matter in 1997 equaled over 250,000 tons per year (EPC 1997), while our estimates indicate that the tree canopy reduces only 1,535 tons of these same pollutant per year (Table 17). Even with the potential additional pollution reduction that is a secondary benefit of energy savings, the total pollution reduction provided by the tree canopy is less than half of one percent of the total emissions. Clearly, the benefit provided by Tampa's urban forest when compared to these large point sources is nearly inconsequential. Despite this apparently limited benefit, we suggest that pollutant sequestration as a result of the tree canopy may provide localized benefits within heavily canopied area of the City of Tampa on those days when the air quality is marginal. In addition, because the tree canopy can contribute to an overall reduction in citywide air temperatures, a leading component of ozone formation, Tampa's tree canopy may further assist in a reduction in the total amount of citywide ozone formation (Nowak 1994a).

Table 17. Comparison between 1997 Point Source Emissions (Hillsborough County) and City of Tampa Tree Canopy Benefits

| | Tons per Year | |
|---|---|---|
| Pollutant | Point Source Emissions | Tree Canopy Reduction |
| CO | 5,249 | 330 |
| NOx | 77,989 | 332 |
| SO2 | 179,867 | 199 |
| PM | 6,547 | 674 |
| Total | 269,652 | 1,535 |

Carbon dioxide, in addition to methane and other gases, contribute to the "greenhouse" effect. The "greenhouse" effect is a natural process by which solar radiation easily penetrates through these gases in the atmosphere but escaping heat is retained, thus keeping the atmosphere at temperatures at which life can be sustained. However, too much of these gases can cause global warming beyond what is natural and could cause a global increase in temperature as well as major climates changes. A secondary effect such as the rise of sea level is of major concern in the Tampa area, where most of the population lives near sea level. The results of this study indicate that carbon sequestration equals approximately 1,500 tons per year and the total carbon "locked" in existing trees is over 336,000 tons. These amounts are nearly insignificant compared the estimated 2.8 million tons of yearly carbon dioxide emissions in Tampa based on average emissions per capita in the United States (American Forests). Despite this apparently limited direct impact on carbon, the process of carbon sequestration also results in the production of a critical component of human life; oxygen. Additional study is required to make a more accurate estimation of benefits related to carbon sequestration and or oxygen production in Tampa.

## Economic Benefits and Future Scenarios

Results of the citywide projections provide a basis for valuation of the City's current urban forest. Using available dollar values for each quantifiable benefit, the total economic value of Tampa's Urban Forest was estimated at over $16 million per year. On a per tree basis, the average tree presents a benefit of approximately $2,000 dollars during the average 100 year life span ($20/year). The result of these models may be valuable when making decisions regarding Tampa's Tree Ordinance. For example, the replacement requirements included in the Tree Ordinance could be evaluated in terms of the loss of these benefits, possibly revised based on the lifetime benefit provided by a tree.

Results of the tree-planting model indicate that the average cost of planting and maintaining a thirty-gallon oak tree will be recovered in approximately fifteen years. When viewed in term of cumulative benefits, the net economic benefit of planting 5,000 trees (a current tree planting

initiative) could total five million dollars after twenty years. Clearly, the potential benefits provided by additional tree plantings could be substantial, and these benefits do not include trees planted every year by homeowners in Tampa. However, these additional benefits could be negated if existing land with abundant canopy coverage is converted to residential or other development patterns with lower canopy coverage.

Although these estimates are based on a number of assumptions about dollar values per benefit, this study should demonstrate that there are real and substantial economic benefits in addition to the aesthetic benefits provided by the tree canopy in the City of Tampa. Future improvements to these models should increase our ability to accurately determine the benefits provided by the tree canopy.

# Recommendations & Future Research

- Expand regional analysis to encompass the entire Tampa Bay watershed, since the majority of new development is occurring in the unincorporated counties of Hillsborough, Pinellas, and Pasco Counties.
- Monitor regional canopy coverage using remote sensing techniques and establish citywide and regional benchmarks for canopy coverage to be monitored using those same techniques every three to four years.
- Use the aforementioned benchmark in key public policy such as the Comprehensive Plan and the Landscape and Tree Protection Ordinance.
- Conduct a more thorough cost-benefit analysis of future tree planting scenarios to determine where to plant trees to maximize economic benefit.
- Investigate the relationship between stormwater management credits and the cities landscape ordinance and determine if credits could be established for trees as a component of stormwater infrastructure.
- Research the most effective policy to prevent the drastic reduction in canopy coverage projected based on the conversion of agricultural and vacant land in New Tampa to residential mixed-use.
- Hold a public meeting with commercial property owners to determine what impediments exist to increasing canopy coverage on commercial and industrial property within the city.
- Use established benchmarks and economic values of trees as criteria in evaluating variances to the tree and landscape ordinance.
- Since residential trees have a relatively low mortality rate, high economic benefits, and are typically maintained by property owners, investigate expanding tree planting efforts by providing subsidized trees to homeowners.

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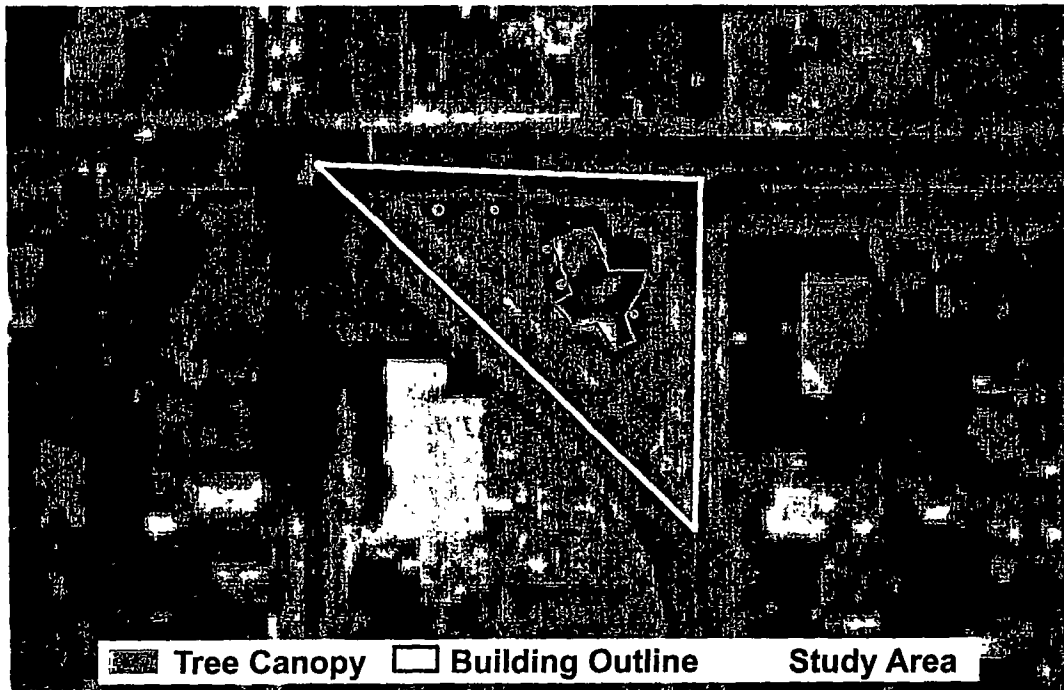
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# Appendix A: Example Field Survey Map



● Trees   □ Buildings   Study Site

# Appendix B: Sample Field Data Sheet

Site: _____ Surveyors: _____ Date: _____ Page __ of __

| Tree ID# | Species | Diameter (2") | Diam. Class | Ht. Class | Red. Ht. | Health |
|---|---|---|---|---|---|---|
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| | | At 4.5 ft. | 1= <10"<br>2= 10-20"<br>3= >20" | 1= <15'<br>2= 15-35'<br>3= >35' | Has tree been topped<br>Yes / No | 1= dead/dying<br>2= poor<br>3= fair<br>4= good<br>5= excellent |

**DO NOT FORGET:**
INDICATE LOCATION OF AIR CONDITIONERS (A), WINDOWS (W), AND WATER BODIES (WATER)
Note: Record diameter of multi-stem trees as total diameter of all stems.

# Appendix C: Study Site Locations and Aerials Views



Tree Canopy ☐ Building Outline Study Area

Study Area: 0.8 (A) Tree Canopy: 0.8% Buildings: 9.1% Impervious: 74.8% Grassland: 9.8% Water: 0%

Figure 9. Light Commercial Study Site 1, Census Block #29_103.



Tree Canopy ☐ Building Outline Study Area
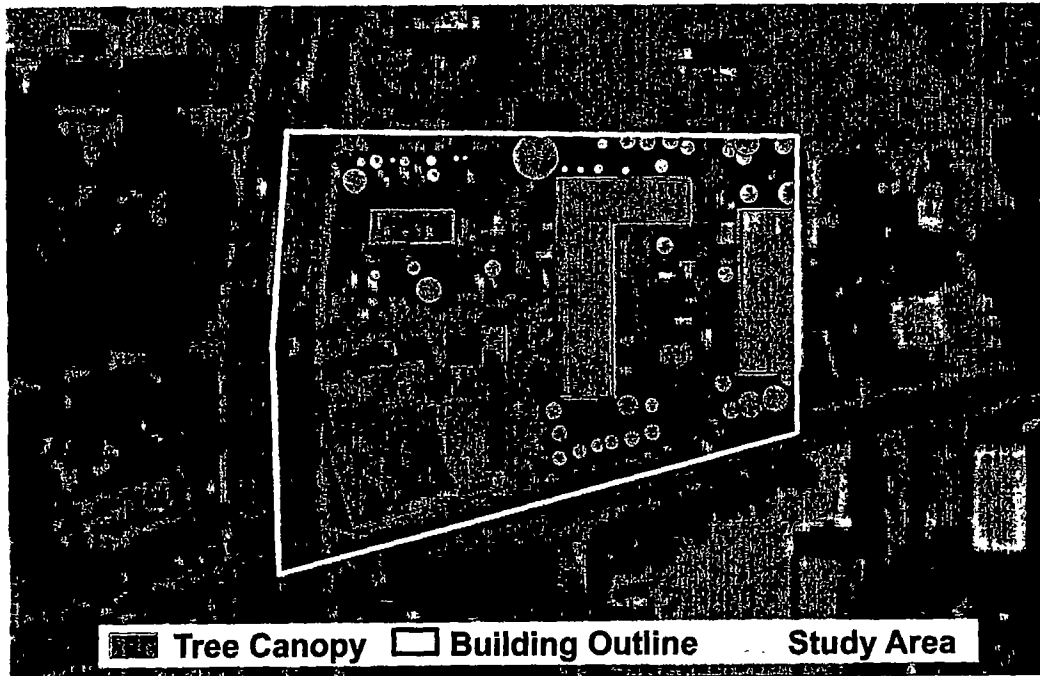
Study Area: 4.6 (A) Tree Canopy: 6.2% Buildings: 26.6% Impervious: 54.9% Grassland: 13.2% Water: 0%

Figure 10. Light Commercial Study Site 2, Census Block #37_436.

**Tree Canopy** ☐ **Building Outline** **Study Area**
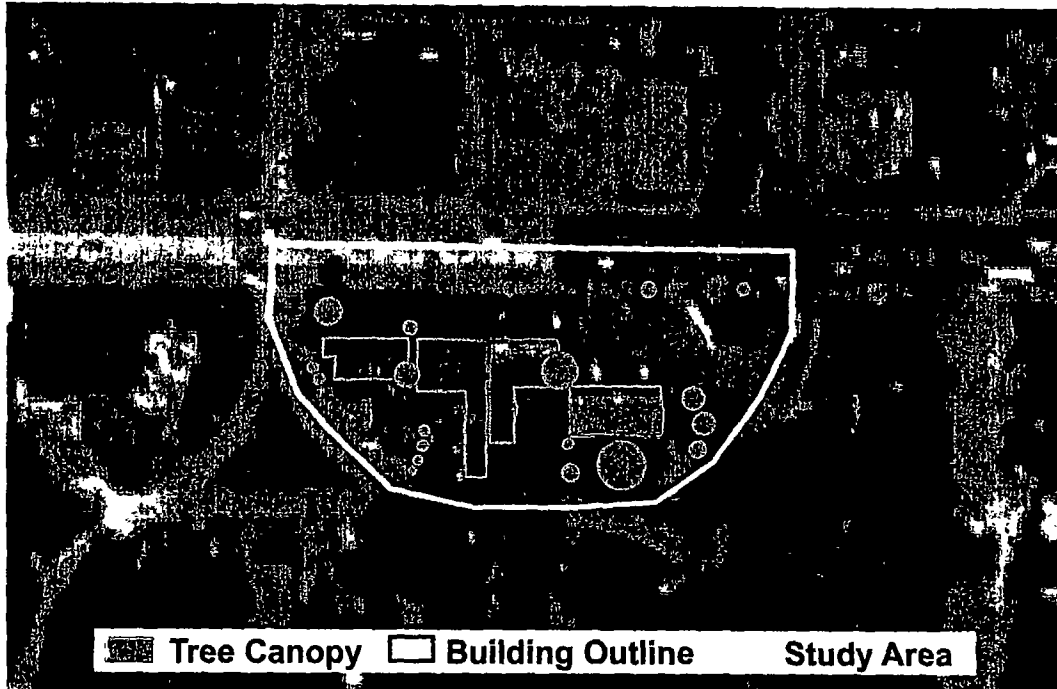
Study Area: 1.9 (A)   Tree Canopy: 7.1%   Buildings: 16.1%   Impervious: 64.7%   Grassland: 15.7%   Water: 0%

Figure 11.  Light Commercial Study Site 3, Census Block #57_102.



**Tree Canopy** ☐ **Building Outline** **Study Area**
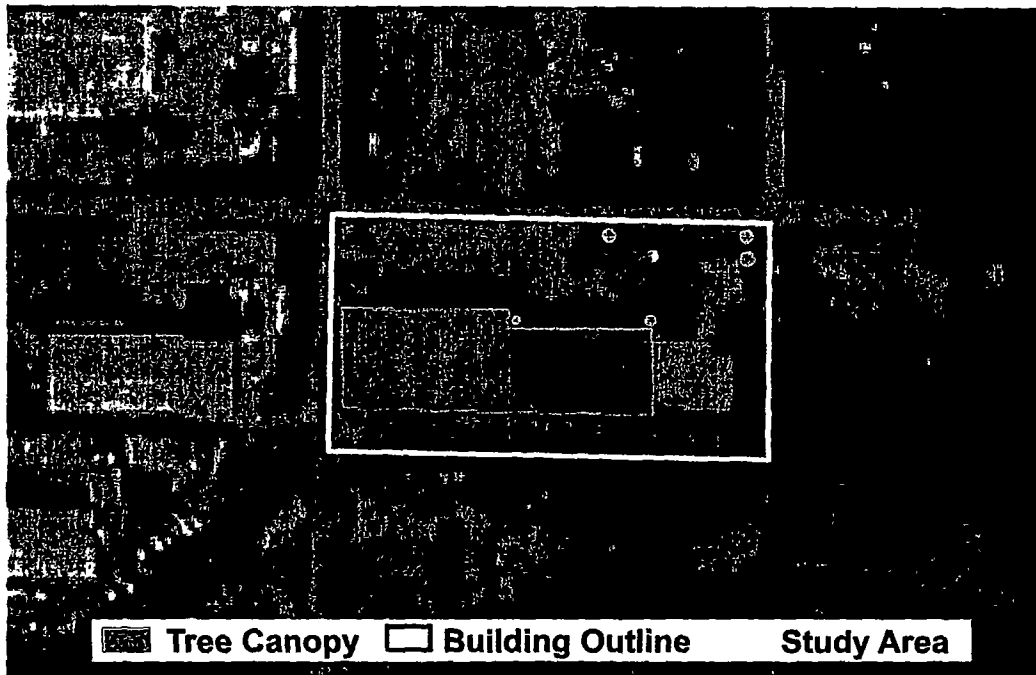
Study Area: 2.7 (A)   Tree Canopy: 0.9%   Buildings: 27.9%   Impervious: 35.5%   Grassland: 33.9%   Water: 0%

Figure 12.  Light Industrial Study Site 1, Census Block #38_322.

**Tree Canopy** ☐ **Building Outline** **Study Area**
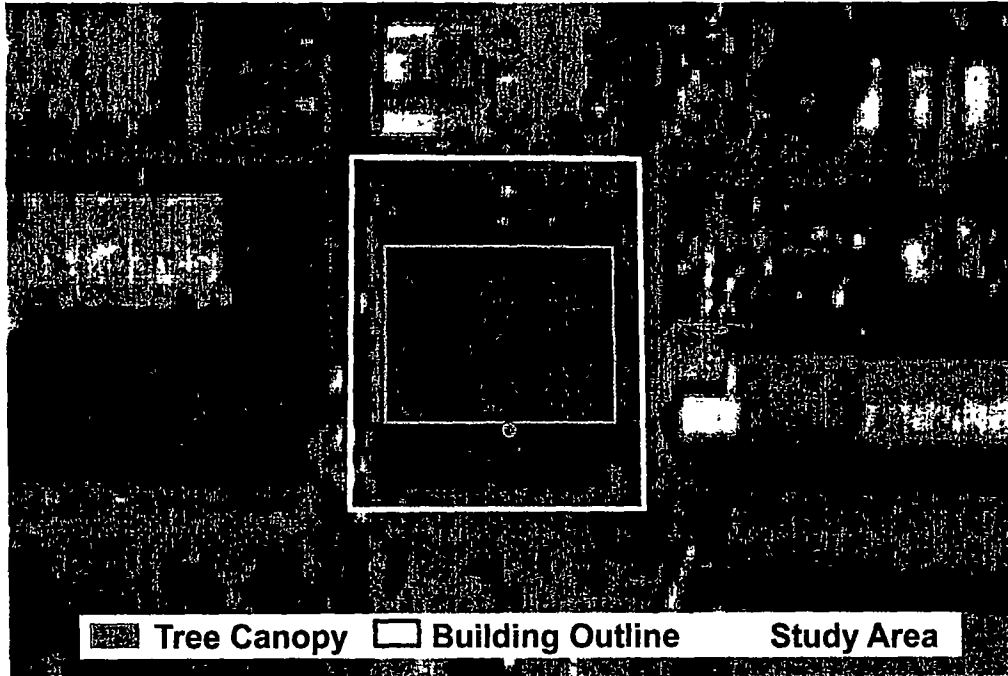
Study Area: 1.8 (A)  Tree Canopy: 0.2%  Buildings: 39.6%  Impervious: 41.9%  Grassland: 14.8%  Water: 0%

Figure 13. Light Industrial Study Site 2, Census Block #39_312.



**Tree Canopy** ☐ **Building Outline** **Study Area**
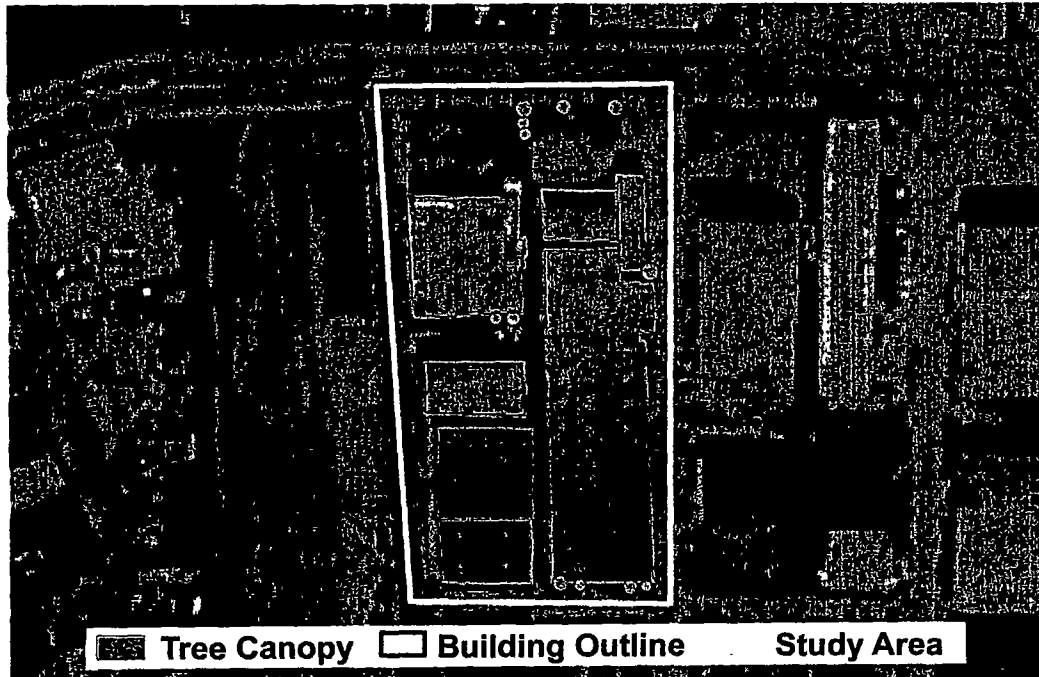
Study Area: 5.1 (A)  Tree Canopy: 1.4%  Buildings: 50.1%  Impervious: 39.9%  Grassland: 5.2%  Water: 0%

Figure 14. Light Industrial Study Site 3, Census Block #53_112.
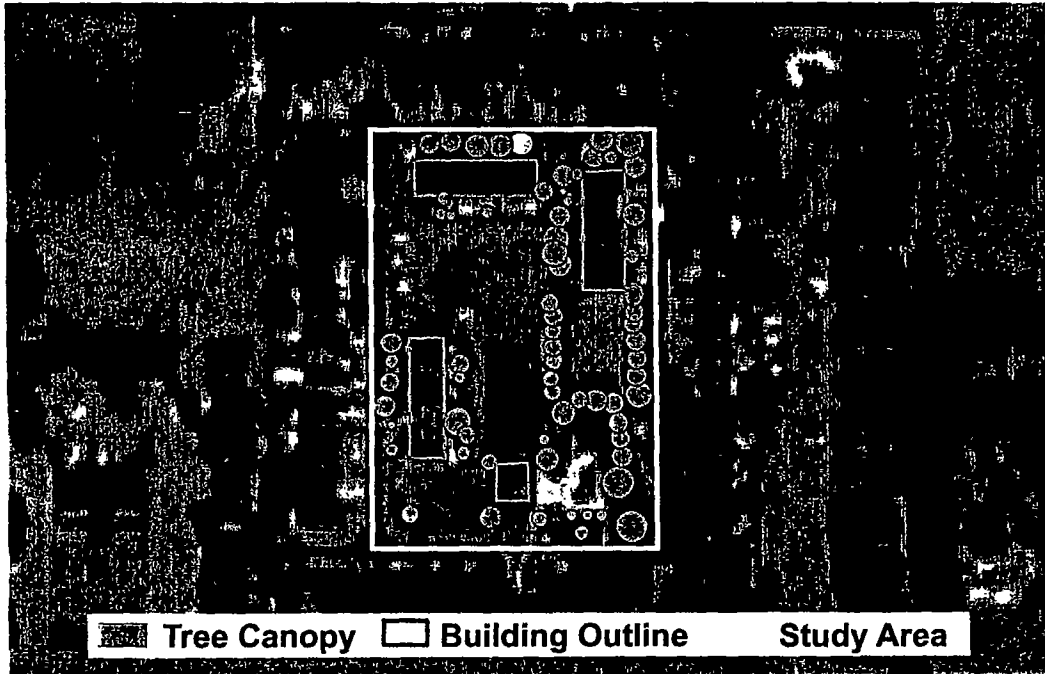
Study Area: 2.7 (A)    Tree Canopy: 17.4%  Buildings: 12.2%  Impervious: 30.5%  Grassland: 38.7%   Water: 14.5%

Figure 15.  Multi-Family Residential Study Site 1, Census Block #1_238.
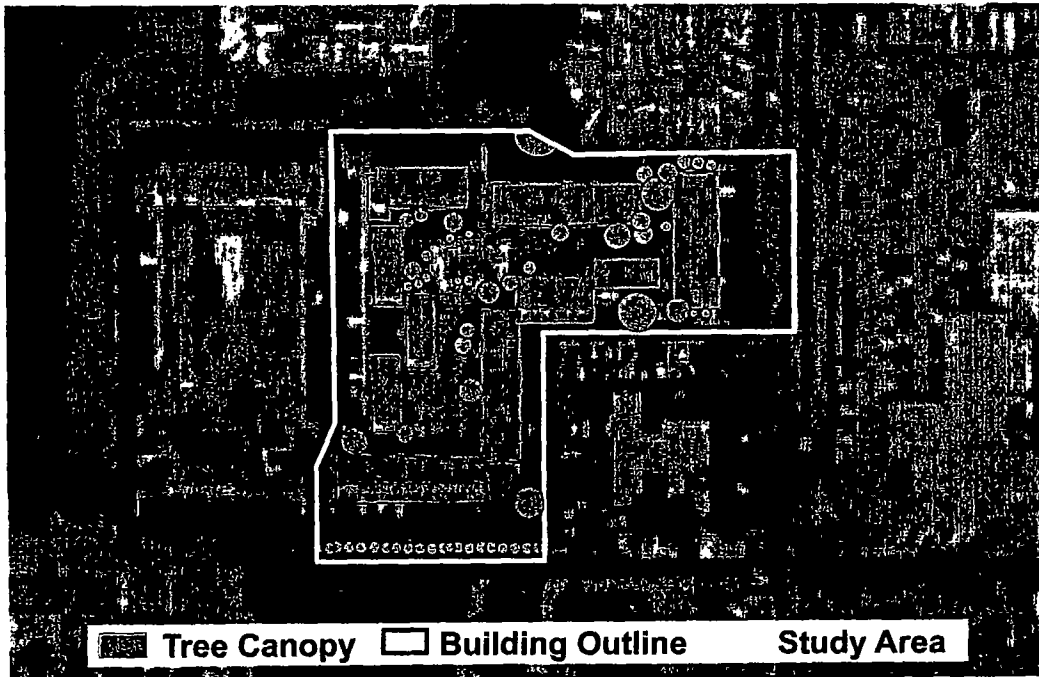


Study Area: 3.3 (A)    Tree Canopy: 10.0%  Buildings: 29.7%  Impervious: 39.0%   Grassland: 28.1%     Water: 0%

Figure 16.  Multi-Family Residential Study Site 2, Census Block #4_145.

| | | Tree Canopy | ☐ Building Outline | Study Area |
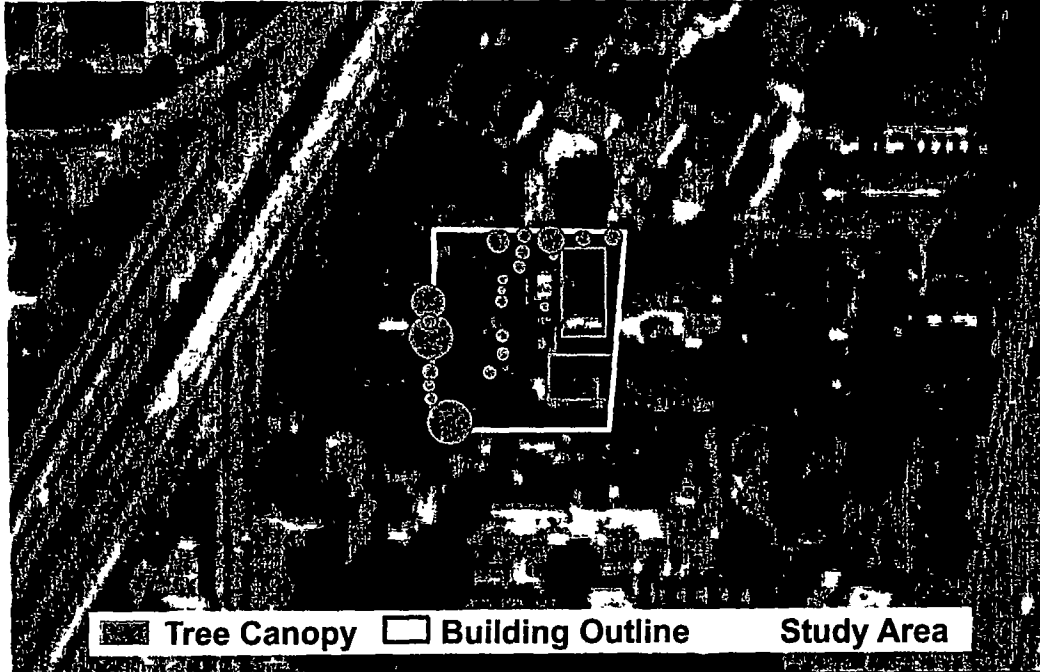
Study Area: 0.9 (A)    Tree Canopy: 4.4%  Buildings: 19.9%  Impervious: 50.0%  Grassland: 36.2%    Water: 0%

Figure 17.  Multi-Family Residential Study Site 3, Census Block #61_702.



| | | Tree Canopy | ☐ Building Outline | Study Area |
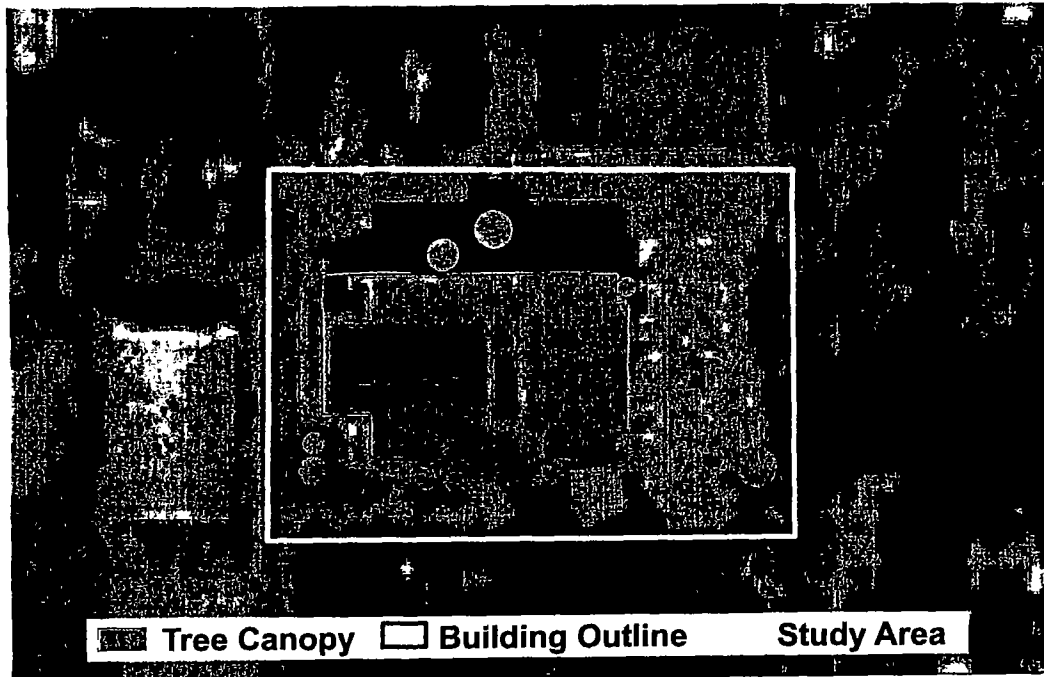
Study Area: 2.5 (A)    Tree Canopy: 3.1%  Buildings: 28.2%  Impervious: 52.9%  Grassland: 11.5%    Water: 0%

Figure 18.  Public Institutional Study Site 1, Census Block #29_324.

| Tree Canopy | Building Outline | Study Area |
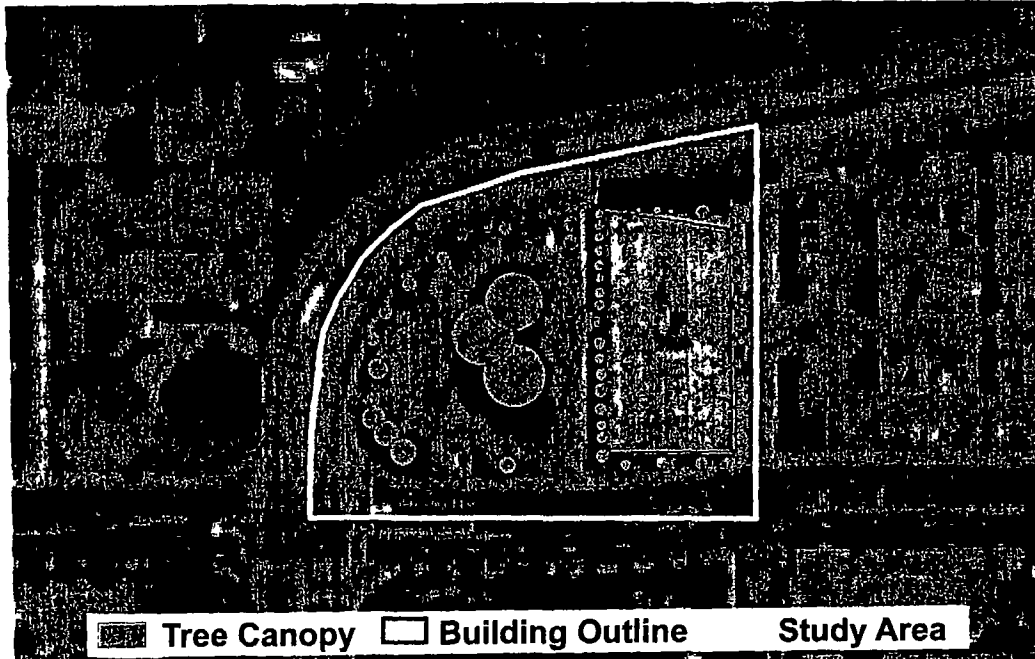
Study Area: 2.7 (A)   Tree Canopy: 10.3%  Buildings: 19.6%   Impervious: 2.7%   Grassland: 1.5%   Water: 0.5%

Figure 19.  Public Institutional Study Site 2, Census Block #39_714.



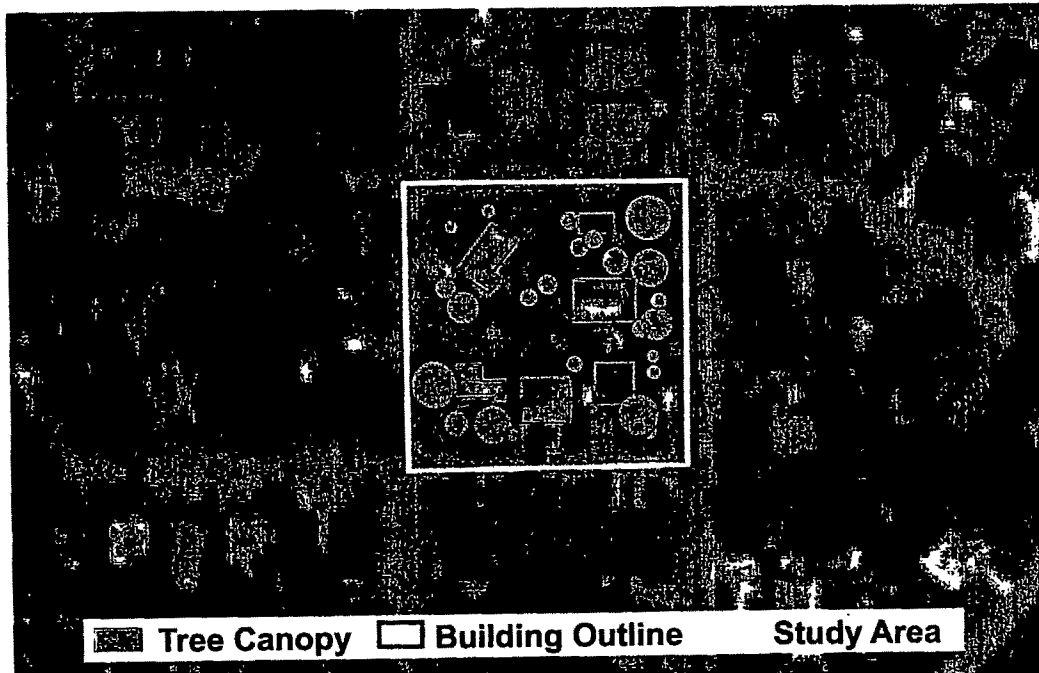| Tree Canopy | Building Outline | Study Area |
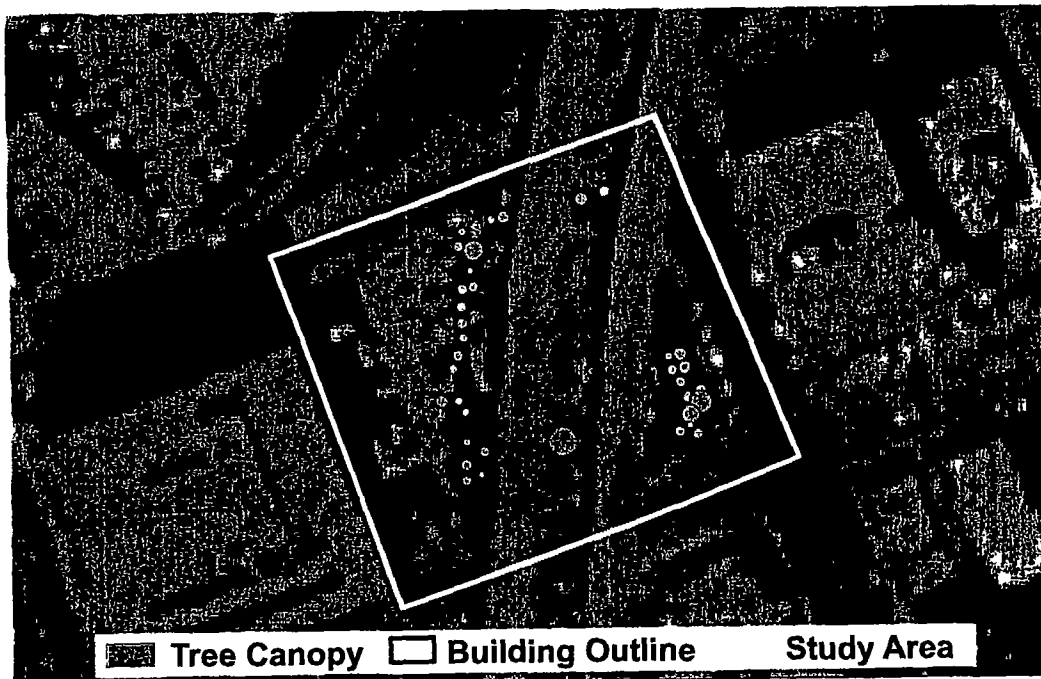
Study Area: 2.1 (A)    Tree Canopy: 2.5%   Buildings: 0.0%  Impervious: 84.9%  Grassland: 11.5%    Water: 0%

Figure 20.  Public Institutional Study Site 3, Census Block #51_318.
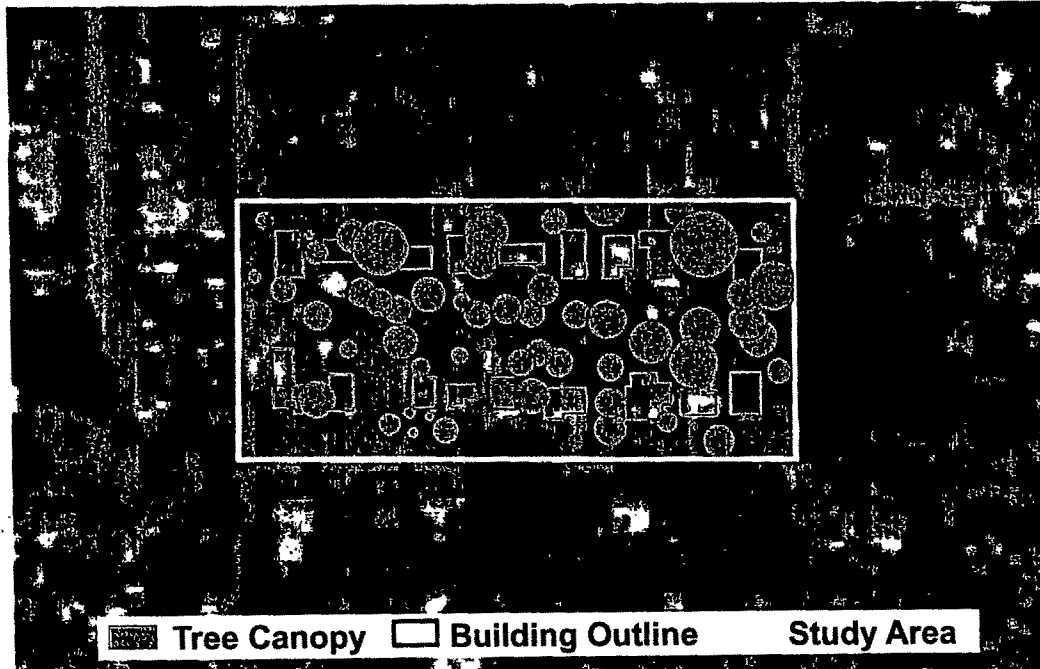
Study Area: 5.2 (A)   Tree Canopy: 29.7%  Buildings: 13.6%  Impervious: 16.9%  Grassland: 64.7%    Water: 0%

Figure 21.  Single Family Residential Study Site 1, Census Block #17_402.
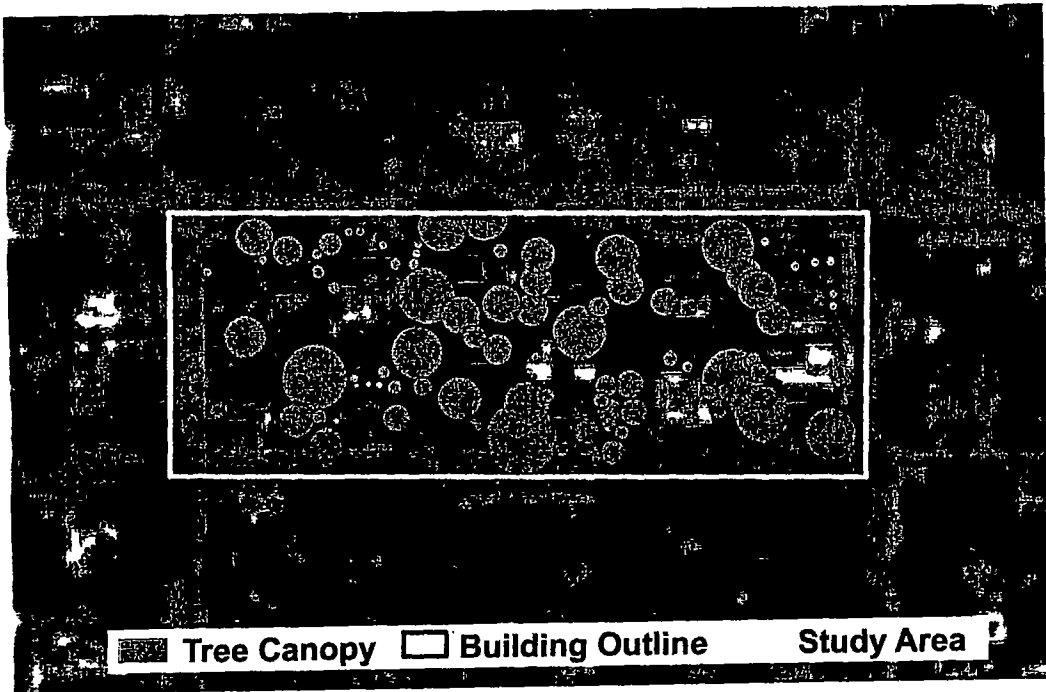


Study Area: 1.5 (A)    Tree Canopy: 16.3%  Buildings: 13.2%  Impervious: 14.0%  Grassland: 66.1%      Water: 0%

Figure 22.  Single Family Residential Study Site 2, Census Block #2_307.

**Tree Canopy** ☐ **Building Outline** **Study Area**
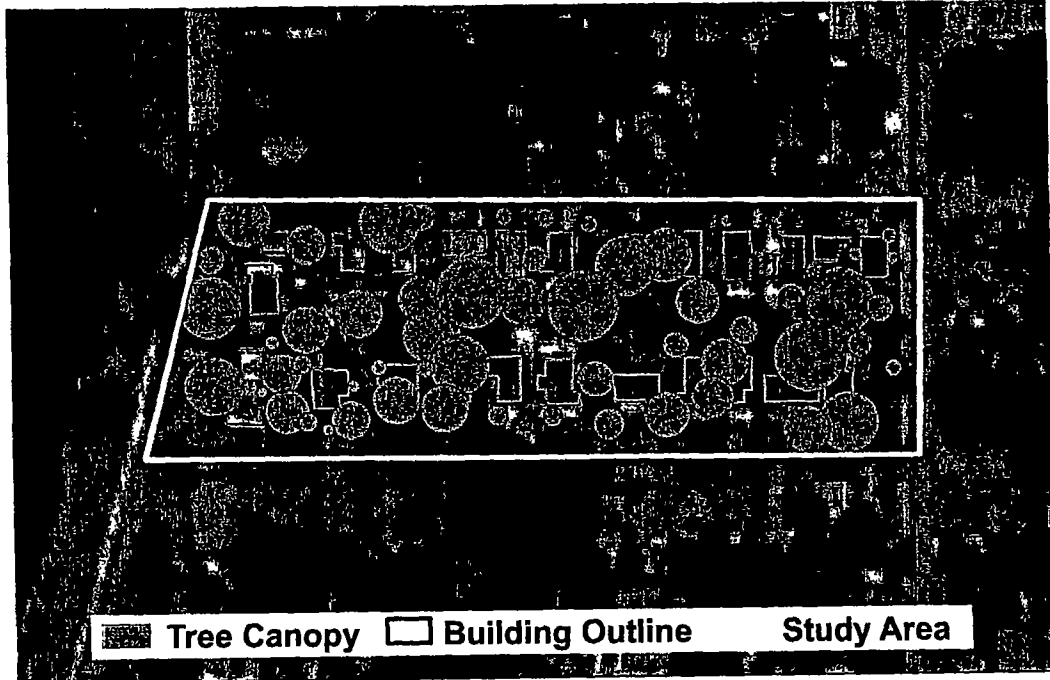
Study Area: 5.3 (A)   Tree Canopy: 37.9%  Buildings: 14.2%  Impervious: 14.4%  Grassland: 66.6%   Water: 0%

Figure 23.  Single Family Residential Study Site 3, Census Block #23_105.



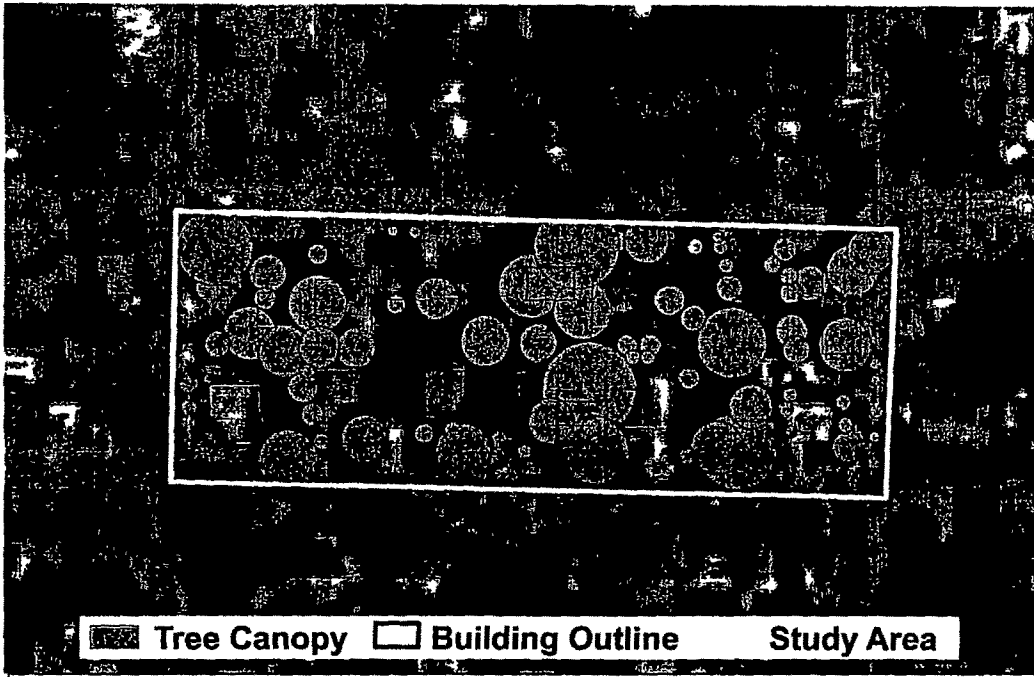**Tree Canopy** ☐ **Building Outline** **Study Area**

Study Area: 3.8 (A)   Tree Canopy: 30.2%  Buildings: 17.0%  Impervious: 25.8%  Grassland: 52.0%   Water: 0%

Figure 24.  Single Family Residential Study Site 4, Census Block #63_105.
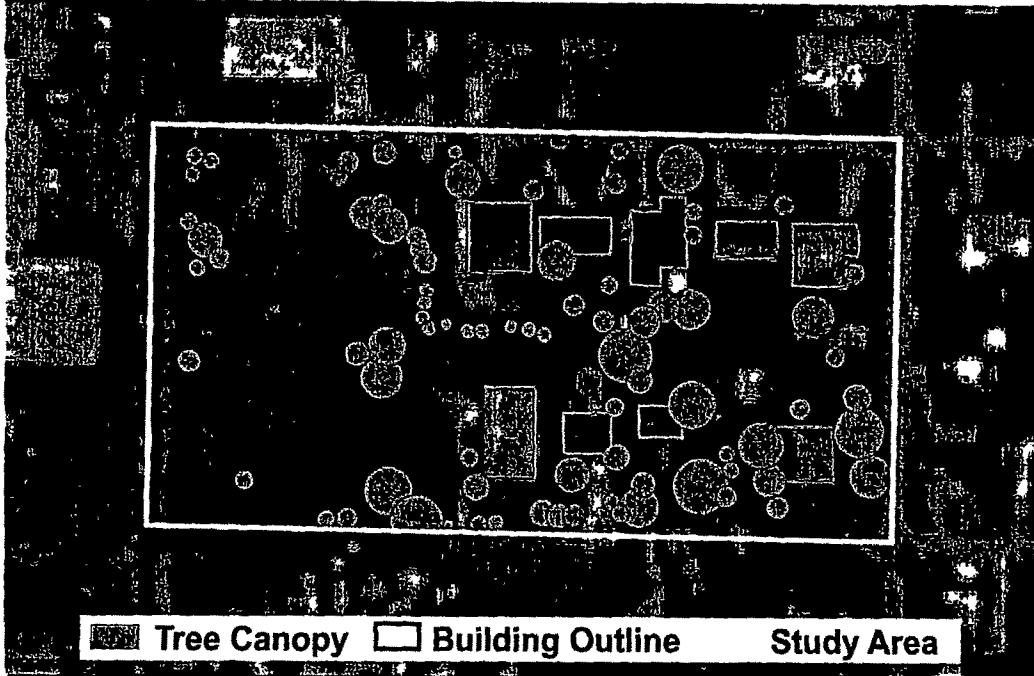
Study Area: 5.6 (A)   Tree Canopy: 16.8%  Buildings: 10.4%  Impervious: 13.5%  Grassland: 73.2%   Water: 0.5%

Figure 25.  Single Family Residential Study Site 5, Census Block #71_319.



Study Area: 3.7 (A)   Tree Canopy: 39.9%  Buildings: 16.0%  Impervious: 30.1%  Grassland: 51.8%   Water: 0%

Figure 26.  Single Family Residential Study Site 6, Census Block #63_710.