Re-engineering Tree Management in Cambridge: The Benefits Provided By Updated Tree Management Techniques

An Interactive Qualifying Project Report
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by

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Abstract

The project analyzed the entire tree management function emplo yed by the City of Cambridge Department of Public Works. It then targeted the areas in which the process could be improved for either efficiency or effectiveness. New methods were implemented and the new process was tested in a test area (Cambridge Common and Walker Street), then the new data analysis tools developed were extrapolated onto the entire existing tree inventory. The result was an optimized, repeatable and reproducible tree management methodology.

Acknowledgements

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Executive Summary

Introduction

The project "Re-engineering Tree Management in Cambridge: The Benefits Provided By Updated Tree Management Techniques" analyzed the entire tree management function employed by the City of Cambridge Department of Public Works. It was a comprehensive assessment of the tree management process that revealed several areas of potential improvement in order to increase efficiency and effectiveness. These bottlenecks were found to be data collection, data input, and data analysis. The resulting deliverables presented targeted these areas of inefficiency and were aimed at streamlining the process. These included a new data collection methodology, a new database with improved data entry forms, and new repo rts for data analysis.

After the recommended changes were implemented and tested, new economic and environmental benefit equations were extrapolated on the entire tree inventory. The analysis of this new information provided insight into the value of tr ees to the City of Cambridge. It also presented the quantifiable economic benefit of tree management, specifically aggressive tree maintenance. Through detailed analysis, improvement of bottleneck areas, and thoughtful accurate recommendations, the proje ct has transformed tree management in the City of Cambridge.

Results

Data Collection

The data collection process was the first area that was identified for improvement. In order to optimize this task we reformulated the way it was done. In our new field manual we detail a field methodology for data collection. This includes new methods such as separating data into two distinct categories, permanent information and dynamic information. Permanent information includes fields that will remain static over the course of a trees life and will only need to be inputted once, such as species and location. Dynamic information changes each time that a tree is surveyed and includes fields such as diameter at breast height (DBH), canopy size, disease, insect infest ation, obstructions, and major visible injuries. One of the benefits of this division is that dynamic data can be collected by anyone properly trained, as outlined in our field manual. This cuts down on the need for an arborist to be present at the time of data collection, greatly reducing cost and increasing potential times for data collection.

Data Input

The task of data entry was one that was also addressed to increase efficiency and accuracy. A graphical interface form was developed to provide the user with greater ease of input (see Figure 1).

It also provides the ability to regulate the information that is entered in order to screen for accuracy. Drop down menus eliminate possible misspellings that would alter search results while simultaneously increasing the ease of data entry.

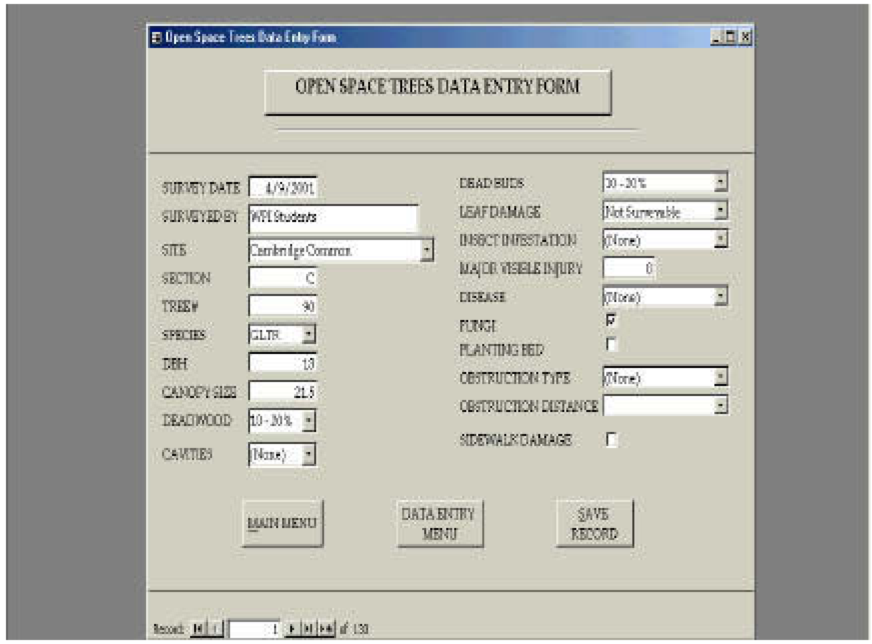

Figure 1: Data entry form for an open space tree

Data Analysis

Data Analysis was improved through the creation of reports of importance to the City Arborist, as well as other data analysis tools. New geographical information system (GIS) layers were created to display and track the tree canopy of Cambridge as well as species distribution. Other tools include record filtering by any field or combination of fields of the entire database. This allows the user to filter records by any desired criteria in order to analyze the tree information. This will aid in the future discovery of data correlations that will assist in tree planting, disease prevention, and urban forestry as a whole.

Analysis

After collecting data from our study areas, the Cambridge Common and Walker Street, we performed analysis on our data to discover new information that would be helpful both to the development of our new tree management system and to the Cambridge Urban Forestry Division as well .

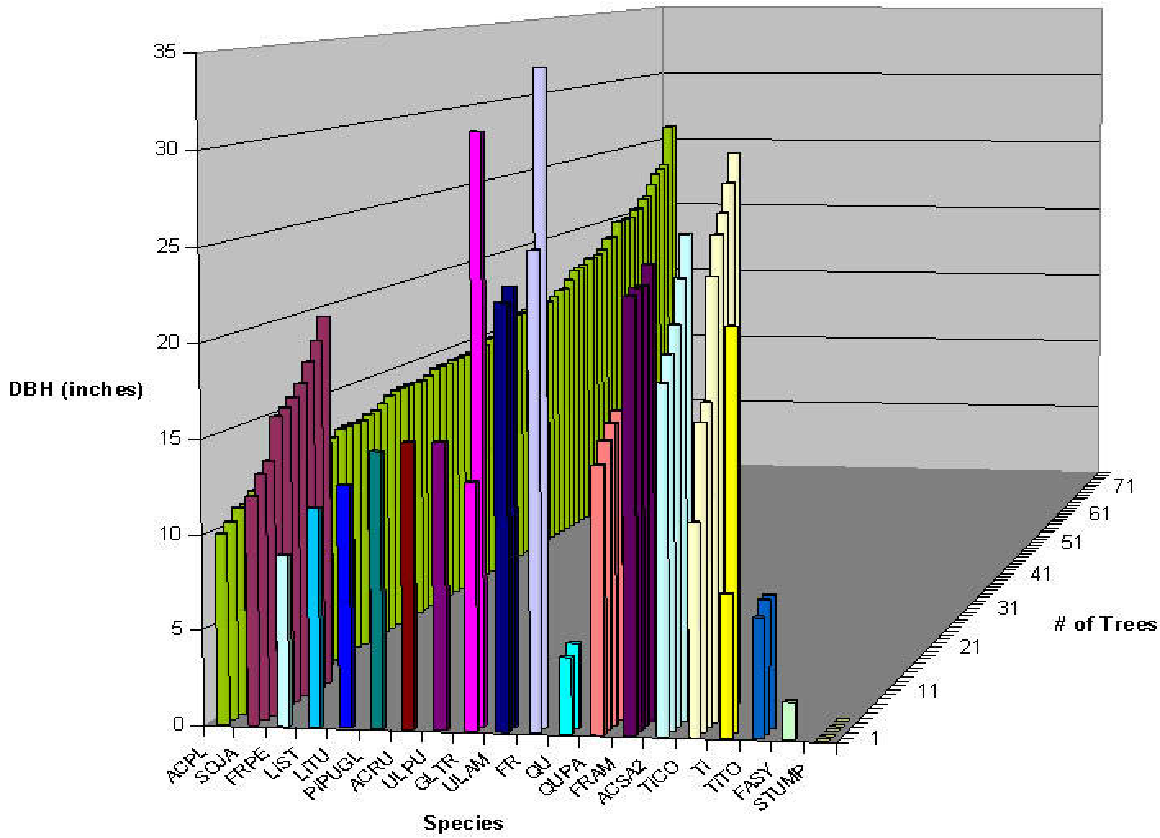

Figure 2: Species distribution with DBH in Cambridge Common

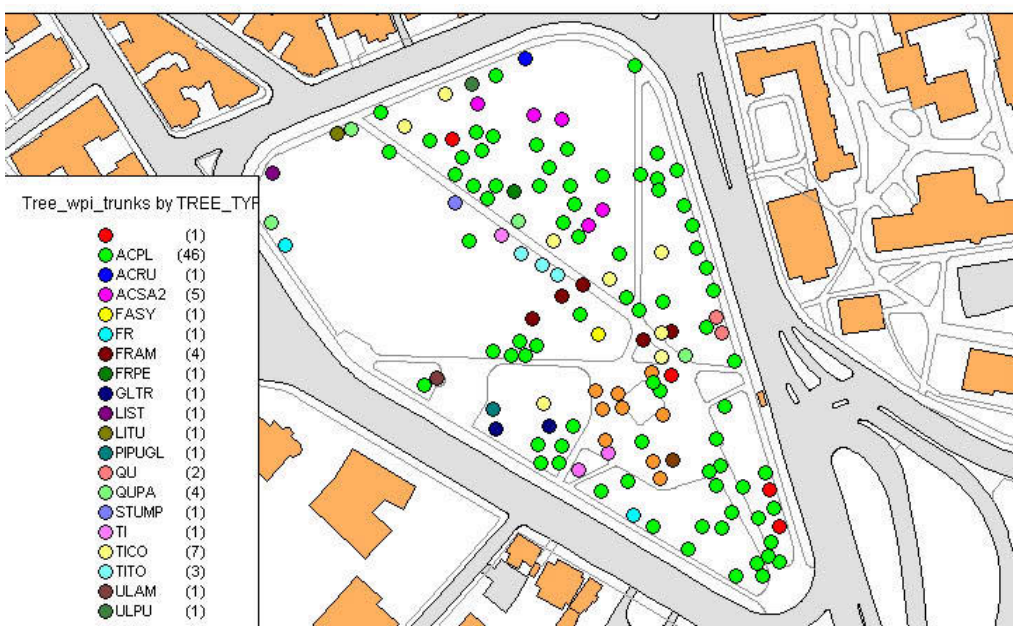

Figure 3: GIS projection of species distribution in the Cambridge Common

Our analysis of species distribution and DBH (to show age) showed that the city has a dangerous concentration of Norway Maples, which were planted very close to each other chronologically as well (see Figure 2). This can also be viewed geographically with the GIS projection (see Figure 3). This is something that should be examined closer for resolutions in order to guard against blight or disease, similar to what happened with Dutch Elm disease.

We also extrapolated our tree value function over the entire street tree inventory which showed both total value, as well as concentrations of valuable trees in Cambridge (see Figure 4).

STNO	FLD002	UNITTYPE	TREE VALUE
563	HURON AV	PLOC	$123,578.16
561	HURON AV	PLOC	$119,353.58
49	YORK ST	PLAC	$111,124.85
48	LEE ST	ULAM	$103,189.99
46	HUBBARD AV	ACRU	$99,332.77
1000	MASSACHUSETTS AV	TICO	$91,838.75
33	LINNEAN ST	ULAM	$84,638.60
97	BERKSHIRE ST	PLAC	$84,638.60
175	CHESTNUT ST	ACRU	$81,148.74
541	HURON AV	PLOC	$74,389.42
535	HURON AV	PLOC	$71,119.97
33	ABERDEEN AV	QURU	$67,923.98
47	ABERDEEN AV	QURU	$67,923.98
136	LAKEVIEW AV	ACRU	$64,801.47
65	YORK ST	PLAC	$64,801.47
75	ABERDEEN AV	QURU	$64,801.47
116	APPLETON ST	FRPE	$64,801.47
115	ABERDEEN AV	QURU	$61,752.43

Figure 4:Table of highest tree values calculated from the street tree database

We also conducted an analysis of the pollutant removing capability of the street tree inventory of Cambridge (see Figure 4). This showed that together the trees are capable of naturally removing large quantities of toxins from the air (see Figure 5). 0

DBH Class	CO	SO_2	NO_2	PM10	O_3	Total
0 - 3 in	0.002204	0.006612	0.006612	0.015428	0.017632	0.048488
3 - 6 in	0.006612	0.017632	0.019836	0.046284	0.050692	0.141056
6 - 12 in	0.015428	0.046284	0.052896	0.12122	0.13224	0.368068
12 - 18.5 in	0.037468	0.119016	0.136648	0.310764	0.337212	0.941108
18.5 - 24.4 in	0.072732	0.229216	0.260072	0.59508	0.647976	1.805076
24.4 - 30 in	0.094772	0.299744	0.34162	0.78242	0.84854	2.367096
30+ in	0.123424	0.392312	0.449616	1.02486	1.11302	3.103232

Units Are Lbs/Yr

Figure 5: Pollutants removed by trees annually with relation to DBH category

While the amount removed pales in comparison to the amount that is produced by cars, it does show an environmental contribution to the city.

Conclusions

Through the presentation of our deliverables and the analysis of results, this project has re -invented the tree management process utilized by the City of Cambridge. Direct effects of the implementation of the new tree management system include a decreased turn-around time for addressing maintenance issues such as obstructions and unhealthy trees. It also results in decreased costs in the form of saved overtime for emergency tree maintenance by providing early notification of potentia l hazards in order to address them before they become problems. An example of this is in decreased claims against the city due to damage caused by trees that were negligently maintained. The new database also provides increased analytical abilities in the form of reports and nearly infinite filtering options. This allows for data to be analyzed and compared in new ways in the future and provides the capability to draw new correlations and conclusions.

This project serves as a foundation for a repeatable and reproducible model for urban tree management. With an overlay of customization onto a standardized base, this project provides for the translation of our tree management into any urban forestry program.

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1. Introduction

The Cambridge Department of Public Works (DPW) Urban Forestry Division has been working to provide maintenance to all the trees in Cambridge for a number of years. They inherently have a number of practices and procedures for maintaining the health of the trees in the parks and along the streets. The processes that were used included methods of tree maintenance and ways that feedback is obtained from the public. There was no tree management system in place for the usage, integration, and storage of data collected. Their database consisted of 11,061 street trees prior to our arrival; updates had not been carried out since the initial steps of the inventory began.

Our project Re-engineering Tree Management in Cambridge, involved surveying open-space and street trees to develop a field methodology to aid the Cambridge City Arborist and project liaison, Mr. Larry Acosta in his management and maintenance duties. The data was archived on GIS maps and a new database we created, complete with photos. We also estimated the environmental and economic benefits of the trees, based on factors such as pollutant removals and appraised tree value. These deliverables are important to our sponsor; the Cambridge DPW and to Mr. Larry Acosta: the analysis of data collected documents the various benefits of trees and can be used as a resource for spreading tree awareness among local citizens and the new tree information system will help our project liaison in his day to day duties as a Tree Warden.

Our major project goals were:

- To reorganize all existing data and research
- To develop a new tree information system
- To create and test a field methodology
- To collect field data and incorporate them into the new information system
- To quantify tree data collected in order to analyze the economic and environmental benefits of trees in Cambridge

In order to accomplish our project goals we needed to obtain background knowledge on the City of Cambridge and also on topics relevant to tree management. We started with a brief history of the city, a description of our project sponsor and project study areas. We acquired information on definitions and relevance of urban ecology to the Boston area and its relationship to sustainability. We described the various benefits of trees and urban forestry to a city; the history, techniques, and practices of arboriculture; and the International Society of Arboriculture. We concluded our background section with information on all technologies used by the DPW Urban Forestry Division and also by us during the project.

In our methodology section we outlined how all of our major tasks were conducted. We assessed methods of collection, and storage and organization of the DPW Tree Information System. After this assessment we developed a new MS Access database for easy data entry and storage and surveyed open space and street trees in the Cambridge Common and on Walker Street. Lastly, we developed various formulae to determine the environmental and economic benefits of trees.

Once all data was collected and stored, we were able to generate various results and map layers based on our raw data. We then analyzed this data for environmental benefits; determined an appraised tree value of all trees surveyed by us and extra polated the formulae onto the street trees surveyed by the DPW. We helped the DPW by re-engineering their information system and provided them with a tool to increase efficiency in tree management.

2. Background

In order to obtain a clear understanding of tree management in Cambridge, we studied the City of Cambridge, its history, government structure, the DPW, and the Cambridge Common. We gained information on urban ecology, sustainability, benefits of trees, and urban forestry. We also researched the study of arboriculture, its techniques and practices, and the International Society of Arboriculture. Lastly we obtained information on tree management technologies used by the DPW and also softwares used by us during our project.

2.1 The City of Cambridge

Cambridge is a cultural city that has a diverse citizenry. It promotes activity and growth in many directions. The city's different green areas create an escape from city pressure as well as increase consciousness about our environment.

Around the mid-1600's there was a movement from England towards the New World. This movement was in response to pressure from the British government. The travelers from England headed for the new colonies in hope of starting a "purer" environment and what they saw as a more Biblical church. The Massachusetts Bay Colony was to be their new home. The colony started building around the entrance to the Charles River, and soon started to grow to neighboring areas.

The City of Cambridge, known as Newtowne prior to 1638, developed into a large village. It consisted of a meetinghouse, a market place and a college for the development of ministers (Harvard). By the time of the Civil War, there were many local artisans, farmers, and tradesmen. During the siege of Boston, General Washington had several earthen forts dug out; the remains of several of them can still be seen today.

After 1845, the Potato Famine in Ireland brought forth another large immigration movement into the United States in the mid-nineteenth century. Many of the Irish settled in Cambridge, along with immigrants from Italy, Poland, France, and Canada.

Today, Cambridge consists of a culturally diverse population of over 95,000. Harvard and the Massachusetts Institute of Technology attract students from around the world. The heavy industry of the late 1800s has been replaced by a large number of technological firms and businesses, which has created a world-class city on a small scale.

2.1.1 Cambridge Government Structure

Cambridge has a Manager-Council form of Government. The mayor is the official spokesperson of the city and chairs the city council; he oversees all the other offices. The next level is the City Manager. The Office of the City Manager is the executive department for the city of Cambridge and consists of the City Manager and the Deputy City Managers. Along with the city managers, there are several assistant managers.

Their duties include community development, fiscal affairs, and human affairs. The city also has the Commissioner of Health and Hospitals who promotes and protects the health of the citizens of Cambridge.

A variety of governmental departments are charged with managing city budgeting, emergencies, human services, and education as well as other types of community services. Among these departments, the one most pertinent to this project is the Department of Public Works (DPW).

2.1.2 The Cambridge Department of Public Works (DPW)

The DPW is responsible for maintaining streets, parks, sidewalks, cleanliness, and sanitation in a manner that provides an efficient and safe community environment. The DPW is comprised of fourteen different divisions. The business and administration divisions organize and coordinate all other divisions within the DPW. Other divisions handle sanitation, vehicle maintenance, and information technologies. More important to this project are the Park Maintenance & Urban Forestry and Cambridge Cemetary Divisions. Some of the other divisions that could also be involved with this project are the Engineering, Street Maintenance, Public Building Construction, and Building Maintenance.

The Superintendent of Parks and the City Arborist work together to run the Parks and Urban Forestry Division of the Department of Public Works. The Parks division is responsible for all of the 120 municipal properties and public grounds in Cambridge, including parks, playgrounds, squares, plazas, medians, and public meeting grounds. The maintenance and care tasks consist of landscape management, repair, preventive maintenance, and cleaning.

The City Arborist and several other skilled tree professionals work together in the Urban Forestry component of the division. Urban Forestry is required to maintain a comprehensive tree care program for the local park and open-air trees. A four-year pruning cycle, a tree care program, and tree planting services have developed through this program. Urban Forestry is also responsible for creating and operating an educational outreach program.

2.1.3 The City Arborist

The City Arborist also acts as Tree Warden for the City of Cambridge. The Tree Warden conducts Public Tree Removal Hearings for all removals that are not considered an emergency. He reviews plans for landscaping and tree planting on public lands with the Committee on Public Planting. The City Arborist also is required to assist contractors in developing and implementing maintenance and upkeep plans for trees on public property.

2.1.4 Public Parks in Cambridge

Cambridge has a wide variety of parks and walkways. The Division of Parks and Urban Forestry devotes much of its time to providing and maintaining a healthy environment for the people of Cambridge. The parks blend an artistic style with well-structured design.

The park system in Cambridge has changed dramatically over the years. In Cambridge's early years people felt that there was no immediate need for parks in the city. As the city began to grow, the changing topography allowed for heavy building in certain areas. Boston's many hills made park integration extremely difficult.

During the mid-nineteenth-century, people took an interest in the development of parks and green spaces. However, the terrain around Cambridge allowed for a limited number of parks. The city asked internationally renowned Frederick Law Olmsted to help design and create several parks. Olmsted decided that, due to the topography of the city, Cambridge would be forced to think in terms of a park system rather then a single park (i.e. Central Park in New York). [1] With Olmsted being preoccupied with the Boston park system in the late 1890s, he couldn't design the park system for Cambridge. Soon after, Boston became the first U.S. city to have a complete park system. This system, often called the "Emerald Necklace", included a long string of connected parks and walks extending from Brookline and West Roxbury to Back Bay and Downtown. Olmsted's design concepts that were used in Boston were later applied to the Cambridge park system.

Cambridge has since created a number of parks using Olmsted's philosophy. Parks are to be designed with the intention of providing people with a place to get away from the noisy urban life. Many of the theories that Olmsted created in Boston are comparable to practices used today. [2] For example, the use of curved paths as opposed to straight paths can be seen in many parks around Cambridge. Curved paths promote ever-changing views of the surroundings by allowing the visitor to pass back and forth, and slow down visitors.[3] For this same reason, Cambridge Common uses un-uniform planting techniques that are similar to many of Olmsted's parks. As in Olmsted parks, Cambridge's park system provides a wide variety of trees and plants to the urban environment.

As mentioned, there are over 120 municipal grounds in Cambridge, roughly eighty of which are parks and play areas. The division of Parks and Urban Forestry maintain these parks and areas on a regular basis. For a full list of the parks in Cambridge see Appendix D. Not including Fresh Pond, the ten largest parks in Cambridge can be seen in Table 1.

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[1] Zaitzevsky, 1982, pg. 33
[2] Zaitzevsky, 1982, pg. 34
[3] Zaitzevsky, 1982, pg. 198

Within parks and cemeteries, and along trees, there are approximately 20,000 trees in Cambridge. The majority of these trees can be found in the public parks and on privately owned land. There are, however many privately owned trees. To manage this vast number of trees, it is important to take a look at the design of parks prior to installation and also to look at layout of the existing parks. Many of the parks found in Cambridge, built on Olmsted's principals of manageability and purpose have been easily maintainable.

TEN LARGEST PARKS IN CAMBRIDGE
Cambridge Common
Danehy Park
Donnelly Field
Glacken Field
Gore Street
Hoyt Field
J.J. Ahern Field
Rindge Field
Russell Field
St. Peter's Field

Table 1: Ten largest parks in Cambridge

Parks provide a buffer zone between the often-harsh urban environment and a city's natural environment. They help preserve a balance in the urban ecosystem by providing a growth area for flora and fauna and by providing homes for urban wildlife. The field of knowledge that looks more deeply into this area is known as urban ecology.

2.1.4.1 The Cambridge Common

The site where Cambridge Common now sits was the intersection of major trade routes linking Boston and East Cambridge during the late 1700's. The Common was granted to Cambridge for use as a military training field in 1769 and eventually became the headquarters of the Continental Army after Washington took command in 1775. The tree where Washington was said to have first taken command of the Continental Army has been created into a monument. In 1830 the Proprietors of Cambridge gave the rights of the Common to the town, and laws were passed to preserve the Common as a park.

Currently, the Cambridge Common is a centralized park adjacent to Harvard Square. There are approximately 170 trees of 27 types in the Common. There is a large Civil War Memorial near the center of the Common, a playing field, a playground, and a network of brick pathways scheduled to be repaired in the next few years.

2.2 Urban Ecology

A basic knowledge of urban ecology and planning is essential to understand the reasons for doing a Tree Management Project. To gain this basic knowledge we researched the history of the subject, current critical topics, and how these issues affect the city of Cambridge.

2.2.1 Urban Ecology Defined

Urban Ecology has no single meaning. A definition cannot be found within the pages of Webster's Dictionary. Even using encyclopedias to define the term raises some problems. One definition, however, lies in the juxtaposition of the two separate words. Urban is a term used to describe anything that has to do with non-rural, developed areas like cities. Ecology is the study of how humans and other creatures interact with their surrounding environment. Thus urban ecology is the study of how humans interact naturally with ecosystems in urban areas to create distinct new systems. Perhaps the reason for the lack of a clear definition for this scientific field is that it is fairly new.

Ecology has been an established field for many years. The German biologist Ernst Heinrich Haeckel introduced the term ecology in 1866.[4] After Haeckel came Charles Darwin, the well-known scientist who put ecology "on the map," so to speak. Darwin and his theories of natural selection are still in debate to this day. He helped bring a scientific topic into public view and even created some excitement about it through the controversy that followed his writings. Since that time, the field of ecology has evolved and public interest in the environment has helped that evolution. Environmental interests also brought the two words urban and ecology together.

2.2.2 Sustainability in Urban Ecology

Every ecosystem that exists has set limits that are not meant to be exceeded. Once these limits are exceeded, the environment cannot recover and it becomes unsustainable. This is how many urban tree species have become either rare or extinct. Sustainability has been an integral part of ecology for a long time. It has become the focus in urban ecology in the past few years as urban growth continues to cause problems worldwide.

Sustainability takes into account every factor that can affect a city and its environment. These factors include wildlife management, soil protection, population density, food and power availability, economics, and, most importantly in this case, urban forestry. If any of these factors exceed their limits, then the city's design is not feasible. This has involved many scientists and architects in the field of natural engineering. No longer are the concerns simply aesthetic or based only on one branch of science. Zev Naveh refers to this as transdisciplinarity. Naveh also makes reference to Emil Jantsch, a "renowned system thinker and planner." Jantsch wrote a paper in the 1970s in which he "provided a hierarchical systems view of transdisciplinarity as the highest multilevel, multigoal coordination toward a common system purpose." [5] That rather wordy and conceptual definition basically means that transdisciplinarity allows for subjects of differing nature to be combined and used to reach a joint goal.

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[4] Encarta Online, 2001

This relates directly to the Cambridge tree assessment. The tree warden's interest in trees extends beyond issues of planting and maintenance to areas of social, cultural, and economic aspects of urban forestry. To carry out his mission, he must have an easy way to catalogue the trees, which can be accomplished with computer databases and inventory software. To help create sustainable forests in the city there must be laws to protect them as well. Tree Warden Acosta is in the process of formulating a city tree ordinance that would allow for the protection of trees. These steps, however, come from careful planning and thinking about how sustainability can be attained.

2.2.3 Sustainability Achieved

Suppose a tree warden plans on keeping a sustainable forest development in an urban area. What can he do to ensure that the urban area will not be detrimental to the forest and that the forest will not harm the immediate environs? Apart from doing a massive amount of research and case studies on the development site, there are a few simple rules to follow. Beatley and Manning propose several steps in The Ecology of Place:

- Respect the limits of the ecosystem
- Make an effort to fix the damage already done not just keep equilibrium
- Consider the whole host of social issues involved with keeping sustainability

Using these three rules, attempts at sustainability are being made in Cambridge.

Every ecosystem has only a certain amount of support that it can offer. This is part of the reason that a tree census and cataloging occurs. If an environment has too many trees, they may have a detrimental effect on the whole ecosystem. This is also why the tree warden creates a pruning cycle. Pruning allows the warden to affect the trees' growth patterns, maintain their health, and to make sure that they don't adversely affect the ecosystem.

If the area in question is already damaged, then the balance may need to be altered. Trees and other plants can be used to help the ecosystem regenerate itself. When closely watched over, this process can undo the damage caused by urban developments. Once this process is completed, the trees can be removed or transplanted, if necessary, to keep the environs in equilibrium. Still, the equilibrium is dependant on the people inhabiting the area as well.

The social considerations and accommodations that have to be made for sustainability are the most difficult thing to control. The forest has to create a sense of belonging and pride for its residents while still being functional and ecologically viable. One must also factor the residents and their actions into the ecological system. The best way to control this factor is through community education about proper environmental conduct. This education comes in the form of outreach programs with schools and

[5] Naveh, 2000

community tree walks in Cambridge. Tony Dominski, PhD, has one more suggestion for creating a sustainable ecosystem: Reduce, Reuse, and Recycle.[6] The slogan has been used nationwide over the past few years in reference to plastic and glass bottles. Dominski, however, is making reference to current housing developments. Contractors can help the environment by reusing old buildings for lumber and other parts or even restore the buildings to their own specifications. This will protect the surrounding forest by making sure that it is not cut down for development of new homes.

2.2.4 Urban Ecology in the Boston Area

After World War II, a great exodus occurred in the United States. Many people began moving out of the cities and into suburbs. Though Cambridge had been an established city for many years, it was still far enough outside of Boston that this great influx of residents affected it deeply.

At the time, many people owned automobiles and the government even offered special programs and subsidized loans for housing in suburbs.[7] Thus, many people chose to purchase a suburban house and travel into the city to work. The plan seemed like a good one, but environmental issues weren't taken into account at the time. Soon after this process began many ecologists, and citizens alike, noticed the problems of pollution. The main focus of urban planning at the time was land use and zoning.[8] As the discipline grew, it began to encompass city planning. The effects of the baby boom became evident in the 1970s and massive city growth led to growth management, the primary goal of which was to make sure that the community could expand in a 'livable' and sustainable way.

Until recently the idea of sustainability had not been applied to the Cambridge community's environmental concerns. Now, though, the city has a Tree Warden who must take all of the factors of the city into account and work with other departments (e.g., GIS System, Cambridge Conservation Commission, Water Department) to create a healthy ecosystem. The environmental concerns of the planet, along with the problems of continued population growth, have gained the public's att ention, so the time is right to make far-reaching changes that will allow the local tree system to prosper.

Urban ecology can help by providing models for urban sustainability. One must begin, though, by gathering basic data about local trees in order to use the concepts of urban ecology.

2.3 Urban Trees

Awareness of the importance of trees in our society is growing, especially in Cambridge. Besides the work that the Cambridge Department of Public Works carries out, there are many projects, organizations and programs dedicated to spreading, maintaining and improving awareness of the benefits of trees in Cambridge.

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[6] Walter, 1992, pp.16-18
[7] Beatley, 1997, p. 40

The National Arborists Association, the Society of Municipal Arborists, the Cambridge Tree Project, the National Arbor Day Foundation and the International Society of Arboriculture (ISA) are some of the many well-known organizations involved in the management of the urban forest. Much of the information in this section comes from the work of these organizations.

2.3.1 Benefits of Trees[9]

Most trees and shrubs in cities or communities are planted to provide beauty or shade. Trees are also important as a balancing factor in the cycle of nature. The benefits of trees can be grouped into social, community, environmental, and economic categories. See Figure 6 for tree benefits figure.

2.3.1.1 Social Benefits of Trees

People like having trees around them as it makes life more pleasant. Most of us respond to the presence of trees beyond simply observing their beauty. We feel serene, peaceful, restful and tranquil in a grove of trees. Hospital patients have been shown to recover from surgery more quickly when their hospital room offered a view of trees. The strong ties of people and trees are more evident in the resistance of community residents to removing trees to widen streets.

2.3.1.2 Community Benefits of Trees

The size of trees often makes them a part of the community even though they may be private property. Since trees occupy considerable space, planning is required if both owners and neighbors are to benefit. With proper selection and maintenance, trees can enhance and function on one's property without infringing upon the rights and privileges of neighbors.

City trees often serve several architectural and engineering functions. They provide privacy, emphasize views or screen out objectionable views, and reduce glare and reflection. They provide backgrounds, or soften, complement or enhance architecture. Trees bring natural elements and wildlife habitats into urban surroundings all of which increase the quality of life for residents of the community.

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[8] Beatley, 1997, p. 18

[9] This excerpt is taken from a brochure published by the International Society of Arboriculture(ISA) as part of its Consumer Information Program.

2.3.1.3 Environmental Benefits of Trees

Trees alter the environment in which we live by moderating climate, improving air quality, conser ving water and harboring wildlife. Climate control is obtained by moderating the effects of sun, wind, and rain. Radiant energy from the sun is absorbed or deflected by leaves on deciduous trees in the summer and is only filtered by branches of deciduous trees in winter. In winter, we value the sun's radiant energy and, because of this, we should plant only small or deciduous trees on the south side of homes. Trees can affect wind speed and direction. The more compact the foliage on the tree or group of trees, the greater the influence of the windbreak. The downward fall of rain, sleet and hail is initially absorbed or deflected by trees and this provides some protection for people, pets and buildings. Trees intercept water, store some of it, reduce storm run-off and the possibility of flooding. Dew and frost are less common under trees because less radiant energy is released from the soil in those areas at night.

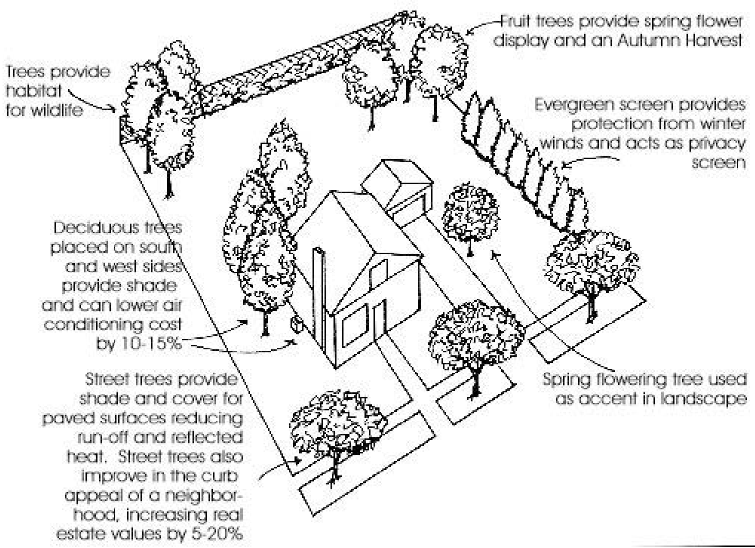

Figure 6: Benefits of Trees

Trees also act as a cooling agent. Temperature in the vicinity of trees is cooler th an it is away from trees. The larger the tree, the greater the cooling it provides. By using trees in the cities, we are able to moderate the heat island effect caused by pavement and buildings in commercial areas.

Air quality can be improved through the use of trees, shrubs and turf. Leaves filter the air we breathe by removing dust and other particulates. Rain washes the pollutants to the ground. Leaves absorb carbon dioxide from the air to form carbohydrates that are used in the plant's structure and function. In this process, leaves also absorb other air pollutants such as ozone, carbon monoxide and sulfur dioxide, and give off oxygen.

In the past several years, tree planting has come to complement other environmental initiatives like recycling as a way of 'making a difference' environmentally. By planting trees and shrubs, we return to a more natural environment. Birds and other wildlife are attracted to the area. The natural cycles of plant growth, reproduction and decomposition are present , both above and below ground. Natural harmony is returned to the urban environment.

2.3.1.4 *Economic Benefits of Trees*

Individual trees and shrubs have value, but the variability of species, size, condition and function makes determining their economic value quite difficult. The economic benefits of trees can be both direct and indirect. Direct economic benefits are usually associated with energy costs. Air conditioning costs are lower in a tree-shaded home. Heating costs are reduced when a home has a windbreak. Trees increase in value from the time they are planted until they mature. Trees are a wise investment of funds since landscaped homes are more valuable than non-landscaped homes. The savings in energy costs and the increase in property value directly benefit each homeowner.

The indirect economic benefits of trees are even greater. These are available to the community or region. Lowered electricity bills are paid by customers when power companies are able to use less water in their cooling towers, build fewer new facilities to meet peak demands, use reduced amounts of fossil fuel in their furnaces and install fewer measures to control air pollution. Communities can also save if fewer facilities must be built to control storm water in the region. To the individual, these savings are small but, to the community, reductions in these expenses are often in the thousands of dollars.

The presence of trees on a property increases the value of a home by 7 – 20%. A fifty-year old tree contributes $57,151 of pollution control to the City of Cambridge over its lifetime. A mature tree consumes 13 lb. of CO_2 a year. You can save up to 25% in air-conditioning and heating costs by properly planting trees. A 40-foot tree releases 60 cu. ft. of pure oxygen each day from 50 gal. of dissolved nutrients. The total surface of roots must balance the total surface of the leaves.

2.3.1.5 *Cost of Trees*

Trees provide numerous aesthetic and economic benefits but also incur some costs. You need to be aware that an investment is required for your trees to provide the benefits that you desire. The biggest cost of trees and shrubs occurs when they are purchased and planted. Initial care almost always includes some watering. Leaf, branch and whole tree removal and disposal can be expensive. To function well in the landscape, trees require maintenance. The informed homeowner can do much. Corrective pruning and mulching will give trees a good start. Shade trees, however, quickly grow to a size that may require the services of a professional arborist. Arborists have the knowledge and equipment needed to prune, spray, fertilize and otherwise maintain a large tree. Garden center owners, cooperative extension agents, community forester or consulting arborist can answer questions about tree maintenance, suggest treatments or recommend qualified arborists.

2.3.2 Urban Forestry

Urban Forestry is the management of trees in urban areas on larger than an individual basis. An urban forest refers to the trees and related organisms in urban settings, whether that is in small towns, villages, communities, or large cities. In order to improve the quality of the urban forest, it is important that one understand and implement the practices necessary for managing the forest.

2.3.2.1 Urban Forestry Handbook[10]

The National Arbor Day Foundation has published an urban forestry handbook for its tree board members – a group of people charged by ordinance, with overseeing the needs of the urban forest.

A city's urban forest is a complex system of ownership and vegetation situations. It is important to know who is responsible for management of the urban forests and also knowing what the forest needs. The three main managers of the urban forest are the city government, the public utilities and individual property owners. City governments generally have responsibility for direct management of the urban forests in parks, other city-owned lands, and along streets and boulevards. Public utilities, both above and below ground, literally cover most cities. Trees often occupy the same space as utility wires, cables, or pipes, and they are sometimes incompatible. Hence, tens of millions of dollars are spent each year across the nation on pruning and otherwise controlling vegetation growth near utility lines. Fortunately, utility companies have developed many excellent programs for care of trees on easements. There are thousands of individual owners, and each has his or her values, beliefs, and knowledge concerning trees. The types of owners are public and private and the types of ownership – residential, commercial, and industrial.

Fundamental to an urban forestry program is having quantifiable information - some type of inventory. There are two kinds of inventories – planning inventories and management inventories. Planning inventories, or surveys, are most applicable in situations where cities are either beginning or revitalizing their urban forestry programs. Management inventories are useful to provide more detailed information about individual trees, including precise locations. An accurate inventory of the trees in your urban forest can be a valuable tool in managing the trees and assuring a healthy forest in the future.

It is vital to understand the following areas - tree health management, fire protection, water management, tree fertilization, wildlife considerations, the relationship between urban development and trees, and pruning in order to value the urban forest. Also, the urban forest has three basic physical needs – planting, maintenance (including protection), and removal.

- **Planting** - Planting is an ongoing need in the urban forest, to replace mortality, to supplement existing trees, and to landscape new areas. Tree planting should maintain or enhance diversity of the urban forest. Trees selected for planting must be consistent with the limiting factors of planting sites (soil, space, climate etc.). The city forestry department, volunteer organizations or individual landholders may do planting.

- **Maintenance** - Maintenance involves those practices necessary to ensure the health, safety, vigor, and function of the urban forest. Included are hazard management, fire protection, and other practices. The relative importance of each varies by time and location, but each must be applied to some degree in every city.
- **Removal and Utilization** - Trees, as a natural part of their life process, are always discarding something – leaves, fruit, bark, and dead branches -and must themselves eventually die. Trees in the urban forest also compete for space with the objects of society and thus must be pruned or occasionally removed entirely. Removal of tree materials is necessary in those parts of the urban forest occupied by people, and is often a major and expensive factor in urban forestry programs.

2.3.2.2 Urban Tree Planting Programs[11]

According to J. Summit and R. Sommer, a large number of communities now support and encourage residents to plant trees, and in many of them, nonprofit organizations have arisen to distribute trees and coordinate planning efforts. The authors' research focused on four tree planting organizations: Tree Fresno, the Sacramento Tree Foundation, the Roseville Shade Tree Program, and the San Francisco Friends of the Urban Forest. All four programs distributed trees at low or no cost; all four programs involve a social component; all of the programs instructed participants in proper planting and maintenance procedures, with one program (the Sacramento Tree Foundation) offering a help line to participants to respond to questions or concerns about trees.

Summit and Sommer wanted to understand the role of the factors present in the above four program plantings but missing in other planting approaches, to determine their impact on residents' experiences and feelings about the tree or trees they received through the program. The research showed evidence that the urban tree planting organizations programs have great potential to increase the numbers of trees planted in cities and suburbs, at an overall energy savings that is likely to be large. Not only will the trees reduce energy consumption, they will improve air quality in the region, making neighborhoods more comfortable and attractive, and perhaps create social support and encouragement for other forms of environmentally sound behavior.

Urban forestry is based on assumptions made from the field of arboriculture. These assumptions and a deeper understanding of arboriculture are necessary to properly manage and maintain trees.

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[10] Grey, Gene W. (1993) A Handbook for Tree Board Members

[11] Taken from an article written by Joshua Summit & Robert Sommer (1997) called Urban Tree Planting Programs – A Model for Encouraging Protective Behavior.

2.4 Arboriculture

Arboriculture is one of the branches of Horticulture, the study of plants intentionally grown for consumption or aesthetic value. There is some debate about the scope of arboriculture; it is commonly understood to be the study and cultivation of trees and shrubs. The debate stems from whether the scope should be extended to include all woody plants such as vines and ground cover plants. This is a new argument and is not generally accepted as of yet.

Arboriculture is a study that is gaining interest and focus as society becomes increasingly aware of the benefits of the planting and maintenance of trees. Currently arboriculture is studied extensively by several organizations both in the United States and throughout the world. Their surveys and experiments serve as a driving force behind both environmental movements as well as landscape planning. Arboriculture is now gaining educational development as technical schools and universities alike are including it in degree studies such as botany, urban forestry, and landscape design. As society continues to become more aware of the value and benefits of trees and landscape planning, arboriculture will continue to expand its research base.

2.4.1 History of Arboriculture

Arboriculture is a field that has a long history. The first known example of the practice of arboriculture dates back to 4000 B.C. in the Egyptian writings that told of the transplanting of trees. Trees were transported by boat with a ball of soil around the roots for distances of up to 1500 miles (2400 km). Arboriculture continued to develop later in Greece. Writers Pliny and Theophrastus both gave directions for planting and maintaining trees. Arboriculture continued to expand through the medieval period as trees were being regularly planted on the estates of wealthy landowners. Also gaining popularity among the wealthy in this time period were botanical gardens. These were large gardens of imported and maintained plants from around the world, some of which still exist today and are open to the public for viewing. It wasn't until the early twentieth century, however, that the study of arboriculture reached the institutions of higher education. It was at this point that the environmental implications of arboriculture were first discovered. From that point the study has led to the solution of disasters such as the Gypsy moth and Dutch elm disease. It has also played a major role in social awareness and government taking an increased role in both the development and preservation of trees.

2.4.2 Plants in the Landscape and Their Benefits

In the landscape, trees and shrubs provide many benefits to the environment and surroundings that they are located in. These benefits are physical, economic, psychological, and aesthetic in nature. The understanding of these benefits initiates a propensity in society towards tree planting and landscape development. The plethora of enhancements provided by trees and shrubs to their environment and surroundings makes them an invaluable part of society and civilization.

Physical benefits provided by trees and shrubs include microclimate enhancement, noise reduction, erosion control, and air purification.

2.4.3 Techniques and Practices

Selecting the appropriate and healthy plant, right climate, soil, analyzing and preparing the planting site, and understanding the plants structure and function are extremely important to the success of a planting and the ease with which it can be maintained.

The following subsections explain some of these key management practices:

2.4.3.1 Nutrient Management

One of the several cultural practices that can encourage the rapid development and continuing health of plants is fertilization. Nutrient management can influence plant vigor, leaf size and color, susceptibility to certain pests and diseases, and tolerance to environmental stresses. There are certain rules of thumb that have been used on fertilization practices for decades. Until recently, woody landscape plants were seldom fertilized in urban and native settings. Off-color foliage and weak growth are typical nutrient-deficiency symptoms which can be brought about by root diseases, girdling roots, drought, compacted or water-logged soil, nematodes, salt injury, and so on. Yet, those involved in growing plants "naturally," without so-called "chemical poisons," have criticized the use of fertilizers.

As older plantings deplete soil nutrients and as the danger increases that excess nutrients will pollute surface and ground waters, more attention must be given to wise nutrient management. An understanding of the inter-relationships among plant, soil, nutrients, and water is essential.[12]

2.4.3.2 Water Management

More causes of suffering in landscape plants arise from moisture-related problems than from any other cause. It is feast or famine, flood or drought, air or suffocation, acceptable or saline water. Water is a primary constituent in the photosynthetic production of organic matter. It is the solvent for nutrient and food transport within plants. Plants are cooled by transpiration. The absorption of water and the turgor it provides aids the roots to extend into soil and shoot tips to grow only. Excessive water is often responsible for the decline and death of plants.

Irrigation is more reliable than rain as a source of water for plants. Plants can be seriously injured by a short dry period and supplemental water may be needed. Horticulturists must reckon with the drawbacks of irrigation, which may, without adequate drainage, create aeration, disease, and salinity problems that are almost as serious as drought. The important factors that affect water use by plants are: the timing and quantity of irrigation, soil salinity, drainage, antitranspirants, hydrophilic gels, and wetting agents.

2.4.3.3 Soil Management

Soil can be protected, maintained or improved by a number of cultural operations other than fertilization and irrigation. Management of the surface soil, tops of plants as well as deeper soil and roots are some of the operations involved.

An integral part of landscape planning is the development and management of the soil surface. Paved surfaces, lawns, ground covers, clean cultivation or chemical weed control are a few methods of handling the soil. The function of the landscape, the type of soil, and the kinds of plants that are grown will depend on the proper handling of the soil surface.

2.4.3.4 Pruning

Pruning is the removal of plant parts – usually shoots and branches, but sometimes buds, roots, and even flowers and fruit. One can control the growth of plants to enhance their performance or function in the landscape, by pruning. Pruning can increase the structural strength of trees, the productive capacity of fruit trees, the trunk quality of lumber trees, the quality and size of flowers and fruit, and the aesthetic appeal of many plants. Pruning as part of the training of young trees can ensure structurally strong trees, which will be safer and require less corrective pruning when mature.

2.4.3.5 Chemical Control of Plants

A number of chemicals are used to stimulate, reduce, or stop the growth of shoots and to initiate, delay, or prevent flowering and fruit set. Those who use chemicals for these purposes want to interfere as little as possible with the health and appearance of plants. Chemicals are also used to kill unwanted plants. Certain chemicals have been employed for years, some are recent, and others are still experimental. An arborist should understand the effects of growth-regulating chemicals and the conditions under which they can be used safely and beneficially.

2.4.3.6 Tree-Hazard Management

Millions of trees in public and private landscapes are maturing and in decline. When these trees fail or obstruct a critical view, in the public or private way, property damage and human injury or death are the risks. Trees, however, cannot be neatly separated into hazardous and non-hazardous groups. Nearly every tree has

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[12] Based on Richard W. Harris, Arboriculture (ISA Press, 1997, New York)

some potential to cause injury. A tree is considered to be hazardous if it is structurally unsound and there is a possible target. In general, an unsafe tree in an area where there is no obstruction or potential target is not a hazard. Nonetheless, complete tree safety cannot be attained without removing many trees. Therefore, arboricultural managers must be able to not only evaluate tree -hazard potential but to also establish an acceptable level of safety at a reasonable cost both to the communi ty and the environment.

2.4.3.7 Preventive Maintenance and Repair

Plants, no matter how well they are maintained, will be injured, develop weak structure, cause damage to buildings, or require removal. Most of these problems can be avoided or at least minimized or postponed by proper selection, planting, and care, as usually only as plants grow and age do the problems become serious. Problems must be anticipated in order to safeguard the plants, people, and property.

2.4.3.8 Integrated Plant Management (IPM+)

The health, safety, function, and attractiveness of plants are the key goals for those who grow plants in the landscape. For a plant to be able to grow and develop to its potential and to be able to withstand and recover from unfavorable environments, noninfectious disorders, diseases, insects and other pests, and unwise cultural practices, plant health is extremely important. Strong structure is essential for large trees to function and be safe. As medicine has become more holistic in its approach to human healt h and well-being, so should arboriculture in its concern for plant health and performance. Integrated pest management (IPM) is leading the way, but is only a part of an enhanced Integrated Plant Management program, hereafter called "IPM+."

An IPM+ approach includes site and plant selection; site preparation; planting and early care; managing nutrient, water, and aeration levels; pruning; monitoring plant performance; preventing or moderating plant problems; and knowing when plants should be replaced. This approach will improve landscape performance and function; increase the efficiency and effectiveness of maintenance; preserve more existing plants; and provide horticulturalists with opportunities to serve clients in the planning, development, and maintena nce phases of their landscapes.[13]

2.4.4 The International Society of Arboriculture[14]

The International Society of Arboriculture (ISA) has served the tree care industry for over seventy years as a scientific and educational organization. ISA was founded in 1924 when a group of forty individuals, each engaged in a phase of tree work or research, were called together by the Connecticut Tree Protection

[13] Based on Richard W. Harris, Arboriculture (ISA Press, 1997, New York)
[14] International Society of Arboriculture. URL - http://www2.champaign.isa-arbor.com

Examining Board to discuss shade tree problems and their possible solutions. It was during this meeting that the group identified a need for gathering tree care information and to provide a means for its dissemination. The National Shade Tree Conference (NSTC) was founded soon thereafter.

Due to its influence and membership spreading beyond the borders of the United States, the organization changed its name to the International Shade Tree Conference (ISTC) in 1968. Only a few years later, in order to more accurately reflect its broadening scope, the name was again changed, this time to the International Society of Arboriculture in 1976.

The ISA continues to be a dynamic medium through which arborists around the world share their experience and knowledge for the benefit of society. ISA, aligned on many fronts with other green organizations, is working hard to foster a better understanding of trees and tree care through research and the education of professionals as well as global efforts to inform tree care consumers.

2.5 USDA Project on Effects of Tree Cover on Vehicle Emissions

Arboriculture and urban forestry projects are extremely important for the area of tree management. The United States Department of Agriculture (USDA) Forest Service was involved in a study called, "Effects of Tree Cover on Parking Lot Microclimate and Vehicle Emissions."[15] A pilot study was performed to measure the difference in parking lot microclimate resulting from the presence or absence of shade tree cover. Microclimate data from contrasting shade regimes were then used as input to a motor vehicle emissions model. Model results were used to estimate the potential for regional increases in parking lot cover to reduce motor vehicle hydrocarbon and nitrogen oxide (NO_x) emissions.

To determine how microclimate, vehicle temperature and emissions scale with tree canopy cover, observations need to be performed for a range of conditions (e.g. parking lot size, paving surface, tree canopy cover and density). A corollary to this issue is a need to develop a parking lot taxonomy which accounts for lot size, patterns of use, occupancy by vehicle type and landscape characteristics. Parking lot taxonomy will also inform benefit-cost analyses for the development of effective parking lot shade treatments, and for estimating potential regional scale vehicle emission reductions.

Comprehensive cost-benefit analyses of parking lot planting programs should consider the stream of costs associated with site preparation, tree planting, maintenance, hydrocarbon emissions from landscape equipment and trees, water use and administration. Benefits to consider include avoided emission vehicles (which will change with the introduction of new low-emission technologies into the vehicle fleet), potential prolonged pavement life due to shade, mitigation of urban heat islands, reduced human exposure to UV radiation due to canopy interception, air pollutant uptake by tree canopies, and mitigation of urban storm

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[15] Journal Of Arboriculture 25(3): 129-142. 1999. Written by Klaus I. Scott, James R. Simpson and E. Gregory McPherson

water runoff. Additionally, the effects of tree cover on business sales, vacancy rates, space leasing rates and other indicators of economic activity need to be addr essed.

2.6 Tree Management Technologies

The Cambridge Tree Canopy Assessment Project involves many data collection and storage processes in order to develop a new field methodology for the surveying of the city's trees. These technologies include Geographical Information Systems (GIS) and the databases that they are run from. This section provides background information on the current technologies and data storage methods that are in use at the Cambridge DPW for tree maintenance.

2.6.1 Data Storage Technology

Databases are data storage structures for the storage and organization of large quantities of interrelated information. Databases are composed of multiple fields and records (categories and entries), which provide the capability to define the qualities or comp onents of an object or idea. Databases provide the ability to query the data and return qualified (matching) results; this enables the extraction of the exact information that is desired from a large compilation of information.

Computer databases date back to the 1960's with the development of the COBOL [16], Prolog, and DB2 computer languages that were designed to create relationships between information. These languages are still used in industry today; however, new languages such as SQL and Oracle have ca ptured the majority of the data storage market. This is due to the flexibility in architecture and ease of programming and ability to integrate these databases to Internet applications.

2.6.2 ACRT Tree Manager

Tree Manager is a digital information maintenance system, which organizes tree inventory data –tree and planting site locations, maintenance requirements, species, condition, work completed, homeowner service requests and total and average costs for work completed –into a user-friendly system. The softw are allows users to not only view the detail of data tree -by-tree but also as an urban forest.

ACRT Tree Manager is a powerful tool for analyzing tree data. It can calculate overall value of a tree and is capable of interpreting individual and group dat a. The software can also generate reports and track maintenance activities.

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[16] Sayles, Jonathan (1996) <u>COBOL and the Business Programming Paradigm</u> [Web Page] URL http://www.tiac. net/users/tangaroa/jss.html

2.6.3 Hansen Software

Currently the City of Cambridge Department of Public Works uses a software package produced by Hansen Information Technologies called the Hansen Version 7 Work O rder System. This system provides a complete set of tools to generate and track work orders for assets. This is an "off the shelf" software package, meaning that it is mass -produced to meet the general needs of tree management; it is not specifically tailored to the City of Cambridge.

2.6.4 Geographical Information Systems (GIS)

Geographical Information Systems (GIS) is a technology that is currently used by the DPW and plays a central role in the Re -engineering Tree Management in Cambridge Project. A compre hensive understanding of Geographical Information Systems (GIS) is essential for this project; this section provides background information on this technology as well as its potential.

2.6.4.1 Background of GIS

Geographical Information Systems (GIS) is a technolog y that analyzes spatially referenced data and maps the data to any spatially referenced data system. Geographical Information Systems (GIS) was developed over thirty years ago as a way to relate seemingly incongruous data in ways in which it had not been analyzed before and extrapolate valuable information from these new relationships. The progression of this technology was slow as the computing power that was required to run the software was currently undeveloped. As computer technology has advanced exp onentially, GIS is again being evaluated as a data storage and analysis model and is being implemented in various fields.

GIS is not auto -mapping. The difference between the two technologies rests in GIS's ability to create multiple thematic layers [17]. Auto-mapping is the development of one master layer; where as GIS leaves the original data system intact and instead layers over multiple layers of data grouped by field. This enables GIS to create r elationships between the data contained in multiple layers while maintaining the individuality of the applied data sets. This feature is especially useful for the creation of relational databases; databases that are able to relate data to data in other data fields and to include these relationships in analysis.

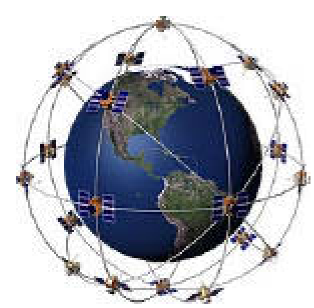

Figure 7: GPS satellite network

The Department uses GIS to map different aspects of Cambridge to help them with their responsibilities. For instance, the Urban Forestry Division currently use GIS to map the position of trees in the Cambridge area. Map layers such as location of trees, utility and power lines, and distance of sidewalks from trees, helps the Tree Warden with maintenance and safety issues. GIS is a powerful tool in the management of landscapes. Such technology wil l play an invaluable role in the Cambridge Tree Canopy Assessment project. Currently there are existing street and geographical maps which can be used as background layers in a GIS system. Onto these layers, thematic layers can be added to pinpoint the location of each public and eventually private tree in the city. These layers can be arranged in many different ways in order to provide a great deal of useful management information about the trees and the canopy cover. All of the data currently stored i n the city's tree database can be linked to thematic layers to create visual output for common queries: trees pruned in the last 4 years, the species distribution throughout the city, and tree maturity. Data projections such as these will be useful tools for the city arborist and all involved in the tree maintenance in the City of Cambridge.

2.6.4.2 Data Collection Methods of the GIS

Currently there are many data collection methods that exist to extract data for the development of thematic layers for GIS. The two predominant collection methods are Global Positioning Systems (GPS) and remote sensing. The DPW uses both types together.

Global Positioning Systems (GPS) is technology that has advanced ra pidly recently. It relies on the infrastructure of a system of twenty-four global positioning satellites.[18] The DPW's system relies on ten satellites and a correction signal from a government station in Rhode Island. The handheld device records a position from a minimum of four satellites and uses a laser gun, which calculates the offset and the exact position of the object being surveyed. A similar device is shown in Figure 8.

Figure 8: Typical handheld GPS unit

A handheld unit (GPS Scanner) receives signals fro m a minimum of four satellites currently in its aspect region.

It then uses trilateration to calculate the exact latitude, longitude, and elevation that the unit is located at. The units transmit and receive signals every second and are thus constantly up dating[19]. GPS is used to capture onsite detailed feature information that is then downloaded into a GIS as a system of points, lines, and polygons. This data can serve as either an addition to a new data layer or as a confirmation of a known geographical location. This helps increase the accuracy of data collected by less accurate methods.

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[17] Easa, Said, & Chan, Yupo (2000). Urban Planning and Development Applications of GIS Reston, Virginia: American Society of Civil Engineers.
[18] (What is GPS?). [Web Page]. URL www.garmin.com/aboutGPS/
[19] (GPS Technical Specifications). [Web Page]. URL www.gpsworld.com/tech_specs.html

There are also methods that are able to increase the accuracy of the measurements. These include the use of a stationary GPS with a known exact geographical location. This method uses the known geographical location of the stationary GPS as an additional reference point for the mobile unit and is able to reduce variance from a couple of meters to less than two feet. The most exacting method involves signal pattern interpretation that analyzes the transmission patterns of the satellite signals. This method is able to reduce variance to a fraction of an inch. Logically, as the GPS systems become more precise, their costs rise dramatically. The determination of which system is most cost appropriate lies in the amount of acceptable variance. To a city planner, two meters may be acceptable when plotting the location of a building but this would not be acceptable to a military command center conducting a strategic operati on.

Remote sensing is the use of data of a location collected from a source other than the location, usually aerial[20]. This method is less accurate than GPS but allows for much faster data collection, especially for data collection over large regions. Met hods include optical sources of satellite and aerial photography as well as sonar, radar, and thermal sources. These methods provide land cover, topography, and weather condition data for large geographical areas. The DPW recently contracted a company to take aerial photographs of Cambridge and build a map archive.

Regardless of the data collection method used, data refinement is essential for the purpose of accuracy. In the case of remote sensing, the process of orthorectification is used to remove dist ortion from aerial photography. After the distortion is removed, the rough maps can be vectorized and then used as base maps or data layers within GIS. A second accuracy dilemma exists in the fact that the Earth is not a sphere, but in actuality is an im perfect ellipsoid. This requires advanced mathematical data refinement techniques to accurately compensate for the uneven curvature of the Earth. This process, which has existed for over 150 years, is known as georeferencing [21] and is extremely important in providing geographical data that is accurate when translating it into two dimensional representation models.

2.6.4.3 Applications of GIS

Currently there are many applications of Geographical Information Systems (GIS). Most of these new applications revolve around the development of the fourth dimension, time. As the technology evolves the need that is being identified is for the ability to track and project over time. As a result, the software is gaining the added ability to morph geographies and landscapes to show changes over time. The desired product from this new technology is to be able to add variables and project the outcomes and visualize them. This is similar to computer projection models that are currently used in the aerospace industry. While the

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[20] Easa, Said, & Chan, Yupo (2000). Urban Planning and Development Applications of GIS. Reston, Virginia: American Society of Civil Engineers.

[21] Easa, Said, & Chan, Yupo (2000). Urban Planning and Development Applications of GIS. Reston, Virginia: American Society of Civil Engineers.

aerospace models are driven by physics equations, it is important to have similar equations for geographical evolution. These can be derived from analysis of the past. GIS is evolving with both the technology and the technological need. This can be seen in the following implementations of the GIS technology in two different areas.

2.6.5 ArcView

ArcView GIS software is a desktop GIS that uses a graphical user interface that lets users easily load spatial and tabular data. This allows the user to display data a s maps, tables and charts. ArcView provides the tools to analyze and query data and present results as presentation -quality maps. It also provides tools for performing spatial analysis, geocoding addresses and displaying them on a map and thematic mappin g.

2.6.6 CITYgreen

CITYgreen software is a desktop GIS application for ArcView that allows cities and conservation groups to conduct their own local ecological benefit studies. CITYgreen is an innovative tool for mapping urban ecology and measuring the econom ic benefits of trees, soils, and other natural resources.

This software the economic benefits provided by trees and other vegetation. These benefits include stormwater runoff reduction, air pollution mitigation, carbon sequestration, avoided carbon emis sions, energy conservation, and wildlife habitat. CITYgreen analyzes existing conditions and can model the impacts of various development and planning scenarios. Growth models are for future benefits projections that can help bolster support for tree pla nting and green space projects.

2.6.7 MapInfo Professional 6.0

The primary mapping software we used for our project was MapInfo Professional 6.0. MapInfo is used in conjunction with applications such as word processors and spreadsheets to create, display and edit a map for presentation, reporting or publishing. This is possible through a process called Object Linking and Embedding (OLE), whereby a server application (such as MapInfo) provides information that is stored in a client application that can accept O LE information (such as a word processor). MapInfo allows you to embed a Map window in any application that accepts OLE objects and to use some of MapInfo's features to create, display and edit the map directly.

MapInfo Map provides a variety of map disp lay, viewing and editing capabilities, including; controlling individual layer properties like display and labeling and creating and modifying thematic maps.

3. Tree Methodology

The primary goal of our project was to re-engineer the Cambridge Department of Public Works' (DPW) entire tree management system, which involved: collection, 'storage and organization', and analysis and presentation of all tree data and information. The key tasks that we accomplished included the organization and analysis of existing tree data, creation of a new field methodology for the DPW on collected tree data, and quantification of tree data collected in order to analyze the economic and environmental benefits of trees in Cambridge.

The principal objectives of our project were:

- To develop a new tree information system
- To collect field data and incorporate them into the new information system
- To quantify the economic and environmental benefits of trees

In this chapter, we describe our area of research, important definitions to our project, the key tasks we achieved, and how we produced our results and deliverables. We explored our key tasks in the order listed above in our objectives.

3.1 Domain of Inquiry and Definitions

The subjects of our assessment were both open-space and street trees. Open-space trees are trees that can be found in green areas such as parks, cemetaries, and playgrounds. Street trees are those that line sidewalks, roads, and street dividers. The trees that we surveyed are planted and maintained by the Department of Public Works and its Urban Forestry Division.

3.2 Study Areas

Due to the sheer number of trees in Cambridge, our study was limited to certain areas. Our surveys were conducted in Neighborhood 10 (see Figure 9), the section of Cambridge bounded by Concord Avenue on the north, Ash Street on the east, the city limits on the south, and the Boston & Maine Railroad on the west. Our study areas within the neighborhood were the Cambridge Common and Walker Street (see Figure 10). The Cambridge Public Cemetary was not surveyed, however, we did create an addressing scheme for future surveys.

Figure 9: Cambridge Neighborhoods

Figure 10: Study Areas in Cambridge

3.3 Information Requirements and Data Sources

To properly assess and inventory the trees for the city, we needed several key items. These items included electronic maps of the city (GIS layers), detailed tree information (a list of specie s/types of trees, data collection forms used by the DPW, and books on tree identification). See Appendix F for data collection form used by the DPW. Several software packages were used, as was previously compiled tree databases, an assessor's table to help analyze economic benefits, and reliable sources of environmental benefit data.

We used electronic maps to analyze tree data that we collected. In the Cambridge Common and Public Cemetary maps, we noticed that GIS mapping placed trees in the middle of paths and streets. Much of this data was corrected individually by hand and then updated on the electronic maps. The maps were used to analyze the total coverage of tree canopy and species distributions.

To conduct our research we utilized the following agencies and people:

- Cambridge Department of Public Works
- The Cambridge Tree Project
- The International Society of Arboriculture
- Cambridge Park Ranger and Local Arborist Jean Rogers

The Cambridge Department of Public Works' Urban Forestry Division has conducted numerous projects and research in the area of tree management. We used their tree data and techniques on data collection and analyses in our research. Interviewing the City Arborist, Larry Acosta, and Cambridge Park Ranger and Local Arborist, Jean Rogers, was helpful.

3.4 Project Schedule

Our work began on March 14th and continued until May 1st, 2001. Our primary concerns were learning the different systems we would be working on and familiarizing ourselves with the DPW. We then worked on improving their tree management systems, gathered all of the necessary tree data, entered new data collected into databases, quantified benefits of trees, and made recommendations on how to update and incorporate existing data into their databases. Once this was completed, we created a manual on the process of tree data collection for future researchers.

3.5 Development of the New Tree Information System

In order to develop the new tree information system for the DPW, it was necessary to determine a list of their requirements. We started by evaluating and organizing their current database system, Hansen. We then arranged the DPW's GIS layers for our purposes, developed a list of additional parameters to add to their tree survey, and created a new tree database with an easy to use front end.

3.5.1 Existing Information

The DPW had done extensive research and collected data on trees in Cambridge. Their database cataloged 11,061 street trees in 1995. This database was fairly well organized but lacked clarity and usability. Approximately 1200 entries were collected after 1995 and were stored on paper and in Excel spreadsheets.

These needed to be updated and organized. Part of our organization of baseline data covered recommendations on how to include data not recorded electro nically into their database.

3.5.1.1 DPW Tree Database

The DPW used ACRT Tree Manager™ to inventory the 11,061 street trees in Cambridge. The database was then moved from Tree Manager™ to the Hansen™ software. When we viewed this database, we found it to be unclear and difficult to decipher. Using the manuals provided by Hansen, and with clarifications from Mr. Acosta, we were able to determine the meaning of several of the field/names. The database contains 11,061 records of street trees covering over 50 speci es. The principle fields are described in Table 2:

FIELD NAMES	DESCRIPTIONS
ADDRKEY	Address code for trees
STNAME	Street name
FLD003	Sidewalk damage (yes/no)
AREA	Neighborhood surveyed
UNITTYPE	Species code
FLD007	Genus
FLD009	Type of maintenance required: pruning, removal and routine work
CONDRAT	Condition rating of tree form 0 –100
FLD011	Clearance issues related to trees: light posts, signs, vehicular or pedestrian traffic
FLDO12	Safety parameters related to trees: electric/power lines

Table 2DPW Field Names:

As can be seen above, these fieldnames are confusing and require appropriate legends for usability. The full DPW database is included in Appendix J.

3.5.1.2 Existing Digital Cartography

The City of Cambridge has a comprehensive system of electronic maps, which detail the geography of the city. These maps served as the framework from which we developed our geographical data. They were used to create computer GIS layers onto which we incorporated our collected field data. The maps we used were orthographic pictures and a planimetric map of Cambridge, which included several layers. The maps proved helpful in planning out our field procedures. We were able to section Cambridge Common into different areas to simplify our tasks.

3.5.1.3 Cambridge GIS layers

The City of Cambridge has several GIS layers that they use for data extrapolation. These layers served as a foundation from which we could incorporate our deliverables to create a complete GIS represen tation of trees in the City of Cambridge. The GIS layers we used included the following (see Figure 11).

- paths and driveways
- utilities
- open spaces
- buildings
- road systems

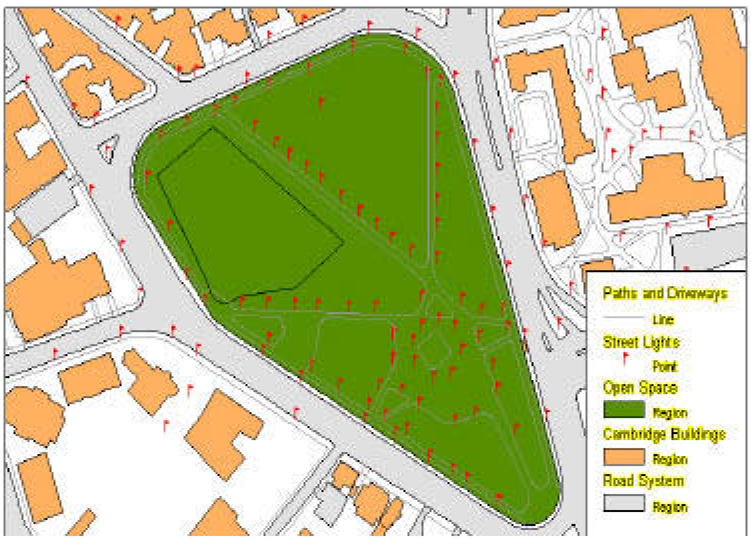

Figure 11: DPW GIS Layers

3.5.2 Design of the Tree Management System

By looking at the design of the old DPW database and talking to the Cambridge Tree Warden and different Arborists, we were able to develop a plan for a new database. This database allowed us to take a more objective view on condition rating of trees and allowed for easy usability. Using the Cambridge Common data that we collected, we were able to test this database and determine which sections we would need to change to make the job of data recording easier. The data that is collected in the field is recorded onto sheets of paper that then can be stored and accessed later for data entry. Our database uses an MS Access form for data entry. The Access form is less intimidating then the table of information and allows for easy entry. All the information is stored in one comprehensive database and can be referenced using queries. Our data structure will stay organized, by having everything stored in one central location.

The final database we created contains the data for both open space and street trees. We developed an easy to use front end to our database. This included data entry forms to make data entry more effective and data view forms to view data surveyed and photographic documentation of each tree. See Figure 12 for structure of the system.

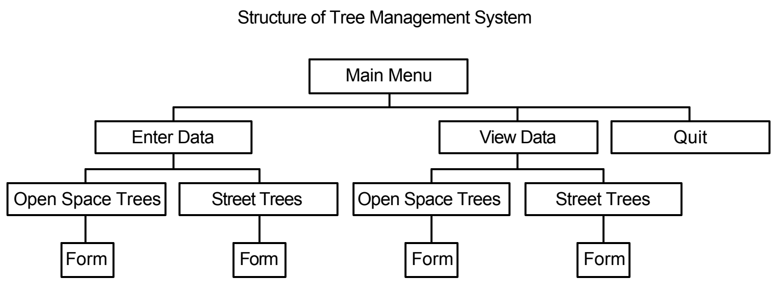

Figure 12: Structure of New Database

Also see attached Database manual in Appendix I for a more in -depth look at the new database.

3.5.3 Permanent Tree Information

Permanent information is data that does not change. This category includes information such as tree code, site/street, section/address, location on GIS maps, tree number, and species. Once recorded, this data will not need to be altered and therefore not collected again.

The maps from the Cambridge GIS department provided us with a way to electronically manipulate and store data. The tree layer map showed some problems with the current system. Mapped objects, in our case trees, were placed inaccurately. In many instances the trees were placed in roads and paths. We decided that we would not be able to rely on this system completely because of this inaccuracy. We also determined all the data that we collect with the GPS system would need t o be moved and correctly placed.

Issues that we attempted to solve were the positions of trees on GIS maps and the vague numbering system of each tree. Once we knew the position of each tree according to data collected, we were able to compare the trees mapped by the GIS system with the actual location of trees in Cambridge. By comparing the two we were able to correctly place the trees on the maps. We also developed a GIS layer of the trees with updated location information for trees in the Cambridge Common.

3.5.4 Dynamic Tree Information

This category contains data that does change over time. The DPW collects the following dynamic parameters: survey date, diameter breast height (DBH), obstruction types, sidewalk damage, condition rating and maintenance priorities. There is, however, more information that can be gathered to benefit the analysis of the trees. We developed several new parameters to improve the effectiveness for timely maintenance of trees such as health and safety parameters, and photographic documentation.

3.5.4.1 Health Parameters

The Urban Forestry Division used several fields to determine which trees needed special attention. These fields were: tree condition and maintenance priority. Criteria for the determination of these parameters were imprecise and subjective. This made the data collected inaccurate. The original condition parameter rated each tree from 0 –100, and was based on subjective knowledge. The determination of maintenance priorities was also done subjectively. There was a list of options for maintenance priorities such as P1 – Pruning 1, P2 – Pruning 2, R1 – Removal 1, R2 – Removal 2, ST – Stump, TR – Training, and PL – Plant. Each person surveying the tree would choose the maintenance priority based on his/her personal knowledge or expertise and not on any consistent factors. This would result in imprecise ratings.

We developed *objective* parameters to calculate condition ratings and maintenance priorities. The new parameters we introduced were as can be seen in Table 3:

FIELDNAME	DESCRIPTION
DEADWOOD %	Percentage of dead wood and branches on tree
DEAD BUD %	Percentage of dead buds on tree
LEAF DAMAGE	Scorching, mining, wilt, and discoloration
INSECT INFESTATIONS	Boring, leaf chewing, gall, tent caterpillar, cambium miner, aphid, scale, spider mite, and termites
MAJOR VISIBLE INJURIES	Number of significant or manmade intrusions
CAVITIES	Number of cavities greater or less than 6 inches
DISEASES	Powdery mildew, anthracnose, blight, Dutch elm, rust, canker, verticillium, wilt, and branch dieback
FUNGI	Whether or not fungi is present
PLANTING BED	Whether or not the tree is in a planting bed
GROW SPACE	The amount of space the tree is allowed to grow in

Table 3: New Health and Parameters

3.5.4.2 Safety Parameters

Safety parameters included information about trees that needed maintenance due to potential hazards to the community. The old database did not include any variable that determined the urgency for maintenance, only types of obstruction. By including a distance to the existing obstruction types, we were able to determine which trees needed immediate attention. We developed a more detailed list for obstruction type for both open space and street trees. Table 4 lists the types of obstructions:

FIELD NAME	DESCRIPTION
OBSTRUCTION TYPE	Buildings, light poles, electric/power lines, tombstones, playground equipment, fences, signs, pedestrian, vehicular or house clearance, traffic signals

Table 4: New Safety Parameters

3.5.4.3 Other Parameters

Other parameters were diameter at breast height (DBH) and canopy size of tree.

3.5.4.4 Photograph documentation

We photographed each surveyed tree and also photographed trees with problems: major visible injuries, cavities, disease, fungi, and insect infestations (See Figure 13 – picture of scale: insect infestation). The photographs were linked to our database with a tree code and thus can be easily searched for. The photographs taken would be helpful with tree identification and providing a visual aid to track growth and development of the trees.

Figure 13: Special Photo of Tree

3.5.5 Presentation of Results and Deliverables

Two deliverable formats exist for this task: new database and updated GIS layers. We created a new database for both open space and street trees with forms to both enter and view data (See Appendix I in Database manual for both forms).

Based on current data, we updated the GIS layers to include a tree layer for surveyed trees, buildings, paths, utilities, and water layers (See Figure 11 for map layers we reorganized). The new database can be found in the database folder of our final CD, while the map layers are in the maps folder.

3.6 Field Collection and New Data Integration

It was important for us, in completing our project, to collect and record accurate data and have this data properly organized. All data collected was then organized and integrated into the new database we created.

In the field, we gathered physical measurements on both permanent and dynamic parameters. These parameters included species, location, maintenance, safety, other parameters, and photos of the trees. These data were collected for open-space trees in the Cambridge Common and street trees on Walker Street. We modified the DPW data collection form to include additional data fields and to incorporate new methods of analysis into our procedures. One example of this was in reviewing th e process for determining tree condition; we realized that some of the fields required expert field judgment in order to complete them. Since arborists do not usually do the data collection, we decided to make the fields more objective than subjective. Our new fields merely document common maintenance and health problems. We created formulas to extrapolate the maintenance need and tree condition from the collected observational data. This provided for both increased accuracy but also improved consistency of subjective interpretation.

3.6.1 Open Space and Street Trees

We surveyed both open space and street trees. Like the study area, our fieldwork was conducted in Neighborhood 10. A great deal of our fieldwork took place in the Cambridge Common. This area was later extended to Walker Street. Below, Figure 14, in red and green are the sections of Cambridge that were surveyed for this project.

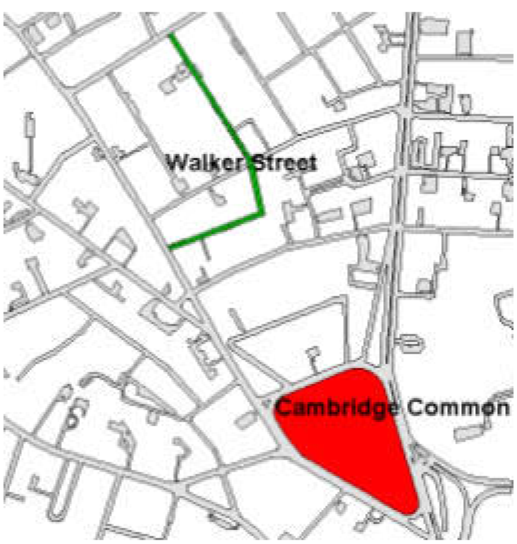

Figure 14: Study Areas

Figure 15: Trees in paths

Each individual section was split up into sub -sections. The Common was divided up into multiple sections to simplify the task of collecting information from open space trees. As can be seen in Figure 15 above there are several places in the park where the pathways were built around the trees. This creates a problem when trying to split the park up into different sections. To compensate this we used the paths to section the different areas of the park. The result can be seen below in Figure 16. Each section was labeled counter-clockwise in alphabetical order. The paths are labeled according to the section to its right. There are 21 regions total in Cambridge Common.

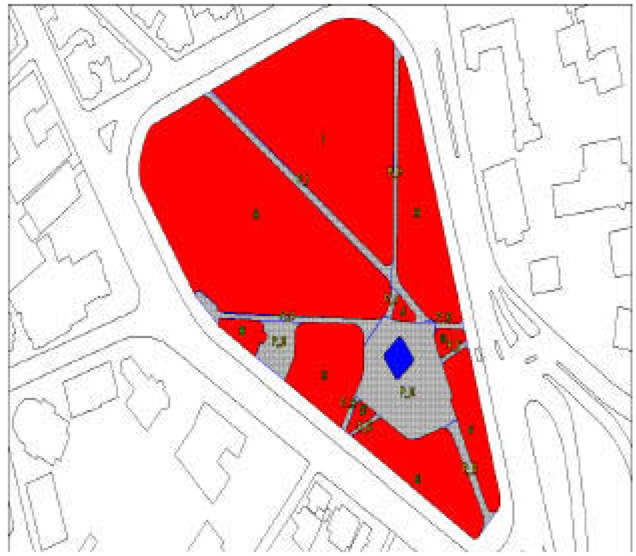

Figure 16: Sections in Cambridge Common

3.6.1.1 Schedule

We started work the week of March 12. During this time we discussed our common project goals and tasks for the next seven weeks with our liaison. The first two weeks we spent familiarizing ourselves with the DPW's internal systems, visiting all sites that we would be working in, and collecting resources required for the development of our field methodology. In the third week we started data collection at the Cambridge Common. The next two weeks were spent completing fieldwork at the Cambridge Common, the Public Cemetary, and several streets in Neighborhood 10. This data was then analyzed for condition rating, species distribution, and environmental and economic benefits. The last week we spent finishing our data base and field methodology manuals.

3.6.1.2 Parameters collected

We gathered physical measurements for both open space and street trees as can be seen in Table 5.

TYPE OF FIELD	PARAMETERS
YES/NO	Fungi, planting bed, sidewalk damage
PERCENTAGES	Deadwood, dead buds
SELECTION	Site surveyed, leaf damage, cavities, disease, insect infestation, obstruction type and distance
NUMBER/OTHER	Tree number, DBH, canopy size, major visible injuries, survey date, name of surveyor(s), section or address

Table 5: Parameters Collected

The parameters that were collected can be split into four types of fields. They are yes/no, percentages, selection, or number / other. The "yes/no" parameters included fungi, planting bed and sidew alk damage. The only responses to this field are yes or no. The percentage parameters are deadwood % and dead bud % with a rating from a 0–10, 10-20, 20-30, 30-50, and 50-100%. The recorder is required to estimate the percentages of deadwood and dead buds on each tree. For site surveyed, leaf damage, disease type, obstruction type and distance, cavities, and insect infestation, the recorder is given several options to choose from. Several parameters require the user to input a number, such as # of maj or visible injuries, tree number, DBH, and canopy size. The 'other' parameters are survey date, name of surveyor(s), and section or address. See field methodology manual in Appendix H for more information.

3.6.1.3 Instruments Used

To measure and record this data we needed specific tools: a handheld/portable GPS locator and data recorder, a digital camera, binoculars, tree diameter measuring tape, and paint. The GPS locator was used to give geographical tree locations and the recorder was used to input tree numbe rs and species. We used the measuring tape to calculate the diameter at breast height (DBH), and also to measure the canopy radius. The binoculars were used to determine percentages of deadwood and dead buds, the paint was used to mark the trees that we surveyed, and the digital camera was used to take pictures of all trees assessed and also for problems such as disease, insect infestation, major injury, and cavities. Also, several books were used to help identify species and different diseases and insec t infestations. These included:

- Shade Trees for the Central and Northern United States and Canada
- A USDA Forest Service Volunteer Training Manual
- Pests of Landscape Trees and Shrubs– An Integrated Pest Management Guide
- Hazardous Tree Evaluation and Management

3.6.1.4 Procedures

We started our data collection at the Cambridge Common. First we decided to start in Section A. Starting in the upper left-hand corner, the recorder stored data. The position was also recorded using the GPS system. We decided to use a zigzagging technique across the field. We started with the tree in northeastern corner and then moved to the next tree. Below in Figure 17 is the pattern we used to record each tree in Section A, the lawn-mowing technique.

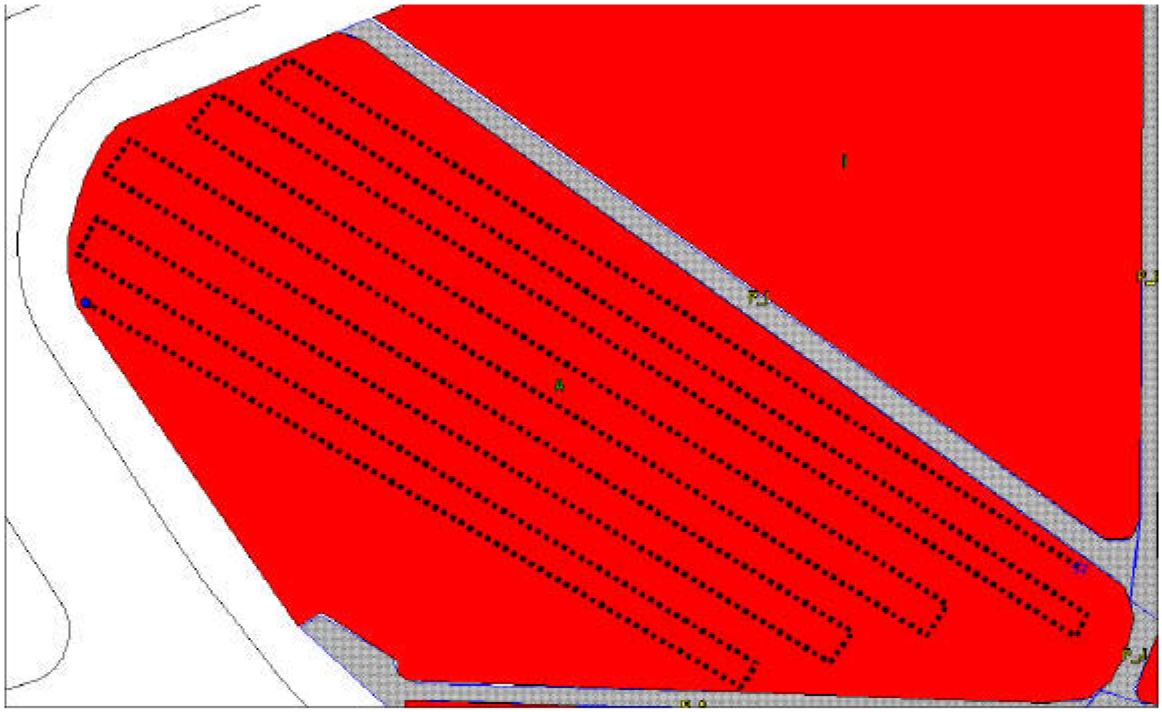

Figure 17: Pattern Used to Survey Trees in Section A

We did run into several problems with our 'lawn-mowing' technique. First it was confusing trying to number each tree with the data recorder in a way that someone would underst and our method. In many instances we had to site trees from all the way across the field. This technique might have worked a better in a square survey area; however, in our circumstance it was not efficient due to the open field in the middle of Section A.

We decided to split up the tasks of collecting the different information on the trees and collected data on two different days. The first day we collected all the static data involving trees. This data included location and species. One person used the GPS device to record the tree position. The species were determined through the help of Arborist, Jean Rogers, and tree identification guides. Data collected on the second day included all the dynamic data. Data such as: DBH, canopy radius, injurie s, cavities, insect infestations, obstructions, diseases, and photographs for each tree and also of any important factors like disease or major injuries. One person used the measuring tape to record DBH and canopy radius, the second photographed and recorded each tree, and the third recorded all data. All three analyzed the safety and condition/health parameters.

We then tested the methodology we developed in order to examine its positive and negative aspects. We verified that all of our measurement m ethods were accurate and viable. After analyzing the first method, we created a new method to number trees in the open -space sections. This technique used a spiral to travel across the common shown below in Figure 18. We chose the northernmost tree in the upper left corner of each section. Then circling counter -clockwise all the trees on the outer edge were surveyed until the first tree was reached.

Figure 18: Spiral Technique in Cambridge Common

The Spiral technique was used to map sections B, C, H, and I. It was found to be quicker than the lawn mowing technique and much easier to number each tree.

3.6.1.5 Archival

The data that we gathered was recorded on standardized sheets and forms, and then enter ed into the new database we developed. See Appendix L for the data collection form developed by us.

We built a new database to incorporate new fields for data collected and for storage of important photographs taken. The data was broken into two sepa rate databases; one for street trees and one for open - space trees. Each of these databases was then divided into a static database and a dynamic database. This will keep the information that does not change separate from the data that will be updated. T hese databases were created in Microsoft Access so that they can then be imported into Hansen by the DPW MIS department.

We developed a database manual (See Appendix I) on how to use and update the database and also a field methodology manual (See Appendix H) on the process of tree data collection we used for future researchers.

3.6.2 Entering of newly collected data

We incorporated all new parameters collected into our database. Updates to several GIS map layers for the Cambridge Common were made to reflect the addition of the new data. Once the data was analyzed we used it to create new map layers showing the characteristics, effects, and benefits of trees.

It was important for our project to collect and record accurate data and have this data properly organized; this allowed for straightforward integration of new data into the database.

(See Appendix I for data entry forms in database)

3.6.3 Field Testing of Methodology in Representative Sites

We developed a field methodology based on all our fieldwork and created a field manual for future researchers. We tested the methodology we developed in order to examine its positive and negative aspects. We did this by gathering information in Cambridge Common and Walker Street and verified that all of our measurement methods and procedures were accurate and viable. For example, we examined the best method for measuring the tree canopy size, determining deadwood and dead buds on a tree, identifying tree species, and also all techniques used for collecting data.

(See Appendix H.)

3.6.4 Completion of Databases and Map Layers for Chosen Sites

We added fields such as canopy size, tree number, species of tree, maintenance parameters required, as well as safety parameters, in order to complete our database. The new data we collected wa s added to these fields in our database in order for it to be analyzed.

Updates to several GIS map layers for the Cambridge Common and Public Cemetery were made to reflect the new maps. Once the data was analyzed we used it to create new map layers showin g the characteristics and effects of trees.

3.6.5 Presentation of Results and Deliverables

We have integrated all trees surveyed in the Cambridge Common and Walker Street into the newly created database (See Appendix I for forms in database manual). The new database can be accessed by an executable file to ensure easy maneuverability and is included on the CD.

All of the photos that we gathered are displayed in the view data form of our database. Since the photographs are organized using new codes, it is possible to link them to the database. (See Database manual in Appendix I for forms to view data collected).

The new data is also reflected in several GIS map layers for the Cambridge Common. See Section 4, Figure 19 and Figure 20, for a map of all trees surveyed. The new GIS layers are included in the maps folder of the CD. Our work in the field resulted in the creation of a new field methodology. We turned this methodology into a formal manual for data collection that we presented to the DPW. This manual can be found in the text folder of the final CD.

3.7 Quantification of Environmental and Economic Benefits of Trees

In the process of upgrading the tree management system in Cambridge, we decided that it would be necessary for our system to output useful information concerning the benefits that trees provide to the city. These data provide the City Arborist, Mr. Acosta, with figures that he can present to both the DPW and the city's residents to prove the true value of the city's trees to the community. The most important data concerned the environmentally and economically beneficial aspects of trees required the use of various formulae to determine. The formulae we chose to use were also dependant on data that had been previously collected by the DPW so that extrapolation was possible across the total range of data available. Once the formulae were applied to all data, several options became available for the presentation of these data to the DPW and the City Arborist.

3.7.1 Formulae Used

For our survey to include benefit data about trees, several formulae were crucial. The main concern was finding equations that used the data that we gathered. Once this issue was resolved our concern was with the extension of these equations to include the data previously collected by the DPW for street trees. The final equations and statistics that we used are explained in the following sections.

3.7.1.1 Environmental Benefits

Trees possess the natural ability to removal harmfu l pollutants from the air and soil. However, the means to provide these types of figures have not been available to the City of Cambridge until now. Typically, to provide a large-scale survey of trees and their environmental effects requires a large amou nt of time and funding, neither of which were available to the Urban Forestry Division. However, by looking into the issues concerning the completion of such surveys, we realized that they could be simplified and applied to Cambridge through our new field methodology.

Numerous surveys and studies have proven that trees consume many chemicals that are harmful to humans. Trees use pollutants like carbon monoxide, which are released through the many automobiles in the city, and sulfur dioxide, which causes a cid rain, in their growth cycle. Other chemicals that trees displace from the environment include carbon, NO_2, ozone, and diesel particles. Using statistics from previous surveys we were able to determine the pollutant displacement for each tree in our s urvey and extrapolate it for the DPW street trees surveyed. The formulae that we used were based on statistics from a 3 -year survey completed in 1994[22] by the USDA Forest Department. The statistics relate pollutant removal to the diameter at breast height of the tree. The trees are then grouped into several diameter ranges as can be seen in Table 6 below.

DBH Class	CO	SO_2	NO_2	PM10	O_3	Total
0 - 3 in	0.002204	0.006612	0.006612	0.015428	0.017632	0.048488
3 - 6 in	0.006612	0.017632	0.019836	0.046284	0.050692	0.141056
6 - 12 in	0.015428	0.046284	0.052896	0.12122	0.13224	0.368068
12 - 18.5 in	0.037468	0.119016	0.136648	0.310764	0.337212	0.941108
18.5 - 24.4 in	0.072732	0.229216	0.260072	0.59508	0.647976	1.805076
24.4 - 30 in	0.094772	0.299744	0.34162	0.78242	0.84854	2.367096
30+ in	0.123424	0.392312	0.449616	1.02486	1.11302	3.103232

Units Are Lbs/Yr

Carbon Stored		Carbon Sequestered	
Mean	SE	Mean	SE
6.612	0.1102	2.204	0.04408
52.896	0.6612	9.6976	0.1102
231.42	3.0856	20.7176	0.2204
879.396	13.224	42.0964	0.6612
2120.248	41.876	76.2584	1.7632
3984.832	112.404	121.8812	3.9672
7021.944	337.212	204.3108	8.816

Units Are Lbs/Yr

Table 6: Pollutants Removed by Trees per Diameter at Breast Height

Since our method used statistics from another survey we had to make several assumptions based on the previous study and our use of its information. The first assumptions that we made were those that were used by the study itself. Since the study was very tho rough the only obvious assumption that was to be made was that the particle removal rate (PM10) assumed 50 percent resuspension of the particles in to the atmosphere. However, the study also mentioned that the numbers in the above table were based on appr oximated relationships between canopy radii and DBHs. This assumption, though it proved most useful to us, can cause some error in data as is shown in the carbon storage and sequestration field of the table which have a standard error for each DBH class. Of course, since this data was taken from the Chicago area we had to make several assumptions of our own to make its usage feasible. First of all, we assumed that the Chicago area's pollutant concentrations were similar to those of Cambridge. Secondly, we had to assume the fact that the trees in Chicago may be of a similar species distribution, which means that their average pollutant removal

[22] McPherson, E. Gregory; Nowak, David J.; Rowntree, Rowan A. (1994). Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep.NE-186Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

rates would match those in Cambridge. Since the data that we collected included canopy sizes and species we have opened the door for those more proficient with arboreal chemistry to remove these assumptions.

3.7.1.2 Economic Benefits

Arboreal life can be proven to be an asset to the community. To go about proving this we needed to use formulae that appraised the tree based on its size and condition and others that related the trees' size to their pollutant removal monetary savings. Appraisal of any tree can be done using a method called the Trunk Formula Method[23]. The general idea behind this method is that the tree that i s being appraised is larger than the largest plantable tree in the area, which determines the replacement cost. The cost of the largest plantable tree is then modified by adding the result from multiplying the value per trunk area (Basic Price) by the species rating and the difference in the areas of the trunks. This value becomes the Basic Value that is then adjusted by location and condition ratings. The full equation can be found below.

Appraised Value = *Basic Value* **x** *Condition* **x** *Location*
Basic Value = *Replacement Cost* + *[Basic Price* **x** *(Difference in Trunk Areas)* **x** *Species]*

Due to the limited time and depth of our survey we had to assume several things, which make the tree values a rough estimate. Our first assumption was that the Replacement Cost w as based on a 7" tree. Mr. Acosta gave this figure and the value of $2000 to us. Our second assumption was that all species are equal. Though we know this is not the case in the city, it was impossible for us to determine ratings for all the species tha t we dealt with in the seven weeks allotted. The third assumption that we were required to make was that all of the locations in the city were equal. Much like our second assumption we know that this is not truly the case, but our time on site was a prec ious commodity. These factors considered, we still needed to apply a condition rating adjustment to the value.

Our simplification of the condition rating for trees split it up into its integral parts; most of the health parameters that were mentioned earl ier are what make up the rating. Once the health parameters are entered in to the database they receive a number from one to five, one being the worst, which depends on the value of the parameter. The parameters that factor into the condition rating are deadwood %, dead bud %, cavities, number of major visible injuries, leaf damage, insect infestation, disease and presence of fungi. The tables below show the value assigned to each parameter based on what was collected in the field and entered into the database.

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[23] Guide for Plant Appraisal (1992). Council of Tree and Landscape Appraisers. Savoy, IL: International Society of Arboriculture.

Deadwood % & Dead Bud %	Value
0-10%	5
10-25%	4
25-50%	3
50-75%	2
75-100%	1

Table 7: Deadwood & dead bud % rankings

Leaf Damage	Value
(None)	5
Discoloration	4
Mining	2
Not Surveyable	5
Scorching	4
Wilt	3

Table 8: Leaf damage and condition rating

Cavities	Value
None	5
< 6"	3
> 6"	1

Table 10: Cavity sizes & condition rating

# of Major Visible Injures	Value
0	5
1	3
> 1	1

Table 9: # of cavities & condition rating

Type of Insect Infestation	Value
(None)	5
Aphid	4
Boring	2
Cambium miner	1
Gall	4
Leaf chewing	3
Scale	3
Spidermites	2
Tent caterpillar	4

Table 11: Insects & condition rating

Disease Type	Value
(None)	5
Anthracnose	4
Blight	2
Branch Dieback	2
Canker	2
Dutch Elm	1
Powdery Mildew	4
Rust	2
Verticillium Wilt	1

Table 12: Diseases & condition rating

Fungi	Value
Yes	3
No	5

Table 13: Fungi & condition rating

After all of these parameters have received a value they are summed. The tree's sum is then divided by the maximum possible sum, or a perfect tree that received a value of 5 for each parameter. This provides us with a value between 0 and 1 that is a percentage, which, unless the tree is perfect, will decrease the value of tree as is expected.

The appraised value is only the a mount of the face value of a tree, much like a baseball card's or antique's appraised value. This value does not look into sentimental value, historical value, or even the value added by the trees' pollution removal abilities.

There is a small value that trees provide through pollutant removal. On a per tree basis the value is minimal because of the fairly small amount of pollutants that the trees can remove by themselves. However using value from 1990 the value of this pollutant removal can be estimated . The values listed in the Chicago tree survey were \$490/ton of O_3, \$920/ton of CO, \$1,307/ton of PM10, \$1,634/ton of SO_2 and \$4,412/ton of NO_2.[24]

Since these equations and statistics were all based on DBH, a value that has been collected on all data that was available to us, we were able to extrapolate results over the entire city with only a few assumptions and issues.

3.7.2 Extrapolations

The true power of these formulae lies in their ability to function with the existing 11,061 -tree database. Our survey only covered approximately 170 new trees. For this data to have immediate significance we needed a larger sample size. The existing database, though it didn't provide everything we needed, proved to be entirely useful for this exact purpose.

3.7.2.1 Environmental Benefit Extrapolation

All of the environmental benefit statistics and formulae used DBH as an index, which allowed us to easily apply the data to the old database; the DPW had already collected the DBH of the trees during their initial survey. All that we did was create a query in the database that would determine the results for each pollutant and place them in a new column. This process was not quite as straight forward for the extrapolation process of economic benefits.

3.7.2.2 Economic Benefit Extrapolation

We were faced with a small problem, due to the fact that our equation for tree appraisal required condition rating for the trees. The street tree database did include this, but it was completed using an entirely different method from our own condition rating. We decided that to get a rough estimate of the cost of each street tree we would use the average condition rating in Cambridge Common as a substitute. This did, however, make the data skewed towards the high side because the average condition rating i n the common

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[24] McPherson, E. Gregory; Nowak, David J.; Rowntree, Rowan A. (1994). Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

was approximately 87%. The rest of the formula is strictly dependant on the diameter of the tree, using our assumptions. This allowed us to simply apply a query to the database and assign each tree an appraised value. The adjustment due to pollutant removal was not included in this value because of its small value per tree. However, once the environmental formulae were applied we were able to apply the monetary savings equations to each tree or sum the total for the city.

3.7.3 Presentation of Results

The goal stated at the outset of this analysis was to not only give Mr. Acosta this information, but to enable him to communicate it to others. Since the data is taken from MS Access it can be manipulated in many ways. Tables, charts, graphs, and maps are all entirely feasible with the software and methods that we have described.

3.7.3.1 Environmental Results

To communicate the results of our environmental analyses we felt that overall reports would be the best option. With over 11,000 trees to display, f ull reports would have been too large. The overall reports show the total environmental benefits and also their relationship to species. This report is very much related to reports on DBH versus Species, since the environmental benefits are based on the DBH measurement. Maps can also be used to communicate the data, but only on the area that we surveyed. This is due to the fact that the area that we surveyed, Cambridge Common, is one of the first to actually be surveyed for tree location and placed on a map.

3.7.3.2 Economic Results

The economic analyses, much like the environmental analyses, have a close relationship to DBH. Therefore, the way the results are presented is nearly the same. We were able to expand our sample range over the old database, so the overall figures for the city were presented in a single report just like the environmental data. Since the appraisal method was based on two values, however, there were differences in the appraised value versus species reports. These reports show not on ly DBH, but condition rating as well, factored in for each species. The value can also be compared to its factors separately to see the differences between how the DBH and the condition rating affected the value for each tree. On the data that we collected in our survey the relationships can be looked at under a microscope, so to say. Diseases or insect infestation types, or any of the other fields that are integral to the condition rating, can be compared to see what effects they separately have on valu es. All of these reports can be shown on maps for our area, as well as through tables, graphs and charts.

4. Tree Results

Upon completion of our fieldwork, we gathered a large amount of data. To communicate these data clearly, we created deliverables to display our results. Each methodology task had different results ranging from reports and databases, to maps and field guides.

After carefully looking at the tree information system used by the DPW, we organized the existing database and GIS layers. The pr evious database and information remained largely unused. This led to our development of a new organized system. The system utilizes an MS Access database for storage and running reports. The database consists of a centralized location for the storage of tree data.

From the development of the new tree information system, we achieved the following results. One of these was the separation of permanent or static data from the dynamic data in the database we created for both open space and street trees by r unning queries. By creating this division, we incorporated increased functionality and usability into the new data structure. Smaller, more manageable databases, allows for more frequent maintenance and updating of the constantly changing data. Another result from this organization is the application of an intuitive nomenclature to the data fields and records. This provides increased clarity and readability to future users. Lastly, GIS layers were reviewed and updated for data accuracy. This created a precise representation of the geographical location of trees for critical data analysis.

The collection and integration of field d ata resulted in new tree data on open -space trees, street trees, as well as visual documentation of both. (See Figure 19 and Figure 20 for maps of all the trees that were surveyed on Walker Street and in Cambridge Common).

Figure 20: Trees on Walker Street

Figure 19: Trees in Cambridge Common

We developed data entry and data view forms for open space and street trees as well as an easy to use front end to our database. Another result was new coding systems for data on open-space trees and all photographs taken.

4.1 DBH Distribution

The newly created database allows users to create many different types of reports. Since there are a wide variety of trees in Cambridge, it would be useful to look at the different ages of trees and compare it to the each species. From this simple report it is possible to see estimate the age of the population of a certain species. Below in Figure 21 it is possible to see that there are approximately 19 different species in Cambridge Common not including the few stumps. There are also a wide variety of ages in the Common. Using this graph the average DBH for each species and estimate the age of the population. For example, we can look at the population of Ash (FR) and notice that they do have a large average DBH. This leads us to believe that these are very old trees. By looking at the number of trees we also notice that there is approximately 2 trees. Using this information one can deduce that in recent years there have not been many plantings of this species. It is also easy to notice which trees dominate the total population, like the Norway Maple (ACPL). Having this many of one type of tree can be devastating to an environment for several reasons. Disease is one of these instances. In the case of Dutch elm disease, many elm trees were infected and eventually killed. This devastated the elm population in cities because for aesthetic reasons there were many elm trees planted in parks and recreation areas.

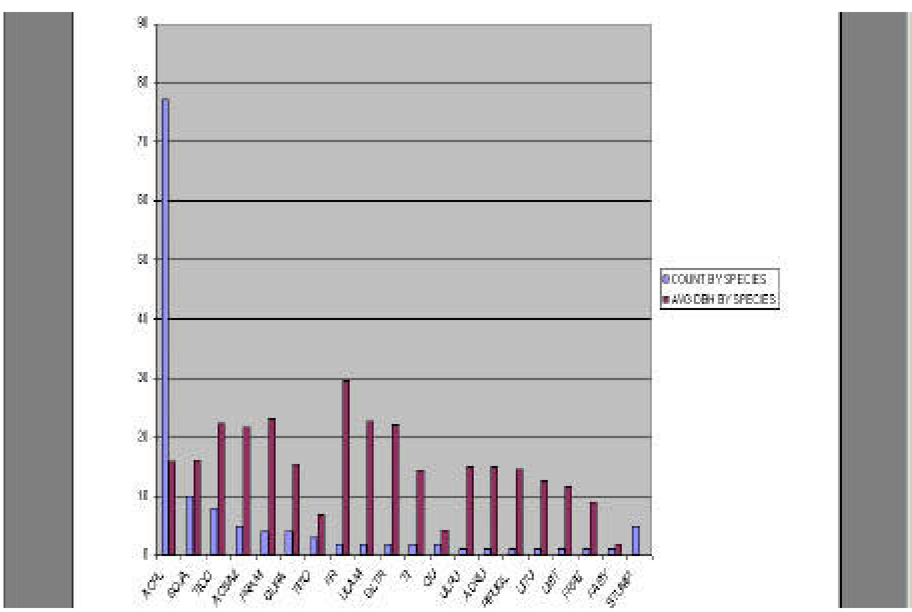

Figure 21: DBH and Species

To look at the maturity of the tree population in Cambridge reports such as the one in Figure 22 can be created. Each tree is grouped into small, medium, and large trees based on its diameter at breast height (DBH). This is important to look at how young the population of trees is. In Figure 22 we can see some of the trees in Cambridge Common. This report can be used to track the maturity of the trees in Cambridge Common. This can also be used to see which species need to be planted.

Tree Report: Trees by DBH

CATEGORY	DBH	SPECIES	CONDITION	TREE CODE	SITE
SMALL	2	FASY	94%	OSCCA140	Cambridge Common
SMALL	4	QU	100%	OSCCH50	Cambridge Common
SMALL	4.5	QU	94%	OSCCH60	Cambridge Common
SMALL	6.3	TITO	89%	OSCCA220	Cambridge Common
SMALL	7	TITO	94%	OSCCA200	Cambridge Common
SMALL	7	TITO	100%	OSCCA210	Cambridge Common
SMALL	7.5	TI	97%	OSCCD10	Cambridge Common
SMALL	9	FRPE	86%	OSCCI190	Cambridge Common
MEDIUM	10	ACPL	100%	OSCCE10	Cambridge Common
MEDIUM	10.4	ACPL	100%	OSCCH120	Cambridge Common
MEDIUM	11	ACPL	71%	OSCCI10	Cambridge Common
MEDIUM	11	ACPL	100%	OSCCJ10	Cambridge Common
MEDIUM	11.1	TICO	100%	OSCCC70	Cambridge Common
MEDIUM	11.5	ACPL	94%	OSCCI290	Cambridge Common
MEDIUM	11.5	LIST	89%	OSCCA30	Cambridge Common
MEDIUM	11.7	ACPL	100%	OSCCI140	Cambridge Common
MEDIUM	11.9	ACPL	80%	OSCCA40	Cambridge Common

Figure 22: Trees by Size of DBH

4.2 Insect Infestation

One of the parameters that we collected during our tree survey was whether or not each tree was infested with insects. Below in Figure 23 there are four types of insects prevalent in the Cambridge Common. As can be seen in there are many cases of boring insects in the Common affecting several different species.

SPECIES	Common Name	INSECT INFESTATION
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Aphid
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACPL	Norway Maple	Boring
ACSA2	Sugar Maple	Boring
ACSA2	Sugar Maple	Boring
FR	Ash	Termites
FRPE	Green Ash	Boring
GLTR	Honeylocust	Boring
LITU	Tulip Tree	Scale
SOJA	Japanese Pagoda Tree	Boring
SOJA	Japanese Pagoda Tree	Boring
TICO	Little Leaf Linden	Boring
TICO	Little Leaf Linden	Boring
TICO	Little Leaf Linden	Boring
TICO	Little Leaf Linden	Boring

Figure 23: Trees with Insect Infestations

As stated previously, there are many types of insects that will infest a tree, one easy method that is easy to detect is by looking at the leaves of the trees. Since we were unable to look at any new leaves during our study there could easily have been more cases of insects in the trees in Cambridge Common.

A study of the different types of insects and which trees they prefer to attack can be easily generated using a similar report. From this report we can suggest that since there are many instances of boring insects attacking Norway Maples, that perhaps these trees attract the same insect. For the future it might be to benefit to plant species other then the Norway Maple to reduce the number of cases of boring insects present.

4.3 Canopy Coverage

As a result of collecting canopy size for all trees, we built a GIS map layer for canopy coverage in the Cambridge Common. From this map we are able to tell which areas of Cambridge Common are denser than others. Below as can be seen in Figure 24 there are approximately 128 trees in the common, as well as four stumps and one vacancy. The vacancies and stumps are shown in blue. From the map below there are several places where the trees are growing closely together and several areas where more trees could be planted. A visual documentation like this of the Cambridge Common is useful in determining tree densities in different areas of a city.

Figure 24: Canopy Coverage in Cambridge Common

4.4 Species Distribution

To ensure the even distribution of trees in one area, it is important to see the concentrations of each species. Below in the species distribution map (Figure 25), it is possible to see where one species has been generously planted in the Common. The Norway Maple, (ACPL) has been planted in high concentrations in the southern and northeastern parts of the park.

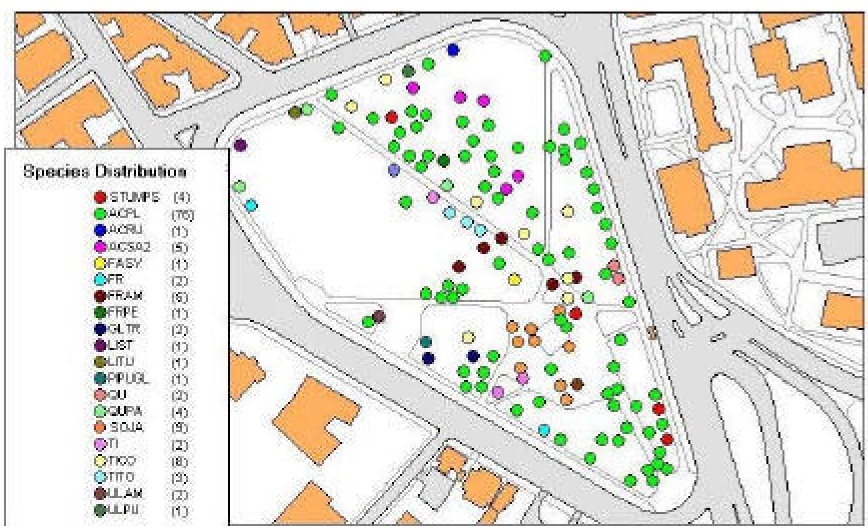

Figure 25: Species Distribution

Surrounding the Civil War monument there are quit e a few Japanese Pagoda trees (SOJA). The dots in red are stumps, trees that have been removed and are potential planting sites.

4.5 Hazard vs. Species

Another result we can produce from the data collected is to run reports or queries on potential hazardous trees in the Cambridge Common. We can run queries on the trees that have obstructions and the distances of these obstructions form the trees. The obstruction distance field helps in determining which trees need immediate pruning or maintenance. As can be seen in Figure 26, there are several Norway Maples, one Red Oak, Little Leaf Linden, and Pin Oak that need immediate attention, as the obstruction distances are zero.

SPECIES	Common Name	OBSTRUCTION TYPE	OBSTRUCTION DISTANCE
ACRU	Red Maple	Light Pole	0
TICO	Little Leaf Linden	Pedestrian Clearance	0
ACPL	Norway Maple	Light Pole	0
ACPL	Norway Maple	Pedestrian Clearance	0
QUPA	Pin Oak	Light Pole	0
ACPL	Norway Maple	Pedestrian Clearance	0
ACPL	Norway Maple	Pedestrian Clearance	0
ACPL	Norway Maple	Pedestrian Clearance	0
ACPL	Norway Maple	Light Pole	1
ACPL	Norway Maple	Light Pole	1
ACPL	Norway Maple	Light Pole	1
QUPA	Pin Oak	Light Pole	1
ULAM	American Elm	Sign	1
ACPL	Norway Maple	Light Pole	2
ACPL	Norway Maple	Light Pole	2
SOJA	Japanese Pagoda Tree	Statue/Monument	2
ACPL	Norway Maple	Light Pole	2
ACPL	Norway Maple	Light Pole	3
ACPL	Norway Maple	Light Pole	3
ACPL	Norway Maple	Light Pole	3
ACPL	Norway Maple	Light Pole	3
SOJA	Japanese Pagoda Tree	Pedestrian Clearance	3

Figure 26: Trees that Need Pruning

4.6 Planting Spaces vs. Stumps

The other reports or queries we can run from data collected is to verify how many stumps (Figure 27: picture of stump in the Common) exist and thus how many vacancies (Figure 28 - picture of vacancy in the Common) or planting spaces exist in the Cambridge Common. As can be seen in Table 14, there are two stumps in Section A and Section F, and one vacancy in Section P_K. This report is useful to the City Arborist to determine how many potential planting spaces or vacancies are unfilled.

Figure 27: Stump

Figure 28: Vacancy

The new data collected and database we created, provided information to analyze data in new ways. In the next section we will discuss some of our analyses, such as condition rating, cost benefit analysis, and the environmental and economic benefits of trees to the City of Cambridge.

SPECIES	SITE	SECTION	TREE#
STUMP	Cambridge Common	A	170
STUMP	Cambridge Common	A	70
STUMP	Cambridge Common	F	80
STUMP	Cambridge Common	F	60
VACANCY	Cambridge Common	P_K	70

Table 14: Stumps and Vacancies in Cambridge Common

4.7 Condition Rating

Using techniques described in methodology section about environmental and economic benefits. By using a variety of fields we were able to create a very objective condition rating of each tree. The condition rating of the tree gives a numeric rating to the overall condition of a tree. This is helpful to City Arborists for several reasons. Using prescribed methods, almost anyone can go out in the field to collect data. This formula allows the Arborist automatically flag certain trees that are going to be a problem. It was decided that there every tree having a condition rating below 75% would be flagged for trees that need immediate attention. Below in Figure 29 are all the trees that have a condition rating less then 75%.

SPECIES	Common Name	SECTION	CONDITION RATING
FR	Ash	A	46%
ACPL	Norway Maple	I	46%
TICO	Little Leaf Linden	I	57%
GLTR	Honeylocust	C	57%
ACPL	Norway Maple	C	57%
TICO	Little Leaf Linden	I	57%
ACPL	Norway Maple	A	60%
ACSA2	Sugar Maple	I	63%
TICO	Little Leaf Linden	H	63%
ACPL	Norway Maple	A	63%
ACPL	Norway Maple	C	66%
TICO	Little Leaf Linden	I	69%
ACPL	Norway Maple	F	69%
ACPL	Norway Maple	P_E	69%
FRAM	White Ash	A	71%
ACPL	Norway Maple	I	71%
ACSA2	Sugar Maple	I	71%
ACPL	Norway Maple	F	74%
ACPL	Norway Maple	H	74%
ACPL	Norway Maple	H	74%
SOJA	Japanese Pagoda	P_K	74%

Figure 29: Trees that Need Immediate Attention

5. Analysis

Our project concludes with the analyses of the trees surveyed in Cambridge Common. Our information from our results chapter can assist in improving the tree management system, help determine the impact of trees in the city, and offer recommendations for further upgrades to the Urban Forestry Division's tree management systems in the future.

Our analysis of tree data led directly into a study of the beneficial effects of trees to the area. Examination of our spatial distribution maps showed that areas of higher tree density have lower amounts of pollution, better energy conservation, and higher property value. The tree canopy co verage maps gave us the opportunity to determine the exact shade coverage in the common. The DPW will use this data to determine how often maintenance and new planting need to occur in these areas.

5.1 DBH and Species Distribution

One problem in tree management is the concentrated planting of few species in parks and along streets. Some diseases often attack specific tree species. In the case of Dutch Elm, thousands of elm trees were infected and killed. Many of the trees planted in Cambridge prior to the disease were elm trees. This was devastating to the tree population and many people attributed this to the population of elms being too large. The DPW has set out to replant and introduce many varieties of trees, to eliminate this problem. To assist the department in determining the over-population of a single species we have compared age and DBH to the different species in Cambridge Common.

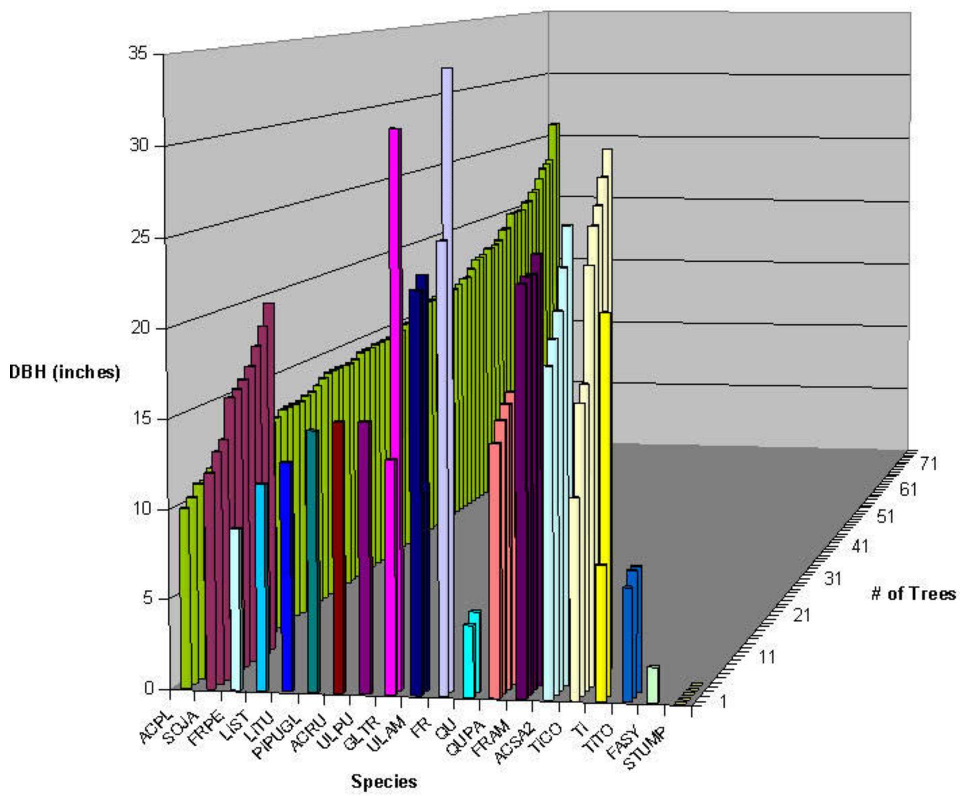

Figure 30: DBH and Species Distribution

Using the distribution of DBH of trees in the Common, the

SPECIES	CountOfSPECIES	Common Name	DIAMETER CATEGORY
ULAM	2	American Elm	LARGE
FR	2	Ash	LARGE
VACANCY	1	Available Tree Space	
PIPUGL	1	Colorado Blue Spruce	MEDIUM
FASY	1	European Beech	SMALL
FRPE	1	Green Ash	SMALL
GLTR	1	Honeylocust	LARGE
GLTR	1	Honeylocust	MEDIUM
SOJA	7	Japanese Pagoda Tree	LARGE
SOJA	3	Japanese Pagoda Tree	MEDIUM
TI	1	Linden	SMALL
TI	1	Linden	LARGE
TICO	7	Little Leaf Linden	LARGE
TICO	1	Little Leaf Linden	MEDIUM
ACPL	38	Norway Maple	MEDIUM
ACPL	39	Norway Maple	LARGE
QU	2	Oak	SMALL

Figure 31: DBH Category and Species Count

approximate ages of each tree can be estimated. The sizes of trees can be related roughly to the age of the tree[25]. Using this relationship we can at least tell whether a tree is young or old. Above in Figure 30, the number of trees vs. species and DBH can be seen. As can be seen in the figure there are approximately nineteen different species, and a variety of ages for each species. There are approximately seventy-six Norway Maples (ACPL) in the Cambridge Common, not including several that have recently been cut down. The average DBH of the Norway Maple is 17.7 inches making these trees some of the older trees in the Common. The Norway Maples comprise of fifty-nine percent of the total population in Cambridge Common. Each tree is given a size rating based on its DBH (see Figure 31). Assuming that as trees age, they grow, we can make the assumption that a small tree is young, and a large tree is old. For Norway Maples, approximately sixty percent are in the medium to large categories. We can then assume that the medium and large trees are the older trees. The Norway Maples are 80% of all the medium -sized trees and roughly 53.4% of the large tree population. This means that the Norway Map les are also some of the oldest trees in the Common. Also using the average condition rating for all Norway Maples (88.75%) in the Common we see the population of these maples is among the average for the trees in the common. Because they constitute the largest number of trees in the Common there could be a large number of trees that will need to be replaced in the next few years.

5.2 Environmental Benefits

Trees provide a number of benefits to its immediate environment. They clean the air around us by removing pollution. They block wind and direct sunlight. They also provide us with the oxygen that we breathe. The five major types of pollution that trees remove in urban environments are c arbon monoxide, sulfur dioxide, nitrogen dioxide, ozone, and other particles such as diesel (CO, SO_2, NO_2, O_3, PM10, respectively). Using the information described in Section 3.7, we estimated the amount of pollution removed annually by the trees in Cambridge Common and all the street trees.

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[25] City Green Estimate for Tree Age

As can be seen in Table 15 it was estimated that the trees in Cambridge Common removed 146.7 lbs of pollutants annually.

SumOfCO	SumOfSO2	SumOfNO2	SumOfPM10	SumOfO3	SumOfTOTAL POLLUTANTS
5.88468	18.577516	21.217908	48.419676	52.613888	146.713668

Table 15: Pounds of pollutant removed by trees in Cambridge Common

This analysis was then extrapolated on the 11,061 street trees surveyed in Cambridge. As can be seen in Table 16 the street trees remove 6745 lbs of pollutants annually. The amounts of removal of carbon

SumOfCO	SumOfSO2	SumOfNO2	SumOfPM10	SumOfO3	SumOfTOTAL POLLUTANTS
274.761660000	853.805356000	972.442268000	2224.32088000	2420.64218	6745.97234400025

Table 16: Pounds of pollutants removed by the 11,061 street trees in Cambridge

monoxide are interesting due to the shear number of cars producing this gas in the Boston – Cambridge area.

Automobiles produce large quantities of pollution roughly 19.11 lbs of CO and approximately 3.10 lbs of NO_x per year.[26] Using the data found in Table 16 we estimated the amount of pollutants absorbed per tree per year (see Table 17: Pounds of pollutants absorbed per tree per year). By dividing the total amount of pollutants produced per car by the total amount of pollutants removed per tree, we calculated that 31 trees are required to remove the NO_x produced per car per year, and 825 trees to absorb the CO produced per car per year.

POLLUTANTS	AMOUNT IN LBS
CO	0.0263
NO_X	0.09315

Table 17: Pounds of pollutants absorbed per tree per year

There are several man-made techniques to cleanse our atmosphere of pollutants. Trees however, are natural scrubbers. Based on a 1990 study on the removal of pollutants a table of the cost for removal of one pound of pollutant seen below in Table 18: Costs to remove one pound of pollutant. We calculate from this data that the street trees in Cambridge save the city $5011.90 in total pollution costs. The list of all of the money saved because of trees is also in the tree below in Table 18: Costs to remove one pound of pollutant. Although these numbers seem minimal, trees are beneficial because besides maintenance costs they provide this naturally.

As noted our study of street trees, by having an organized method to maintaining trees, the cost for maintaining trees can go down and more trees can be planted and their health can be monitored. An increase

[26] Estimates based on information provided by the WPI IQP study Evaluating the Downtown Boston Parking Freeze,2001, where the amount of pollution that one car produces assumes a car traveling 20mi/hr and traveling 2 miles

in the number of trees will also have an effect on the environment. By increasing the amount of trees in Cambridge, the total pollution amounts and savings will a lso increase.

POLLUTANT	COST TO REMOVE ONE POUND ($)	TOTAL SAVED BY TREES ($)
O3	0.245	593.05
CO	0.46	126.39
PM10	0.65	1445.81
SO2	0.817	697.56
NO2	2.21	2149.10

Table 18: Costs to remove one pound of pollutant

5.3 Economic Benefits

A tree can contribute significantly to value of properties and land economically. A tree can add as much as seven to twenty percent to the value of a property and as much as $57, 011 in pollution control in its lifetime. If trees can provide so much m onetary value to a city then it would be worthwhile to invest some time to create and manage the trees in an efficient manner.

In our study we surveyed approximately 133 open -space trees, stumps and vacancies in Cambridge Common. Using the condition ratin g and some other factors described in Chapter 3.7.1.2, we were able to calculate the values of every species and also the overall value of the trees in the Common. We could then take that formula and apply it to the large street tree database to estimate the overall value of trees in Cambridge excluding private trees. In the figure below (Table 19: To tal and average tree value for each species in Cambridge Common) are the results of that analysis. The total value of trees in Cam bridge Common was estimated to be over $1.2 million. The average tree values range from less than $1000 to $25,000. Trees can add a substantial amount of money to a property.

When we applied the same formula to the street trees in Cambridge, we found that the approximate value of all the trees in Cambridge was substantially more. A couple assumptions were made to apply this formula to the old data. We noticed out in the field that the street trees looked to be in much better condition than the open sp ace trees. We decided to use our high condition rating to predict that all the street trees would be relatively the same, 89%. When this number was used the value of all the street trees in Cambridge are worth an estimated $65,637,494.79.

According to the old software at DPW, Tree Manager, the total value of the street trees in Cambridge was approximately $10 million. Because several assumptions about the average tree condition rating were made it is likely that the Tree Manager software used a condition value much smaller then the value we assumed. After looking more closely at the previous data, we noticed that the average condition rating for each tree old data used a default condition rating of 70 for each tree.

SPECIES	Common Name	CountOfSPECIES	SumOfTREE VALUE	AvgOfTREE VALUE
ACPL	Norway Maple	77	$726,034.59	$9,553.09
TICO	Little Leaf Linden	8	$124,650.97	$15,581.37
SOJA	Japanese Pagoda Tree	10	$100,017.40	$10,001.74
ACSA	Sugar Maple	5	$79,796.26	$15,959.25
FRAM	White Ash	4	$77,211.21	$19,302.80
FR	Ash	2	$48,749.74	$24,374.87
ULAM	American Elm	2	$38,263.01	$19,131.51
QUPA	Pin Oak	4	$37,810.13	$9,452.53
GLTR	Honeylocust	2	$31,160.11	$15,580.06
TI	Linden	2	$19,364.53	$9,682.26
ACRU	Red Maple	1	$9,184.05	$9,184.05
ULPU	Siberian Elm	1	$8,396.85	$8,396.85
PIPUC	Colorado Blue Spruce	1	$7,601.20	$7,601.20
LITU	Tulip Tree	1	$6,207.39	$6,207.39
TITO	Silver Linden	3	$5,528.11	$1,842.70
LIST	Sweetgum	1	$5,089.79	$5,089.79
FRPE	Green Ash	1	$3,022.98	$3,022.98
QU	Oak	2	$1,480.01	$740.01
FASY	European Beech	1	$154.12	$154.12
STUM	Tree Stump	5		

Table 19: Total and average tree value for each species in Cambridge Common

There are several conclusions that we can draw from this. First, the average condition rating is lower then the one used in the calculation, which would leave us to believe that our rating wo uld be more ideal than actual. In the future if trees can be well maintained and the average condition rating could be increased then we could drastically increase the overall value of the street trees in Cambridge, as much as six times in dollar amount for a rise in condition rating from 70% to 89%. The second conclusion would be, that having a default condition rating causes a majority of trees measured to have a false condition rating.

In conclusion, the health and condition of each tree is important to maintain, because these factors can have a drastic effect on the value of trees. By using an organized and well -maintained pruning schedule to increase the overall health of the tree and thus increase the condition rating, then it will be economically beneficial.

6. Conclusions

Through the presentation of our deliverables and the analysis of our results, this project has re-invented the tree management process utilized by the City of Cambridge. Direct effects of the implementation of the new tree management system include a decreased turn-around time for addressing maintenance issues such as obstructions and unhealthy trees. It also results in decreased costs in the form of saved overtime for emergency tree maintenance by providing early notification of potential hazards in order to address them before they become problems. An example of this is in decreased claims against the city due to damage caused by trees that were negligently maintained. The new database also provides increased analytical abilities in the form of reports and nearly infinite filtering options. This allows for data to be analyzed and compared in new ways in the future and provides the capability to draw new correlations and conclusions.

While there are many direct ways in which the project has served to improve tree management in the City of Cambridge, there are also specific ways in which it has indirectly improved it as well. One of these indirect ways is in increased condition rating. As noted earlier, trees that are maintained and pruned regularly are proven to have higher condition ratings than those that are not maintained as aggressively. Thus having a tree management system in place which provides for accurate cyclical pruning and preventative tree maintenance will indirectly increase the condition ratings of the trees in the city. A second indirect benefit that has been provided is quantification of value of the entire street tree inventory in the City of Cambridge. Directly, by determining the tree value for each tree, the City Arborist will be able to settle claims fairly when a tree is injured by a citizen. The real benefit is indirect however, and that is in knowing that the street tree inventory is a $65 million asset. This will aid in the viewing of street trees as an actual asset that needs to be maintained. This project has not only improved tree management in the City of Cambridge, it has also proven the importance of it.

The project was both a challenge and an experiment to create a more efficient and effective process for urban tree management. The resulting management system that was developed addressed all of the major needs of the Cambridge Department of Public Works Urban Forestry Division while also optimizing the entire process. Through a combination or standardization and customization, we have created a process that is both repeatable and reproducible. With the application and implementation of the field and database manuals and data structures produced for this project, any city could upgrade their tree management to a more efficient process.

7. Recommendations

Our project, re-engineering the tree management system at the Cambridge Department of Public Works, we proposed several tasks that were not feasible during our project due to time constraints. Along with our deliverables, we compiled a list of ideas we wished we had gotten a chance to take part in. These ideas range from the data collection, to inclusion of private trees into the analysis, and determining the long-term effects that management has on systems.

7.1 Data Collection

While we were revising our field methodology with a local arborist we brainstormed several different methods for the collection of tree data in Cambridge. These methods allowed for interaction with the community and local schools. By simplifying the task of collecting data, it would be possible to include children into the learning process. Along with the Field Manual, guidelines for conducting a tree identification lecture to students could be included. By involving schools in such a program, we can increase awareness and interest in trees within the Cambridge Community. We hope that the new field methodology provided through our study will be the foundation for many such socially interactive programs between the Urban Forestry department and the citizens of Cambridge. Another program that may assist the DPW in surveying would be to involve volunteers in the collection process. Now that the survey has become more simplistic, the ability to call on the general public's assistance is possible. It is our recommendation that the DPW actively seek out and develop these types of programs to keep the database complete and up-to-date.

One other way to keep all of the tree data current is to involve the landscaping companies involved with the city's pruning contracts. The tree warden in the city can stipulate that the dynamic data for each tree be collected before pruning. Since each pruning company needs to have a certified arborist look at each tree before pruning begins this process does not add too much work to the contract. This would allow for regular updates to the tree data because of the pruning cycle already in place.

7.2 Development of a Preliminary Methodology for the Inclusion of Private Trees

There are several approaches that the city could take to build a database of private trees. A survey could be created to obtain information from the public about a private tree census. The purpose of this survey would be to get feedback from homeowners about their feelings towards a tree census and their concerns about trees in the city. The survey would also help determine the level of knowledge that property owners have about the economic benefits of trees. The results of this initial survey could then be used to determine the next course of action regarding what type of survey to use.

7.2.1 Tree Census

If the initial survey shows that the cities citizens would support a full tree census then we suggest collecting private tree information such as tree species, estimated condit ion, and physical measurements in a private tree inventory. The same field techniques that we used for this survey should be applied to collection of the private tree data. These data provide background information that can lead to better tree management. The individual needs of each tree can be identified and considered in benefit analyses, as well. This allows the tree warden to look at trees in the private sector to make sure that they are not adversely affecting public trees as well. The statutory legal requirements of tree owners regarding safety and tree benefit issues can also be addressed during planned management thus reducing risk to people and property. If the results of the initial survey prove to be different, though, there are other optio ns available to the city.

7.2.2 Non-Intrusive Methods

Without owner's consent the city would be unable to obtain the actual location and condition rating values for the tree. The only currently available option available in the way of non -intrusive methods would be to take aerial photographs, or use current orthographic maps, of the area and mark the locations of the trees. This would at least give the DPW an idea of the number of trees that exist in the private sector. Based on this data the city can further decide whether or not to complete an all -inclusive tree census.

7.3 Monetary Waste Prevention Analysis

To determine the true value of our work combined with the current pruning schedule in Cambridge, it would be necessary to look at several different sets of d ata available to the DPW. We suggest that this analysis be completed so that the tree warden can show the true worth of his preventive maintenance system.

The data that is needed to make this analysis are the cost of tree accidents on a yearly basis, th e amount of overtime caused by tree emergencies on a yearly basis, and the cost to keep every tree under the preventive maintenance umbrella per year. These values will change from year to year and can be compared to see what amounts of monetary savings o r waste are caused by the pruning schedule. Since the pruning schedule can be fine-tuned using our method the data will also show how the new methodology can decrease overall costs and make the entire tree management system more efficient.

Using these recommendations the department of urban forestry can see the effects of everything that it does. It also holds the potential to expand the domain of influence of the department by including the private tree sector. The goal of our work was to help improve t he efficiency and effectiveness of the tree management system in Cambridge. Much has been done towards progressing this cause; there is still much work that must be done, however, to make the system perfect. We hope that future project groups, or the DPW itself, will have as much success as we did in completing their tasks.

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Appendix

Appendix A: Annotated Bibliography

Acosta, Larry. (Cambridge Department of Public Works: Urban Forestry. [Web Page]. URL: http://www.ci.cambridge.ma.us/~TheWorks/forestry.html

- Provides services to the city of Cambridge including: tree management, service requests, volunteer activities

Adams, L.W. (1994). Urban Wildlife Habitats. (pp. 18-40) Minnesota and London: University of Minnesota Press.

- This book covers a variety of topics ranging from how wildlife lies in the city to how cities affect the environment.
- The author attempts to link negative environmental effects due to the paving of roads, deforesta tion for development, and air, water, and soil pollution.
- This source concludes that these negative effects can be avoided if properly planned around.
- This source was used primarily as background knowledge to learn what the effects of the urban environment on the ecosystem can be.

Beatley, Timothy, & Manning, Kristy (1997). The Ecology of Place. Washington D.C. and Covelo, CA: Island Press.

- This book is about urban planning and city development. It covers topics including the environmental considerations that must go into planning a city community.
- The main topic of this source is urban planning. It covers the different aspects in broad detail that are a part of successful urban planning.
- The source concludes that current methods of urban planning are con ducted too haphazardly. It continues that the current approaches have both economic and social cost. It concludes that urban planning must be a vision that is implemented carefully and completely not a series of "quick fixes".
- This source will be used to provide background on urban ecology. It will provide current trends and emerging theories in urban planning.

Cambridge Municipal Code: Administration and Personnel [Web Page]. URL http://bpc.iserver.net/codes/cbridge/index.htm [2001, January].

- This source provides a list of personnel and their appointed tasks.

- This site also has a variety of maps, including several on the park systems in Cambridge.

Perry, Doane. (Cambridge Tree Project. [Web Page]. URL: http://ourworld.compuserve.com/homepages/DoanePerry/

- Organization composed of citizens' groups and individuals working together to assist the City of Cambridge in building support for the protection and management of community trees
- Provides valuable information on street tree types, quantities, and percentages
- Current local environmental news source

Dominski, T. Ph.D. (1994). The Three Stage Evolution of Eco -Cities – Reduce, Reuse, Recycle. In B. Walter, L. Arkin, R. Crenshaw (Eds.), Sustainable Cities (pp. 16-18). Los Angeles, CA: Eco -Home Media.

- This article covers the topic of sustainability in an urban community and possible ways in which it can be attained.
- The author uses the slogan "Reduce, Reuse, Recycle" to illustrate how it can be applied to communities. He includes a section on the social aspects of creating a sustainable community.
- This source will be used to show how we and the tree warden are working towa rds sustainability in the Cambridge area

Pauleit, S., Duhme, F. (GIS Assessment of Munich's Urban Forest Structure for Urban Planning [Web Page]. URL http://www2.champaign.isa-arbor.com/JofA/abstracts/joamay00.html [2000,May].

- Created a GIS for Munich to assess open space and environmental effects of the urban forest
- Used environmental data and infrared photography to show that trees lower the air temperature on hot days
- Resulted in proposal to add new forest areas and expand existing ones

Easa, Said, & Chan, Yupo (2000). Urban Planning and Development Applications of GIS. Reston, Virginia: American Society of Civil Engineers.

- The authors reviewed and summarized articles regarding GIS. They included a ctual and proposed implementation plans in the review.
- Conclusions included the need for spatial -relational databases for optimal use of GIS data. Also concluded was the validity of GIS as a tool for urban planning and environmental development.
- This book covers the major topics regarding the background and implementation of Geographic Information Systems (GIS). Topics include: spatial data and data structures, georeferencing systems,

remote sensing, regional planning, and implementation. Spatial data st ructures for databases are analyzed and critiqued; SQL and Oracle are evaluated as storage options. Georeferencing is clarified and defined as GPS calculations based on Earth's ellipsoid shape. Remote sensing based on satellite imagery is shown as a tool for regional planning. It is concluded with implementation plans and prospective uses.

- This source is used to develop the background of technological aspects relative to both the field and the project deliverables. It is also a resource for evaluation o f data storage techniques.

Hall, L. (1995). Olmsted's America: An "Unpractical" Man and His Vision of Civilization. Boston: Bulfinch Press.

- The longevity of Olmsted's work through adversity
- History of Olmsted's Life

Grey, Gene W. (1993). A Handbook for Tree Board Members. Nebraska City: The National Arbor Day Foundation.

- Educational source for urban forestry planning and maintenance, legal authority for tree boards, and tree board management

Korbitz, William E., (1976). Urban Public Works Administration. Washington D.C.: International City Management Association.

- This book is about general administration of urban Public Works departments. The topics covered include computer applications in public works and the social implications of the Public Works.
- This source is a manual directed at Public Works Administrators. It is presented in textbook format covering a multitude of topics
- The book concludes that through careful Public Works Administration, the quality of urban life can be raised significantly. It further concludes that there are several topics and clearly delineated steps that can be followed to achieve this goal.
- This source will be used as a background on the Public Works department. It will also serve to provide information on both the social impacts of urban ecology, as well as a history of computer applications used in the field

Summit, Joshua, & Sommer, Robert (1997). Urban Tree -Planting Programs – A Model for Encouraging Environmentally Protective Behavior. Landscape and Urban Planning, October.

- This article discusses public awareness about the benefits of urban tree planting. It discusses the effect of public awareness on the public action level that is exerted toward a cause. It identifies behavioral interventions that will increase awareness as well as the benefits of urban tree planting.
- The article is a journal article att empting to link the concerted effort of individuals to public awareness. It contends that increased awareness through behavioral interventions will lead to increased momentum in the urban tree -planting cause.
- The article concludes that increased awareness of the benefits of trees or any other environmental cause will lead to increased public response.
- This source will be used as a background for the benefits of urban tree planting, as well as an implementation plan reference.

Zaitzevsky, C. (1982). Frederick Law Olmsted and the Boston Park System. Cambridge: The Belknap Press of Harvard University Press.

- Topographical history of Boston
- History of park system
- Olmsted's contribution to Boston Park System
- Olmsted's definition of a park

Microsoft Encarta Online. (2001). Ecology. [Online]. URL: http://encarta.msn.com/find/Concise.asp?z=1&pg=2&ti=761576703 [2001, Feb. 2].

Naveh, Z. (2000, April). The Total Human Ecosystem: Integrat ing Ecology and Economics. BioScience. [Online]. URL: http://www.findarticles.com/cf_0/m1042/4_50/61557027/print.jhtml [2001, Feb. 2].

- This article provides a general unders tanding of how urban ecology has grown into a wider field.
- The author looks closely at the trend of transdsciplinarity necessary in the practice of sustainability.
- The conclusion of this article was that many fields of expertise are intertwined to make th e human ecosystem work.
- This source will be used to show the justification of our project in the background and to show that we must use knowledge from all of our collective fields to succeed.

The Massachusetts Constitution: A Citizen's Edition (1975) Mar iner Books, Arlington Heights, MA

- This source provides us with the entire Massachusetts Constitution.

Appendix B: List of Street Trees in Cambridge

COMMON NAMES OF TREES	NUMBER OF TREES	PERCENTAGE OF TREES
American Sycamore	194	1.7
Amur Corktree	59	0.5
Ash, Green	567	5.1
Ash, Other	1	0
Black Locust	4	0
Buckeye, Ohio	4	0
Catalpa, Northern	1	0
Cherry, Kwanzan	34	0.3
Chestnut, American	2	0
Crabapple	10	0.1
Crimean Linden	6	0.1
Elm, American	188	1.7
Elm, Chinese	5	0
Elm, Other	5	0
Elm, Siberian	3	0
Ginkgo	119	1.1
Hawthorn, Washington	16	0.1
Honeylocust	938	8.4
Horsechestnut	8	0.1
Japanese Pagoda Tree	148	1.3
Japanese Tree Lilac	5	0
Kentucky Coffeetree	5	0
Linden, American	2	0
Linden, Bigleaf	4	0
Linden, Little Leaf	935	8.4
Linden, Other	68	0.6
Linden, Silver	112	1
London Plane Tree	85	0.8

Magnolia, Saucer	1	0
Maple, Amur	4	0
Maple, Hedge	123	1.1
Maple, Japanese	1	0
Maple, Norway	3330	30
Maple, Norway	166	1.5
Maple, Norway-Cr	9	0.1
Maple, Other	2	0
Maple, Red	976	8.8
Maple, Silver	19	0.2
Maple, Sugar	304	2.7
Maple, Sugar-Columnar	25	0.2
Oak, Northern Red	171	1.5
Oak, Pin	615	5.5
Oak, Scarlet	2	0
Oak, Water	3	0
Oak, White	2	0
Other Species	164	1.5
Pear, Callery	730	6.6
Planting Site Large	60	0.5
Planting Site Medium	312	2.8
Planting Site Small	206	1.9
Serviceberry, Other	8	0.1
Stump	158	1.4
Sweetgum	14	0.1
Tulip Tree	1	0
Zelkova	184	1.7
Total	11118	100

Source: ***Cambridge Tree Project***

Appendix C: List of Public Parks in Cambridge

PARK ID	PARK NAME	LOCATION	MAP LOCATION	USE
1	Agassiz School/Alden Park	Oxford St.	3B	Playground
2	Alberico Park	Pleasant St.	4D	Basketball, Playground
3	Alewife Brook Reservation (MDC)	Acorn Park	1B	Open Space
4	Bergin Park	Haskell St.	2B	Playground, Passive Use
5	Bishop Allen Plaza	Bishop Allen Drive	5C	Passive Park
6	Cambridge Common	Garden St.	3B-3C	Playground, Soccer,Softball, Passive Use
7	Cambridge Rindge & Latin High School/War Memorial Pool/Mid-Cambridge Library Park/Joan Lorenz Park	Broadway	4B	Indoor,Center, Playground, Swimming, Tennis, Passive Use
8	Charles Park	Rogers St.	6B	Passive Use
9	Centanni Way	Otis St.	6B	Passive Use
10	Clarendon Ave. Playground	Clarendon Ave.	2A	Playground, Passive Use
11	Columbia Street Park	Columbia St.	5C	Basketball, Playground
12	Comeau Field	Rindge Street	2B	Little League Baseball
13	Cooper Park	Hancock St.	4C	Playground, Water Play
14	Corcoran Field	Upland Rd.	2B	Basketball, Playground, Softball

15	Corporal Burns Park	Flagg St.	4C	Basketball, Playground, Street Hockey, Water Play, Passive Use
16	Costa Lopez/Taylor Park	Third St.	6B	Basketball, Playground, Passive Use
17	Dana Park	Magazine St.	4C-5C	Basketball, Playground, Totlot, Passive Use
18	Danehy Park	Garden St.	2B	Exercise Circuit, Softball, Soccer, Playground, Picnic Area, Passive Use, Water Play
19	Elm/ Hampshire Plaza	Hampshire St.	5B	Passive Use
20	Flagstaff Park	Massachusetts Ave.	3C	Passive Use
21	Fletcher School	Elm St.	5B	Basketball, Playground, Totlot
22	Fort Washington Park	Waverly St.	5D	Passive Use
23	Franklin Street Park	Franklin St.	4C	Passive Use
24	Fresh Pond Municipal Golf Course (Fresh Pond Reservation)	Huron Ave.	1C	Golf
25	Front Park	Cambridge Parkway	6B	Passive Use
26	Fulmore Park	Putnam Ave.	5D	Playground, Passive Use
27	Gannett/ Warren Pals Park	Marion St.	5B	Playground, Water Play
28	John C. Gibbons Park	Seagrave Rd.	1A	Playground, Passive Use

29	Glacken Field (Fresh Pond Reservation)	Huron Ave.	1C	Basketball, Playground, Soccer, Softball, Tennis, Passive Use
30	Gold Star Mothers Pool	Berkshire St.	5B	Swimming
31	Gold Star Mothers/ Gore Street Park	Gore St.	5A	Basketball, Playground, Softball, Water Play
32	Gore Street Skating Rink (MDC)	Gore St.	5A	Skating Rink
33	Harrington School/ Donnelly Field/ Frisoli Youth Center	Cambridge St.	5B	Little League Baseball, Basketball, Indoor Center, Playground, Softball
34	Haggerty School	Cushing Street	2D	School, Playground
35	Harvard Street Park	Harvard St.	5B	Community Garden, Playground, Tennis, Passive Use
36	Hastings Square	Brookline St.	5D	Passive Use
37	Hoyt Field/ Moore Youth Center	Montague St.	4C	Basketball, Playground, Softball, Tennis, Playground, Totlot, Water Play
38	Hurley Street VFW Park	Hurley St.	5B-6B	Playground, Water Play
39	JFK Memorial Park (MDC)	Memorial Drive	3C	Passive Use
40	Kennedy School/ J.J. Ahern Field	Charles St.	5B	Basketball, Indoor Center,

				Playground, Running Track, Softball, Soccer, Street Hockey, Water Play
41	King School	Putnam Ave.	4C	Basketball, Indoor Center, Playground, Totlot
42	Kingsley Park (Fresh Pond Reservation)	Fresh Pond Parkway	2C	Biking Paths, Jogging Paths, Passive Use
43	Larch Road Park	Larch Rd	2C	Basketball, Playground
44	Lechmere Canal Park	Otis St.	6A	Playground, Passive Use
45	Linear Park	Harvey St.	2A	Biking , Jogging, Passive Use
46	Longfellow Park	Mount Auburn St.	3C	Passive Use
47	Longfellow School	Broadway	4B	Basketball, Playground
48	Lopez Street Park	Lopez St.	5C	Playground
49	Lowell Park (MDC)	Brattle St.	2C	Passive Use
50	Lowell School Playground	Mount Auburn St.	3C	Basketball, Playground
51	Lusitania Field - (Fresh Pond Reservation)	Concord Ave.	2B-2C	Passive Use
52	Magazine Beach (MDC)	Memorial Drive	4D	Biking, Canoe Ramp, Jogging, Soccer, Softball, Swimming, Passive Use, Water Play
53	Maple Avenue Park	Maple Ave.	4B	Playground

54	Market Street Park	Market St.	5B	Playground, Passive Use
55	McCrehan Pool (MDC)	Rindge Ave.	2B	Swimming
56	McMath Park	Pemberton St.	2B	Community Garden, Passive Use
57	Memorial Drive	Memorial Drive	3C	Playground
58	Morse School/ Lindstrom Field	Memorial Drive	5D	Little League Baseball, Basketball, Indoor Center, Playground
59	Mount Auburn Veterans Memorial Plaza	Huron Ave.	2C	Passive Use
60	David Nunes Park	Brookline St.	5D	Basketball, Street Hockey, Playground, Passive Use
61	Pacific Street Open Space	Pacific St.	5C	Soccer, Passive Use
62	Paine Park	St. Mary Rd.	4B	Basketball, Playground, Passive Use
63	Peabody School	Walker St.	3B	Basketball, Indoor Center, Playground
64	Pine Street Playground	Pine Street	5C	Water Play, Totlot
65	Rafferty Playground/Sancta Maria Field	Griswold St.	1B	Basketball, Playground, Softball, Tennis
66	Reverend Williams Playground	Cedar St.	2A	Basketball, Playground, Passive Use, Water Play

67	Rindge Field/ Fitzgerald School/ Gately Youth Center	Pemberton St.	2B	Baseball, Basketball, Indoor Center, Tennis
68	Riverside Press Park	River St.	4D	Basketball, Playground, Tennis, Passive Use, Water Play
69	Roethlisberger Memorial Park/ Garden Street Glen Park	Hazel St.	2B	Passive Use
70	Russell/Samp Field	Clifton St.	2A	Football, Little League Baseball, Soccer
71	Sacramento Field	Sacramento St.	3B	Basketball, Soccer, Softball
72	Sennott Park/ Area 4 Youth Center	Norfolk St.	5B	Indoor Center, Playground, Soccer, Softball, Basketball
73	Silva Park	Cambridge St.	5B	Playground, Passive Use
74	St. Peter's Field	Sherman St.	2B	Baseball, Basketball, Playground, Softball
75	Sullivan Park	Green St.	4C	Playground, Community Garden, Passive Use
76	Tobin School/ Fr. Callahan Playground	Concord St.	2B-2C	Little League Baseball, Indoor Center, Baseball, Playground
77	Vellucci Plaza	Cambridge St.	4B	Passive Use
78	Wilder/Lee Park	Lee St.	4B-4C	Playground,

				Passive Use
79	Winthrop Square	Winthrop St.	3C	Passive Use

Appendix D: Map of Cambridge – Parks annotated

(Attached)

Appendix F: Cambridge DPW Data Collection Form

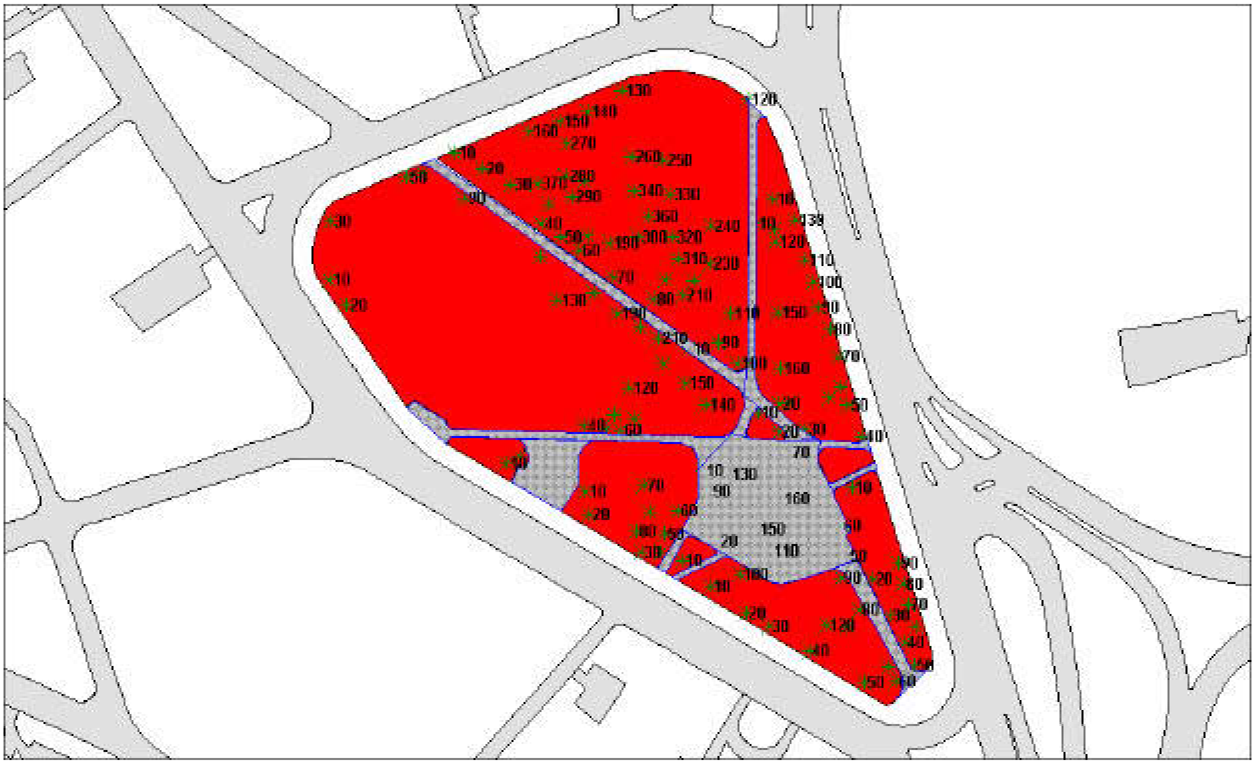
Appendix G: Cambridge DPW Tree Database in Hansen

Appendix H: Field Manual

Appendix I: Database Manual

Appendix J: Database of Trees Surveyed (April 4 – 25, 2001)

Appendix K: Maps of Trees in Cambridge Common - Surveyed (April 4 – 25, 2001)



Appendix L: Data Collection Form created by us

Appendix not included in original submission

IQP/MQP SCANNING PROJECT