A METHODOLOGY TO ASSESS AND INVENTORY URBAN FORESTS IN THE UNITED STATES

URI Working Paper #12

A Report to American Forests and the USDA Forest Service

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PREFACE

Much attention has been given over the last several decades to broad environmental issues:

- the poor air quality and water quality resulting from decades of intense, largely unregulated industrialization
- the loss of global rainforests due to large-scale clear cut and burn methods of deforestation and the subsequent impact on global warming
- environmental regulations imposed as a result of the establishment of EPA, and subsequent effects on development and utilization of natural resources

Whenever one thinks of forestry and the U.S. Forest Service, most would envision broad expanses of pristine wilderness in the northwest or Alaska, and the logging industry. Often forgotten is the fact that large expanses of forest have been destroyed since colonial times, especially in the eastern part of the country. Expanding development continues to nibble away at remaining forested areas to make room for an ever-expanding population. As remaining stands of trees continue to give way to new or expanded freeway systems, subdivisions, and commercial development, little concern has been given to the effect of this seemingly minor deforestation from an environmental perspective. Only recently have some states begun to establish planning policies that consider the effects of continued destruction of these forest resources.

not increasing!

American Forests, a non-profit organization in Washington, D.C., is dedicated to the preservation of our natural forest heritage. And, of significant concern is the recognition of the value of trees in an urban environment, the Urban Forest. Professionals may disagree on the definition of the term "Urban Forest". Some would argue that urban forests include street trees within downtown municipal environments while others would prefer defining an urban forest as significant expanses of relatively pristine old-growth stands in close proximity to the urban setting. But, few would disagree that yard trees, street trees, and urban parks are valuable assets for their aesthetic value, offering a cooling respite from harsh summer sun. In fact, the combined affect of these individual trees can:

- Reduce energy consumption within homes and buildings by providing shade in the summer and blocking cold winds in the winter
- Reduce the "heat island" effect of cities through natural shading of streets and other hard surfaces and through evapotranspiration
- Improve the quality of regional air through filtering and carbon sequestration
- Improve the quality of regional streams through filtering of runoff and reduction of water temperature from shading

One of the problems associated with attempting to get planners, politicians, and citizens interested in the concept of retaining and improving the state of the urban forest is the lack of tools available to quickly and quantifiably assess and monitor the state of the urban forest, and to project the economic, environmental, and social impacts of either allowing continued destruction of or aggressively promoting conservation and improvement of the existing urban forest asset. The last decade has seen tremendous advancements in a number of technologies that can assist in this regard. The emergence and growth of the micro or personal computer industry has made computer technology available to virtually everyone. The space industry and advances in sensor technology, along with development of tools to utilize data captured by spaceborn and airborne sensors, provide a means to repetitively capture and examine information that was virtually unattainable only three decades ago.

This study, funded by American Forests, demonstrates how microcomputer tools, developed over the last 20 years, can be utilized to assist in the evaluation, planning, and monitoring of our urban forests. The procedures outlined herein demonstrate the use of remote sensing, Geographical Information System (GIS), and urban forestry concepts for the purpose of quantifying environmental, economic, and social benefits to be derived from informed stewardship of our urban forest resources and resource potential. Any planner, developer, politician, or individual with access to commonly available personal computer technology, appropriate software, and available data can utilize this methodology to evaluate the existing urban forest and forest potential for either a large or small environment, and to predict the potential benefits of proper urban forest management.

Technology is ever-evolving, and an ultimate software package for use in the described methodology does not exist. Anyone with access to image processing, computer-aided drafting (CAD), database analysis, or GIS software will have some or all of the tools necessary to utilize the computer technology described herein in the urban forestry analysis process.

This report does not pretend to provide instruction in remote sensing or GIS functionality. Many texts are available for that purpose, and some recommended texts are referenced herein. Neither is this report intended to be an exhaustive analysis of the relative capabilities of competing software packages. The intent of this report is to provide the reader with sufficient review of the concepts of remote sensing and GIS to understand their applicability to the urban forest initiative, and to describe how the tools could be used to achieve urban forestry objectives.

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Chris Daniel

EXECUTIVE SUMMARY

American Forests, a non-profit organization dedicated to the preservation of our natural forest heritage, contracted Comp-Tron, Incorporated to develop a computerized tool or methodology to assess and inventory urban forests in the United States. Hence, the National Urban Forest Inventory and Assessment Computerized Methodology was developed to assist planners, foresters, and natural resource managers in evaluating and managing urban forests. The methodology utilizes data of various scales to examine the environmental, social, and economic impacts of urban forest areas. Geographic Information Systems (GIS), Computer Aided Drafting and Design Systems (CADD), database and word processing software, and image processing techniques were integrated and utilized to satisfy the requirements of the methodology. The methodology consists of five basic components:

A. Establish urban forest inventory and assessment objectives.
B. Identify data sources to satisfy objectives selected and collect the appropriate data.
C. Prepare and manipulate the data for computer analysis.
D. Refer to the objectives established earlier and analyze the prepared data sets.
E. Present the results of the analysis.

These components were addressed in order to create a computer-based natural resource information system data bases for selected study sites located in Baltimore, MD, South Miami, FL, and Frederick, MD. Regional and community urban forest inventory and assessment goals and objectives were established to address environmental, social, and economic issues concerning air and water quality, wildlife management, energy conservation, tree management, and urban temperature ("heat-island") reduction. Consequently, digital and hard-copy data sets including satellite imagery, aerial photographs, planimetric plans, topographic maps, and socio-economic databases of various scales and accuracy levels were identified, collected, and associated with field studies to satisfy the inventory objectives selected for each study site. Once collected, the data sets were prepared for computer analysis in a GIS, CADD, database, or image processing system. This phase of the methodology was the most time consuming and labor intensive of the methodology. The preparation phase involves scanning and conversion (digitizing), georeferencing, geo-rectification, database entry, and field study in order to build GIS data sets for analysis. Once prepared, the GIS data sets were used in the analysis to satisfy the inventory and assessment objectives selected during the initial phase of the methodology. Results of the analysis were recorded, printed, and presented to local policy-makers, planners, and foresters for their review.

Comp-Tron and the Yale School of Forestry and Environmental Studies worked together to develop and evaluate the methodology on a citywide, regional, and community level in Baltimore, MD. The methodology was applied to the entire city proper, the Gwynns Falls watershed, and the Sandtown - Winchester community. After completing the methodology, it was demonstrated that GIS/image processing systems allowed users to spatially relate socio-economic and environmental databases with digitized map features such as building structures, street trees, census tracts, or roads. This allowed foresters and planners to examine the urban forest in a different perspective. For instance, in Sandtown - Winchester, one can spatially view GIS graphic files illustrating existing tree and housing databases and examine relationships between home ownership and the health and overall condition of urban trees. In the Gwynns Falls study area, one can map and suggest potential reforestation and afforestation areas to

improve water quality and wildlife habitats. And, finally, on a citywide perspective, a user can map thermally conducive areas or "hot spots" in order to effectively determine planting strategies to decrease the urban "heat-island" effect.

The methodology will be used in performing urban forest damage assessment analysis in urban areas throughout the country. In the City of South Miami, satellite imagery and scanned aerial photos, both before and after Hurricane Andrew, will be examined and correlated with field studies, performed by the Dade County Department of Environmental Resource Management, in order to assess the damage done by the hurricane and to determine appropriate replanting strategies with respect to energy conservation (shading) and community involvement. Future study sites, located in Frederick, MD, will be used to determine the effectiveness of urban trees to reduce energy consumption levels per household. Energy consumption data from Potomac Edison, a local utility company, will be correlated with tree inventory information, building structure data files, and demographic databases in order to accomplish this bold task.

The National Inventory and Assessment Computerized Methodology provides a forester or planner with a means to quantifiably assess and manage urban forests. The method is a "cookbook" for successfully utilizing today's computer technology, especially GIS/image processing systems, to map, analyze, and present urban forest related information. The methodology does not exhaust all the sources of information or the techniques for integrating and analyzing data related to urban forestry. However, the methodology does provide a solid computer-based foundation from which to examine regional and community forestry issues throughout the United States.

SECTION A

THE BALTIMORE CITY CASE STUDY

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METHODOLOGY

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CHAPTER I: INTRODUCTION

A. Background

For the past three years, Yale University's School of Forestry & Environmental Studies' Urban Resources Initiative (URI) has worked with the City of Baltimore (Maryland) to develop an urban watershed and community forestry program that connects urban revitalization with environmental restoration. Local resources of the city include 6,500 acres of park land; 300,000 street trees; 85 miles of streams that flow directly into the Chesapeake Bay; 6,900 abandoned lots (city and privately owned); 276 neighborhoods; and 736,014 people. Other resources include 17,000 acres of city-owned watershed properties in surrounding Baltimore County. The region also experienced the highest rate of deforestation in the northeastern United States in the late 1970s and early 1980s due to metropolitan sprawl (180,000 acres over 10 years).

B. Introduction

The information needed for forestry activities depends on how the information will be used (policy, planning, management, or evaluation) and how it will be analyzed (on a national, state, regional, community, or household scale). This is significant, since foresters need different kinds of data and use different approaches to assess the reliability and validity of the data as they develop policy, strategies, and evaluations (Burch and Parker 1992).

In order to integrate many different sources of information, staff from URI have developed a Geographic Information System (GIS) with Baltimore City, federal, and state agencies, non-profit organizations and private businesses (Appendix A) that relates environmental and socioeconomic information (databases) to geographical points (houses, trees), lines (streets, streams), and boundaries (neighborhoods, forested areas). Map layers of landuse, vegetative cover, streams, watersheds, soils, roads, and census tracts can be overlaid to form a single, comprehensive map. Different layers, or coverages, can be selected and grouped together (Appendix B) to develop regional landuse plans, city forest inventories, and community resource maps.

In addition to its immediate applications for urban forest policy, planning and management, a GIS can facilitate several types of urban ecological research. This research is increasingly important as our society continues to urbanize and as we work to understand and to restore degraded lands in inner-city areas and to conserve forested and agricultural lands along the urban fringe. Specific types of ecological research include:

1) landscape ecology—relationships between spatial structure and material fluxes (e.g. water, carbon, and nutrients);
2) ecosystem ecology—explicit links between the biotic and abiotic environment;
3) community ecology—associations of populations and their environment; and
4) organismal ecology—relationships between individuals and their environment (Allen and Hoekstra 1992).

In all of these research types, studies may include plant, animal and/or human ecology.

In order to explore urban forest issues in terms of application and research, we examine a number of variables that are related to urban watershed and community forestry at three levels of analysis—citywide, watershed and community (Figure 1). We recognize that we have not exhausted the realm of possibilities for which a GIS urban forestry inventory can be developed or used. However, we have provided a set of examples from our forest inventory that illustrate the effectiveness of GIS to map and to analyze urban watershed and community forestry programs.

Figure 1. Satellite view of the City, Watershed and Community Sites—Baltimore City, the Gwynns Falls Watershed and the Sandtown-Winchester Community. (SPOT satellite imagery, 1992)

CHAPTER II: INVENTORY AND ANALYSIS

A. Citywide Inventory and Analysis: the City of Baltimore

A citywide forestry approach includes a number of objectives. For instance, an effort to improve stream water quality incorporates a citywide approach and is critical to regional resources, since nearly 30 percent of all non point source pollution comes from urbanized areas in the Chesapeake Bay watershed.

URI staff plan to develop a computer modeling project with the City of Baltimore, Maryland Department of the Environment, U.S. Geologic Survey, and U.S. Forest Service that will integrate a GIS with a hydrologic modeling program. This would enable state, county, and city foresters to estimate non point source pollution from urban areas and to model strategies for reducing water pollution flowing into the Chesapeake Bay. It requires extensive data on land use characteristics (Figure 2), contour delineations (Figure 3), precipitation records, and sediment loadings. However, data already organized for the Baltimore GIS project can also be formatted for the hydrologic model. For example, runoff curve numbers (to model sediment loading) can be calculated by applying an algorithm to data in existing GIS coverages. Additionally, many GIS systems have functions designed for hydrologic analysis. Thus, foresters and planners can create a predictive model for non point source pollution and identify areas of high sediment and nutrient loading in order to model alternative strategies before implementing forest projects (p. 66, Section B).

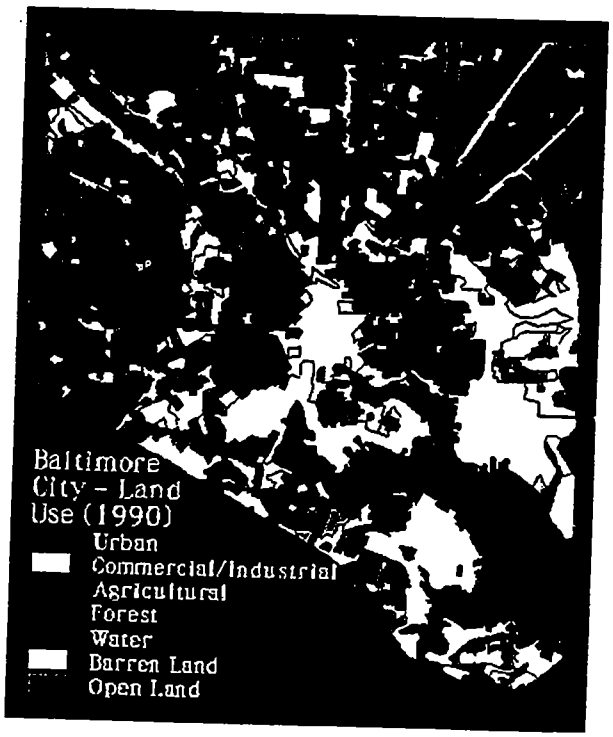

Figure 2. Baltimore City Landuse (1990) (source: MD Dept. of Planning).

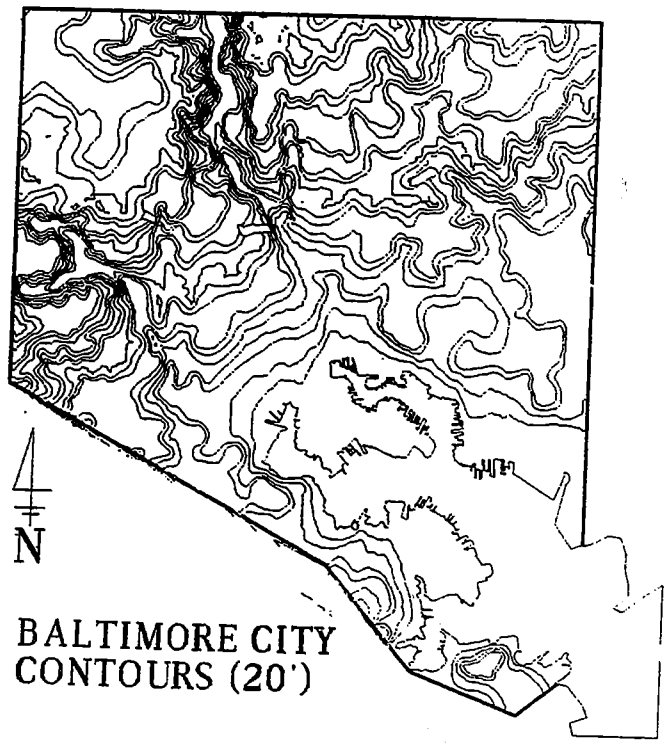

Figure 3. Baltimore City Contours (20') (source: USGS).

Forestry staff, Parks Bureau personnel and Maryland Save Our Streams staff can also use this type of information in community outreach programs to reduce litter and dumping, increase forest cover, and improve land management in order to reduce non point source pollution. These outreach programs involve communities in planning and evaluation, while increasing public awareness and appreciation of their relationship to the city's natural resources. By using the hydrologic model and GIS in outreach programs, citizens can see firsthand the effects of illegal dumping, trash accumulation, and stream pollution on the water quality of their streams and the Chesapeake Bay (Figure 4). Aerial maps with streams enable residents to see where they live and their connections to nearby streams and the Bay.

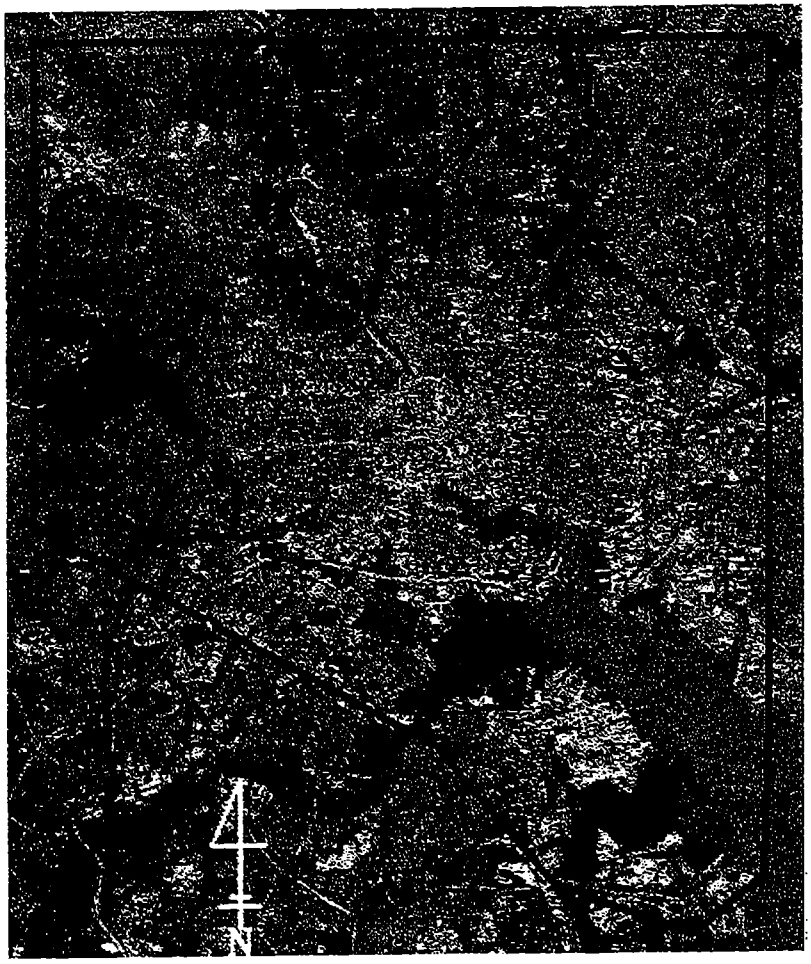

Figure 4. Satellite Image of Baltimore City with Streams. (source: SPOT Panchromatic Satellite Image, 10m resolution, 1992).

Other objectives for the Forestry Division staff include inventorying and assessing the role of the urban forest for storing and sequestering carbon, mitigating the effects of the urban heat island and measuring forest health and stress on a citywide basis. For instance, after completing both supervised and unsupervised satellite image landcover classifications and estimating the average street tree canopy diameter, Comp-Tron, Inc. determined that contiguous forested areas and street tree canopies cover approximately 21% of Baltimore City (Figure 5). This forest cover figure was combined with Rowntree and Nowak's equations to determine carbon sequestration and storage capacities for an average tree distribution. Based upon these equations, Comp-Tron, Inc. determined that Baltimore City's forests store nearly 515,000 tons of carbon and sequester carbon at a rate of 950 tons per year. The total fresh weight biomass of the predominantly hardwood forest is approximately 1,909,300 tons and the total dry weight biomass is approximately 1,143,300 tons (p. 57, Section B).

Other satellite information shows temperature variation (Figure 6) in the city (p. 69, Section B). This information can be overlaid with landuse data and city property records (city-owned vacant lots) to identify vacant areas that are suitable for afforestation or reforestation (p. 65, Section B). City planners and foresters can use this information to estimate the capacity as well as the costs and benefits of using the urban forest to reduce atmospheric carbon, to conserve energy, and to cool city areas. This information can be used as a component for developing urban forest policy, planning and management strategies that will reduce energy consumption and atmospheric carbon. For instance, if community groups and Forestry Division staff reforested all the abandoned lots that are shown in Figure 6, these areas could store an additional 43,530 tons of carbon (Table 1).

Table 1. Comparative Estimates of Approximate Carbon Storage and Sequestration Rates for Baltimore City's Urban Forest.

	Carbon Storage	Carbon Sequestration Rates
Pre-settlement (forested)	2,609,570 tons	4,540 tons/year
Current Conditions	515,000 tons	950 tons/year
Potential Reforestation	558,530 tons	1,000 tons/year

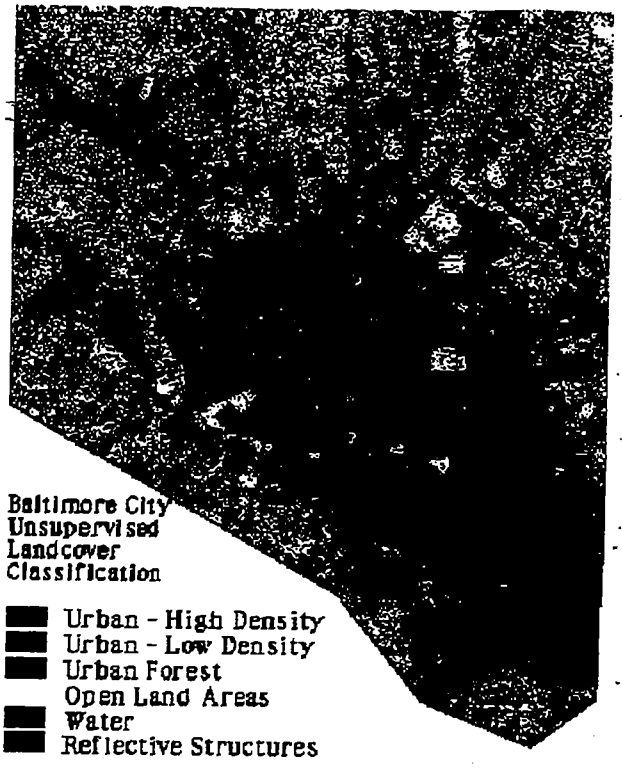

Figure 5. Unsupervised Satellite Classification of Carbon Storage in the City (derived from SPOT satellite data, May 1992).

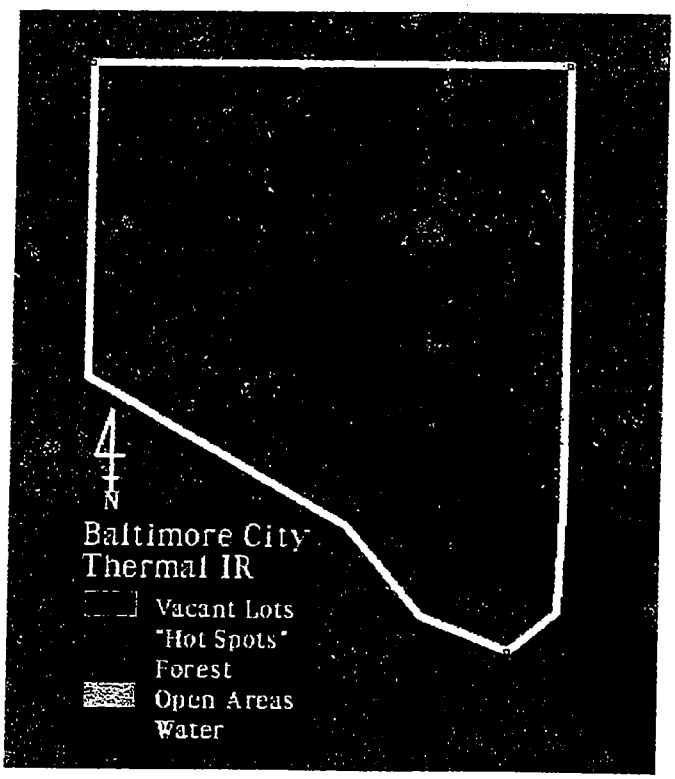

Figure 6. Heat Island Effects in the City and Location of Abandoned Lots. (Derived from Landsat Imagery and Baltimore's Department of Housing and Community Development, 1993).

In order to develop forest management plans, foresters can use satellite information to measure forest health and to identify areas of forest stress (Figure 7) (pp. 64 and 68, Section B). These data can be used with a citywide street tree and forest inventory of species diversity, distribution, age, health, and growth rates (p. 73, Section B) for more detailed information. In this case, the existing tree inventory database is "address matched" and combined with the GIS to develop work plans, to identify problems, and to recognize trends by area and by species. In addition to organizing the data according to spatial variables, the GIS reduces the amount of time needed for updates, map production, and information storage on a citywide basis. Further, the inventory and the GIS enable the city arborist to estimate the costs of different levels of forest/tree care while demonstrating the monetary and non-monetary benefits of Forestry Division activities (Calvin, J., 1993).

Satellite data on forest cover can be integrated with socioeconomic information as well in order to assess a number of different relationships (pp. 70 and 77, Section B). In particular, foresters can work with city planners to measure the relationship between forest cover and home ownership patterns (value, owner/renter/vacancy, residence time, neighborhood stability, etc.) in order to develop strategies to attract individuals and households to move back to the city (Figure 8).

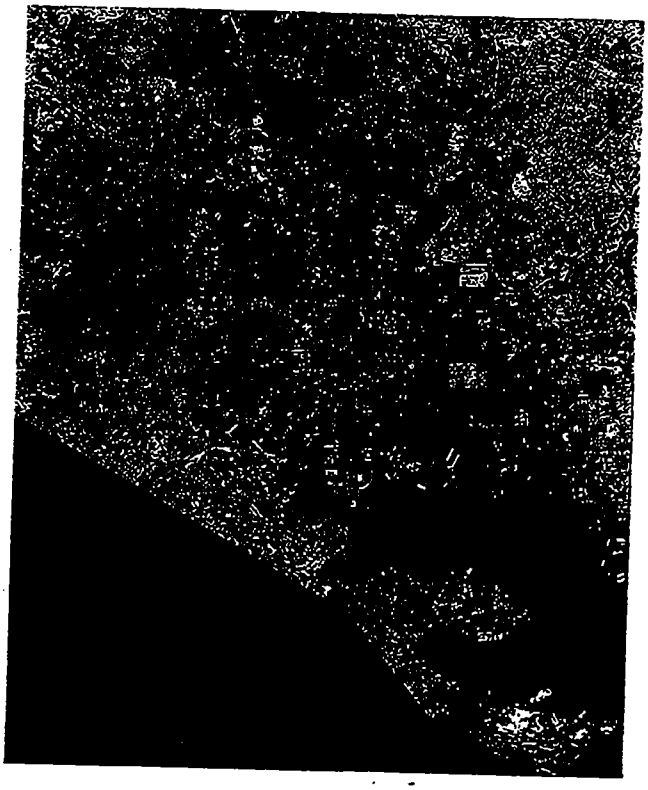

Figure 7. Forest Health Index for Baltimore City (source: SPOT multispectral color infrared, May, 1992).

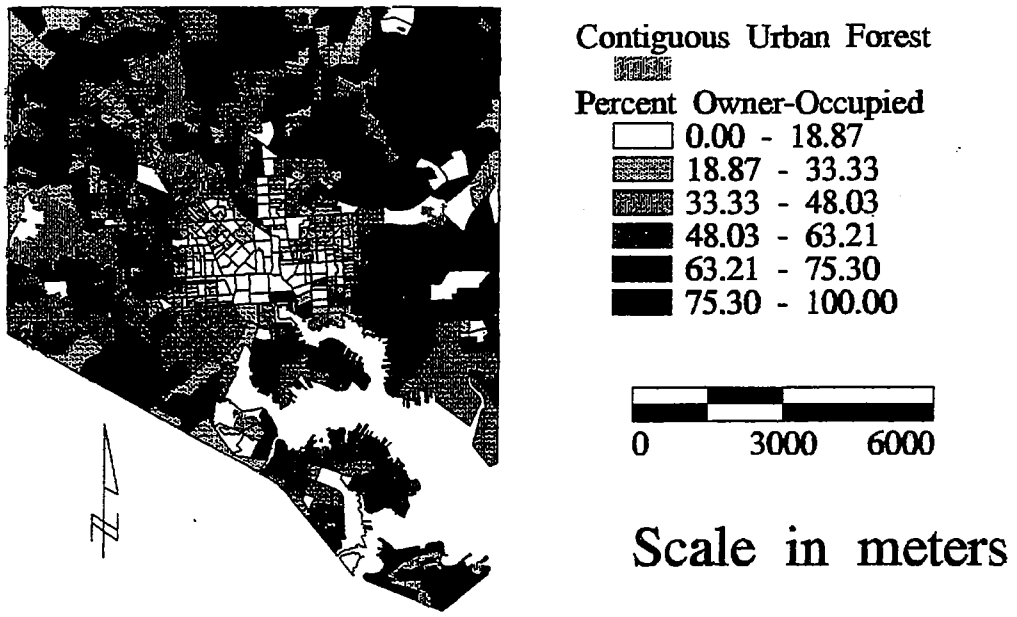

Figure 8. Distribution of Owner-occupied Homes and Forest Cover for Baltimore City (sources: Baltimore City Department of Housing and Community Development; 1993 and SPOT satellite imagery; 1992)

Histogram of Percent Owner-Occupied Households by Census Block Group in Baltimore, 1990 Census.

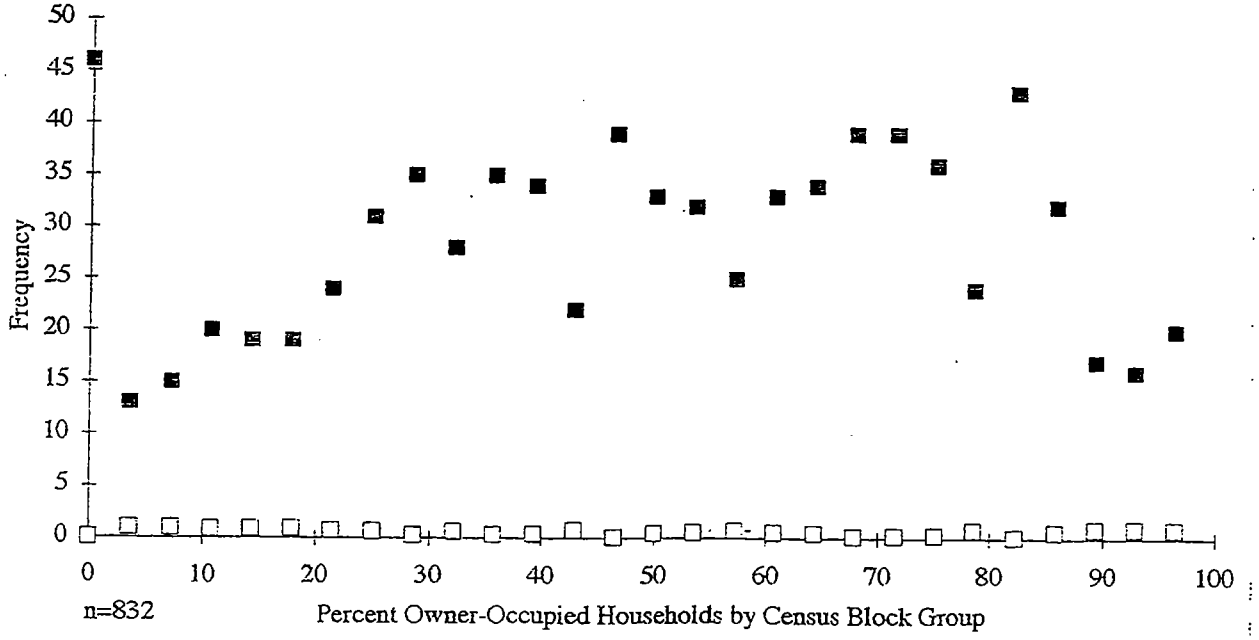

Figure 9. Histogram of Percent Owner-occupied Households by Block Group in Baltimore City, 1990 Census.

B. Watershed Inventory and Analysis: the Gwynns Falls Watershed

URI's foresters work with city and state agencies on programs to manage stream conservation areas and greenway corridors through the city's three stream valleys. For instance, the Gwynns Falls Greenway project uses information from satellite and aerial photographs to delineate vegetation and forest cover. Data on forest structure, diversity and size can be used (p. 68, Section B) to identify potential habitat areas for bird species threatened by forest fragmentation (Figure 10). City planners and foresters combine this information with land use coverages (park areas and conservation easements on commercial, industrial, and institutional properties) to locate potential reforestation areas (Figure 11). Once city planners and foresters have identified these sites, they can use additional information such as soils and contour map layers to select appropriate tree species for these sites (Figure 12).

Forestry staff also overlay coverages of streets, schools, and community demographics (median income, percentage vacancy, percentage single parents, etc.) to develop park programs for local and regional users of the Gwynns Falls Greenway (Figure 13).

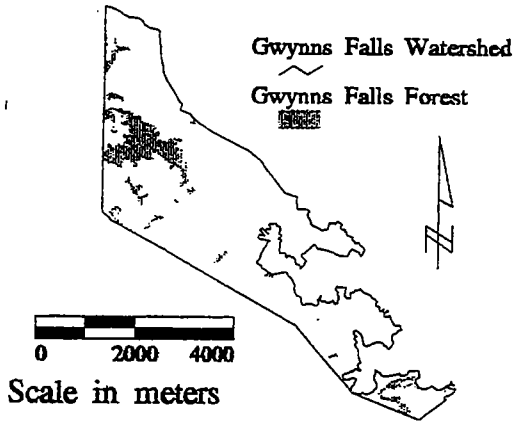

Figure 10. Gwynns Falls Forest Cover (source: MD Department of Planning, 1990)

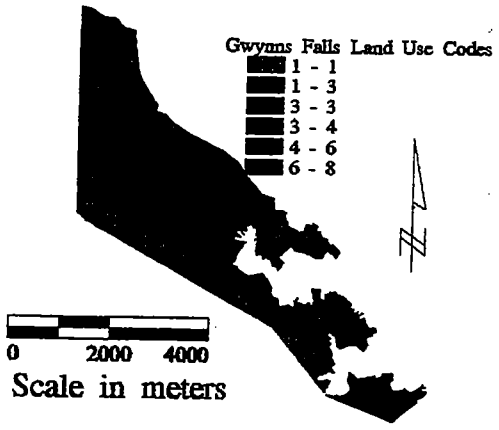

Figure 11. Landuse for the Gwynns Falls Watershed (source: MD Department of Planning, 1990).

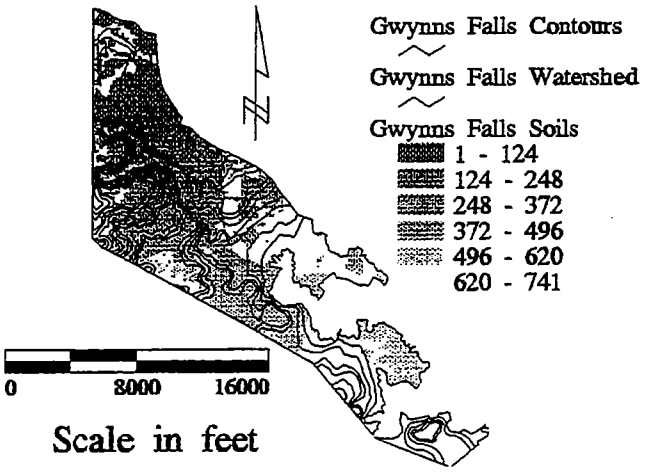

Figure 12. Soil and Contour Map of the Gwynns Falls Watershed (source: the Baltimore Council of Regional Governments, 1992)

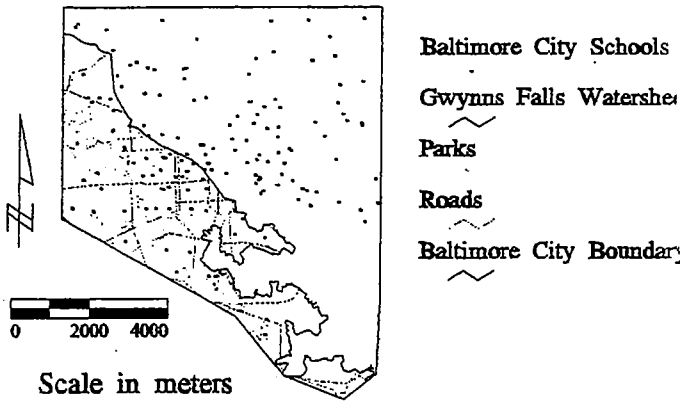

Figure 13. Schools, Parks, and Streets in the Gwynns Falls Watershed (source: the Baltimore Council of Regional Governments and the United Way of Central MD, 1992).

C. Community Inventory and Analysis: the Sandtown-Winchester Community

Community resource maps play an essential role in urban forestry projects. For example, staff from Baltimore's Forestry Division and URI work with local residents to identify potential planting areas, such as street tree pits, abandoned lots, derelict properties, and stream valley areas. Computer data files from the Department of Housing and Community Development (HCD) that identify these areas are linked with the GIS street coverage to locate each property by its street address. A GIS "address match" process creates a citywide abandoned lot map (approximately 6,900 lots) in about 50 minutes. HCD files are updated monthly, and new maps can be made in much less time than it would take to redraw the maps by hand.

This process plays an essential role in the ability of Forestry Division staff to evaluate the effectiveness of community forestry programs and park management strategies by comparing areas with community participation in planning and management to areas without community participation. Based on initial measures of tree survival rates, replacement costs, and labor (breaking concrete for new tree pits, planting, and maintenance), community participation could save the Forestry Division approximately $43,000 for each 100 trees planted over a 10-year period. The Forestry Division plants nearly 2,900 trees per year, which represents a potential savings of $1,247,000 over a 10-year period.

Forestry staff can combine Forestry Division data on tree location, species, health, and empty pit location with HCD files to map potential planting sites, select tree species (p. 73, Section B), and identify appropriate areas for energy conservation (p. 75, Section B and Figure 14), as well as to monitor tree survival rates and tree health. Coverages of streams, parks, schools, and recreation centers also identify planting areas and potential participants. Once the community organizations or individuals within a community have selected its preferred sites, forestry staff can help disseminate information to the community by determining who owns the property, how the community may gain access to its use, and which forestry projects would be most appropriate (Figure 15).

In addition to using GIS to disseminate information, community members and forestry staff work together to collect information by identifying various environmental and sociocultural issues and then converting them into GIS coverages and maps. For example, they may identify where children like to play, where elderly people gather, and where problems exist with erosion or heavy traffic noise. These GIS maps, along with information from individual and group surveys, help forestry staff and local residents understand community needs and assess available resources.

Figure 14. Site Selection for Reforestation and Energy Conservation in the Sandtown-Winchester Community. (source: January, 1993 black and white aerial photograph Aerial Photographics Inc., Martinsburg, WV)

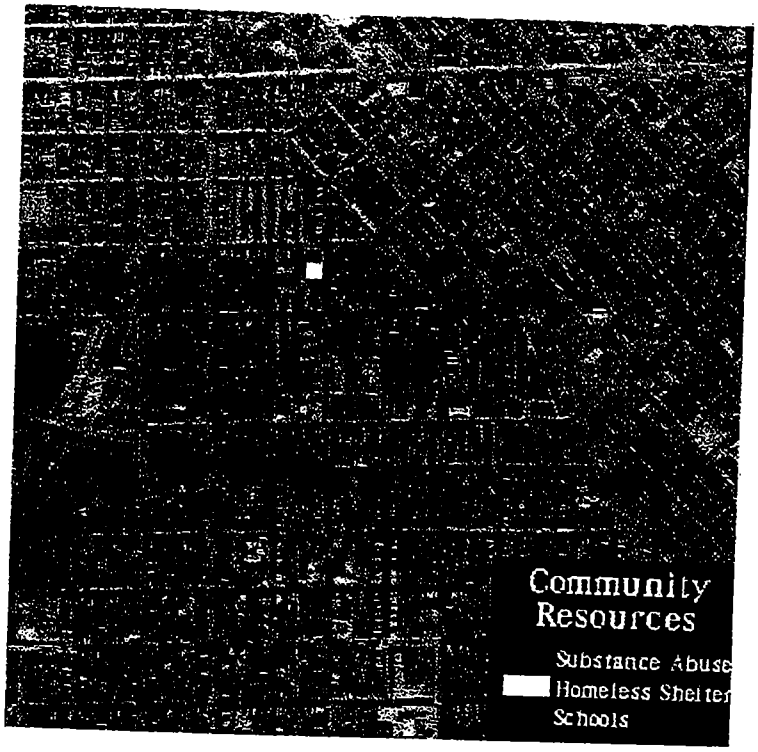

Figure 15. Aerial Map of Community Resources in Sandtown-Winchester 1993 black and white aerial photograph provided by Aerial Photographics Inc., Martinsburg, WV).

The Department of Recreation and Parks uses a laptop computer with its GIS in community meetings to involve local residents in decision making and planning activities. This is an essential element of community forestry, since it helps community members participate effectively in the governmental processes affecting their neighborhoods. Thereafter, forestry staff tailor forestry projects to specific neighborhoods as community members assess the potential success or limitations of a project. If community members and forestry staff realize that they do not have enough information for the project, strategies are developed jointly to gather more information from state or city agencies or through neighborhood surveys. Using GIS maps to analyze different types of information and to present ideas provides a powerful means for community members to re-envision their community, to improve data accuracy, and to evaluate forestry projects.

Community leaders see forestry activities as an important element of neighborhood revitalization and increased home ownership (p.77, Section B). GIS can be used to test this hypothesis. For instance, in a community near Sandtown-Winchester (Greenmount), residents observed that people began to move back into the community after some neighbors began a tree nursery in an inner block area. Community forestry staff can test this hypothesis by using HCD files to track changes in home ownership in both the Greenmount and Sandtown-Winchester area. The forestry staff can also use a GIS to compare Sandtown-Winchester to similar neighborhoods without

community forestry projects and examine whether home ownership patterns have changed.

The Forestry Division can also use the HCD files to identify neighborhoods that have a high percentage of rental units and where tree survival is low, street trash is common, and the community is economically depressed. The Forestry Division could approach these neighborhoods and their neighborhood associations to discuss opportunities for using forestry projects to stabilize and revitalize neighborhoods (Figure 16).

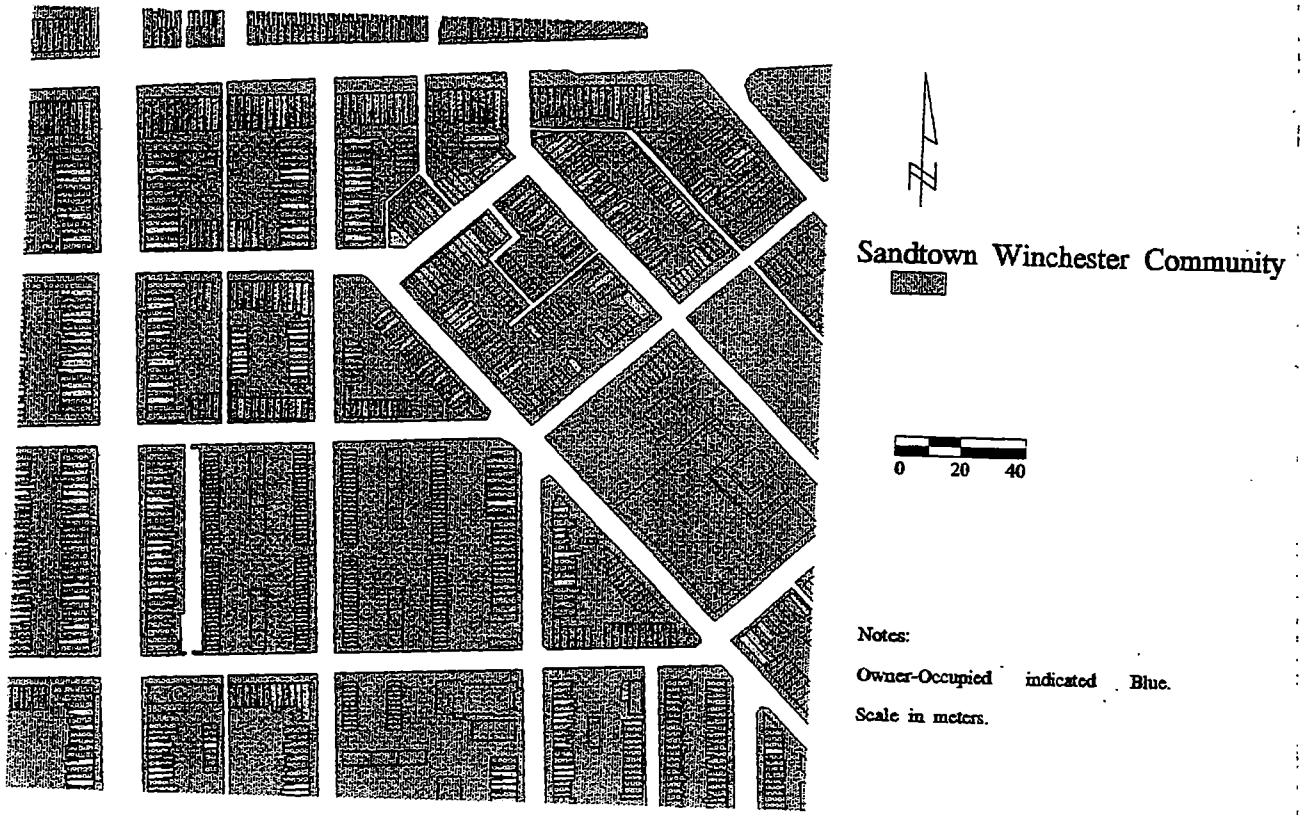

Figure 16. Homeownership in a Neighborhood Area of the Sandtown-Winchester Community. (source: Enterprise Foundation, 1993).

CHAPTER III: CONCLUSION

Geographic information systems help foresters to meet the challenge of integrating environmental and sociocultural information in order to identify complex interactions between people and their environment. This approach increases a forester's effectiveness in examining the inputs and outputs of a system and in identifying the patterns and processes within the system (Bormann and Likens 1979). This type of system analysis will help foresters convert well-meaning goals into substantive benefits. A GIS enables foresters to realize both what they do know and what they do not know, and thus improve their management strategies.

At the same time, this information must be constantly refined to develop successful strategies for urban revitalization and environmental restoration. Although a GIS is an excellent tool, information always needs to be updated and new data to be added. New management strategies will require different sets of information. And inevitably, policy makers will ask for a piece of information that is not in the GIS system. Foresters should remember that a GIS is only a tool, a means by which to solve problems. It presents the danger of too much information. Common sense must be used to determine when a GIS has become an all-consuming goal rather than a tool.

Ultimately, a GIS challenges forestry professionals to move beyond a traditional conception of an urban watershed or community forester to the concept of a community resource professional, working to reintegrate people and the non-human environment.

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APPENDICES

Appendix A: List of Cooperators

Federal
USDI Geologic Survey (USGS)
USDA Forest Service

State
Maryland Department of Natural Resources
- -Forest Service
- -Greenways
- -Planning

City
Department of Planning
Department of Public Works
- -Stormwater Management

Department of Recreation and Parks
- -Bureau of Parks
- -Division of Forestry
- -Division of Capital Improvements and Planning

Non Profits
Parks & People Foundation
Maryland Save Our Streams
Enterprise Foundation

Private Businesses
Comp-Tron, Inc.
Daft-McCune-Walker
Environmental Systems Research Institute (ESRI)

Individuals
Don McCluskey
Sarah Buikema

Appendix B: Type and List of Coverages

A. Satellite Imagery

SPOT Panchromatic Satellite Image
LANDSAT Satellite Image
Supervised Landcover Classification
Unsupervised Landcover Classification

B. Aerial Photography

C. Ground Survey

BAFOREST	Forested areas in Baltimore County
BALU	Landuse in Baltimore County
BCFOREST	Forested areas in Baltimore City
BCLU	Landuse in Baltimore City
BG90	Block group tracts and block group data (3a)
BOUNDARY	City boundary
CENTRACTS	Census tracts and census tract data (1a)
CIRCLES1	1 mile radius around recreation centers
CIRCLES2	1/2 mile radius around recreation centers
CONTOURS	Topographical contours (20')
COUNCIL	Council districts 1990 census
GUNSHED	Gunpowder watershed boundaries and streams
ISTAT	Interstates
LANDCLAS	Vegetative cover and impervious surfaces
LANDZON	Land zoning
NHOODS	City neighborhoods
PARKDIST	Park districts
PARKS	Parks over 5 acres
PATSHED	Patapsco watershed boundaries and streams
RAILROAD	Rail lines
REC2	Recreation centers
RECDIST	Recreation districts
ROADS	Baltimore City roads
SOILS	1991 Soil Conservation Service class.
STREAMS	Primary, secondary, tertiary streams
SUBSHEDS	Baltimore city sub-watersheds
TRAILS	Trails
WATER	Reservoirs and bays
WATERFRO	Waterfront boundary
WATERSHD	Major stream watersheds

Appendix B: Type and List of Coverages (continued)

D. Digital Data

VACLOTS Vacant lots owned by Baltimore City
VACHOUSE Vacant houses

Appendix C: List of Figures

Figure 1. Satellite view of the City, Watershed and Community Sites—Baltimore City, the Gwynns Falls Watershed and the Sandtown-Winchester Community. (source: SPOT satellite and Baltimore Council of Regional Governments).

Figure 2. Baltimore City Landuse (1990). (source: MD. Dept. of Planning)

Figure 3. Baltimore City Contours (20'). (source: USGS)

Figure 4. Satellite Image of Baltimore City with Streams. (source: SPOT Panchromatic Satellite Image, 10m resolution, May, 1992).

Figure 5. Unsupervised Satellite Classification of Carbon Storage in the City (source: SPOT satellite data, May, 1992).

Figure 6. Heat Island Effects in the City and Location of Abandoned Lots. (source: Landsat satellite imagery, 1993, and Baltimore City Department of Housing and Community Development, 1993).

Figure 7. Forest Health Index for Baltimore City. (source: SPOT multispectral color infrared, May, 1992).

Figure 8. Distribution of Owner-occupied homes and Forest Cover for Baltimore City. (sources: Baltimore City Department of Housing and Community Development; 1993 and SPOT data, May, 1992).

Figure 9. Histogram of Percent Owner-occupied Households by Block Group in Baltimore City, 1990 Census.

Figure 10. Forest Cover for the Gwynns Falls Watershed. (source: Baltimore Council of Regional Governments, 1992).

Figure 11. Landuse for the Gwynns Falls Watershed. (source: Baltimore Council of Regional Governments, 1992).

Figure 12. Soil and Contours Map of the Gwynns Falls Watershed (source: Baltimore Council of Regional Governments, 1992).

Figure 13. Schools, Parks and Streets in Gwynns Falls Watershed (source: Baltimore City Council of Regional Governments and the United Way of Central Maryland, 1992).

Appendix C - List of Figures (continued)

Figure 14. Site Selection for Reforestation and Energy Conservation in the Sandtown-Winchester Community. (source: 1993 black and white aerial photograph obtained from Aerial Photographics, Inc.).

Figure 15. Aerial Map of Community Resources in Sandtown-Winchester. (source: 1993 black and white aerial photograph obtained from Aerial Photographics, Inc.).

Figure 16. Homeownership in a Neighborhood Area of the Sandtown-Winchester Community. (source: Enterprise Foundation, 1993 digitized vectors).

CHAPTER I: INTRODUCTION

The National Urban Forest Inventory and Assessment Computerized Methodology was developed to assist urban planners, natural resource managers, and urban foresters in understanding and improving the role of the urban forest in achieving broad environmental, economic, and social objectives in our urban environment. Urban forests are an important natural resource which reduce soil erosion and runoff velocities, improve water quality and wildlife habitats, store and sequester carbon from the atmosphere, and reduce temperature and energy consumption levels. The inventory method presented herein will allow local, regional, and national planners, natural resource managers, and foresters to quantifiably assess the existing condition of urban forests and to evaluate potential areas for reforestation, afforestation, or management. Using PC-based technology, carbon storage and sequestration averages, biomass assessments, energy conservation measurements, tree maintenance problem areas, and planting opportunities can be assessed and mapped by a planner or forester on a citywide basis.

Geographic Information Systems (GIS) and Computer-Aided Drafting and Design (CADD) software can be used to implement the methodology on a personal computer or UNIX workstation platforms. GIS packages such as Microimage's Map and Image Processing System (MIPS) and Environmental Systems Research Institute's ARC INFO, ARC CAD, and ARC VIEW, were used in the case studies to perform image and vector processing, while the CADD systems, such as AutoCAD 12, were used to digitize map features. In addition, desktop packages such as DBase 4.0, EXCEL, and Word Perfect 5.1 were utilized in conjunction with the GIS software to integrate databases with geographic points or areas. These software packages were used during the evaluation process, the methodology can be applied with a variety of image processing, GIS, CADD, or desktop publishing systems. During the last year, the methodology was applied to study areas in Baltimore City, MD and Dade County, FL.

In Baltimore, MD, Comp-Tron and the Yale School of Forestry and Environmental Studies worked together with the Department of Natural Resources and the Department of Public Works-Division of Forestry to evaluate the methodology's ability to assist local planners, environmental personnel, and community leaders in assessing and inventorying the economic, environmental, and social impacts of urban forests, ie. street trees, residential park areas, and forested areas, in Baltimore City. The methodology was applied to the entire city proper, the Gwynns Falls Watershed, and the densely urbanized Sandtown -Winchester neighborhood. After collecting, preparing, and analyzing satellite data, aerial photography, topographical information, planimetric maps, field studies, and demographic databases, the group estimated biomass levels, carbon storage, carbon particulates sequestered, determined potential reforestation sites, and identified trees contributing to water quality, wildlife, and energy conservation.

In Dade County, Comp-Tron and American Forests utilized the methodology as a tool to assess the severe tree damage wrought by Hurricane Andrew and to provide conceptual reforestation plans designed with an emphasis on energy conservation for study areas in South Miami and Florida City. Local authorities, including the Dade County Department of Environmental Resource Management, the U.S. Army Corps of Engineers, and the Federal Emergency Mapping Agency provided materials, databases, and maps for this study. As a result, computerized inventories and conceptual reforestation plans are now being implemented in Florida.

CHAPTER II: METHODS

The computerized methodology for assessing and inventorying urban forests is designed to provide urban planners, natural resource managers, and foresters with a tool to measure and evaluate urban forests in the United States. In terms of space, time, and quantity, this methodology consisted of five phases or stages:

A. Establish urban forest inventory objectives and determine policy, planning, and management strategies.
B. Identify and collect data.
C. Prepare data for computer analysis.
D. Analyze urban forestry data.
E. Present the results of the analysis.

These components are essential to building any geographic information system related database.

A. Establish Objectives

Establishing clear objectives (ie. How and by whom the database will be used in terms of policy, planning and management) prior to beginning a forest inventory is probably the most important step in the entire methodology. This component dictates what datasets are to be collected, prepared, analyzed, and presented. The computerized methodology is designed to address social, economic, and environmental issues concerning urban forests. For example, the inventory tool can be used to calculate environmentally sensitive data concerning fresh and dry weight biomass, carbon sequestration, carbon storage, wildlife, and water quality. In addition, demographic variables concerning census and housing data can also be incorporated in evaluating potential reforestation and afforestation areas as well as in allocating resources to proactively manage existing urban forests and in encouraging community participation and stability. Also, an urban forest's economic impacts upon energy consumption and property values can be estimated in order to provide planting incentives for homeowners. Consequently, it is imperative that one carefully plan or choose objectives prior to applying the assessment tool. Below is a table of examples of urban forest regional and community objectives. Table A, page 26, summarizes the regional and community urban forest objectives explored in this methodology.

<u>Regional Objectives</u>

Environmental

1. Assess how urban trees and forests reduce carbon dioxide amounts in the atmosphere by estimating carbon sequestration and storage levels utilizing satellite imagery and field inventory data.

2. Assess the health of the urban forest in order to examine tree maintenance effectiveness. Use satellite imagery, aerial photointerpretation, and field surveys to accomplish this objective.

3. Identify vacant areas suitable for reforestation or afforestation using housing databases.

4. Assess the effect of urban forests on wildlife by relating previously completed field studies with medium scale aerial photography in order to spatially determine migration patterns or habitats of species.

5. Examine the effect of urban forests upon water quality by associating previously completed field documents with medium scale aerial photography. A graphic representation of the water quality data can be digitized, attributed and associated to a data base for analysis. For example, water testing station locations could be associated with tree buffer zones encompassing sewers and non-tree buffered sewer zones to examine the effectiveness of forested stream buffers. Point and non-point pollution sources can also be examined during this process.

6. Landsat satellite data (25 meter spatial resolution) can be used to determine the effects of urban forests on the urban heat island effect. Data is collected, georeferenced, geocorrected, and classified to determine hot-spots. Hot areas are associated with treed areas by incorporating the forest coverage analysis or vector overlay completed earlier. Correlations can be identified and recorded.

Economic

1. Associate socioeconomic data with forest coverage vectors to determine the effect of urban forests and trees on land use, property values, and crime. Associate and address match housing and census databases with forest and street vector elements and display or query the results.

2. Briefly examine the costs and benefits of afforesting areas on citywide basis.

Social

1. Correlate the health and condition of trees with home ownership in order to examine management conditions. Correlate the results of the tree health assessment (Regional Objectives/Environmental/#2) and the census tract or block group data to examine trends, ie. "Do home owners take better care of their trees than do renters?"

2. Explore and suggest innovative maintenance or education programs in order to proactively improve the condition of our urban forests.

3. Examine the effects of landuse upon urban forests over time. Overlay vector data including urban forests and landuse over aerial photography or satellite data taken at different time intervals in order to perform change detection analysis. Satellite data acquired during different time periods can also be classified to determine landuse and land cover change over time.

Community Objectives

Environmental

1. Street tree inventories can be conducted by using large scale aerial photography and associated field studies to assess the health, species, and distribution of the trees of the urban forest community using GIS/image processing systems.

2. The same objectives examined in the regional analysis can be analyzed and calibrated in the community assessment as well. Please see Regional Objectives/Environmental for further information.

Economic

1. Identify energy conservation planting opportunities that can be used to reduce household energy consumption levels by planting trees in strategic locations adjacent to the house.

2. See the Regional Objectives/Economic section for additional information.

Social

1. Spatially correlate the community tree inventory data to determine costs and benefits of the community forest.

2. See the Regional Objectives\Social section for additional information.

Table A on the following page briefly summarizes the regional and community objectives.

TABLE A - OBJECTIVES SUMMARY

Critical Issues	Citywide, Regional, and Community Objectives
Environmental	Estimate carbon storage capacity and sequestration rates to determine the role of urban forests in reducing carbon amounts in the atmosphere. Assess the health and condition of the urban forest and evaluate tree management/maintenance. Identify landcover areas suitable for reforestation or afforestation. Assess urban forest wildlife for effective management. Examine the effects of urban forests upon water quality. Determine the effects of urban forests upon the urban heat-island effect.
Economic	Determine the effects of urban forests on land use, property values, crime, education, and urban revitalization. Identify potential energy conservation planting opportunities adjacent to residential, industrial, and commercial building structures to reduce energy consumption levels and, indirectly, carbon amounts into the air from the burning of fossil fuels. Examine the costs and benefits of urban forests.
Social	Spatially correlate the condition of the urban forest with socio-economic data from the Census Bureau or city housing agencies. Identify potential educational opportunities to promote and encourage citizen involvement in urban forest management. Examine the effects of land use upon urban forests over time.

Once the inventory objectives have been selected, the data necessary to satisfy these objectives can be identified and collected.

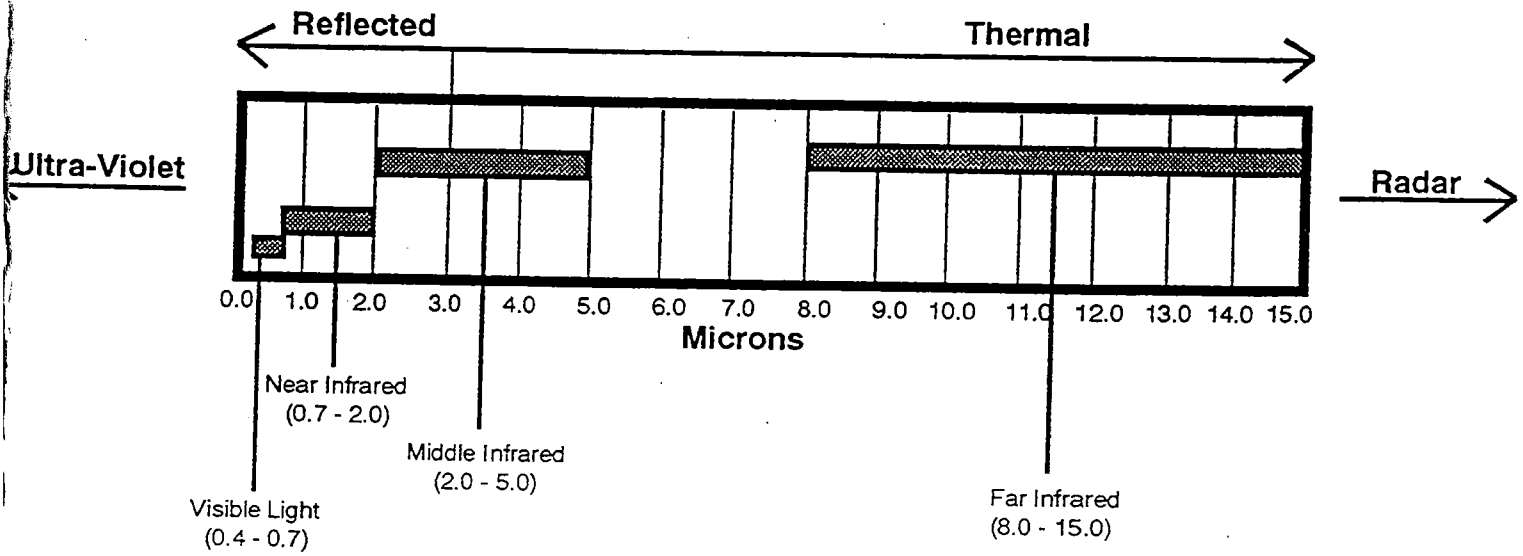
B. Identify Data Sources and Collect Data

The data collected is solely dependent upon the objective selected. In this section, a variety of forest inventory related data resources for obtaining satellite imagery, aerial photography, digitized map features, and database information is listed. This listing is by no means a complete listing of possible data sources, however, it does provide a solid foundation from which to begin research. These data resources can be used to evaluate individual forestry assessment and inventory objectives including biomass calculations, carbon storage and sequestration measurements, computerized tree inventories, energy conservation evaluations, water quality, and wildlife impacts.

Satellite Data

Imagery of the Earth's surface is acquired from remote sensing scanners aboard orbiting commercial and government satellites. Satellite sensors convert electromagnetic radiation energy into digital values. Electromagnetic radiation is energy that passes through space in the form of electric and magnetic waves. Sensors on the satellite are designed to interpret multispectral and panchromatic wavelengths of the electromagnetic spectrum. The electromagnetic spectrum depicts the range of electromagnetic radiation energy from ultra-violet waves to radio waves. Figure #1 illustrates the electromagnetic spectrum.

Figure #1: The Electromagnetic Spectrum.



The sun's electromagnetic energy advances through the atmosphere and reflects off land and water features located on the Earth's surface. Terrestrial features reflect different wavelengths or signatures of radiation that can be recognized by most remote scanning sensors. For example, a heavily forested area will reflect a different terrestrial wavelength signature than an impervious surface. Consequently, based on the knowledge of the study area and the interpretation of reflective wavelength signatures, one can distinguish features on the Earth such as forests, cropland, developed areas, geologic characteristics, etc.. In order to improve the accuracy of satellite interpretation or classification, a high or detailed resolution is necessary.

Resolution refers to the number of dots or pixel cells displayed on a monitor or the spatial area that a pixel or picture element represents on the Earth's surface. However, when referring to satellite imagery, resolution can be defined differently. Basically, satellite imagery resolution can be defined spectrally, spatially, temporally, and radiometrically.

Spectral resolution refers to unique wavelength variations in the electromagnetic spectrum that can be recorded in either broad or narrow band intervals. For example, a SPOT panchromatic sensor has a large or broad spectral resolution between .51 and .73 microns, while a single Landsat Thematic Mapper narrow band has a spectral resolution between .43 and .52 microns. The Landsat TM can therefore more precisely distinguish spectral data within a given band of the electromagnetic spectrum than can the SPOT satellite, and would therefore be a preferable source of multispectral data in that regard. The term spatial resolution refers to the area of the Earth's surface represented by a pixel cell. A spatial resolution of 10 meters provides greater detail than a resolution of 80 meters. Features on the Earth that are smaller than the spatial resolution of the imagery may be undetectable. However, if the feature contrasts sufficiently with background data, then it may still be noticeable. Moreover, the spatial resolution of a satellite image will remain consistent, even if the scale is altered. Temporal resolution refers to the time an image is acquired. Temporal resolution variances are necessary when implementing a change detection analysis. Radiometric resolution is the range of available values in each spectral band. For instance, 8-bit data has a radiometric resolution 256 possible data values (2 to the eighth power), while 7-bit data contains a resolution of 128 possible data values (2 to the seventh power), (ERDAS; 13-21).

In order to satisfy citywide urban forest inventory and assessment objectives using satellite imagery (i.e. estimating biomass and carbon storage/sequestration levels), a spatial resolution less than or equal to 30 meters per pixel cell is necessary. In addition, a narrow spectral resolution with several bands representing wavelengths of the electromagnetic spectrum ranging from visible light (.4 to .7 microns) to thermal and far infrared energy (.7 to 15.0) is preferable. This is commonly referred to as multispectral resolution. Also, an 8-bit radiometric resolution, displaying 256 possible data values and leaf-on or summer temporal resolution is preferred.

Generally, the Earth Observation Satellite Company's (EOSAT) Landsat Thematic Mapper or TM (30 meter spatial resolution) and the SPOT Corporation's SPOT panchromatic (10 meter) and multispectral (20 meter) data satisfy the resolution criteria necessary to complete urban forest inventory objectives (See Figures #2 & #3). Landsat TM and SPOT multispectral and panchromatic data can also be combined together, given that the two images have been resampled to the same pixel cell size, lines, and columns. This allows the operator to increase the accuracy and flexibility of their study by introducing more bands for analysis (Landsat has 7 bands) at a greater resolution (SPOT 20 meter or 10 meter spatial resolution). The National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite imagery (1.1 km per pixel) and EOSAT's Multispectral Scanner (MSS) imagery (80 km per pixel) have spatial resolutions that are too large to be used for urban forest inventory studies. However, EOSAT's MSS data may provide the accuracy required if a very large urban study area or macropolis is to be analyzed. A detailed list of multispectral and panchromatic satellite data sources are listed in APPENDIX A.

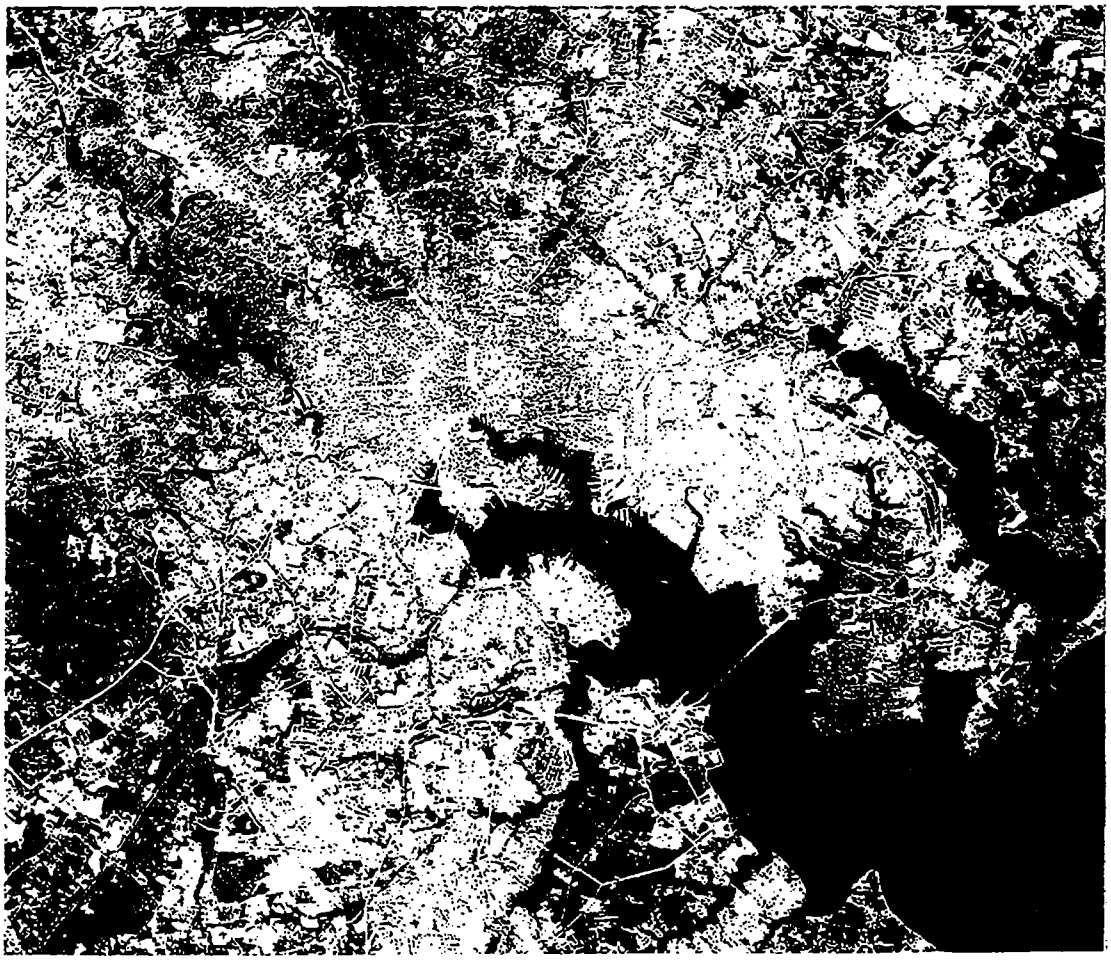


Figure #2: Landsat Image of the Baltimore City Metropolitan area (EOSAT, 1992).

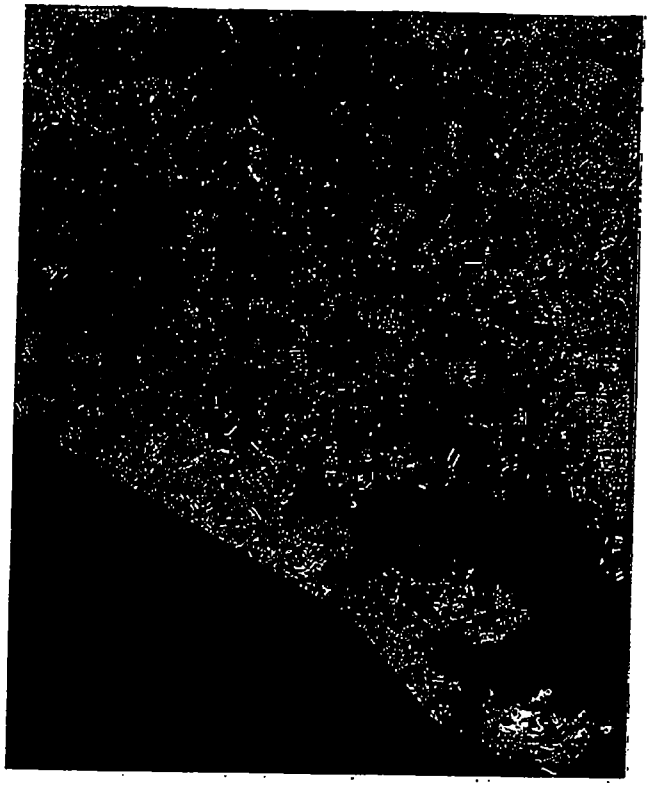


Figure #3: SPOT XS or multispectral image of Baltimore, MD (SPOT Image Corp., 1992).

Aerial Photography

Aerial photography has been used as a means of remote sensing since the United States Civil War. There are several different types and scales of black and white, color and color infrared aerial and multispectral airborne photography and orthophotography that can be used in the forest inventory methodology. The success of photo interpretation depends on the quality, the scale, the time flown, and the experience of the photo interpreter. Aerial photos, once collected, can be scanned into a GIS/image processing system, georeferenced and geocorrected to match a selected map projection. In addition, a photo can be digitally enlarged, thereby increasing the scale in order to identify tree species, estimate biomass distributions, distinguish energy-conserving trees, ascertain carbon storage/sequestration levels, determine land cover/land use, assess trees contributing to wildlife and water quality, and map potential reforestation areas.

Types of Aerial Photography

Aerial photographs can be oblique, panoramic, or vertical. Oblique photos are taken from an angle rather than vertically, and tend to cover a larger area of the Earth's surface. However, obliques are not good for measuring or map making because of the intense rectification or geocorrection that is necessary. Panoramic photos have a wide-angle field of view, approximately 100 degrees and a relatively high resolution. However, since the photo is taken at an oblique angle to nadir or to the principal center point of the photo, distortion is evident. This distortion restricts the use of panoramic photos in the methodology. Vertical photographs provide the interpreter with a reliable overview of a study area. This decreases the time the interpreter has to spend in the field. The interpreter must determine the scale necessary to complete the objectives of the urban forest inventory or assessment. Photographs are considered vertical when a camera axis is held vertical to the ground during exposure. Photos are considered oblique if the camera axis is off 4 degrees or more, or if the average deviation is off 2 degrees or more for a group of vertical photos. Vertical photos are the suggested aerial photo media type of the urban forest methodology.

Black and White Aerial Photos

Black and white, or panchromatic, aerial photo interpretation is commonly used by the United States Forest Service for identifying rural and urban forests. The level of accuracy required in an urban forest inventory will determine the temporal resolution (season flown) and photographic scale necessary to accomplish inventory objectives. Large to medium scale black and white photos, generally 1 inch = 6,000 inches or better, are used when a high level of detail is required. Summer black and whites are good, especially when a red filter is used to increase contrast levels, for determining mixed urban forest vegetation. Experienced photo interpreters can identify and inventory individual tree species with large scale photos. Small scale black and white photography is primarily used for planning, managing, or mapping large urban forests. However, the level of detail or accuracy diminishes as the scale decreases. For example, it is extremely difficult to use 1" = 24,000" scale black and white photo to conduct a street tree inventory, even with the enlargement capabilities of a GIS/image processing system. A larger scale like 1" = 2400" would be a better choice of scale. Figure #4 illustrates a black and white photo of the Sandtown-Winchester Neighborhood in Baltimore City on the following page.

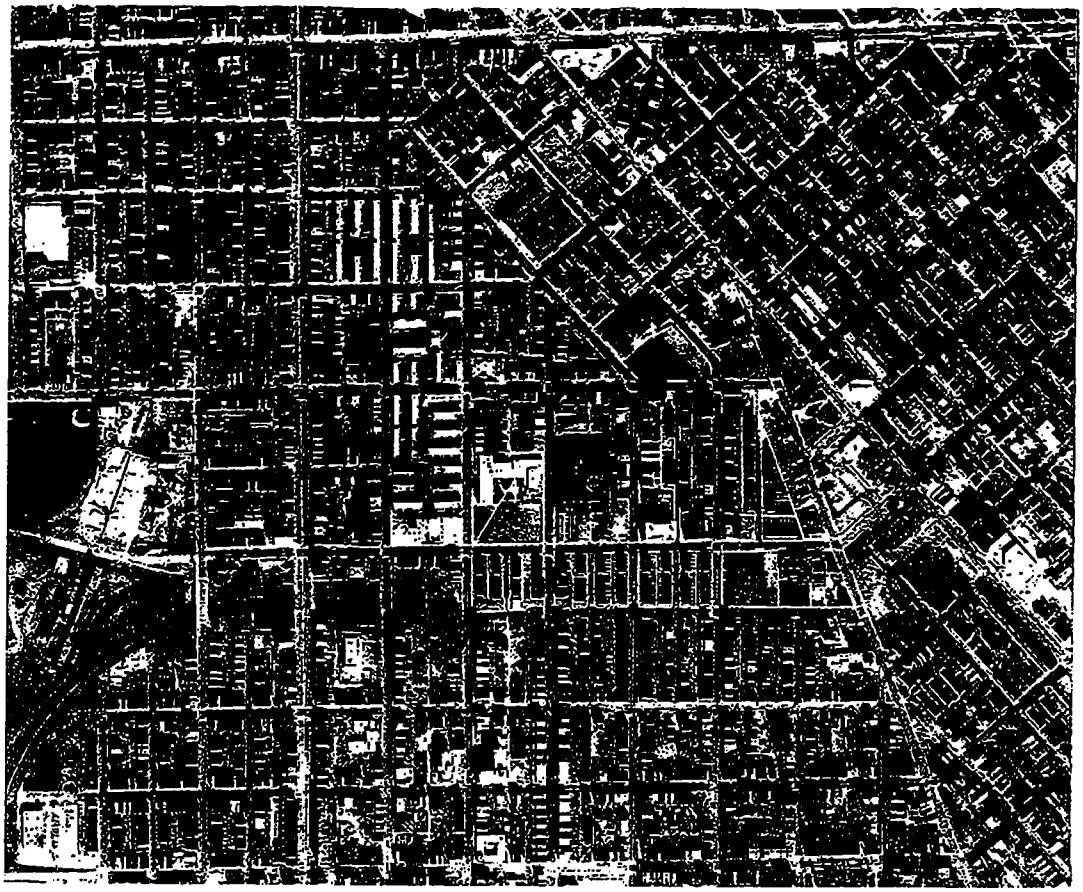


Figure #4: Black and White aerial photo of the Sandtown-Winchester neighborhood in Baltimore, MD (Enterprise Foundation, 1993).

Color and Color Infrared Aerial Photos

Color and color infrared photos are the best media sources available for assessing urban forest tree genus, species, health, and biomass. Early summer color and color infrared photography provide the best source for identifying land cover and tree species because deciduous trees are in leaf, and the ground is not completely hidden from site. In addition, late summer to early fall reveals increased reflectance levels in deciduous trees, while reflectance levels in coniferous trees decrease. However, spring and fall photos yield greater contrast variation, which allows an interpreter to distinguish deciduous and coniferous vegetation differentiation. Also, winter photos can be used to examine differences between upland and bottomland forest types due to the fact that one can distinguish the bluish gray concentrations of water absorption and soil moisture on the earth's surface, especially with high-altitude color infrared photos. The inventory objective determines the time of year and the scale used.

Large-scale color or color aerial photos are very useful when a precise level of accuracy is required to calculate biomass, examine tree health, and identify tree species. Large-scale color infrareds are the best photographic source available for satisfying most of the objectives addressed in the methodology. Small scale high-altitude photography, such as the Department of the Interior's National Aerial Photography Program's or NAPP photos (1":40000"), are useful in determining variations between deciduous and coniferous vegetation. But, as with black and white aerial photography, it is difficult to accomplish detailed urban forest inventory and assessment objectives in this methodology with smaller scales.

Figure #5: An example of a color aerial photograph (RK&K Engineers, 1992).

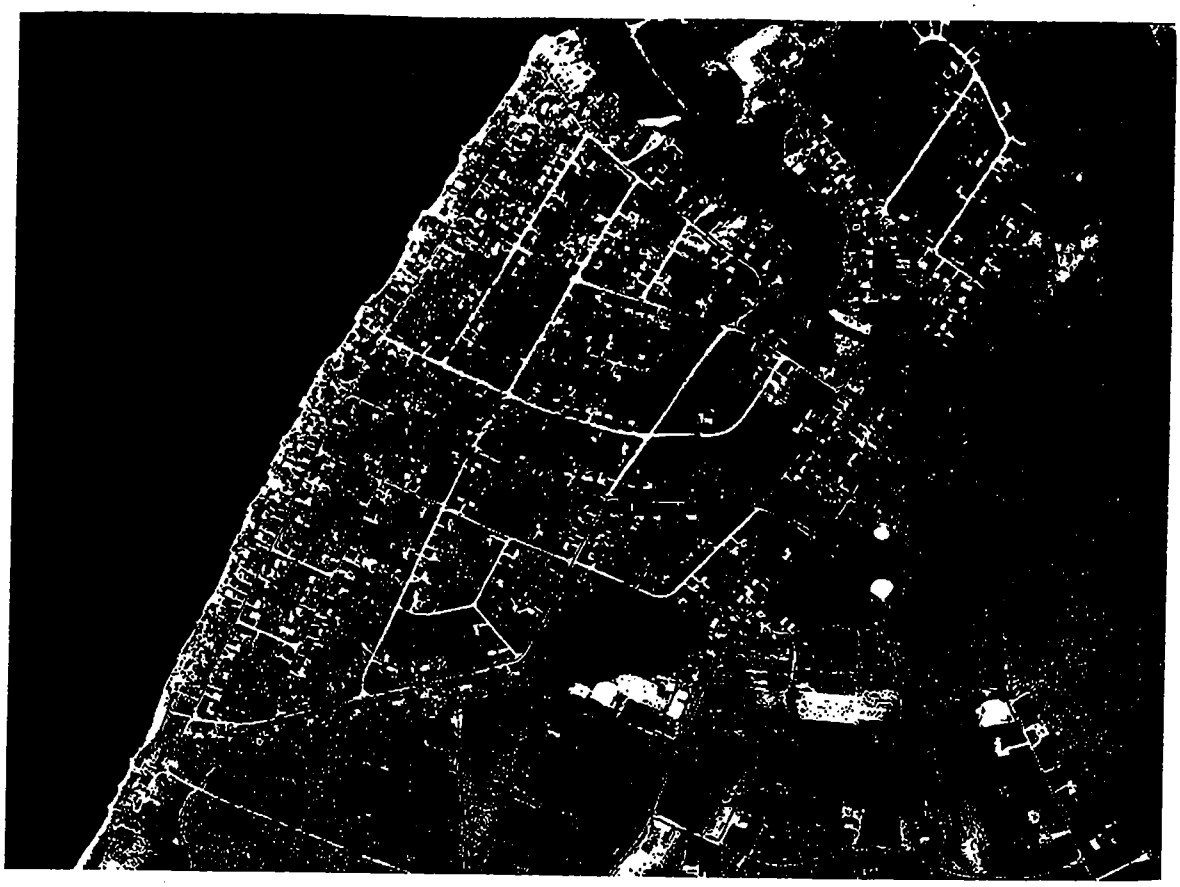


Figure #6: Color infra-red photo example (NAPP, 1988).

Multispectral Aerial Photography

The multispectral scanner technology utilized on-board aircraft is no different from those scanners used aboard satellites. Essentially, multispectral aerial photography offers between 5 to 12 spectral bands of data within the visible, infrared, and thermal ranges of the electromagnetic spectrum. The spatial and spectral resolution varies with each commercial or government agency or service providing the photography. Usually, a spatial resolution of 5 meters or better can be obtained from government agencies such as the National Aeronautical and Space Administration (NASA). With the spatial and spectral resolution offered by multispectral aerial photography, a higher level of mapping accuracy can be obtained when performing visual and computerized classification techniques. Tree genus identification, tree health, biomass assessments, carbon storage/sequestration measurements, and potential reforestation sites can be identified with this data source. Potentially, this could be the best data source available for cost effectively mapping urban forests in the United States. Currently however, this data is expensive and somewhat difficult to obtain.

Figure #7: An example of a multispectral aerial photograph (NASA, 1992).

Orthophotography

Orthophotography is a geocorrected or rectified aerial photograph that corresponds to a cylindrical, conic, or planar map projection. The rectification process corrects the original camera distortion, inherent in any aerial photograph due to the curvature of the Earth, as well as any displacements due to terrain or topographical differences. An orthophoto is produced to National Map Accuracy Standards which means that it is spatially accurate to within approximately one fiftieth of an inch at publication scale 90% of the time. (Forest Handbook, p.1153).

Distinguishable urban forest features necessary to complete inventory objectives can be scanned and digitized from an orthophoto base. These features would then correspond to their actual or true point on the Earth's surface, and no rectification would be required. Furthermore, orthophotos are usually accompanied by digital contour or terrain data, which may assist the user in determining bottomland/wetland urban trees from upland urban tree species. When combined with aerial photographic interpretation or satellite classification techniques, effective urban forest mapping can be accomplished. However, when used as a single data source, accurate orthophoto interpretation is somewhat difficult due to photo resolution degradation caused by the geocorrection or rectification process. Orthophotos are also very expensive and take a longer time to produce when compared to color or black and white prints.

Stereo Photography

Stereo photo pairs, especially large-scale photos, are used extensively by the U.S. Forest Service to assess, identify, and inventory forested areas. Stereo pairs, when viewed through a stereoscope, depict a photographic three dimensional representation of the Earth's surface. The photos are taken at opposite angles to the principal or center point of the photograph. These oblique photos, displaying the same area, are then matched and viewed through a stereoscope to visualize the 3-D effect. Since stereo pairs depict vertical as well as horizontal phenomena on the earth, photogrammetrists utilize these photos to create elevation and topographic maps. GIS/image processing systems can also be used to examine stereo photos in order to calculate elevation models in relation to forestry or watershed analysis. Stereo pairs, although somewhat expensive, can be purchased or collected from local, state, and federal government agencies or private aerial survey firms.

Availability of Photography

Panchromatic as well as color and color infrared aerial photography can be obtained at a minimal cost from most local, state, or federal government agencies responsible for surveying, natural resource planning, transportation, or GIS implementation. Orthophotos, because of their expensive nature, are not as readily available. Commercial aerial survey firms may also have the photography that is necessary to complete an inventory, although the cost may be higher. The United States Geological Survey is an excellent source for small scale black and white as well as color and color infrared aerial photography, while local government urban and natural planning agencies or private aerial survey firms are good sources for obtaining larger scale aerial photos. Please refer to Appendix A for a list of data sources and addresses.

Digitized CADD or Vector Data

Map features evident on panchromatic or multispectral satellite imagery, aerial photographs, topographic maps and planimetric sheets can be digitized or imported into computer CADD or GIS (vector) files and used in a CADD or GIS system. Depending upon the capabilities of the user's GIS or CADD software, vector and CADD files can be created by digitizing map features directly from a tablet or from a monitor (on-screen). Heads-down digitizing work, tediously completed from a digitizing tablet, is the most commonly used process of introducing data into a CADD or GIS system. On-screen digitizing allows a user to interactively digitize scanned map features from a raster, a horizontal array of pixels, without constantly viewing both a monitor and a digitizer. On-screen digitizing is ergonomically easier on the operator, and in the long run, is probably the best technique for digitizing a plan or photo-base map.

Digitized data can be prepared by the user or imported from another data source. Digitized CADD and vector data can appear in a variety of different formats. A partial list of commonly used CADD and vector file formats are listed below. (Note: some formats can be used in both applications.)

CADD

.dxf (AutoCAD exchange file)
.dwg (AutoCAD)
.dgn (Microstation)
.igs (Microstation)
.mmi (MapInfo)
ASCII
GSMAP (U.S.G.S. digitizer format)
DMDF (Digital map data record format)

VECTOR

.dxf (AutoCAD exchange file)
.moss (Map Overlay and Statistical System)
.e00 (ARCINFO interchange file)
TIGER (U.S. Census Bureau)
GRASS (U.S. Army Corps of Engineers)
ASCII (Standard Text file)
GSMAP (U.S.G.S. digitized format)
DMDF
TYDAC (Spans VEH/VEC vector format)
.dlg (U.S.G.S. digital line graph's)
.mmi (MapInfo format)
COVERAGE (ARCINFO file)
WORLD DATA BANK II (CIA generated)
ETAK (Enhanced TIGER files)

Differences Between CADD and GIS

The type of file format that is selected depends on the inventory objectives and the capabilities of the CADD or GIS software package used to complete an urban forest inventory and assessment. CADD files are graphic drawings of geometric elements that can be displayed, manipulated, and plotted. CADD drawing elements graphically display map features or plan objects. However, the graphic elements are not "intelligent". GIS vector elements such as lines, nodes, and polygons, are intelligent because they maintain topological relationships and can be related or attached to common database files. Topology refers to the interrelationship or connectivity of map features. These computer-linked relationships allow the computer to process large datasets quickly, store data more efficiently, and overlay geographical phenomena for spatial analysis. Topological relationships describe lines joining nodes, lines connecting at vertices to form polygons, and lines with left and right polygons. (See Constructing Vector Topology, p. 51).

In addition to topology, attribute data and database files can be associated with vector elements in order to enhance the GIS. Tabular database records are linked with a particular vector element attribute with the identical numerical or character value. This allows the user to query database information and to display results graphically.

The analysis portion of the methodology will function more efficiently if GIS or vector data is utilized. CADD data, used to overlay data layers of geographic phenomena for visual or display purposes, is rather limited when conducting an urban forest analysis or assessment due to the lack of topology. However, Autodesk, the manufacturer of AutoCAD products, may develop

a capability to attach external databases to CADD elements in the near future, possibly by 1994. This will enable CADD greater analytical flexibility in an urban forest related analysis.

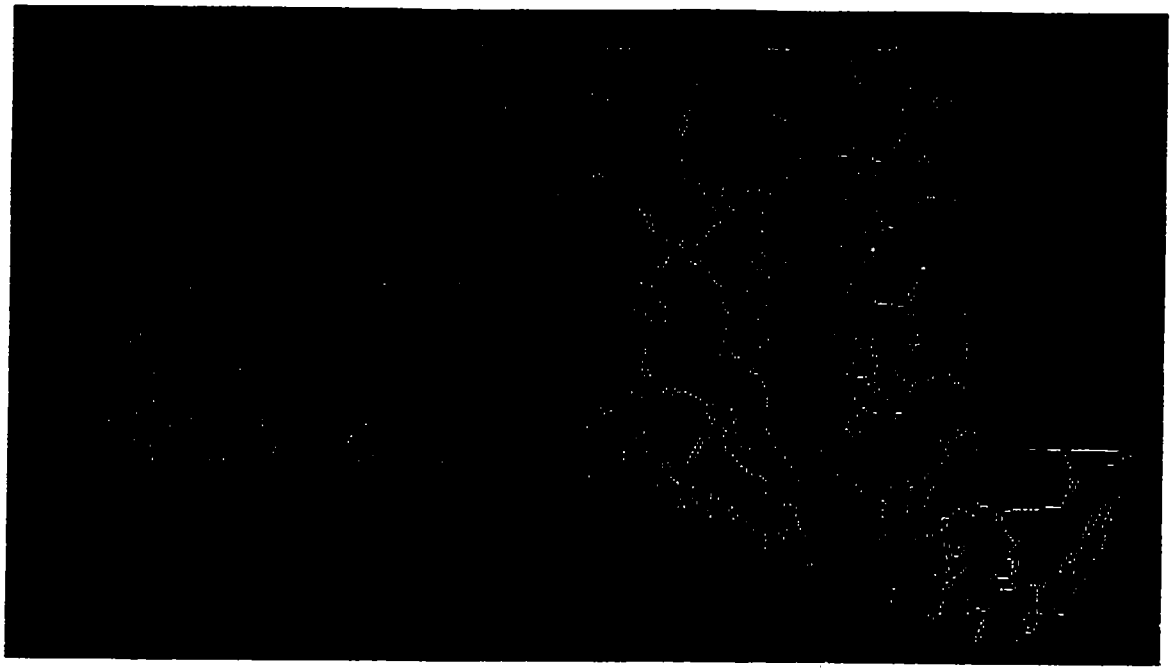


Figure #8: An illustration of topologically correct vectors.

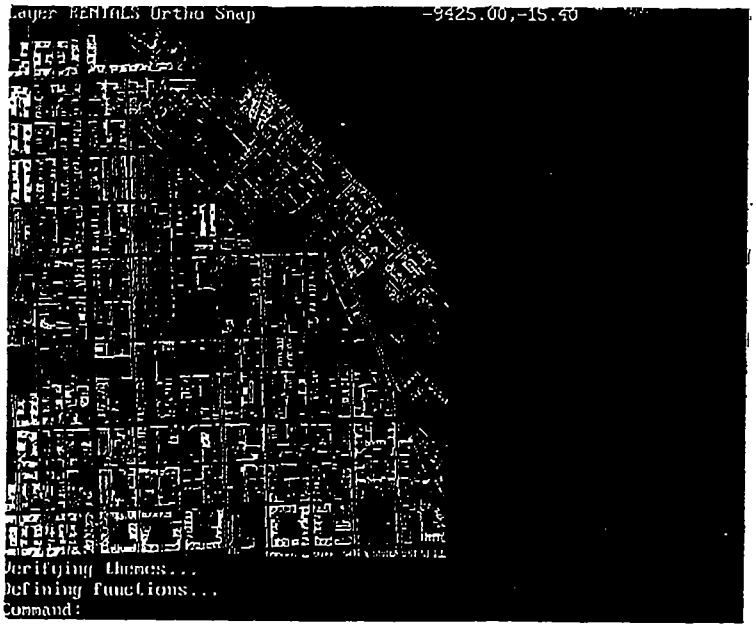


Figure #9: A view of a CADD file with layers of data instead of topologically correct vector data.

Database Information

As mentioned earlier, databases enhance the quality of vector data by associating record values of a given field to line, point or polygon elements of a vector file. A database consists of columns or fields with several records or rows. Each record contains specific information about each field. Customarily, record values, associated with a particular field, are linked to vector elements in order to graphically display the database. A reliable link is critical to the success of the database - vector merge. The definition or structure of the database field must coincide with the element, or the link will be unsuccessful. For example, if a database field is defined as a character field with a space between characters (ie. Cool St.), then the attribute of the element must be entered the same way. Address-matching programs, which link address-based databases to street network files, may have the ability to recognize character patterns even if spaces are added or addresses are misspelled. However, a standard data entry format would still increase accuracy levels and decrease errors during the database merge or address-match process.

Several database software packages such as DBASE III+, DBASE IV, EXCEL, FOXPRO, Advanced Revelation (AREV), ORACLE, etc.. can convert databases into compatible files in order to communicate with existing GIS software packages such as ARCINFO, GRASS, MIPS, ERDAS, etc... Generally, most GIS packages can import and use DBASE or ACSII (IBM's standard character format) compatible data files. Additional programming may also be administered to facilitate database communication links with GIS software. Consequently, prior to collecting database information, the user should examine the database formats that can be imported or "read" into a GIS.

Available Databases

There are several varieties of database files which contain economic, social, political, and environmental information a user may want to include in a forest inventory and assessment. These databases originate primarily from federal, state, and local government agencies. Digital database records representing individual street, park, or yard tree inventories may already exist. Other databases including demographic data, geographic place names, wildlife, and plant species can also be accessed through federal agencies and non-profit organization such as the U.S Fish and Wildlife Service, the U.S. Census Bureau, the U.S. Geological Survey, and the Nature Conservancy. A brief listing of some of these databases is listed below. See Appendix A for additional information.

TIGER - U.S. Census Bureau demographic database
Nature Conservancy - National Endangered Species
U.S. Fish and Wildlife Service - National Wetland Inventory
U.S. Geological Survey - Geographic Place Names

.TABLE B - DATA TABLE

Data Type	Source	Format	Scale or Spatial Resolution	Geocoding Available	Cost	Uses
Landsat TM Full Scene (185 x170km) Quarter Scene (92.5 x 80km)	EOSAT 4300 Forbes Blvd. Lanham, MD 20706 703-648-6892	Band Sequential (BSQ)	28.5m/ pixel	Yes	$4,500.00 May decrease significantly	Used for land cover or land use classifications. Can be used to assess vegetation conditions and cover.
Landsat MSS Full Scene (185 x 170km)	EOSAT 4300 Forbes Blvd. Lanham, MD 20706 703-648-6892	Band Interleaved by Line Band Sequential Band Interleaved by Pixel	80 x 57m/pixel	Yes	$4,500.00 May decrease significantly	Used to classify land cover of large areas on the earth's surface.
SPOT PAN Level 1B	SPOT Image Corp. 1897 Preston White Dr Reston, VA 22091-4326	Band Interleaved by Line	10m/pixel	Yes	$2,450.00	The PAN 10 meter is currently the best satellite resolution available. A more precise land cover classification can be derived with SPOT PAN imagery when combined with other bands of statistically resampled data.
SPOT XS Level 1B	SPOT Image Corp. 1897 Preston White Dr Reston, VA 22091-4326	Band Interleaved by Line	20m/pixel	Yes	$2,450.00	A good source for classifying forest cover features. However, SPOT does not have as many infra-red bands as does Landsat. Therefore, vegetative analysis may be somewhat limited.
USGS DEM 1:24000 1:250000	USGS-ESIC 507 National Center Reston, VA 22092	ASCII (DEM)	1:24000 1:250000	Yes	Call local distributer for pricing.	Great data source for determining elevation of the study area. When combined with satellite imagery, can identify trouble spots in the satellite classification.
NAPP Color Infra Red Photos	Sioux Falls - ESIC U.S. Geological Survey Sioux Falls, SD 57198	Hardcopy Film or Print Photos	1:40000	Yes	$18.00 (small print) to $65.00 (large print)	These inexpensive color infra-red photos are flown over each state every 5 years. NAPP photos can be scanned into a GIS/image processing system and used to map citywide or regional forest cover.

TABLE B - DATA TABLE (continued)

Data Type	Source	Format	Scale or Spatial Resolution	Geocoding Available	Cost	Uses
TIGER files and Census demographic databases	U.S. Department of Commerce - Bureau of the Census Washington D.C. 20233 4300 Forbes Blvd. Lanham, MD 20706 703-648-6892	TIGER/Vector format		Yes	Contact the Census Bureau for additional information	Excellent data source that illustrates the socioeconomic status of the United States by census tract, by census block group, and by census block. This data source can be used to satisfy local as well as regional urban forest objectives related to economic and social factors.
ETAK Databases	ETAK, Inc. 1430 O'Brien Dr. Menlo Park, CA 94025	ETAK/Vector format	1:24000 1:100000	Yes	Contact ETAK for current pricing information.	ETAK enhances the quality of Census DIME, TIGER, or street files.
USGS Topographic Quadrangles	USGS-ESIC 507 National Center Reston, VA 22092	DLG/Vector format	1:24000 1:62500 1:100000 1:2000000	Yes	Contact USGS for current pricing information.	A great data source which depicts hypsography (contours), hydrography, vegetative cover, non-vegetative features, transportation routes and railroads, survey features, cultural landmarks, and political boundaries.
USGS Landuse and Landcover Maps Level 1B	USGS-ESIC 507 National Center Reston, VA 22092	LULC	1:100000 1:250000	Yes	Contact USGS for current pricing information.	Another good data source for large areas (small scale). Land use and land cover data may be sufficient for a metropolitan or regional study.

C. Data Preparation

The data preparation phase is the most labor intensive and time consuming of the entire process. Data that has been collected has to be entered into the computer for analysis. Procedures such as scanning, digitizing, framegrabbing, data entry, and importing are used to acquire suitable datasets. Once the data has been captured, issues concerning georeferencing or map projection registration, geocorrection, topology or vector relationships, vector attributing, and database association may be addressed. In this section, a description of the data preparation process is outlined for each available data source.

Satellite Data

Import or Download Data

Satellite data commonly is delivered from commercial companies and government agencies on 9 track reel to reel tape or on 8 millimeter exabyte tape. One must have a 9 track or 8 millimeter tape drive and associated software in order to "read" and download the data (See Appendix C for listing of tape drive devices). Most image processing software packages such as ERDAS, MIPS, and PCI have the ability to import satellite directly from either tape format. However, the software "driver" programs must be compatible with the kind of tape drive device and controller or adapter card being used. Refer to specifications for tape drive and controller card compatibility in the software/hardware technical manuals of the particular GIS/image processing package. Generally, it is recommended to download the "raw" satellite data with a GIS/image processing software driver directly rather than copying the data from tape to a hard drive using the software that accompanies the tape drive. Using the GIS/image processing software tape import drivers, the downloading process captures and converts the raw satellite data directly into a compatible GIS file format.

Georeferencing and Geocorrection

After the data has been converted into a compatible file format, it must be georeferenced and geocorrected. Satellite data can be purchased with or without georeferencing and geocorrection or rectification from SPOT and EOSAT. A georeferenced dataset contains at least three control points or coordinates which the user places manually or imports automatically. The user may register the data into map projection coordinate systems such as the Lambert Conformal Conic, the Universal Transverse Mercator (UTM), the Mercator, or the State Plane coordinate systems. The earth can be mapped or projected from a spherical surface to a cylindrical, a conic, or a planar surface. Cylindrical projections such as the Mercator and Miller Cylindrical projections depict continental formations or true shapes accurately, but they do not show correct size. Land formations are typically distorted. Conic map projections such the Conic, Polyconic, and the Lambert Conformal Conic projections accurately represent middle latitude areas, but, as one moves poleward distortion increases. Most State Plane projections in the continental U.S. are based on conic projections. Planar projections, including the Lambert Equal-Area Projection, assumes a plane touching the earth at single point. Distances close to the center point will be accurate, but the distance distorts as one moves further from the center point. Polar regions are usually mapped with this projection.

In the United States, the Lambert Conformal Conic or the Transverse Mercator map projections are used to calculate State Plane coordinate systems because they display minimal amounts of distortion in the middle latitude areas. This allows a geographer to map regions and areas more accurately in the U.S.. The Maryland State Plane coordinate system, derived from the Lambert Conformal Conic map projection, was the projection used for mapping in the Baltimore, MD case study.

Georeferencing must be completed prior to geocorrecting or rectifying a distorted image to real world coordinates. Geocorrection algorithms or warping transformations, incorporated in GIS/image software packages, rectify the satellite data into a real world coordinates. The rectification algorithm used in the study depends upon the number of control points placed in the satellite image. For example, if three control points are used to reference an image, then an affine algorithm should be used. However, if four points are used, then a planar or an affine rectification method can be utilized. Below is a list of additional warping transformations that are utilized by GIS/image processing packages;

Warping Transformations

Transformation Algorithm	Control Points
Affine	3+ points
Planar Projective	4+ points
Bilinear	4+ points
2nd Order Polynomial	6+ points
3rd Order Polynomial	10+ points
4th Order Polynomial	15+ points
Piecewise Affine	3+ points
Piecewise Planar	4+ points

Polynomial and bilinear algorithms realign control points from their original orientation. The amount of displacement depends upon the accuracy of the control points used to rectify the image. If the control points are placed near their actual location, then the displacement will be minimal. Therefore, when placing coordinate or control points on the image, take time to accurately georeference the image. Accuracy residuals, a measurement of accuracy between the transformation model and the placed control points, should be close to 1.00 for minimal displacement.

During the image transformation process, the original image is statistically resampled to define the pixel values in a new transformed image file. There are three primary resampling methods used to calculate pixel values: nearest neighbor, bilinear, and cubic convolution interpolation. Nearest neighbor interpolation determines the output pixel value by computing the distance between the center of each cell in the output raster to the nearest 4 cells of the input raster. This method is commonly used when pixel cell values depict nominal (labeled) or ordinal (ranked) statistics. Bilinear interpolation computes output pixel values from a 2x2 neighborhood of cells. The output pixel value is determined after the distance between the four input pixels is weighted and calculated. Cubic convolution interpolation is a more intense and slightly slower resampling process. Output pixel values are determined by assigning a cubic polynomial surface to a 4x4

neighborhood of cells. In other words, the output pixel values are calculated the same way as the bilinear interpolation method, except that the cubic convolution method uses 16 weighted values (4x4) in the input image. The bilinear and the cubic convolution interpolation methods are used most commonly with images containing continuous data values such as elevation images. The GIS/image processing software automatically resamples and warps the image once the user has selected the warping algorithm and the resampling interpolation method. The time duration of this process depends upon the file size of the image to be transformed. Large satellite scenes can take 1 to 3 days to warp using an IBM compatible 386 or 486 personal computer. Therefore, the user may want to electronically extract the study area from a larger satellite scene with the GIS/image processing software prior to warping and resampling pixels.

Once the image is "rubbersheeted" and resampled to real world coordinates, then "true" vector or CADD elements can be drawn directly on the image. The new vectors or CADD elements will retain coordinate values and can be utilized in accurately mapping land cover, existing forests, potential reforestation sites, individual trees, etc... The revised image output file should be saved on a storage device capable of holding large amounts of data for further use once it has been warped and resampled. Raster imagery tends to fill space in hard drives rather quickly due to its large file size. Consequently, before saving, make sure that there is enough space on the hard drive to save the data.

Aerial Photography

Aerial photography can be scanned or imported into a raster format compatible with your software. In fact, some software packages provide driver programs to instruct a software supported scanner to scan aerial photos, maps, plans, or documents directly into a compatible file format. However, before purchasing a scanning device, make sure that it is supported by the GIS/image processing software that you are using. Otherwise, the scanning software that is delivered with the scanner must be used. Whenever possible, use the GIS/image processing scanning software to scan data directly into a compatible file format.

Scanning aerial photographs is a reliable technique of entering data into the urban forest inventory system. The user must be aware of the scanner's specifications or limits. Matters concerning the photo's physical size, scale, color, contrast and brightness are important issues to consider when scanning. In addition, the user must also be concerned with the scanning resolution as well as the file format necessary to successfully complete the scan. The following list illustrates the scanning specifications required to scan black and white, color, and color infrared photography for use in the methodology.

Specifications for Scanning an Aerial Photo or Map

1) Scanning hardware must be configured correctly.

A computer technician should configure the scanner to work properly on the users workstation. The scanner comes with a controller card which is placed in an available bus slot on the computer's motherboard and connected to a port on the scanner with an appropriate cable. Address conflicts, memory difficulties, and software configuration problems may arise after the scanner is "hooked up". Consequently, it is best to assign the configuration duty to a computer technician. Refer to the scanner's hardware and software technical manuals for assistance.

2) Scanning software must be configured to drive or run the scanner.
As mentioned earlier, scanning can be performed with the GIS/image processing system or with software that accompanies the scanning device. Generally, a software driver program has to be inserted into the configuration file in order to instruct the computer to communicate with the scanner.

3) The scanner must have enough available scanning area to successfully complete a scan.
Available scanning area depends upon the size of the scanner used. Scanners come in various sizes ranging from page scanners (8.5" x 11") to large format scanners (40" up to 100 feet and more). When ordering aerial photos for scanning, make sure that the size of the photos does not exceed the size limitations of the scanner.

4) The scanner must be capable of scanning grayscale or color photos.
The scanner must be able to scan at least 8-bits per pixel. 8-bit raster images have 256 possible values per pixel (0 to 255). Each scanned pixel value represents a graytone or a color value. A black and white photograph is scanned into a grayscale file format that should be compatible with your GIS/image processing software or to a standard grayscale raster format such as an uncompressed TIFF (Tagged Image File Format) file. A color or color infrared photograph can be scanned in grayscale, however, the photo image will appear black and white. Some scanners do not have the capability of scanning color photos or documents into colored raster images because they only support grayscale or binary (blueprint) scanning. A color scanner can be used to scan color, color infrared, and black and white photos as well as binary documents plans and maps. Color scanners create color table files when scanning color photos or documents. These color tables enable the scanning software to interpolate the color values that are apparent on the photograph.

5) Automatic or manual contrast and brightness adjustment capabilities should be available.
Brightness and contrast tables or files can be saved in the photograph file when scanning. This will allow a user to lighten, darken, or enhance a photo raster image interactively or automatically.

6) Resolution settings must satisfy requirements of the project or methodology.
Photos can be scanned at a high or low resolution depending upon the level of accuracy required in an urban forest inventory. As the resolution increases, so does the number of pixels or dots per inch (dpi). In addition, an increase in resolution enlarges the output raster file size. An example of a low resolution file size would be approximately 100 dpi, while a good resolution would be about 500 dpi. Generally, a scan of 200 to 300 dpi satisfies the resolution requirements recorded in the urban forest methodology.

7) The aerial photo or map should be oriented toward north.
In order to decrease the amount of time necessary to rotate a raster image file in the computer, it is suggested that the user insert the photo face down into the scanner with the north direction inserted first or at the top of the scanner. Therefore, when the scan is complete, the photo will appear on-screen with north depicted at the top of the monitor. This makes merging processes much easier for operators, so that they can group a series of adjacent photographs together without having to rotate them first.

8) Sufficient hard drive space should be conserved for the scanned raster file.
The virtual memory capacity or size of a scanned raster image depends upon the size of the photograph or document and the resolution desired. Formulas for calculating the storage capacity of a raster image are given on the following page.

Formulas for calculating file sizes of a scanned photo or map:

L = Length of the photo
W = Width of the photo
dpi = Dots per inch or resolution

8 - Bit Raster (256 possible color or grey values per pixel)

1. (L x W) dpi x dpi = 8-bit raster file

16 - Bit Raster (32,768 possible color or grey values per pixel)

1. (L x W) dpi x dpi = 8-bit raster file

2. 8-bit raster file size x 2 = 16-bit raster file

24 - Bit Raster (8,388,608 possible color or grey values per pixel)

1. (L x W) dpi x dpi = 8-bit raster file

2. 8-bit raster file x 3 = 24-bit raster file size

If the user does not have a scanner available for use, then he or she may be able to solicit the services of a scanning agency or company to scan and convert the photos into a usable raster file format. Once the photos have been scanned, then the raster images can be used directly or imported into the user's system. Importing digital aerial photography is another way of introducing data into an urban forestry GIS. For example, some aerial photogrammetric companies can provide scanned digital aerial photography in a generic or customized raster format. These raster formats can be converted into a file format compatible with GIS/image processing software. If the file format that is to be imported is not supported by your GIS/image processing software, then the user should contact the software manufacture's technical support personnel. They should provide a solution to the situation or at least provide a suitable alternative. However, if they do not satisfy such a request, then seek the services of a computer programmer in order to create a conversion utility program to import the digital photo.

Georeferencing and Geocorrection (Aerial Photography)

If the scanned or imported data is not registered to a map projection, then the vertical aerial photos must be georeferenced and geocorrected in order to rectify the distortion inherent in aerial photography. As mentioned earlier, the Earth is mapped or projected from a sphere to a cylindrical, a conic, or a planar surface. Cylindrical projections such as the Mercator and Miller Cylindrical projections depict continental formations or true shapes accurately, but the land formations are distorted. Conic map projections such the Conic, Polyconic, and the Lambert Conformal Conic projections accurately represent middle latitude areas like the United States, however, as one moves poleward, map distortion increases. Most State Plane projections in the continental U.S. are based on conic projections. Planar projections, including the Lambert Equal-Area Projection, assumes a plane touching the earth at single point. Distances close to the center point will be accurate, but the distance distorts as one moves further from the center point. Polar regions are usually mapped with this projection. The Maryland State Plane coordinate system, derived from the Lambert Conformal Conic map projection, was used to project the mapping in the Baltimore, MD case study.

There are several methods that can be used to georeference a scanned photograph to a map projection. The best method to reference aerial photography is to place surveyed control panels or tics, based on known geodetic map coordinates, in the study area prior to flying. The coordinates of these control panels, which should be visible on the scanned photo image, can then be manually entered into a GIS/image processing software package for referencing. Another georeferencing method includes manually registering a photo to a map projection by using a Global Positioning or GPS device to determine landmark, intersection, or other known feature location coordinates. GPS base stations coupled with hand held units, utilize a network of orbiting satellites to locate a point on the Earth generally within 2 to 5 meters. For example, if at least three coordinates are known, which preferably correspond to visible land features on a given photo, then most GIS/image processing packages will download GPS data in order to perform a manual reference (see Appendix B for additional GPS manufacturer information). In addition, previously digitized and geocorrected vector or CADD files can be used to register the photo by overlaying and warping the vector or CADD file to the raster image file. This technique is commonly referred to as vector or CADD to raster map projection registration. Also, previously georeferenced raster image files of the exact area can be used to register an unreferenced image if they are the same size. The lines and columns and radiometric resolution of the rasters must be the same in order for a raster to raster registration technique to work successfully. The raster to raster technique is used with temporal datasets for change detection studies or analysis.

Once the raster photo image has been georeferenced, then it should be rubbersheeted to conform to the map projection registration. Warping transformation algorithms and statistical resampling techniques are used to geocorrect the data (refer to pages 42 - 44 for warping and resampling information). After geocorrection is performed, the photo image may be distorted. This may prevent the user from interpreting certain features on the photo image. Therefore, it is a good idea to save a copy of the photo image, prior to warping, so that it can be used for classification purposes. A warped raster should be used when actually tracing or drawing vectors or CADD elements. The warped photo image should be saved after georeferencing and geocorrection procedures have been completed.

A rubbersheeted raster can be enlarged or reduced to satisfy a desired scale requirement. In addition, portions of a raster can be extracted and saved to another file in order to concentrate on smaller areas of study and to improve processing speeds and efficiency levels during the Analysis phase of the methodology. In addition, the photograph can be used to visually identify, interpret, and map land features on-screen. CADD and vector elements as well as text labels can be drawn directly on the warped photo image and saved to a separate file. The map projection registration of the photo image will be copied to the vector or CADD elements digitized. Furthermore, linear, areal, and angle measurements can be taken if the raster photo has been properly referenced. Once the raster has been referenced and rectified, save the file on a hard drive or storage device.

Aerial Video

Aerial video is a relatively inexpensive technique used for entering or introducing data into a GIS/image processing system. Video is used in natural resource management, planning, police agencies, and military departments to analyze or investigate recent trends. A VHS video tape can be displayed in a computer environment if an adequate display adapter card and associated monitor is utilized. For example, AT&T's TARGA 16+ adapter card has the ability to display video from a VCR directly to a multisync monitor screen. Depending upon the software that is utilized, one may be able to perform framegrabbing functions. Framegrabbing programs allow the user to freeze frames on the video and save them as raster images. Aerial video can be georeferenced, but it may be difficult to geocorrect, because it may be too oblique. However, once rasterized, the image can be manipulated or edited, analyzed, vectorized or converted, and stored into a GIS dataset without geocorrection. Video is especially good for wildlife and range management, while thermal aerial video is an excellent data source to determine "hot spots" in a given study area for thermal or heat related analysis.

Hardcopy Data Conversion

Digitizing

Digitizing tablets and pucs, mouses, track balls, and other cursor devices are used to digitize features of maps, plan documents, aerial photos, or satellite images into the GIS/image processing system for use in the urban forest assessment methodology. The features can be digitized directly from a digitizing tablet or on-screen.

Digitize from a Digitizing Tablet

In order to digitize data directly from a digitizing tablet, the user must have the hardware and software configured properly. A computer technician can assist in configuring the digitizing

workstation. If a technician is unavailable, refer to the digitizer's technical manual for assistance. The user needs a computer with the necessary number of communication ports available to support or connect to a digitizer (normally, in a PC environment, digitizer cables connect to the serial ports of IBM compatible computers). Once the digitizer has been properly attached to the correct computer port, a CADD or GIS software package that supports that particular digitizing tablet can be used to configure or set up the digitizer. Occasionally, configuration problems or errors occur. Incorrect mode settings, port designations, baud (communication speed) rates, parity settings, and data and stop bit designations can cause problems. Refer to the digitizer's technical documentation as well as the GIS/image processing or CADD software manuals in order to properly set up or configure the digitizer.

After successfully configuring the digitizing hardware and software, the GIS or CAD package should be initiated. The media is placed on a digitizing tablet and the minimum and maximum extents of the document, map, or photo to be digitized are defined. Generally, CADD packages such as AutoCAD and Microstation require 2 control or reference points to define the minimum and maximum extents. The two points are placed at the lower left corner and upper right corners of the media. GIS packages like MIPS and ARC INFO require 4 or more reference points, representing the four corners of the object to be digitized. The reference points entered into the software may be cartesian (X,Y) coordinates or real-world decimal based coordinates such as State plane or Universal Transverse Mercator. Spatial accuracy increases as the number of control points increases. Once the minimum and maximum extents of the media object have been established, the CADD or vector elements digitized are registered in accordance with the specified reference points.

Whenever possible, digitize map projection tics directly into the system from the digitizing tablet. This avoids map projection registration procedures and saves valuable processing time. Generally, plans, maps, and orthophotos are projected in some kind of map projection coordinate system. Therefore, warping or map rectification of these sources is unnecessary. However, if features are digitized from an unrectified aerial photograph, then the data will have to be warped due to the distortion of the photograph. If no map projection is required, then warping is unnecessary.

On-Screen Digitizing

CADD and GIS/image processing software such as CAD Overlay, MIPS, ARC INFO (UNIX environment), ERDAS, and Microstation, supports on-screen digitizing. On-screen digitizing allows the user to convert scanned images, visible on the computer monitor screen, into vector or CADD elements with a mouse or cursor device. This method of digitizing allows the user to view a scanned raster file in order to digitize features quickly and accurately from the computer screen. On-screen digitizing is less physically cumbersome than tablet digitizing. The operator can keep his/her head forward instead of constantly bending over to enter points from a digitizer. Consequently, on-screen digitizing is preferred by most CADD and GIS digitizer operators.

In order to digitize on-screen, the media object to be digitized must be scanned at a sufficient resolution to convert specific features from raster to vector or CADD objects. In addition, the raster file format of the scanned image must be compatible with the GIS/image processing or CADD software (see Specifications for Scanning Aerial Photos or Maps, p.44). Various raster formats can be used with CADD or GIS/image processing packages. For example, CADOverlay ESP requires a binary raster file format (.rlc) in order to perform on-screen digitizing techniques. Raster to vector software packages which utilize binary raster formats can only be used with black and white based media such as blueprints, mylar overlays, or documents. Other software including MIPS and ERDAS allow a user to utilize a variety of binary (black and white), color (8-bit), or grayscale (8-bit) raster file formats such as **.tif, .gis, and .rvc.**

Once the media is scanned into a GIS/image processing system, the raster image should be registered or georeferenced to a desired map projection. Some CADD systems with raster capabilities such as Raster CAD may not permit map projection registration on the raster itself. Therefore, real world coordinates must be placed on the graphic elements that are traced or imposed over the raster. Media that has previously been geocorrected such as USGS topographic quadrangles or Soil Conservation Service Soil Map overlays will not require rectification. However, if the media object has not been geocorrected prior to scanning, then rectification and warping is necessary in order to accurately draw graphic elements or place vector objects in their proper real world coordinate space. Geocorrection programs may not be available in all GIS/image processing and CADD systems. Refer to the documentation describing the capabilities of your software in order to determine geocorrection capabilities.

After the image has been properly referenced and corrected, the user can begin to draw or digitize CADD elements or GIS vectors, depending on the software package, over the raster that is clearly visible on the monitor view screen. The user can pan, zoom, adjust contrast levels, and edit the raster in order to view unclear areas prior to and during digitizing. As the digitized elements are created, map projection coordinates on the raster are transferred to the vector or graphic display automatically. The newly created vector or CADD coordinates are saved when the vector or graphic file is saved.

After converting or digitizing data into a compatible file format, the user should investigate the imported file for correct topology, attribute and associated databases, and georeferenced/geocorrected coordinates. Currently, CADD programs can not calculate topological relationships as do GIS programs. Therefore, it is better to convert data into a GIS-based program whenever possible.

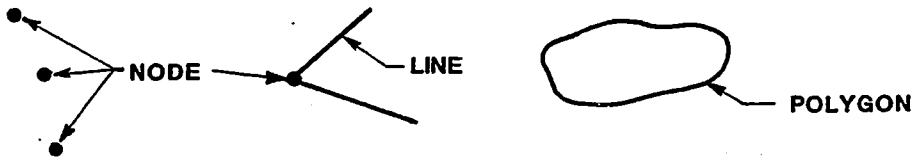
Constructing Vector Topology

Topology refers to the spatial interrelationship of map features that we interpret intuitively, but must be made explicit for a computer. Topological relationships between vector line, point, and polygon elements, representing map features, should be constructed each time a vector file is imported, created, or edited.

Nodes - X,Y coordinate points that connect arcs or lines together at intersections and end-points.

Lines - Arcs with direction composed of two nodes (end points). Vertices may be present.

Polygons - Adjoining lines that connect to define an area.



The illustrations below and on the following page describe the contents of a topological database for a line, a point, or a polygon created in GIS software packages.

Point Topology

Internal ID#	User ID#	X,Y

Internal ID# - The software's internal reference number associated with vector elements.
User ID# - An identification attribute classified by the user.
X,Y - A coordinate pair indicating the location of the point in space.

Line Topology

Start Node	Finish Node	Left Polygon	Right Polygon	Length of Line	Internal ID #	User ID

Start Node - The beginning point of a line.
Finish Node - The end-to point of a line.
Left Polygon - The polygon to the left of the line.
Right Polygon - The polygon to the right of the line.
Length of the Line - Line distance measurement.
Internal ID# - The software's internal reference number associated with vector elements.
User ID# - An identification attribute classified by the user.

Polygon Topology

Area	Perimeter	Internal ID#	User ID#	Connecting Lines

Area - The measure of a planar region or of the surface of a solid.
Perimeter - The outer boundary of an area.
Internal ID# - The software's internal reference number associated with vector elements.
User ID# - An identification attribute classified by the user.
Connecting Lines - A connected series of lines that form a closed polygon area

Vector topology allows a user to store data more efficiently, process large data files quickly, intersect vectors together, and overlay on additional raster or vector layers. When vector elements are topologically linked, they are considered to be "intelligent". In comparison, CADD data is not intelligent; it is a graphic representation of the data or drawing only. It is also important to note that if a vector file is manipulated or edited in any way, then topology must be re-established in the GIS.

Importing Digital Data

The conversion or importation of a raster, vector, CADD, or database data file into a file format compatible with your GIS or CADD software package depends upon the importing or file conversion capabilities of your software. The ability to import previously completed datasets can save the user valuable time in digitizing. Many GIS/image processing systems such as MIPS and ERDAS have the ability to import a variety of raster, vector, and CADD files into their system. However, CADD packages like AutoCAD and Microstation have somewhat limited importing or file conversion capabilities.

Included on this page is a standard list of raster, vector, CADD, and database file formats that can be converted into most GIS/image processing or CADD programs.

Raster Formats

Binary
.rlc - CADOverlay ESP raster format
.hrf - Hitachi Raster format
.igs - Image Systems format
.pcx - PC Paintbrush (Z-Soft Corp)
.rle - Intergraph raster format
.tif - Tagged Image File format
.rvf - MIPS file format
.rvc - MIPS file format

Grayscale or Color
.tif (Tagged Image File Format)
.lan - Erdas file format
.gis - Erdas file format
.rvf - MIPS file format (version 3.3 /earlier)
.rvc - MIPS file format (version 4.0 and later)
.bil - Band Interleaved by Line (multispectral)
.bip - Band Interleaved by Pixel
Grass - GRASS GIS
.tga - AT&T Truevision format
.dem - Digital Elevation Model (16 bit)
.img - Simple Array (raw imagery/no headers)

Vector Formats

.dxf - AutoCAD/Microstation drawing exchange file
.moss - Map Overlay and Statistical System (USFWS)
.e00 - ARCINFO interchange file
TIGER - U.S. Census Bureau demographic data
GRASS - U.S. Army Corps of Engineers
ASCII - Standard text format
GSMAP - U.S.G.S. digitizer format
DMDF - Digital map data record format
TYDAC - Spans VEH/VEC vector format
.dlg - U.S.G.S. digital line graph
.dem - U.S.G.S. digital elevation model (3D)
.mmi - Map Info Map Interchange format
COVERAGE - ARCINFO file
WORLD DATA BANK II - U.S. Central Intelligence Agency generated
ETAK - Enhanced TIGER files

CADD Formats

.dxf - AutoCAD/Microstation drawing exchange file
.dwg - AutoCAD drawing
.dgn - Microstation design file
.igs - Intergraph/Microstation format
ASCII - Standard text file
GSMAP - U.S.G.S. digitizer format
DMDF - Digital map data record format

The file conversion capabilities of software are listed in the software reference manual of the GIS or CADD package.

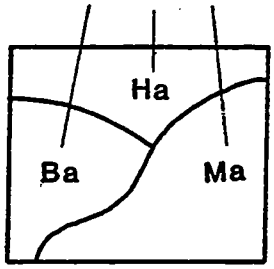
Building GIS-Vector Datasets

In a GIS program, attributes are attached to vector elements so that they can be automatically linked to external or internal (user created) databases once topology has been established. In order to ensure a successful link, the values and type of data entered in a database field or column must agree with the attribute values associated with the vector elements. The graphic below illustrates the database linking process.

Database (Tabular Information)

Soil Type	Hydric	Slope
Ha	Yes	0 to 3%
Ba	Yes	0 to 3%
Ma	No	3 to 6%

Attribute Data (Soil Type) = **Ba, Ha, Ma**



Note: The attributes, indicated in bold, are the link between the vector file and the database. The value or type of the attribute is crucial to the success of the link. For example, both entries are character-based with no spaces entered between letters.

Some vector files such as TIGER (Census Bureau) and .MOSS (U.S. Fish and Wildlife Service) data can be delivered with databases that are specific to the attributes. This provides the user with additional data that can be enhanced with additional data links, georeferencing, and geocorrection. The user should also verify topological relationships prior to attributing or analyzing the data. If the topology converts incorrectly, then relationships between the vectors need to be reconstructed or "cleaned". If data is imported or converted from another package, topology must also be confirmed or reconstructed.

D. Analyze Data

This phase of the methodology addresses analytical and technical processes utilized to satisfy community or regional urban forest inventory or assessment objectives. The prepared data sets can be displayed, queried, and spatially analyzed to illustrate and satisfy the objectives of the study. Statistical programs can produce computer models, histograms, scatterplots, and regression analysis with socioeconomic and environmental variables to examine urban forests in different ways. Data sets including satellite imagery, aerial photography, aerial video, vector elements, CADD drawings, and database information can be utilized to address environmental, economic, and social objectives. Analysis techniques used in the methodology depend upon the regional or community objectives selected. For example, satellite data is sufficient for regional urban forest analysis, however, it is not spatially detailed enough for a local or community forest assessment. In contrast, large scale aerial photography may provide the best analytical tool for examining community forests, but may be somewhat expensive and time consuming to study a large number of photos as opposed to one satellite image. In this section, analytical techniques used in GIS and image processing systems will be listed according to the regional or community environmental, economic, or social objectives selected.

Regional Analysis

Environmental Objectives

A. Assess how urban trees and forests reduce carbon dioxide in the atmosphere by estimating urban forest carbon storage and sequestration levels.

Multispectral satellite classifications and street tree surveys can be used to estimate forest canopy coverage, calculate study area acreages, and determine trunk diameter (dbh) distributions. Supervised and unsupervised satellite landcover classifications can be used to estimate contiguous urban forest canopy coverage (see pages 58-62). However, since the spatial resolution of the satellite imagery does not precisely identify individual trees, tree inventories, utilizing field sampling and computerized photointerpretation techniques, have to be performed in order to estimate the street tree canopy coverage, trunk diameters, and type distributions. McPherson and Rowntree (1989) found three dominant trunk diameter distribution types in analyzing twenty-two street tree populations (Figure 10).

Figure #10: Urban Forest Distribution Chart (from Rowntree and Nowak, 1991)

Type 1 = A relatively young population distribution.
Type 2 = A mature population distribution.
Type 3 = An even distribution among all diameter classes.

Distribution Type	**Diameter Class**					
	0-6	**7-12**	**13-18**	**19-24**	**25-30**	**>30**
Type 1	42	27	14	10	6	1
Type 2	21	29	26	8	8	8
Type 3	23	15	20	16	18	8
Avg.	29	24	20	11	11	6

Determine Tree Distributions and Estimate Canopy Coverage

The average crown diameter for each trunk distribution type should be estimated after collecting field inventory data. The average diameter estimations can then be used to calculate the total canopy coverage of street trees. In order to estimate the total street tree canopy coverage, the average crown radius for each distribution type must be squared, multiplied by Pi or 3.14, and the approximate number of trees in that class. The sum of all calculations for each sample will determine the total canopy coverage. For example;

City "A":

Inventory Sample #	# of trees	Trunk Distribution	Average Crown Radius
1	500 trees	Type 1	10 feet
2	300 trees	Type 1	15 feet

Total street tree canopy area in sq.ft. = [(pi) x (10x10)] x 500 + [(pi) x (15x15)] x 300

Total street tree canopy area = 367,950 sq.ft. or 8.44 acres

The estimate of the total street tree canopy coverage can be added to contiguous urban forest canopy coverage estimates, determined using satellite imagery, in order to derive an estimation for an entire city. The process for determining contiguous canopy coverage using satellite imagery is explained on pages 58-62. Analysis of entire urban forests (i.e., not just street tree populations) indicates that the urban forest may soon have a smaller diameter distribution than exhibited by the Type 1 distribution. Analyses from Shorewood, Wisconsin and Oakland, California indicate greater than 60% of the trees less than six inches in diameter (Nowak, 1993).

Calculate Carbon Storage and Carbon Sequestration

In order to calculate carbon storage and carbon sequestration rates, Rowntree and Nowak associated a multiplier to each tree distribution type.

Carbon Storage
Type 1 = .3226
Type 2 = .4423
Type 3 = .5393
Avg = .4303

Carbon Sequestration
Type 1 = .00727
Type 2 = .00077
Type 3 = .00153
Avg = .00335

If the diameter distribution is unknown, the average diameter distribution multiplier is likely the best selection to use for calculating carbon storage and sequestration levels in urban forests because it represents an average distribution. Once the distribution, canopy coverage, and study area are known however, then total carbon storage can be calculated by applying a formula created by Rowntree and Nowak. **Study area in acres x % canopy coverage x distribution multiplier for carbon storage or sequestration = total carbon storage or sequestered by existing urban forest biomass distribution.** For example, City "A" has a total area of approximately 59,000 acres, a 15% forest canopy closure, and an average distribution. Therefore, the total amount of carbon storage for City "A" is 378,969 tons (59,000 x 15% x .4303). Consequently, the total amount of carbon sequestered annually for an average distribution with 15% canopy coverage is equal to 2,950 tons (59,000 x 15% x .00335).

Once carbon storage and sequestration rates have been determined, fresh weight and dry weight biomass estimates can be calculated. Generally, the total carbon stored in a tree is 45% of the dry weight biomass. Therefore, the total dry weight biomass for City "A" is 842,154 tons (total carbon stored x 2.22). Moreover, total dry weight biomass is approximately 60% of the total fresh weight biomass for hardwoods, and 46% of total fresh weight biomass for conifer species. For example:

Total Dry Weight Biomass

Total carbon stored x 2.22 = Total Dry Weight Biomass

Total Hardwood Fresh Weight Biomass

(Total Dry Weight Biomass x % Hardwood Species) x 1.67 = Hardwood Fresh Weight Biomass

Total Conifer Fresh Weight Biomass

(Total Dry Weight Biomass x % Conifer Species) x 2.17 = Conifer Fresh Weight Biomass

Biomass calculations, carbon sequestration and storage estimates are used to quantify and measure an urban forest's ability to reduce carbon levels in the Earth's atmosphere. With growing global concern over the "Greenhouse Effect", these quantifiable measurements may promote the planting of trees as a means to reduce carbon levels. The greenhouse effect is created when carbon dioxide and other gases, naturally and artificially released into the atmosphere, trap terrestrial heat energy, which warms the earth's surface. Carbon dioxide allows short wave solar energy to penetrate through the atmosphere en route to the earth's surface. Once the solar rays reach the earth, they are reflected in the form of long wave energy back into the atmosphere. However, the carbon dioxide prevents the long wave energy from passing through the atmosphere and into space, thereby, trapping heat and gradually warming the Earth. The proper placement of urban forests may play a key role in reducing the effects of carbon pollution either directly, through carbon sequestration/carbon storage, or indirectly, with energy conserving tree plantings.

Satellite Classification Procedures to Estimate Contiguous Urban Forest Canopy Coverage

Multispectral satellite imagery can be used, as mentioned earlier, to assess contiguous urban forest structure and estimate urban forest biomass, carbon storage, and carbon sequestration. Satellite imagery classifications can be performed at varying levels of accuracy to determine land coverage features on the earth's surface. Level I classifications identify simple features such as water bodies, farmland, and forested areas, while Level II classifications distinguish slightly more complex features such as coniferous and deciduous or hardwood vegetation. Level III classifications are the most detailed classifications. For example, a Level III classification allows one to identify tree species in a forest. However, Level III classifications are very difficult to attain in an urban environment due to the diversity of land use and land cover. In order to classify satellite multispectral data into the accuracy levels desired, supervised and unsupervised pattern recognition statistical algorithms are used to cluster similar pixel cells.

Supervised Classification

A supervised classification permits the user to manually select pixel cells representing a certain class (ie. land cover, deciduous trees, coniferous trees, etc.) from a reference raster or image and apply the classification designations to multispectral processing rasters of the same cell size (lines and columns). Processing masks, or small areas on the image which represent the whole raster, are then used to select and classify sample pixels into classes representing land cover, agriculture, forest, etc.(feature on the earth's surface). The user can classify as many classes as he/she chooses. The processing mask technique allows the user to process several small masks or study areas at one time instead of classifying the entire raster. This decreases the amount of processing time and, when coordinated with field studies, the masks can increase the accuracy of the classification. After the pixels in the processing mask have been identified, a maximum-likelihood pattern recognition statistical algorithm is used to apply the processing mask results or training sets to the entire raster image. Maximum-likelihood algorithms apply the supervised classification to the raster quickly and efficiently. Once the processing is complete, the newly created raster will have clustered similar pixels together into the classes designated by the user. Since throughout the processing, multispectral rasters retained the same pixel size. Consequently, area calculations or statistics can be generated for each class identified in the study, including contiguous forests. The pixels representing the contiguous forest coverage can

be added together in order to calculate the total contiguous forest area in acres.

The following procedures describe the technique of using a supervised satellite classification and a tree field inventory to calculate carbon storage, carbon sequestration, and biomass.

General Procedures to Estimate Carbon Storage, Carbon Sequestration, Biomass, and Canopy Coverage - Supervised Classification Technique

1) Identify study areas in the imagery and extract.

a. Collect available field data, topographic, planimetric, hydrological, and aerial photography of the study area.

2) Select multispectral rasters for processing.

a. Select rasters that will address your objective.
Infrared commonly used to assess crops and soils
Blue bands used to determine water content
Green band used to identify healthy vegetation
b. Refer to Section 2.2 Satellite Data for additional information.

3) Select a reference raster image to identify features.

a. Use a panchromatic satellite image of the same area as the processing rasters.
Cell size, scale, and lines/columns should be the same

4) Develop processing masks encompassing your study sites.

a. Be careful not to introduce bias into the dataset.
b. Select mask that represent the pixel distribution for the entire raster.

5) Spectrally classify and cluster land/forest cover pixel cells in the satellite imagery into required accuracy levels. Incorporate prior knowledge of the site as well as other data resources such as large scale aerial photography when classifying or identifying features in the imagery.

a. Level I classification = Low level i.e. water, farmland, forested areas, urban, etc.
b. Level II classification = Medium level i.e. coniferous, deciduous, emergent, shrub, etc.
c. Level III classification = High level i.e. oaks, maples, firs, ash, spruce, pine, etc.

6) Determine trouble spots in the data set.

a. Pixels representing one landcover type may reflect the same electromagnetic signature as a completely different landcover pixel. This may occur due to variations in topographic position, slope, or water inundation.

7) Use additional aerial photos, field studies, topographic, planimetric, and hydrological information, which may be obtained from the U.S.G.S., to refine the classification masks if necessary.

8) Once mask identification is complete, apply the classification to the entire image using a Maximum-Likelihood or similar statistical algorithm in the image processing software.

9) After the entire image is classified, use the new image histogram, which reveals the number of pixels in each class identified, and calculate the total area for each land/forest cover pixel class by multiplying the # of pixels in the cover class by the pixel's spatial resolution.

a. Calculate the total forest canopy coverage in acres (all pixels of the forest cover class x pixel resolution). Be careful, pixel resolution may be in sq. meters.
b. Calculate the total study area in acres using the GIS/image processing system (all pixels within study area x pixel resolution). Be careful, pixel resolution may be in square meters.

10) Generate a statistics text file of the new classified histogram and save the classification results for use in the carbon storage and sequestration equations.

11) Add street tree canopy coverage estimates (discussed on pages 55 and 56) to contiguous urban forest estimates derived from the satellite classification. Pay attention to the distribution type identified most frequently by the field inventory.

12) Apply Nowak and Rowntree's formulas in order to calculate carbon storage and carbon sequestration.

13) If necessary, calculate fresh and dry weight biomass according to the formulas depicted on page 57.

14) Save the data for presentation purposes.

Figure #11: A Baltimore City Supervised Classification. Each color represents a different landcover. Forests are illustrated in green while impervious surfaces or developed areas are indicated in purple. In addition, water bodies are shown in blue, while grass areas are indicated in yellow. (SPOT, 1992).

Unsupervised Classification

The unsupervised satellite classification method utilizes a pattern recognition program to automatically cluster multispectral raster pixels of similar reflectance values based upon the number of classes that the user selects. Pattern recognition algorithms such as Fuzzy C-Means, ISOCLASS, and K-Means are used to automatically cluster pixels, maximize statistical distances between classes of dissimilar cells, and provide area estimates for pixel cell classes. Unsupervised classifications are used to classify satellite images and multispectral photography because they yield fast, yet accurate results. The unsupervised classification process is usually less time consuming than a supervised classification. Once the automatic pattern recognition program processes the multispectral rasters, the new unsupervised classification, usually output in grayscale, can be color coded by class. For adequate results in a vegetation-related study, the user should select at least 20 classes to process. This increases the classification accuracy by increasing the number of possible classes to identify during the color coding process. After

the raster has been color coded, save the new color table and histogram. Use the histogram and automatically or manually calculate the areas for each pixel class, including those pixels representing contiguous urban forests. The pixels representing the contiguous forest coverage can be added together in order to calculate the total contiguous forest area.

A step by step description of the process necessary to complete an unsupervised classification and calculate carbon sequestration, storage, and biomass is listed below.

General Procedures to Estimate Carbon Storage, Carbon Sequestration, Biomass, and Canopy Coverage - Unsupervised Classification Technique

1) Select study areas.

2) Collect available field data and aerial photography for analysis.

3) Select processing rasters.

a. See Section 2.2 Satellite Data for more information concerning band wavelengths

4) Assign training classes desired.

a. A selection of 20 or more classes provides a good sample

5) Use a block-clustering algorithm to arbitrarily create discrete classes or clusters of pixel cells for each electromagnetic band.

a. Pattern recognition algorithms such as K-Means, ISOCLASS, and Fuzzy C-Means will:

Automatically cluster pixel cells of similar reflectance values
Maximize statistical distance between classes of dissimilar pixels
Provide area estimates for the individual pixels

6) After the automatic processing is complete, color code classes into corresponding land or forest cover types (ie. deciduous vs. coniferous).

7) Calculate classified pixel cell areas to determine forest coverage and total acreage of the study site.

8) Create a histogram of the classification with the image processing system.

9) Use the new image histogram, which reveals the number of pixels in each class identified, and calculate the total area for each land/forest cover pixel class by multiplying the # of pixels in the cover class by the pixel's spatial resolution.

a. Calculate the total forest canopy coverage in acres (all pixels of the forest cover class x pixel resolution). Be careful, pixel resolution may be in sq. meters.

b. Calculate the total study area in acres using the GIS/image processing system (all pixels within study area x pixel resolution). Be careful, pixel resolution may be in square meters.

10) Generate a statistical text file of the new classified histogram and save the classification results for use in the carbon storage and sequestration equations.

11) Add street tree canopy coverage estimates (discussed on pages 55 and 56) to contiguous urban forest estimates derived from the satellite classification. Pay attention to the distribution type identified most frequently by the field inventory.

12) Apply Nowak and Rowntree's formulas in order to calculate carbon storage and carbon sequestration.

13) If necessary, calculate fresh and dry weight biomass according to the formulas depicted on page 57.

14) Save the data for a presentation.

Figure #12: This is an example of an unsupervised classification of Baltimore, MD which was derived from an isoclass algorithm. Each of the classes that were statistically derived from the pattern recognition algorithm were color coded in accordance with their respective land cover. (SPOT, 1992)

After assessing the existing biomass, carbon sequestration rates, and annual carbon storage factors, planners, foresters, or resource managers can project or estimate the impact of new tree plantings upon the urban environment on a citywide basis by multiplying the Type 1 carbon storage and sequestration distribution multipliers by the proposed forest cover area and the total study area. This provides a rough estimate of the approximate annual carbon storage total and sequestration rate. Biomass can then be calculated with the formulas listed on page 57.

B. Assess the health of the urban forest in order to examine and promote tree maintenance effectiveness.

Infrared satellite imagery, infrared aerial photography, and aerial video are scanned, imported, or framegrabbed in to a GIS/image processing system in order to determine the condition or health of an urban forest. Once entered into the GIS, the data should be georeferenced and geocorrected. The infrared characteristics of the data permit the user to interpret healthy from non-healthy areas by visually panning or enlarging the data or by classifying or clustering similar

pixel cell values together with pattern recognition formulas. Typically, healthy trees are represented by a vibrant dark-red reflectance, while the unhealthy trees are depicted as a dull lifeless pink color. An automatic classification algorithm or a visual interpretation can be inferred from the infrared photography. After interpreting the data, record results in a word processor, database, or digitize into vectors for display and presentation purposes.

C. Identify landcover areas suitable for reforestation.

Satellite imagery, aerial video or photos, hardcopy maps, or existing digital features which represent and describe the landcover for a given area can be used to identify potential reforestation areas. Scanning, framegrabbing, digitizing, and importing techniques can then be utilized to import the data into a GIS/image processing system. Also, the collection and incorporation of field data into potential reforestation site location design increase the accuracy of the study. Georeferencing and geocorrection algorithms should then be used to register and rectify the data to a map projection coordinate system. This provides real-world applicability to the data. After preparing the data, visual and automated identification and classification procedures can be combined with field studies to determine potential reforestation sites. Open areas, vacant lots, stream valleys, parks, or large grass areas adjacent to developed properties are the areas best suited for afforestation. These areas should also have suitable soil material and water sufficient to support vegetative/forest cover. The selected reforestation/afforestation areas can then be mapped and classified by drawing vector polygons and associating attributes to each polygon. This identifies the area and content of the polygon. Once completed, save the file for later use in a compatible map projection that satisfies the study requirements.

Figure #13: This illustration depicts potential afforestation areas in green over a black and white aerial photograph (Comp-Tron, 1993).

D. Examine the effect of urban forest upon water quality by associating previously completed field documents with aerial photography or satellite imagery.

The user should collect as much data about the study site as possible. Field collected data is critical in this process. Variables such as water temperature, particulate content, salinity levels, aquatic and wetland vegetation, fish and wildlife activity, and oxygen content should be examined by an experienced biologist to assess the quality of the water or stream. Global Positioning Systems (GPS) can be used to establish the location of water samples extracted in the water body for spatial analysis. In addition, GPS can also be used to collect data by entering descriptive codes into a data collector. After completing a water quality survey, the user can download water sample point locations and associated descriptive data from the GPS unit into a personal computer data base or word processing file. If a GPS unit is not available, then record notes in a field book and place sample points on a hardcopy map of the study site.

The field data can be used with satellite data (for large water bodies), aerial photography, or videography to spatially illustrate and analyze water quality. Scanned aerials and imported satellite imagery visually depict those areas of a stream, river, lake, or bay which are buffered by trees, wetlands, agricultural activity, and development. If available, collect different years of imagery or photography to examine or determine changes in land use and its affect on water quality. Visual digital data can be correlated with field data in order to define and quantify

water quality in the study area. Digital imagery and point data should be georeferenced and geocorrected, if possible, prior to spatial analysis in the computer. This allows the user to overlay and query field data in a real-world coordinate system such as UTM or State Plane. The results of the analysis should be recorded and saved into a GIS data base file for presentation purposes.

General Procedures

1) Collect data such as aerial photography, satellite imagery (regional sites), hardcopy maps or plans, and field data which is sensitive to water quality characteristics including water temperature, particulate content, salinity levels, aquatic and wetland vegetation, fish and wildlife activity, and oxygen content. If available, use a GPS to collect data in the field. This reduces digitizing and data base entry time.

2) Download satellite data (if available), field data (GPS), digitize map features, framegrab aerial video (if available), or scan aerial photographs prior to analysis.

a. Download satellite data.
Use satellite data as a base to map water quality.
b. Field Data (GPS may be used).
Create a data base from the sample points collected in the field. The data base should be compatible with the data base utilized by your GIS. GPS units can be used to locate and monitor water quality.
c. Digitize Data.
Digitize previously mapped water sample points or digitize directly from an aerial photo.
d. Scan Aerial Photos.
Scan aerial photographs for photointerpretation in the GIS or image processing system in order to determine water quality trends.
e. Aerial Video.
Framegrab aerial video frames with a GIS/image processing system for interpretation.

3) Georeference and rectify data sets to a real-world coordinate system. The GPS coordinates taken in the field can be used to rectify the data.

4) Associate a unique identifier or attribute to the vector points which represent the water samples. The attribute assigned to the point should link to a data base field value.

5) Overlay, query, and visually analyze data to determine water quality levels in areas of different land use and land cover.

a. Water testing station locations could be associated with tree buffer zones. Point da non-point pollution sources can be handled the same way.
b. Water temperatures can be correlated by land use to determine possible heat sources.

6) Record the results of the analysis in a GIS data base and save for presentation purposes.

E. Assess the effect of urban forests on wildlife by relating previously completed field studies with scanned aerial photography or imported satellite imagery in order to spatially determine the migration patterns and habitats of a particular species.

Collect environmentally sensitive documentation, mapping, aerial photography, aerial video, or satellite imagery that depicts wildlife habitat areas or migration patterns of species within the study area. Scan aerial photography, framegrab video sequences, digitize maps, and review documentation concerning the study site in order to prepare data for analysis. Georeference and geocorrect data sets as necessary. Once registered or referenced, the data sets can be overlaid, queried, classified, and visually interpreted by the user. The results of the study should be recorded and verified by field study.

General Procedures

1) Collect data such as aerial photography, satellite imagery (regional sites), hardcopy maps or plans, and field data which is sensitive to wildlife habitats and migration patterns. If available, use a GPS to collect data in the field. This reduces digitizing and data base entry time.

2) Download GPS and satellite data (if available), field data, digitize map features, framegrab aerial video (if available), or scan aerial photographs prior to analysis.

a. Download satellite data
Use satellite data as a base for mapping wildlife habitats and migration patterns.
b. Field Data (GPS may be used)
Create a data base from the sample points collected in the field. The data base should be compatible with the data base utilized by your GIS. GPS units can be used to locate and describe wildlife phenomena on the earth's surface.
c. Digitize Data
Digitize previously mapped wildlife habitat ranges or migration patterns or digitize potential habitats or migration patterns from aerial photography.
d. Scan Aerial Photos
Scan aerial photographs for photointerpretation in the GIS or image processing system in order to determine potential wildlife habitats or migration patterns.
e. Aerial Video
Framegrab aerial video frames with a GIS/image processing system for interpretation.

3) Georeference and rectify data sets to a real-world coordinate system. GPS coordinates taken in the field can be used to rectify the data.

4) Associate a unique identifier or attribute to the points which represent the water samples. The attribute assigned to the point should link to a data base field value.

5) Overlay, query, and visually analyze data to determine wildlife trends in areas of different land use and land cover. Example queries are listed below;

a. What wildlife species thrive in urban forests?
b. Are there any endangered species in the urban forest?

c. Is wildlife overpopulation a danger to the urban forest?
d. Is insect damage a problem to the urban forest?

6) Record the results of the analysis in a GIS data base and save for presentation purposes.

F. Landsat satellite data (25m spatial resolution) can be used to determine the effects of urban forests on the urban heat island effect.

Thermally sensative Landsat data is collected from EOSAT, georeferenced, geocorrected, and classified to determine the "hot-spots" in urban areas throughout the world. Hot areas are inferred from the thermal infrared band, band 6, and associated with treed areas by incorporating a forest coverage analysis or vector overlay completed earlier. Correlations are identified and recorded.

General Procedures

1) Collect satellite data from EOSAT with 25 or 30 meter resolution as well as any mapping information which depicts the extent of forests within your study area.

2) Download the satellite data from tape, 8mm cassette or 9 track reel to reel, into a GIS file format compatible with your computer.

3) Digitize the forested areas from available mapping such as the U.S.G.S. 7.5 minute quadrangles.

4) Georeference and geocorrect satellite data. The vector data, if digitized off of the U.S.G.S. quadrangle, should be georeferenced. However, geocorrection is unnecessary because the quad is already rectified.

5) Display and overlay the vector data over the Landsat data depicting the thermal layer to visually analyze. Display the green or red bands (band 2 or 3), infrared band 4, and the thermal band (band 6) to emphasize thermal areas (dark red) and vegetation (green), or just display Band 6 to examine thermal reflectance characteristics. If Band 6 is displayed by itself, then "hot spots" will appear to be white in color.

a. Look for correlations between treed areas and terrestrial heat emission.

6) Save and record the results of the analysis for presentation.

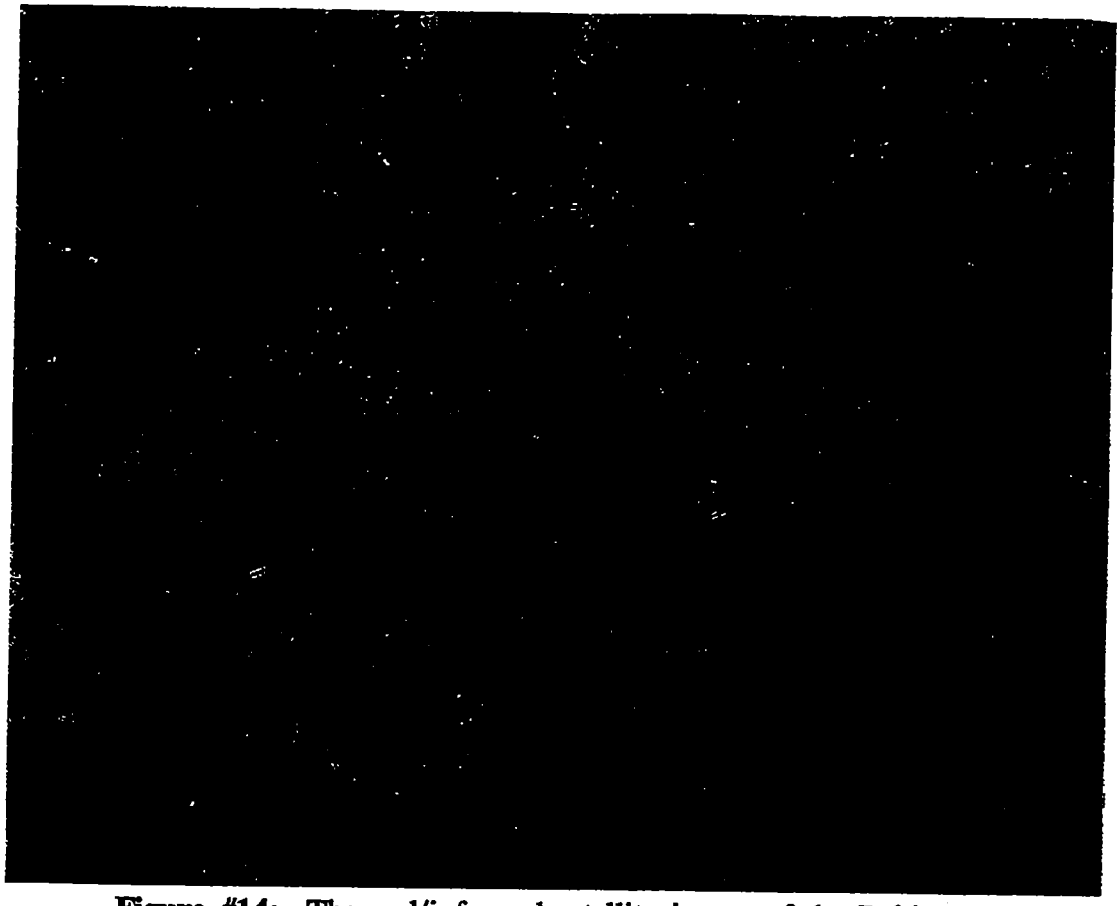


Figure #14: Thermal/infra-red satellite image of the Baltimore metropolitan area (EOSAT, 1992). Bands 6, 4, & 2. Hot-Spots are illustrated in red. Vegetated and cool areas are green.

Economic

A. Associate socioeconomic data with forest coverage vectors to determine the effect of urban forests and trees on property values, tree maintenance, and crime. Associate or address-match housing and census databases with forest vector elements and display or query the results.

Housing and U.S. Census (Tiger) demographic data bases reveal statistics that may be related to an urban resource such as urban forests or parks. Property values, tree maintenance costs and benefits, and even crime statistics may be associated by address to urban forest GIS data sets. This type of analysis may or may not reveal statistical correlations between socio-economic factors and urban resources, however, the data will enable planners to analyze and improve urban landscaping and architectural design techniques used when planning or revitalizing an urban community.

General Procedures

1) Collect U.S.G.S. 7.5 minute topographic quadrangles for the study site.

2) Collect housing and demographic data from the U.S. Census Bureau TIGER and local or state housing authority databases, if possible. Crime statistics may be difficult to attain.

3) Digitize the forest coverage (park area) or the individual trees (street trees) in the study area from the U.S.G.S. quadrangle. Utilize field inventory to verify the results of the off-site computer survey.

4) Georeference the digitized forest coverage to the census data map projection.

5) Overlay the data sets and query the census/housing data to illustrate correlations.
   a. Examine the effects of forested areas or street trees on criminal activity by correlating geographically located crime statistics with GIS based forest inventory.
   b. Assess property values of homes and average household worth for a given neighborhood to determine whether trees areas increase property values.
   c. Assess and reallocate tree maintenance efforts on a large regional scale.
   Home owners may take better care of their landscape than do renters, therefore, city foresters or planners can concentrate maintenance efforts and resources in rental areas rather than owner occupied dominated areas.

6) Save the results and record in a GIS data base.

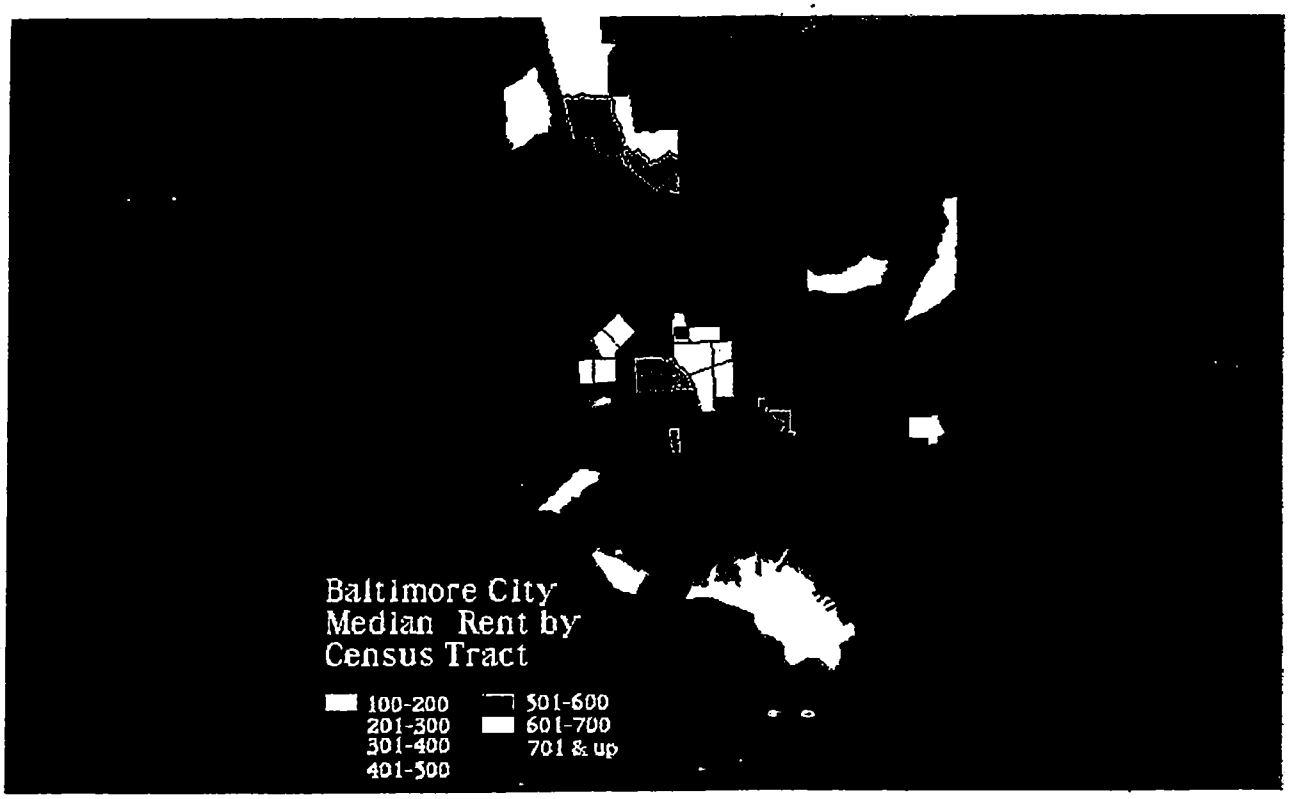


Figure #15: Census Tracts of Baltimore City which depict medium rent levels (Census, 1990).

Social

A. Explore and suggest innovative maintenance or learning programs in order to proactively improve the condition of our urban forests.

Non-profit cooperative organizations, such as the Urban Resource Initiative, are creating and implementing programs that encourage volunteer participation in the maintenance and the planting of urban trees. The urban forest assessment and methodology tool should assist groups like URI or local governments in gathering, preparing, analyzing, presenting data to improve the urban forest condition. The technology used to implement programs initiated by these organizations can also be taught to students within the study area.

School locations can be spatially displayed or queried to identify the schools located in the study area. Consequently, these schools can be notified of urban forestry-related programs such as the Urban Resources Initiative or Green Shores program and begin to learn about and take care of the forests in their community. School students from a community can learn and use the urban forest methodology and GIS technology to improve the condition of their own urban environment. In addition, the students may realize that there are job or career opportunities available in the fields of environmental or resource planning, GIS, or CADD. Encourage student internship and community involvement to ensure the success of a long-term maintenance or planting program.

B. Examine the effects of land use upon urban forests over time.

Identify data sources with medium scale aerial photography such as the National Aerial Photography Program (NAPP) taken in different years. Scan the photos into a GIS/image processing system, georeference to known control points, and rectify to the selected map projection. Digitize the most recent forest cover for the study areas, using the vector editing capabilities of the GIS/image processing software, and overlay on the aerial photography taken during different time intervals. Visually analyze and record the results for each photo. Then, digitize the forest coverage for the study region for each photo scanned. Once completed, overlay the resulting vectors to illustrate change over time. Canopy coverage area and tree inventories can be completed for your site in this fashion.

In addition to this vector edit technique, a raster change detection analysis technique can be used to determine change over time. The georeferenced and geocorrected photos, as long as they are the same scale, cell size and resolution (line and column size), can be algebraically added or subtracted to determine the pixel cells that have changed over time. These results can also be recorded in the GIS for later use.

Community Analysis

Environmental

A. Street tree inventories can be conducted by using large scale aerial photography and associated field studies to assess the health, species, and distribution of the trees of the urban forest community using GIS/imaging processing systems.

A detailed urban forest inventory analysis will enable a forester or planner to allocate or budget maintenance and planting costs more efficiently, estimate biomass levels, determine carbon storage and sequestration amounts, and examine direct and indirect energy conservation values of trees.

General Procedures

1) Scan or convert large scale aerial photos, aerial video, hardcopy maps or planimetric plans, and existing digital data into a digital file format compatible with a GIS/image processing system.

2) Conduct a field inventory, with field inventory data sheets, to determine the health, species, age/size distribution, and energy conservation value of the trees in the study area.

3) Enter the results into a data base compatible with your GIS.

4) Georeference and rectify the scanned aerial data with real-world map projection coordinates in the GIS/image processing system.

5) Digitize individual trees, as points, from the planimetric sheets and attribute or uniquely identify each tree.

6) Associate the tree inventory attributes to field records in the data base with a relational or join program in the GIS. The join program should allow a user to join unique attributes in a vector topological data base to another database as long as there are similar values in both data bases. In short, make sure that your unique attribute is identified and listed in the data base to which you are attaching.

7) Overlay datasets and associate field data to identify tree health, species, and diameter/age distribution, and energy conservation contribution over an aerial photo. Canopy coverage can be digitized to assess biomass and carbon storage levels.

8) Save and record data for presentation purposes.

Figure #16 on the following page illustrates a sample urban forest inventory field inventory sheet.

INVENTORY SHEET

Community _____ North Street: _____ East Street: _____ Block #: _____

Date _____ South Street: _____ West Street: _____ Land Use: _____

	A	B	C	D	E	F	G	H	I	J	K	L
	Tree ID#	Species	Diameter DBH	Height Class	Crown Condition	Trunk Condition	Root Condition	Conflicts	Grd Cover	Surface Shading	Photo #	Address
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

D. Height Class
A = 0-10 feet
B = 10-20 feet
C = 20-30 feet
D = 30-40 feet
E = 40-50 feet
F = > 50 feet

E. Crown Condition
1 = Excellent
2 = Good
3 = Fair
4 = Poor
5 = Very Poor
6 = Dead

F. Trunk Condition
1 = Excellent
2 = Good
3 = Fair
4 = Poor
5 = Very Poor
6 = Dead

G. Root Condition
1 = Excellent
2 = Good
3 = Fair
4 = Poor
5 = Very Poor
6 = Dead

I. Ground Cover
1 = Scrub/Shrub
2 = Tall Grass
3 = Mowed Grass
4 = Pavement
5 = Exposed soils
6 = Wetland
7 = Other

J. Surface Shading
1 = Building with Air conditioner
2 = Air conditioning unit
3 = Dark Surfaces (i.e. asphalt)
4 = Light Surfaces (i.e. concrete)
5 = None of the Above

Name of Inventory Person: _____ Phone #: _____ Page _____ of _____

B. The objectives listed in the regional/environmental analysis can also be analyzed in the community assessment as well. However, larger scale aerial photography and detailed field surveys should be used to achieve a better level of accuracy. See Regional Analysis/Environmental objectives for further information.

Economic

A. Energy conservation planting techniques can be used to reduce household energy consumption levels by planting trees in strategic locations adjacent to the house.

The trees placed around building structures will require maintenance, involving cost, but the environmental and aesthetic value of the tree will help to improve the condition of the community. Notice that the steps necessary to collect and prepare the data are essentially the same when performing a computer aided tree inventory.

General Procedures

1) Scan or convert large scale aerial photos, aerial video, hardcopy maps or planimetric plans, energy consumption data and existing housing or census data into a digital file format compatible with a GIS/image processing system. Energy consumption data may be attained from a local utility company.

2) Conduct a field inventory, with field inventory data sheets, to determine the health, the species, the age/size distribution, and energy conservation value of the trees in the study area.

3) Enter the results into a data base compatible with your GIS.

4) Import the energy consumption data base from the utility company into a data base format that is compatible with your GIS software.

5) Using a GIS, such as ARCINFO or MAPINFO, build an address file for the Tiger or Census street file. A census street file illustrates the center lines of roads which serve as boundaries for census tracts and block groups. See Figure #15, p.71. The address file enables the user to identify any address depicted and recorded in the street file data base. This file can be enhanced by the user to add streets, walkways and ally-ways not illustrated in the census file. ETAK, a GIS service company, provides enhanced or value added census data for clients throughout the United States.

6) Georeference and rectify the scanned aerial and vector data (if necessary) to real-world map projection coordinates in the GIS/image processing system. Vector data may already be rectified if digitized from a planimetric sheet or a topographic quadrangle.

7) Digitize individual trees, as points, from the planimetric sheets and attribute or uniquely identify each tree by address.

8) Associate the tree inventory attributes to field records in the data base with a relational or join program in the GIS. The join program should allow a user to join unique attributes in a vector topological data base to another database as long as there are similar values in both data bases. In short, make sure that your unique attribute is identified and listed in the data base to

which you are attaching.

9) Build a point file which indicates the addresses of the homes in the energy consumption data base with the census street address file with an address-match algorithm. An address-match program will associate address records in the energy data base with the address values inherent in the census street file data base, and locate addresses along the geographically located street address file.

10) Overlay the existing community tree inventory over the photo in order to examine the condition of the trees on the photo.

a. Identify wind break planting and shade opportunities:
air conditioning units could be shaded
wind break along the north and north west of building structures (depending upon what climate region you are living in)

11) Examine and query energy data base to access consumption data per household or block. Search for any correlations with tree plantings...ie. "Do properly shaded homes conserve more energy than do unshaded homes?" Identify those homes that conserve more energy due to tree plantings and highlight.

12) Create a conceptual planting plan to reduce energy consumption in your sample area.

a. Strategically place trees (nodes) around households on the aerial photo in order to maximize energy conservation levels.

Trees are placed around homes in accordance with the climate of the region and the direction of the house. For example, in Baltimore, a humid sub-tropical climate dominates the area with warm summers and cold winters. Tree plantings should be placed along the north and northwest side of the home to provide a wind break from the winter winds. In addition, trees could be planted along the south, west and east side of the home to protect from the summer sun's rays. If planted along the southern end of the structure, the tree should be trimmed high, so that the winter solar energy can penetrate through the foliage to warm the household.

13) Save results and present at a community meeting, home owners, or government agencies.

B. The regional and community objectives overlap. See Regional Analysis / Economic for listing of objectives. Please add more if possible.

Social

A. Associate socioeconomic data with forest coverage vectors to determine the effect of urban forests and trees on property values, tree maintenance, crime, and other demographic factors. Associate or address-match housing and census databases with forest vector elements and display or query the results.

Housing and U.S. Census (Tiger) demographic data bases reveal statistics that may be related to an urban resource such as urban forests or parks. Property values, tree maintenance costs and benefits, and even crime statistics may be associated by address to urban forest GIS data sets for statistical analysis. This type of analysis will enable planners to improve urban landscaping and architectural design techniques used when planning or revitalizing an urban community.

General Procedures

1) Scan or convert large scale aerial photos, aerial video, hardcopy maps or planimetric plans, and existing housing or census data into a digital file format compatible with a GIS/image processing system.

2) Conduct a field inventory, with field inventory data sheets, to determine the health, the species, the age/size distribution, and energy conservation value of the trees in the study area.

3) Enter the results into a data base compatible with your GIS.

4) Import the energy consumption data base from the utility company into a data base format that is compatible with your GIS software.

5) Using a GIS, such as ARCINFO or MAPINFO, build an address file for the Census street file. A census street file illustrates the center lines of roads which serve as boundaries for census tracts and block groups. The address file enables the user to identify any address depicted and recorded in the street file data base. This file can be enhanced by the user to add streets, walkways and ally-ways not illustrated in the census file. ETAK, a GIS service company, provides enhanced or value added census data for clients throughout the United States.

6) Georeference and rectify the scanned aerial and vector data (if necessary) to real-world map projection coordinates in the GIS/image processing system. Vector data may already be rectified if digitized from a planimetric sheet or a topographic quadrangle.

7) Digitize individual trees, as points, from the planimetric sheets and attribute or uniquely identify each tree by address.

8) Associate the tree inventory attributes to field records in the data base with a relational or join program in the GIS. The join program should allow a user to join unique attributes in a vector topological data base to another database as long as there are similar values in both data bases. In short, make sure that your unique attribute is identified and listed in the data base to which you are attaching.

9) Build a point file with an address-match algorithm found in packages such as ARCVIEW. Residential and commercial addresses in the housing data base are matched with or attached to the appropriate census street address file index. An address-match program will associate address records in the housing data base with the address values inherent in the census street file data base.

10) Overlay the data sets and query the census/housing data to illustrate correlations.
    a. "Do heavily forested urban areas have more criminal activity than non-forested areas?"
    b. Assess property values of homes and average household worth for a given neighborhood to determine whether trees areas increase property values.

    c. Assess and reallocate tree maintenance efforts on a large regional scale. Home owners may take better care of their landscape than do renters, therefore, city foresters or planners can concentrate maintenance efforts and resources in rental areas rather than owner occupied dominated areas.

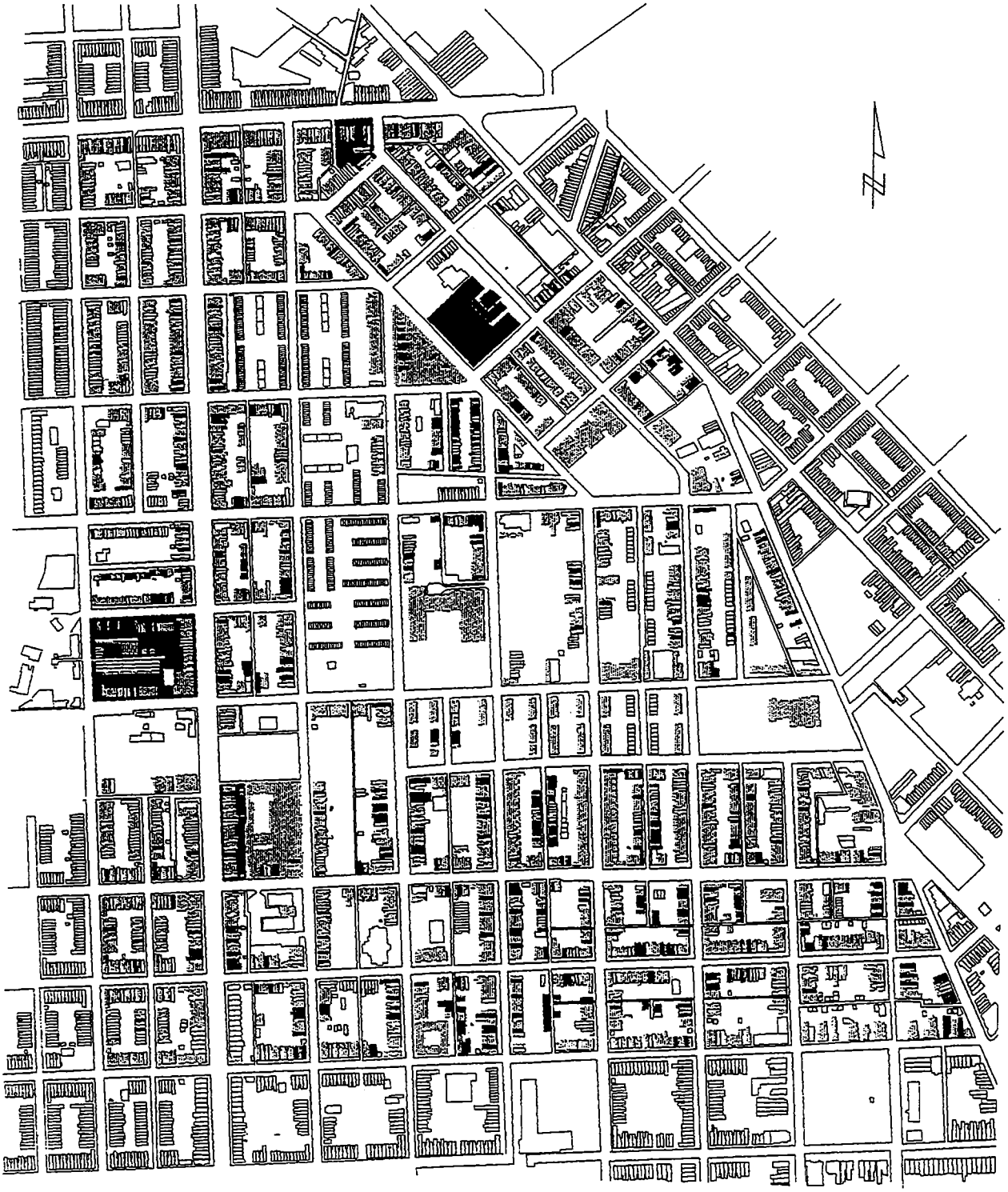
11) Save the results for presentation in a GIS data base.

B. See Regional Analysis \ Social objectives for additional objectives. Data sets of larger scale should be used for Community Analysis programs.

Figure #17, Sandtown-Winchester Rentals vs. Vacant building structures (Enterprise Foundation, 1993) is illustrated on the following page.

Sandtown - Winchester

Rental and Vacant Property Distribution



0 200 400

Scale in meters

Vacant Units

Rentals

Sandtown Winchester Community

E. Present the Results

The results of the analysis can be presented in a video or document format with illustrations depending upon the display and printing capabilities of the GIS/image processing or CADD software that you are using. GIS and CADD systems support a variety of printers and plotters. Please refer to the technical manual of the software in order to determine compatible printing and plotting devices. Various types of thermal, paintjet, or laserjet printers and electrostatic, paintjet, or pen plotters can be used to generate different fonts and colors of text and imagery. Typically, printers are used to print small documents or images (Paper size A to C), while plotters plot to large paper media (Paper sizes A - E).

Paper Sizes
A = 8.5" x 11"
B = 8.5" x 14"
C = 11" x 17"
D = 24" x 36"
E = 34" x 42"

Thermal printing technology uses a thermal heating filament to heat a color ribbon element that applies color to the output paper. Printers with thermal printing capabilities are manufactured by companies such as Tektronix, Mitsubishi, Calcomp, Xerox, and Shinko. Dye-sublimation printing involves a thermal heating transfer process that produces a high quality, almost photographic, image resolution which is much better than other thermal output devices with the same resolution. Mitsubishi and Shinko produce dye-sublimation color printers for use on personal computers and unix-based workstations. Paintjet or inkjet printing devices consist of printing cartridges and guns that apply black and white or colored ink to paper-based media. After printing, the ink on the paper must be allowed to dry for a few minutes. A laserjet device, both color or black and white, contains a metal drum that is electrified with a fixed charge which represents the characters to be typed. A laser then transfers the charge to the toner which creates text or images on the paper media. Hewlett-Packard is the renown leader in paintjet, inkjet, and laserjet technology.

Electrostatic and pen plotting devices plot or draw CADD or GIS generated text, drawings, or images to large size paper media. An electrostatic device applies an electrical charge, which corresponds to the image or drawing to be plotted, directly to the paper, mylar, or velum media. The charged media is then scrolled through the plotter to the monochrome or color toner cartridges. When the toner comes in contact with the charged media, the drawing or image is plotted. Environmental conditions have to be strictly controlled in order for an electrostatic plotting device to work properly. Generally, room temperatures need to be about 65-70 degrees Fahrenheit with approximately 60% humidity. Versatec and Calcomp are companies that produce electrostatic plotters. Pen plotters utilize colored drawing pens to draw vector or CADD drawings or text onto paper, mylar, or velum. Pen plotters can not draw or plot images. Paintjet plotters, such as NovaJet, apply paintjet technology to large format printers. Large format paintjet printers plot color and monochrome images and drawings, but color image plotting uses extensive amounts of color toner.

In addition to printing and plotting, video graphic array's (VGA computer screens) can be projected onto a wall or screen in order to demonstrate the results of a project in real time. The ability to project an image from the computer depends upon the display adapter or controller card that is used. The video card must have a connecting port compatible with the display projector. See Appendix C for a manufacturer listing of compatible projectors and display adapter cards.

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GLOSSARY

-A-

address-matching - The process of linking address-based database files to street-address vectors and creating points illustrating the location of the linked addresses.

airvideography - Use of vertical aerial video images to manage natural resources.

ARC/INFO - A vector based GIS system produced by the Environmental Systems Research Institute.

ASCII - American Standard Code for Information Interchange. 256 characters used as a computer's alphabet.

AutoCAD - A computer aided design software package produced by AutoDesk.

AVHRR - Advanced Very High Resolution Radiometry from NOAA satellites.

-B-

bilinear interpolation - A mathematical method for interpolating a new cell's value within a 2 x 2 neighborhood of cells.

binary - A base 2 number system that uses only data values 0 and 1.

binary raster - A raster whose cells contain only values 0 or 1.

biomass - The amount of plant material per unit of ground area, recorded either as dry or fresh weight.

bit - A single value, either 0 or 1.

board - A controller or electronic circuit board that can be installed into a personal computer.

byte - A data element consisting of 8 bits and having 256 possible values.

byte-oriented - Each cell is represented with one byte of information or 8 bits per cell. 256 possible data values can occur per pixel.

-C-

CADD - Computer Aided Drafting and Design.

classification - Clustering cells from coregistered rasters according to an image feature type.

clustering - The grouping of multiple, overlapping, georeferenced rasters into a single raster.

control points - Reference points that register rasters, vectors, CADD files, and databases together or to a geographic position.

cubic convolution - A resampling process in which a new cell value is determined by applying a cubic polynomial surface to a 4 x 4 neighborhood of cells.

cursor - A shape on a monitor that indicates the position of a cursor device (e.g., a mouse or digitizer).

-D-

database - A computerized tabular array of lines or records and columns or fields.

DEM - Digital Elevation Model.

digitizer - A device that converts an analog signal to a digital signal.

display board - An electronic circuit board installed in a microcomputer that translates the computers display data into signals for the monitor.

display histogram - A graph or chart that depicts the occurrence of data values in a raster display plotted with the range of possible data values.

DLG - Digital Line Graph. USGS topographic quadrangles are digitized into DLG format.

DOS - Disk Operating System. Provides management utilities for the personal computer.

driver - A set of computer commands that control an input or output process written for a particular hardware device.

-E-

ERDAS - Earth Resources Data Analysis System. A raster oriented microcomputer image processing and GIS system.

export - Transfer a file to another file format.

-F-

file - A digitally stored collection of related material or data.

file format - A defined pattern for computer files so that programs can be utilized efficiently.

frame-grabbing - The process of extracting raster images from video with a compatible video framegrabbing interface controller or adapter card.

fuzzy C-means - An unsupervised classification or clustering process developed by Robert Cannon.

-G-

GIS - Geographic Information System. A GIS is designed to collect, manipulate, manage, interpret, and analyze geographically referenced datasets, attributes, and databases.

GRASS - Geographic Resources Analysis Support System public domain GIS software package produced by the US Army Corps of Engineers' Construction Research Lab in Urbana, IL.

-H-

histogram - A graph of the number of times a value occurs over a range of possible values.

-I-

importing - Decoding data values of raster, vector, CADD, text, or database file formats into a compatible format.

-K-

K-Means - An unsupervised clustering program. The n-dimensional raster space is divided into K clusters. The clusters are used to determine class membership. After all of the cells are processed, new cluster means are established and the entire process repeats until convergence is achieved.

-L-

Landsat data - The output of a satellite that collects multispectral images.

line - An ordered string of coordinates which define a path in space.

-M-

maximum-likelihood - A supervised image processing routine or algorithm that is applied to multivariable or multispectral imagery. Training sets are applied to entire images with the maximum-likelihood program.

MOSS - Map Overlay and Statistical System developed by the United States Fish and Wildlife Service.

MSS - Multi-Spectral Scanner. Sensing device on the Landsat satellites that collects simultaneous images over multiple ranges of the electromagnetic spectrum.

multispectral images - Images optically acquired in more than one spectral or wavelength interval.

-N-

NAPP - National Aerial Photography Program color infra-red or black and white aerial photos. 1:40000 scale.

nearest neighbor resampling - Resample a source raster to yield a new raster with a different cell size, orientation, and/or internal geometry by computing the distance between the center of each cell in the output raster to the nearest 4 cells in the input raster.

NOAA - National Oceanographic and Atmospheric Administration.

node - A single point defined by a set of coordinates in space.

NWI - National Wetlands Inventory mapping established by the United States Fish & Wildlife Service.

-O-

orthophoto - An aerial photo which has been scanned, rectified, and reconstructed so as to represent its features in a map projection without the geometric distortion and perspective inherent in aerial photos.

-P-

photointerpretation - Analyzing, measuring, and categorizing features from aerial photography.

polygon - A connected series of lines which assemble to form a closed shape.

-R-

RAM - Random Access Memory. Read/write memory for programs and data.

raster - A horizontal array of lines and columns. A single, related, two dimensionally grouped set of numbers of a single data type.

rectification - The removal of geometric distortion from a raster image or a vector drawing.

registration - Geometrically aligning sets of image data such that corresponding features are coincident.

resample - Interpolate cell values in a raster and create a raster with larger or smaller cell sizes.

resolution - The level of detail or sharpness determined by how many pixels are displayed on the monitor.

rubbersheeting - A process by which a raster is stretched to match a new set of geometric constraints.

-S-

scanner - A digitizer that produces a computer image from input material such as aerial photos, maps, documents, plans, etc.

spectral band - A well-defined continuous wavelength range in the spectrum of reflected or radiated electromagnetic energy.

SPOT - The French satellite company Satellite Pour l'Observation de la Terre.

supervised classification - A user supervises the classification by interpreting features interactively. Sample sets are used to train the computer so that the users classification scheme can be applied to multiple coregistered images.

-T-

Terra-Mar - A microcomputer image processing system and GIS.

TIFF - Tagged Image File Format. A commonly used raster format adopted by Microsoft, Aldus, and others to transfer images to and from different software packages.

TM - Thematic Mapper. A sensing device on LANDSAT satellites that stores 7 individual images in spectral bands ranging from the visible to thermal infra-red spectrum.

-U-

unsupervised classification - Using pixel clustering algorithms, a user can automatically classify multispectral imagery without interacting with the data. The computer performs statistical calculations based upon pixel cell similarities and the number of classes chosen.

-V-

vector - A line with a distance and direction.

-W-

warping - A process in which a vector is differentially stretched so as to alter its internal geometry.

APPENDICES

Appendix A - Data Sources

Federal Government

National Aerial Photography Program (NASA)
NAPP photos are an excellent low cost medium scale photographic medium.

Sioux Falls-ESIC
U.S. Geological Survey
Sioux Falls, SD 57198

National Aeronautics and Space Administration (NASA)
NASA has multispectral photography for some regions of the country, especially those that have just experienced a natural disaster.

400 Maryland Avenue, SW
Washington, DC 20546
202-453-1000

National Oceanic and Atmospheric Administration (NOAA)
NOAA has digital vector data of coastal and maritime dominated areas in addition to National Geodetic information systems.

National Geodetic Information Branch
N/CG174 Rockwell Bldg.
Room 24
National Geodetic Survey
NOAA
Rockville, MD 20852
(301)443-8631

National Geophysical Data Center
NOAA E/GC3
325 Broadway
Boulder, CO 80303
(303)497-6376

Washington Science Center
Building 5
6010 Executive Blvd.
Rockville, Maryland 20852

Tennessee Valley Authority
Tennessee Valley Authority Geographic Information System
Tennessee Valley Authority
Mapping Services Branch Map
Information Unit
200 Haney Bldg.
Chattanooga, TN 37401

United States Department of Commerce
The Census Bureau provides demographic data and street or TIGER files on CD-ROM. These are valuable when performing socio-economic analysis.

Bureau of the Census
Data User Services Division
Customer Services
Washington, DC 20233
(301)763-4100

United States Fish and Wildlife Service
The USFWS has several wildlife, range management, water quality and wetland publications available for reference. National Wetland Inventory Maps have been digitized for the majority of the country.

U.S. Fish and Wildlife Service
National Wetlands Inventory
9720 Executive Center Dr
St. Petersburg, FL 33702
(813)893-3624

Migratory Bird and Habitat Research Lab
U.S. Fish and Wildlife Service
Laurel, MD 20811
(301)498-0329

U.S. Fish and Wildlife Service
National Ecology Center
2627 Redwing Rd
Creekside One
Fort Collins, CO 80526-5363
(303)226-9363

Cornell Laboratory of Ornithology
159 Sapsucker Woods Rd
Ithaca, NY 14850
(607)254-2414

United States Forest Service
The USFS may have accurate digital or hardcopy forest stand mapping, terrain data, orthophotos, or other base mapping information on urban forests available for your study area.

Forest Service
Washington Office
Engineering Staff
PO Box 96090
Washington DC 20090-6090
(202)453-9426

Alaska Region
Federal Office Building
P.O. Box 21628
Juneau, AK 99802
907-586-8863; FTS 586-8863

Eastern Region
310 Wisconsin Avenue
Milwaukee, WI 53203
414-297-3693; FTS 297-3693

Intermountain Region
324 25th Street, Federal Building
Ogden, UT 84401
801-625-5605

Northern Region
Federal Building
P.O. Box 7669
Missoula, MT 59807
406-329-3511

Pacific Northwest Region
319 SW Pine Street, P.O. Box 3623
Portland, OR 97208
503-326-3625

Pacific Southwest Region
630 Sansome Street
San Fransisco, CA 94111
415-705-2870

Rocky Mountain Region
11177 West Eighth Avenue, P.O. Box 25127
Lakewood, CO 80225
303-236-9427

Southern Region
1720 Peachtree Road NW
Atlanta, GA 30367
404-347-4177

Southwestern Region
517 Gold Avenue, SW
Federal Building
Albuquerque, NM 87102
505-842-3292

United States Geological Survey
US Geodata sets including digital elevation models, land use/land cover, digital line graphs, and geographic names database can be obtained from the U.S.G.S. In addition, NAPP photography, satellite image maps, and orthophotos can also be obtained. Below is a listing of regional offices who may be able to assist your digital needs.

Anchorage-ESIC
4230 University Drive, Room 101
Anchorage, AK 99508-7011
907-786-7011; FTS 868-7011

Anchorage-ESIC
Room G-84
605 West 4th Avenue
Anchorage, AK 99501
907-271-2754; FTS 868-2754

Denver-ESIC
169 Federal Building
1961 Stout Street
Denver, CO 80294
303-844-4169; FTS 564-4169

Lakewood-ESIC
Box 25046, Federal Center, MS 504
Building 25, Room 1813
Denver, CO 80225-0046
303-236-5829; FTS 776-5829

Menlo Park-ESIC
Building 3, MS 532
345 Middlefield Road
Menlo Park, CA 94025
415-329-4309; FTS 459-4309

Reston-ESIC
507 National Center
Reston, VA 22092
703-860-6045; FTS 959-6045

Rolla-ESIC
1400 Independence Road
Rolla, MO 65401
314-341-0851; FTS 759-0851

Salt Lake City-ESIC
8105 Federal Building
125 South State Street
Salt Lake City, UT 84138
801-524-5652; FTS 588-5652

San Francisco-ESIC
504 Custom House
555 Battery Street
San Francisco, CA 94111
415-705-1010; FTS 465-1010

Sioux Falls-ESIC
EROS Data Center
Sioux Falls, SD 57198
605-594-6151; FTS 753-7151

Spokane-ESIC
678 U.S. Courthouse
West 920 Riverside Avenue
Spokane, WA 99201
509-353-2524; FTS 439-2524

Stennis Space Center-ESIC
Building 3101
Stennis Space Center, MS 39529
601-688-3544; FTS 494-3544
Washington, DC-ESIC

United States Soil Conservation Service

The USDA's Soil Conservation Service is in the process of converting all of their soil maps into a digital format. Please check with your local SCS office to see if your area has been completed. If not, then your local SCS office has several soil mapping and associated soil information publications that can be used as a reference. The following reference may be contacted directly to inquire about digital soil data.

Soil Conservation Service
National Cartographic Center
501 Felix St.
Fort Worth, TX 76115
(817)334-5559; FAX (817)334-5290

Soil Conservation Service
Resources Inventory Division
PO Box 2980
Washington, DC 20013
(202)447-4530

State Governments (Check your local listings)

Arizona

Arizona Land Resource Information
Arizona State Land Department
State Land Office
1624 W. Adams St., Room 302
Phoenix, AZ 85007
(602) 255-4061

Arizona Wildlife Data
Arizona Game and Fish Department
2222 West Greenway Road
Phoenix, AZ 85023
(602)942-3000

Arizona Traffic Data
Arizona State Department of Transportation
Information Systems Group
217 South 17th Ave.
Phoenix, AZ 85023
(602)255-7300

California

California Natural Diversity Database
California State Department of Fish and Game
Natural Diversity Database
1416 Ninth St, 12th Floor
Sacramento, CA 95814
(916)322-3812

California Transportation Data
California State Department
of Transportation
Planning Division
PO Box 942874; 1130 K Street
Sacramento, CA 94274-0001
(916) 445-8238

Colorado

Colorado Automated Mapping System
Colorado Department of Local Affairs
Planning Division
Denver, CO 80203
(303) 866-2351

Delaware

Delaware Geographic Information System
Delaware Department of Natural Resources/Wetlands
89 Kings Highway, PO Box 1401
Dover, DE 19903
(302)736-4793

Florida

Florida Resources and Environmental
Analysis Center
NCIC Coordinator, J. Anderson
361 Bellamy Bldg.
State University
Tallahassee, FL 32306-4015
(904) 644-2882

Georgia

Georgia Atlas
Geovision, Inc.
5680 Peachtree Parkway
Suite B
Norcross, GA 30092
(404) 448-8224

Georgia Department of Community Affairs
State Information Sources
NCIC Coordinator, M. Adams
100 Peachtree St
1200 Equitable Bldg,
Atlanta, GA 30303
(404) 656-5527

Hawaii

Hawaii Department of Planning and Economic Development
250 South King St
Honolulu, HI 96813
(808)548-3042

Idaho

Idaho Department of Water Resources
450 West State St.
Boise, ID 83720
(208) 334-4440
or

1301 N. Orchard St.
Boise, ID 83720
(208) 327-7900

Idaho State Department of Fish and Game
600 Walnut Street
PO Box 25
Boise, ID 83707
(208) 334-9098

Soil Conservation Service
Soils Division/Carto-GIS Lab
304 N. St., Room 345
Boise, ID 83702
(208) 334-1525

Illinois

Illinois Geographic Information System
Department of Energy and Natural Resources
Natural History Survey Division
172 Natural Resources Bldg./607 E. Peabody Dr.
Champagne, IL 61820
(217)244-2111

Kentucky

Kentucky Natural Resource Information System
Kentucky Natural Resources and
Environmental Protection Cabinet
Capital Plaza Tower
14th Floor
Frankfort, KY 40601
(505)564-5174

Louisiana

Louisiana Areal Resource Information System
Louisiana Office of State Planning
Louisiana Areal Resource
Information System
PO Box 94095
Baton Rouge, LA 70804
(504) 342-7410

Maine

Maine Geographic Information System
University of Maine Resource Information
Management and Spatial Analysis Laboratory
College of Forest Resources
Orono, ME 04469
(207)581-MAPS

Maryland

Maryland Automated Geographic Information System
Maryland Department of State Planning
Geographic Information Systems -
Office of Planning Data
301 West Preston Street
Baltimore, MD 21201-2365
(301)225-4450

Massachusetts

Massachusetts Geographic Information System
MASS-GIS Project
80 Boylston St., Suite 955
Boston, MA 02116
(617) 727-6930

Minnesota

Minnesota Land Management Information System
Minnesota State Planning Agency
Metro Square Bldg., Room LL-65
7th and Roberts Streets
St. Paul MN 55101
(612) 296-1202

Mississippi

Mississippi Automated Resource
Information System (MARIS)
Mississippi Research and Development Center
Geographic Information Systems Division
3825 Ridgewood Road
PO Drawer 2470
Jackson, MS 39211-6453
(601) 982-6128

Missouri

Missouri Geographic Information System
University of Missouri
Geographic Resources Center
Columbia, MO 65201
(314)882-3617

Missouri Fish and Wildlife Information System
U.S. Fish and Wildlife Service
Ecological Services
(ES, Columbia)
705 Hitt St, PO Box 1506
Columbia, MO 65205
(314) 875-5374

Nebraska

Nebraska Center for Advanced Land Management Information Technologies
University of Nebraska Institute of Agricultural and Natural Resources
Conservation and Survey Division
901 N. 17th Street, 113 Nebraska Hall
Lincoln, NE 68588-0517
(402)472-3471

Nebraska Natural Resources Division
Nebraska Natural Resources Commission
Data Bank Section
301 Centennial Mall South
PO Box 94876
Lincoln, NE 65809
(402) 471-2081

New Jersey

New Jersey Geographic Information System
New Jersey Department of Environmental Protection
Office of Science and Research
401 E. State St.
Trenton, NJ 08625
(609)984-2243

New Mexico

New Mexico Natural Resource Information System
New Mexico Department of Natural Resources
408 Galisteo St, Villagra Bldg.
Santa Fe, NM 87503
(505) 827-7830

New York

New York Land Use and Natural Resource Inventory
New York Department of Commerce
99 Washington Ave
Albany, NY 12245
(518) 474-7721

Cornell University
Soil Information Systems Lab
Bradfield Hall
Ithaca, NY 15853
(607) 255-2278

North Carolina

North Carolina Land Resource
Information Service
Department of Natural Resources
and Community Development
Center for Geographic Information
and Analysis (CGIA)
PO Box 27687
Raleigh, NC 27611-7687
(919) 733-2090

Oklahoma

Oklahoma Geographic Information Retrieval System
Oklahoma State University
Center for Applications of Remote Sensing
111 Thatcher Hall
Stillwater, OK 74078
(405)624-5178

Rhode Island

Rhode Island Statewide Geographic Information System
University of Rhode Island
Natural Resource Sciences
Kingston, RI
(401)792-2370

South Carolina

South Carolina Natural Resources
Information System
University of South Carolina
Computer Services Division
Digital Mapping Services
1244 Blossom St
Columbia, SC 29208
(803) 777-7366

Texas
Texas Natural Resources Information System
Texas Department of Water Resources Systems
Central
Box 13231 Capital Station
Austin, TX 78711-3231
(512) 475-3321

Virginia

Virginia Commonwealth Data Base
Virginia Polytechnical Institute
Department of Geography
Blacksburg, VA 24061
(703) 961-5841

Washington

Washington State Department of
Natural Resources
Information Management Division
1102 South Quince St, EV-31
Olympia, WA 98504
(206)753-1262

Washington State Department of Wildlife
600 N. Capital Way, GJ-11
Olympia, WA 98504-0091
(206) 583-2755

Washington State Department of Transportation
Cartography Section
Transportation Building
Room 1B18, MS, KF-01
Olympia, WA 98504
(206)753-7050

Please check your local listings for state agencies such as:

Department of Natural Resources

Department of Transportation

Department of Planning or Tax Assessments

Department of Information Systems or GIS/Mapping

Local Government (Check your local listings)

Planning Department

Engineering Department

Public Works Department

Natural Resource Department

Development Review Department

Local Forester

Commercial Businesses (Check your local listings)

Earth Observation Satellite Observation Company (EOSAT) - Landsat Data

Digital Imagery and Maps:
EOSAT (Earth Observation Satellite Company)
4300 Forbes Blvd. Lanham, MD 20706

Image Maps
United States Geological Survey
503 National Center Room 1-C-402
Sunrise Valley Drive, (703) 648-6892.

Cost: Full Scene 185km x 170km (Raw Data) = $4,500.00 (as of Feb. 1993). With the advent of recently proposed legislation, the price for digital satellite data from EOSAT may decrease dramatically. Contact EOSAT or your local congressman for further information.

The Landsat satellite program, which began in 1972, includes Multispectral Scanner (MSS) data, and Thematic Mapper (TM) data. In the early '70's, Landsat's 1,2,& 3, recorded MSS imagery with a swath path of approximately 185 km from an altitude of 705 km. The spatial resolution of the MSS scanner sensors are approximately 79 x 79 meters. However, the actual resolution may be 57m x 79m. MSS imagery has a spectral resolution of four bands.

Band 1: Green, .5 microns (um) to .6 um. This band, within the visible portion of the electromagnetic spectrum, is good for mapping healthy vegetation and large water bodies.

Band 2: Red, .6 um to .7um. Band 2, also within the visible spectrum, is effective in determining vegetation differences, soil boundaries, and geological variances.

Band 3: Reflective Infrared, .7 um to .8 um. This band is used primarily for crop identification and land/water differences.

Band 4: Reflective Infrared, .8 um to 1.1 um. Good for vegetation identification and penetrating particulates in the atmosphere.

The Landsat Thematic Mapper (TM) data has a better spatial, spectral, and radiometric resolution than MSS data. The spatial resolution of TM data is 30 meters per pixel, with the exception of Band 6 (the thermal band), which has a spatial resolution of 120 meters per pixel. However, in order to standardize the spatial resolution, EOSAT resamples the pixel cell size of the thermal band to equal 30 meters. This provides a uniform spatial resolution throughout the TM dataset or scene. The radiometric resolution of each pixel is 8-bit, which means that 256 possible data values are available per pixel. Finally, there are 7 multispectral bands located in a Landsat scene; therefore, TM data has a spectral resolution of seven.

Band 1: Blue, .45 um to .52 um. This visible band is succeptable to atmospheric particulate diffusion or image blurriness. However, this band is good for mapping forest cover, soil and vegetation dynamics, and coastal areas.

Band 2, Green .52 um to .60 um. Again, this is a visible light band and is succeptable to particulate diffusion in the atmosphere. It is primarily used for assessing and mapping wild vegetation and agricultural crop vitality or health.

Band 3, Red .63um to .69 um. Subject to atmospheric diffusion or image blurriness, this band is useful for determining plant species, soil and geological boundaries, and social/political or cultural features.

Band 4, Reflective Infrared, .76 um to .90 um., This band is not subject to atmospheric diffusion, and is primarily used for crop and plant identification as well as biomass assessments.

Band 5, Middle Infrared, 1.55 um to 1.74 um. This band is not subject to atmospheric diffusion, and is used for determining drought conditions because it is sensitive to water concentration levels in plants.

Band 6, Thermal Infrared, 10.4 um to 12.5 um. This band measures the thermal conditions resulting from vegetation stress, pollution, human or geologically related activity. This band may be incorporated to assess urban heat-island effect in cities throughout the world.

Band 7, Mid-Infrared, 2.08 um to 2.35 um. Band 7 is utilized to measure soil moisture, soil differentiations, and physical relief.

SPOT Image Corporation (SPOT) - SPOT Data
SPOT Image Corporation
1897 Preston White Drive Reston, VA 22091-4326

Cost: (Prices good as of Feb. 1993.) Panchromatic Full Scene (60 km x 60 km) raw data is $2,450.00; Multispectral Full Scene (60 km x 60 km) raw data = $2,450.00.

The SPOT satellites, the first of which was launched in 1986, records spectral imagery in panchromatic (PAN) and multispectral (XS) formats. SPOT panchromatic imagery has a spatial resolution of 10 meters per pixel and a spectral resolution displaying one broad band. This band provides greater accuracy to the user when used visually to interpret features on the Earth's surface or when combined with resampled XS multispectral data for supervised and unsupervised classification procedures (See 2.4 Analysis, pp 35-39). XS SPOT data is multispectral (3 bands) and has a spatial resolution of 20 meters per pixel. The XS data can be used to interactively or automatically classify features on the Earth's surface. Both the SPOT PAN and XS data have a radiometric resolution of 8 bits (0 -255 pixel values). In addition, SPOT data can be acquired in streographic pairs, so that GIS/image processing systems can generate topographic (elevation) and planimetric (horizontal) maps.

SPOT XS Multispectral Data (20 meter)

XS BAND 1 - Green band (spectral resolution in the electromagnetic spectrum = .50-.59 um) Examines the healthiness of vegetation.

XS BAND 2 - Red band (spectral band = .61-.68 um.) Delineates plant species and can determine soil and geologic/physical relief boundaries.

XS BAND 3 - Reflective Infrared (spectral band =.79-.89 um.) Assesses biomass and is used to identify crops, soil types, and land use.

SPOT PAN Panchromatic Data (10 meter)

PAN - A single band with a spectral resolution .51 to .73 um. Panchromatic imagery is used to visually interpret features on the Earth or it is combined with other statistically resampled multispectral data sources to provide greater levels of accuracy.

American Digital Cartography
3003 W. College Ave.
Appleton, WI 54914
(414)733-6678

Donnelly Marketing Information Services
70 Seaview Ave.
Stamford, CT 06902

ETAK, Inc.
1430 O'Brien Dr
Menlo Park, CA 94025
415-328-3825
GPS Technology Corporation
11999 Katy Freeway, Suite 320
Houston, TX 77079
713-558-6418

Hunter GIS, Inc, (GIS-Video)
1121 Wood Ridge Center Dr
Suite 170
Charlotte, NC 28217
(704)525-8620

Also Check:
Utility Companies or Commissions - Phone, Gas & Electric, Sewer/Water
Aerial Survey Companies

Appendix B - Software Products

CADD

Autocad

Autodesk
2320 Marinship Way
Sausalito, CA 94965
415-332-2344

MicroStation

Intergraph corp.
One Madison Industrial Park
Huntsville, AL 35807
205-772-2000

GIS/GPS

Environmental Systems Research Institute (ESRI)
380 New York Street
Redlands, CA 92373
714-793-2853

MicroImages
201 N. 8th Street
Suite 15
Lincoln, NE 68508-1347
402-477-9554

Facility Mapping Systems
38 Miller Ave., Suite 11
Mill Valley, CA 94941

ERDAS
2801 Buford Highway
Suite 300
Atlanta, GA 30329
404-248-9400

Terra-Mar Resource Information Service, Inc.
1937 Landings Drive
Mountain View, CA 94043
800-727-4899
415-964-6900

Tydac Technologies
1655 N. Fort Myer Drive
Suite 320
Arlington, VA 22209
703-522-0773

PCI Remote Sensing
1925 N. Lynn Street
Suite 803
Arlington, VA 22209
703-243-3700

MapInfo
Hendrick Hudson Building
200 Broadway
Troy, NY 12180
518-274-8673

Atlas GIS
Strategic Mapping Inc.
4030 Mogrpark Ave., Suite 250
San Jose, CA
408-985-7400

IDRISI
Clark University
Graduate School of Geography
Worcester, MA 01610
508-793-7526

Trimble Navigation (GPS)
645 N. Mary Avenue
P.O. Box 3642
Sunnyvale, CA 94088-3642
408-730-2900

Magellan Systems Corp.
960 Overland Ct
San Dimas, CA 91773
714-394-5000

Appendix C - Computer Hardware Companies

CPU DEVICES

AST Computer Corp.
1-800-876-4AST

NEC Computers
1-800-NEC-INFO

DELL
1-800-433-7305

GATEWAY 2000
1-800-846-2063

ZEOS Systems
1-800-554-7172

COMPAQ
1-800-888-5807

MONITORS

PHILLIPS
1-800-835-3506

NEC Monitors
1-800-374-8000

SAMSUNG
1-800-933-4110

TATUNG
1-800-829-2850

VIEW SONIC
1-800-888-8583

PRINTER/PLOTTERS

ENCAD NOVAJET II
1-800-356-2808

HP DESIGN JET 650C
1-800-851-1170

CALCOMP
714-821-2000

RASTER GRPAHICS
1-800-441-4788

DIGITIZERS

GTCO
410-381-6688

CALCOMP
1-800-458-5888

HITACHI
1-408-747-0777

KURTA
1-800-445-8782

SCANNING DEVICES

TANGENT ENGINEERING
303-799-6766

HOWTEK
603-882-5200

HEWLETT PACKARD
1-800-SCANJET

TAPE DRIVE DEVICES

EMERALD SYSTEMS
619-1994

DISPLAY PROJECTORS

SHARP
1-800-642-2122

DISPLAY ADAPTERS

METHEUS
1-800-638-4387

TARGA
410-523-7330 (Comp-Tron)

VIDEOVGA
410-523-7330 (Comp-Tron)