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SYNTHESIS REPORT

URBAN TREE CANOPY ASSESSMENT: A Community's Path to Understanding and Managing the Urban Forest

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SUMMARY

An Urban Tree Canopy (UTC) assessment, which provides a measure of a community's tree canopy cover, is important for understanding the extent of a community's forest or tree resource. UTC assessments are often used for establishing and implementing municipal tree canopy goals as part of broader urban greening and sustainability initiatives.

Most useful when it is combined with other information—such as the extent of impervious surfaces, socioeconomic and health data, traffic density, and heat island maps—UTC assessment contributes to broader urban greening goals, enabling communities to craft management plans and make policy decisions to optimize benefits from urban forests.

This report provides an overview of the approaches, methods, and data sources used in UTC assessments, focusing on the initial steps of project planning, assessment, and analysis. The report also provides general guidelines for conducting UTC assessments and analysis to ensure useful, quality results that can be applied in management and decision-making efforts, and resources for planning and implementing the UTC assessment process. The report is designed to help personnel involved in urban natural resource planning move forward with UTC project planning and assessment.

CONTENTS

INTRODUCTION

Urban Tree Canopy is the leafy, green, overhead cover from trees that community groups, residents, and local governments maintain in the landscape for beauty, shade, fruit production, wildlife habitat, energy conservation, stormwater mitigation, and a host of public health and educational values.

In its most basic form, a UTC assessment provides a measure of a community's tree canopy cover as a percentage of the total land area and serves as a baseline for setting tree canopy goals and measuring progress. Communities assess their tree canopy to determine the extent of their tree resources at various scales or by location, ownership, neighborhood, watershed, zoning, or land use. A UTC assessment is most useful when it is analyzed with other data layers, such as impervious surfaces, socioeconomic information, traffic density, and heat island maps.

In this report, the term "UTC project" is used to describe a comprehensive approach to a UTC assessment—one that includes project planning and goal setting, a UTC assessment and subsequent analysis, implementation of UTC goals through various activities, and continual UTC monitoring and project evaluation. As part of a broader UTC project, a UTC assessment enables communities to craft management plans and make policy decisions to optimize benefits from the urban forest. It can also provide foundational information for meeting specific sustainability goals and objectives.

When thoughtfully planned and implemented, a UTC project can take a community beyond simple tree canopy targets to strategic, focused planting that aligns with other critical social, environmental, and economic goals.

Beyond the Assessment

A UTC assessment provides strategic information for setting overall goals and priorities associated with a locality's tree canopy growth and management. Daily management of the tree resource requires additional data and tools. Tree inventories and on-the-ground assessments are critical for determining tree species diversity, tree size, and tree condition, for example, and interactive tools can help tree stewards and residents engage in tree care activities and report concerns.

Brief History of UTC Assessments

In 2003, the Forest Service, an agency of the U.S. Department of Agriculture (USDA), funded a study of the City of Baltimore's UTC conducted by the Maryland Department of Natural Resources using satellite imagery with 1-meter (m) resolution. (Irani and Galvin 2003). The data were combined with the city planning department's geographic information system (GIS) to illustrate how Baltimore's overall 20 percent canopy cover was distributed across neighborhoods, zoning classifications, and land use types (residential, commercial, transportation corridors, and others). Existing and possible UTCs were identified for the first time at a parcel level and in a format and resolution that could be used to direct planning and planting priorities based on community capacity for stewardship and other considerations (Locke and others 2013).

This information was used by the city to develop a prioritized tree planting plan and set a tree canopy goal of 40 percent by 2030 as part of Baltimore's 2009 Sustainability Plan. A mayor's initiative, formed with multiple city agencies and nonprofit organizations, has successfully galvanized public interest and participation to achieve the goal (Locke and Grove 2016).

With this Baltimore study, a new UTC assessment industry was born. Assessments were conducted by the Forest Service in Washington, DC, New York City, NY, and Philadelphia, PA, in each case resulting in city-elected officials establishing a tree canopy goal for their municipality. The accuracy of tree canopy quantification steadily improved with the application of object-oriented classification and the addition of light detection and ranging (LiDAR) technology advanced by the University of Vermont Spatial Analysis Laboratory that separates trees from shrubs and includes trees in shadow. For example, repeated analysis using this newer method showed that the original Baltimore canopy cover was closer to 27 percent rather than 20 percent (O'Neil-Dunne 2009).

From 2006 through 2012, studies were replicated throughout the ecologically sensitive Chesapeake Bay Watershed and in cities across North America.[1] These data also enabled novel scientific inquiry into the social correlates of tree canopy on private residential land and a discovery of the importance of lifestyle in explaining the spatial distribution of this critical natural resource (Troy and others 2007).

The private sector became involved in applying UTC assessment technology around 2010. Engaging with innovative local government officials, consultants experimented with combining UTC assessments with i-Tree modeling tools (**www.itreetools.org**) to inform local planting priorities. The gears were set in motion to prioritize and potentially optimize canopy cover based on air quality improvement, carbon capture, stormwater management, and energy conservation goals.

[1] The locations of dozens of assessments can be found at **www.nrs.fs.fed.us/urban/utc**, with the underlying data freely available at **gis.w3.uvm.edu/utc/**. (15 August 2017).

FIVE KEY STEPS TO IMPLEMENTING A UTC PROJECT

1	**PROJECT PLANNING** Set clear goals and strategies for the UTC project.
2	**ASSESSMENT** Complete data collection and classification to obtain current UTC data.
3	**ANALYSIS** Integrate UTC data with stakeholder input and other datasets to answer questions about where to protect, plant, and manage trees for social, environmental, and economic benefits.
4	**IMPLEMENTATION** Develop a suite of products to share UTC information and help inform policies and planning.
5	**MONITORING AND EVALUATION** Implement short- and long-term monitoring to assess tree canopy change and progress in reaching goals.

This Forest Service report focuses on the first three steps of a UTC project: initial project planning, assessment, and analysis, and provides examples to help build an understanding of step 4, implementation. The report also highlights the importance of monitoring tree canopy change and UTC project evaluation—step 5—but does not cover this topic in depth. The report will be most helpful to natural resource practitioners and community organizations that are ready to move forward with a UTC assessment and are in need of a summary of current practices, key UTC project considerations, and insider tips.

STEP 1: PROJECT PLANNING

The purpose of UTC project planning is to provide goals aligned with community needs and values for the UTC. The key to setting goals is the definition of the UTC assessment area in terms of boundaries and land ownerships and incorporating broader community goals such as air and water quality, public health, and livability. Goals are used to form the priorities that guide tree planting and other programs and to inform requests for proposals from contractors when needed to carry out priority projects.

Setting UTC Project Goals

An important first step in conducting a UTC assessment is to establish goals for the project that align with community objectives. Setting goals at the start helps to focus the project and fully maximize the partnerships, datasets, and deliverables that are involved. Ideally, project goals are developed in collaboration with key stakeholders, incorporating broader community needs and values related to considerations such as stormwater management, shading, livability, commerce, environmental equity, and public health.

A common purpose for obtaining UTC information is to set a tree canopy goal for a particular locality. Cities across the United States are embracing tree canopy goals, usually in the form of percent tree canopy, to improve sustainability and livability. UTC assessments are often conducted to establish a baseline UTC measure and to monitor change—and thus progress—towards meeting a municipality's target.

A UTC project can address a number of other community objectives, such as stormwater runoff (or in contrast, frequent drought), adequate access to parks, increasing home values, attracting more visitors to a business district, providing more shade, and/or resilience planning. A list of common UTC project goals is provided in **Box 1**. Later in the report (Step 4: Implementation) we provide details of how specific communities have used UTC data to initiate projects designed to meet some of these objectives.

Having clear goals outlined at the start of the UTC project will help determine the appropriate UTC assessment approach and the complexity or simplicity of the technology employed. Goals will inform the UTC analysis in terms of data needs, level of stakeholder input, expected products, and other project considerations. A common deliverable of a UTC project, for example, is a tree planting prioritization analysis, presented as a map or GIS data layer.

Priorities can be based on a range of factors, including the amount of available planting space, proximity to riparian corridors, opportunities to conserve energy, or safe routes to schools. Knowing and adequately describing UTC project goals at the start of the project is critical to ensuring that desired products are delivered, whether using an outside contractor or performing the work in-house. Articulating goals in narrative to a contractor is key: "We would like a map to use as a baseline for measuring tree canopy by land use and detecting change over the next 10

BOX 1. Examples of Urban Tree Canopy Project Goals

Establish a baseline measure to monitor urban forest canopy cover and change:

- To set policy and goals (e.g., minimum canopy).
- To inform land use and comprehensive planning.
- To develop ordinances.
- To evaluate programs.

Prioritize tree planting efforts in support of:

- Environmental justice.
- Urban heat island mitigation and energy conservation.
- U.S. Environmental Protection Agency voluntary air quality plans (State Implementation Plan).
- Stormwater management.
- Lower crime.
- Economic considerations (e.g., real estate values, retail sales, tourism, commercial districts).
- Community walkability.
- Physical and psychological health.

Develop disaster preparedness, response, and mitigation plans that may include:

- Floodplain conservation to address catastrophic and recurring flooding.
- Debris planning and management.
- Forest recovery and restoration.
- Community resilience.

Support watershed planning with local partners to:

- Enhance forested riparian zones.
- Improve stormwater management (flooding, infiltration).
- Implement forest-to-faucet concepts (connecting water users to the headwaters).
- Enhance regional greenspace and recreation.

Support an Urban Forest Sustainability and Management Audit that:

- Includes a robust inventory and monitoring component.
- Supports Tree City USA and Tree Campus USA designations and program growth awards.

Adapted from: Kimball, L.L.; Wiseman, P.E.; Day, S.D.; Munsell, J.F. 2014. Use of urban tree canopy assessments by localities in the Chesapeake Bay watershed. Cities and the Environment. 7(2): article 9.

years," for example; or, "We would like a map to target tree planting for stormwater management, prioritizing areas of lowest canopy cover."

Identifying the UTC Assessment Area

Identifying the area of interest for a UTC assessment often depends on the objectives and desired outcomes of the UTC project. A UTC assessment can be developed based on environmental boundaries such as watersheds, subwatersheds, or riparian areas. Or, the objective of the UTC project may necessitate using jurisdictional, political, or social boundaries such as voting districts or census block groups. A UTC assessment can be analyzed at different scales at the same time; a statewide UTC assessment, for example, can be evaluated at the State, county, city, town, and parcel levels.

Once the assessment area is defined, it is important to identify the types of geographies, or boundaries, to consider for analysis. The objectives of a UTC project may require that the assessment be conducted using land-use zoning, for example, or parcel boundaries for delineation. Analyzing the landscape across different ownership types—private/residential, commercial, and public, including public rights of way—is essential for meeting urban sustainability goals. Incorporating private land in the assessment is particularly critical because it is the dominant ownership type in urban areas and holds the most opportunity for tree planting, long-term urban forest management, and delivery of ecosystem services.

Developing a Request for UTC Project Proposals

UTC assessments are technically complicated and require dedicated training, experience, and tools that might not be readily available in some communities. In addition, the methodology of UTC assessments (algorithms, software, hardware, and implementation tools) is rapidly changing and becoming more advanced. Many communities turn to UTC experts or contractors for assistance in completing an assessment and for analysis.

Once UTC project goals are established and the study area defined, the desired analysis and final deliverable products can be identified and included in a request for proposals (RFP) for UTC contract work. The UTC assessment RFP provides a baseline of communication between the contractor and the community or contracting agency. The RFP defines project goals, outlines the scope of work, details project requirements and tasks, and identifies deliverables.[2] The RFP may also specify land cover classification methodologies, use of ancillary datasets, and procedures for quality assurance (QA) and quality control (QC).[3] A detailed description of the contractor's land classification process and workflow should be included in a list of deliverables.

The RFP should clearly describe expectations of the contractor as well as a timetable for deliverables and project completion. Ambiguous statements will be problematic for both the contractor and the contracting agency. There are a number of key components in any RFP:

- Clear UTC project objectives.
- A description of the UTC area of interest.
- Data provided to the contractor and metadata requirements **(see Box 2)**.
- QA/QC requirements.
- Desired/required products and deliverables.
- A reliable contact person who will respond to questions from the contractor.

BOX 2. **Metadata**

Metadata describe the content, quality, condition, origin, and other characteristics of data or other pieces of information. Metadata for spatial (geographic information system [GIS]) data may describe and document the subject matter: how, when, where, and by whom the data were collected; availability and distribution information; projection, scale, resolution, and accuracy; and reliability with regard to some standard.

Metadata are associated with properties and documentation. Properties are derived from the data source (e.g., the coordinate system and projection of the data), while documentation is entered by a person (e.g., keywords used to describe the data). There are standard formats for embedding this type of metadata into the GIS data layers.

STEP 2: ASSESSMENT

In its most basic form, a UTC assessment provides a measure of a community's tree canopy cover. The assessment merges information about the location of trees with land cover and land ownership information to provide a picture of the existing tree canopy, usually in the form of a map with canopy quantified as percent cover.

A UTC assessment can also provide information on *possible* tree canopy, or how much space is available for planting in terms of owner, location, neighborhood, zoning, watershed, and/or land uses **(Figure 1)** (Locke and others 2014). "Possible tree canopy" includes all of the non-road, non-building, non-water, non-forested areas—places that can hypothetically support tree canopy. This information can be used to set tree canopy goals and prioritize planting activities.

The UTC assessment is designed to document conditions of the urban forest at one point in time. UTC assessments should be repeated over an appropriate time interval, usually every 5 to 8 years.

UTC Assessment Approaches

Land cover and tree canopy distribution are the central elements of a UTC assessment and are typically determined using remote sensing imagery, including imagery generated from LiDAR data and/or high-resolution digital satellite aerial photographs or satellite images. Understanding the different capabilities and limitations of various types of remote sensing data and land use/land cover classification methods, as well as differences in resolution, costs, and accuracy, is essential to choosing the right set of tools to meet information objectives.

The most common remote sensing approaches used in UTC assessment (data and land classification) are described below:

- **LIDAR MAPPING**. UTC assessments have traditionally used aerial or satellite imagery for mapping. One significant disadvantage of these types of imagery for mapping urban tree canopies is that the shadows of buildings often conceal trees (and possible planting sites), thus negatively affecting UTC accuracy. To account for this limitation and improve accuracy, UTC assessments are increasingly incorporating LiDAR.

  LiDAR detection uses an active laser sensor operated from an airplane or a helicopter. The instrument produces laser pulses that travel to the earth's surface, where they are reflected and returned to the aircraft. Part of the reflected radiation returns to the

[2] A comprehensive **UTC RFP template** developed by Urban Forestry South is available at **www.urbanforestrysouth.org/resources/library/ttresources/urban-tree-canopy-recommended-components-for-an-rfp**. (15 August 2017).

3 See Appendix A in the Treasure Valley, Idaho Urn Tree Canopy Assessment for an example of the QA/QC process: **parks.cityofboise.org/media/901369/2013_Treasure_Valley_UTC_Project_Report-Final_-071013-.pdf**. (15 August 2017).

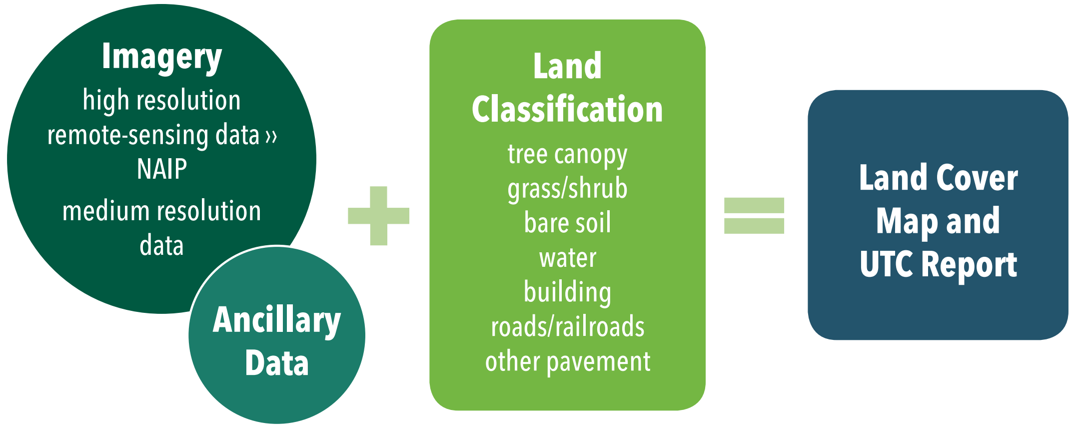

Figure 1. Elements of an Urban Tree Canopy (UTC) Assessment. NAIP = National Agriculture Imagery Program; NLCD = National Land Cover Database.

laser sensor, where it is detected and used to produce a point cloud from which accurate estimates of the height of features can be measured. The advantage of LiDAR is that it essentially sees through shadows, resulting in a more accurate and visually coherent representation of a city's tree canopy. In New York City, for example, LiDAR was used to obtain a more accurate representation of the city's UTC (O'Neil-Dunne and others 2014).

The aboveground height information provided by LiDAR data is useful for distinguishing vegetation from other features, identifying individual tree species, and providing detailed descriptions of tree structure, such as tree height and crown cover. LiDAR can be obtained at the same time as digital photos, and the combined information—rich spectral and accurate height information—is useful for more accurate land cover classification.

Highly accurate, LiDAR has become the gold standard for UTC assessments, but obtaining LiDAR data can be expensive. While LiDAR data may be beyond the budgets of many urban forestry programs, the data have uses far beyond forestry, and many municipalities are acquiring LiDAR for analysis of a range of city services. Urban foresters should consider collaborating with other agencies to share data or create justification for using municipal funds to obtain critical data that crosses program boundaries

- **HIGH-RESOLUTION IMAGERY AND LAND CLASSIFICATION.** With high-resolution land cover classification, land cover features are extracted from high-resolution aerial or satellite imagery using automated techniques that yield an accurate, high-resolution cover map.

High-resolution imagery has a resolution of approximately 1 m (3.3 feet) or smaller, meaning that each image pixel represents an area on the ground 1 m x 1 m or smaller. High-resolution imagery is necessary for locating individual trees.[4] One major advantage of this approach is that it integrates well with GIS, allowing data to be summarized at a broad range of scales from parcel to watershed and analyzed with a range of demographic, infrastructure, and biophysical data.

- **SPECTRAL IMAGERY.** As seen when light passes through a prism, many different colors (wavelengths) make up the spectra of sunlight. When sunlight strikes objects, certain wavelengths are absorbed, and others are reflected or emitted. The unique way in which a given type of land cover reflects and absorbs light is known as its spectral signature. The varying pigments of the leaves, the amount of foliage per square foot, and the age of the plants contribute to the unique spectral signature of different species (NASA 1999).

Most imaging satellites or airborne digital cameras are sensitive to specific wavelengths of light, including infrared wavelengths that cannot be seen with the naked human eye. Multispectral sensors generate data that range from the visible (red, blue, and green) to the near infrared (NIR) portion of the electromagnetic spectrum. Hyperspectral imagery includes hundreds of spectral bands. To differentiate between types of land cover and their attributes, researchers manipulate the colors recorded by the satellite to get the combination of wavelengths that best distinguishes the spectral signature of the land cover they wish to identify. Different types of vegetation have unique

[4] To see the difference between medium-resolution and high-resolution imagery, read how Chelsea, MA, improved its UTC assessment and analysis through use of high-resolution imagery: **www.fs.fed.us/nrs/utc/reports/UTC_Report_Chelsea.pdf**. (15 August 2017).

spectral signatures, and the shape of the reflectance spectrum can be used to distinguish vegetation from other land cover types and to further identify vegetation type—typically trees versus grasses and shrubs—as well as other land use/land cover types (Zongyao Sha and Yu 2008).

One of the most common sources of high-resolution data for remote sensing classification is the 1-m resolution imagery produced by the USDA's National Agriculture Imagery Program (NAIP). This multispectral NAIP imagery consists of four bands of data (the three visible bands and one NIR band). These data are often more accessible to smaller communities than commercial data options.

- **THE NATIONAL LAND COVER DATABASE (NLCD) ANALYSES**. The NLCD includes tree and impervious cover maps (30-m resolution) for the entire contiguous 48 States with percent tree and percent impervious cover estimated for each pixel. These maps and data are available for free and can be loaded into the free i-Tree Vue program to estimate tree cover at a relatively coarse scale.

- **AERIAL PHOTOGRAPHY INTERPRETATION**. Another approach is a "dot grid method," which uses digital aerial images and a series of random points that are interpreted to determine the cover type at each point's center. The presence or absence of tree canopy cover at the specific point position is tallied for each of the sample points, and the proportion of sample points that fall on the tree canopy represents the percentage of urban forest canopy cover in the study area. Aerial photograph interpretation can be very simple to implement—i-Tree Canopy is a free software tool, for example, that can be used free of charge, from anyone's desk **(see Box 3)**. The primary disadvantage of the dot grid method and tools like i-Tree Canopy is that they provide a simple cover estimate and do not produce detailed cover maps.

BOX 3. User-Friendly Tools for Understanding Canopy Cover

There are many software tools available to help in Urban Tree Canopy (UTC) assessment. The following are three examples of free software tools developed by the Forest Service and partners to support UTC projects.

I-TREE CANOPY. i-Tree Canopy uses Google Maps aerial imagery and allows the user to use a random sampling process to easily estimate tree cover and classify ground cover types. i-Tree Canopy is a point-based method, providing a statistical sample rather than a spatially explicit census of the landscape. The user creates a defined project area directly on the online map; i-Tree Canopy then generates random sample points within the project area. Users are able to zoom in on each point and choose from a list of cover types based on the map image. This canopy cover tool can provide excellent accuracy but is only valuable for broad or general information needs, since results are in the simple form of a percent tree cover for the project area and information cannot be reasonably subdivided into different land uses, watersheds, parcels, or other boundaries for a full UTC assessment. **www.itreetools.org**.

I-TREE LANDSCAPE. i-Tree Landscape is a web-based tool that overlaysnational land cover data and available high-resolution imagery with U.S. Census demographic data. Urban forest and city managers, planners, and tree advocates define their area of interest and then explore tree and people interactions with maps and graphs. i-Tree Landscape allows communities of all sizes and anyone interested in maximizing the potential of their urban forests to create maps and summaries that convey information for more effective urban forest management and advocacy efforts. i-Tree Landscape is not designed to replace other assessment tools, but augments them by allowing users to quickly show where the tree canopy is, estimate the services trees provide, and prioritize stewardship efforts based on pertinent demographic data. Results and analysis can help justify further assessment projects or natural resource management actions such as undertaking an i-Tree Eco assessment or a more detailed UTC analysis. i-Tree Landscape supports planning that extends beyond public spaces and truly encompasses all lands including urban and rural forests, including the backyards, commercial landscapes, corporate campuses, and other private ownerships that makeup the majority of the urban forest that falls outside the scope of typical public tree management agencies. i-Tree Landscape supports an across-boundary, landscape-scale approach to capturing the services trees provide regardless of where they have their roots.

TREES AND HEALTH APP. The Trees and Health app delivers a neighborhood-by-neighborhood map of tree cover for 13 U.S. cities. The app is designed to be an easy-to-use online tool to view and analyze such factors as demographic data, traffic-related air quality, and urban heat islands. The app offers a framework for prioritizing at-risk neighborhoods and then estimating the number of trees needed to make a positive impact on the lives of residents. The web tool was developed through empirical research by Portland State University with support from the Forest Service. **map.treesandhealth.org/**.

High-quality, high-resolution aerial photography can also be used to determine tree species in the area of interest and to assess the accuracy of the other remote-sensing UTC methods; accuracy can be increased by adding more points.

High-resolution imagery coupled with LIDAR is the best for an accurate and meaningful UTC assessment and sound decision making at the municipal scale. The coarser the data resolution, the higher the probability that on-the-ground conditions are different from what the data describe. Low- or medium-resolution imagery (30 m) "sees the forest but not the trees." LiDAR technology is the gold standard because of the ability to discern trees and shrubs hidden in shadows. For UTC assessments to monitor change over time, high-resolution imagery and LiDAR are critical.

Ancillary Data

Ancillary data can be used together with remote-sensing imagery to assist in classification and analysis of land cover and distinguish between land cover categories of interest. The use of ancillary data typically results in higher overall map accuracies and is often needed to address specific UTC project goals.

Ancillary data sources include:

- **BUILDING FOOTPRINTS**. Data layers outlining all building footprints can help to distinguish between buildings and other impervious surfaces such as roads, parking lots, and sidewalks.

- **LAND USE MAPS AND PARCEL BOUNDARIES**. Local municipalities often maintain detailed land use classifications as part of parcel records. These maps can be used to determine existing and possible tree canopy in different land use zoning categories such as residential, industrial, open space, and different transportation and right-of-way corridors.

- **FIELD INVENTORIES**. City-based field inventories (such as i-Tree Eco and data provided by the emerging Forest Service Urban Forest Inventory and Analysis program (UFIA) can provide a tree canopy assessment and important ancillary information for high-resolution UTC methods. Field inventories are limited by their cost and the need for field crews, training, access to private property, and continuous resampling for information on canopy change.

Verifying Data and Land Classification Accuracy

It is essential for the UTC project manager or forest professional to understand land classification methods and know how to verify the quality and accuracy of remote imagery assessments (Hartel 2015a). In remote sensing, accuracy reviews are generally performed for the classification process—a review compares the land cover (i.e., the classified image) to an image that is assumed to be correct, such as a high-resolution aerial photo. An error matrix presents a comparison of the value assigned during the classification process to the actual value interpreted from an aerial photo or other type of base imagery.

In addition to an error matrix analysis, the UTC contractor should provide clear information regarding the following issues (Hartel 2015b).

- **MINIMUM MAPPING UNITS (MMU)**. For a given scale, the MMU is the size in map units below which a narrow feature (e.g., a river) is represented by a line, and an area (e.g., a forest stand) is designated by a point. Consequently, an entity such as a forest stand mapped as a point at one scale may be represented as a polygon on a map at a finer scale. Recognition of MMUs is important since the representation of features on a particular map is not unconditional, but rather a feature of map scale, data resolution, and mapping conventions. These issues, which should be identified by the contractor, play a fundamental role in determining the reliability and usefulness of mapping and land cover data for analysis and use in specific decision-making processes.

- **FILLING "HOLES AND GAPS."** Typically, there are "gaps" and other small irregularities in the land classification, and a method has to be adopted to fill them with a classification value and otherwise provide consistency across the entire area of interest. The contractor should provide detailed descriptions of how gaps were filled and other methods used to improve the overall classification quality that leads to "high end-user confidence" (O'Neil-Dunne and others 2014).

- **INTEGRATING ANCILLARY DATA**. As described above, integrating ancillary data into the land classification can often significantly improve the accuracy of classification schemes. The contractor should detail the datasets used and methods for integrating ancillary datasets into the accuracy assessment. Some ancillary data may be useful post-classification for UTC analysis and the development of specific products (e.g., a planting prioritization map for energy savings might use one- and two-story building footprints).

- **POST-CLASSIFICATION EDITING**. Any changes made to the mapping products by the contractor for error correction should be detailed in terms of the number and extent of corrections, as well as the methodology used.

UTC assessment quality is based on a review of the methodology used to conduct the classification and the associated accuracy review, as well as third-party verification. Ideally, the UTC project manager or urban forest professional produces his or her own accuracy review of the classification products and generates an error matrix that can be compared to the error matrix provided by the contractor.

An accuracy review[5] is an important component of a UTC assessment and should be used as a quality check. It can also be used to understand mapping error and its likely causes and implications (O'Neil-Dunne and others 2014). Accuracy should be verified at two levels: the contractor should verify and report accuracy according to methods detailed in the RFP, and an independent or third-party verification should be completed for all accuracy reviews and project deliverables/products.

In addition to accuracy reviews, a UTC assessment report should be evaluated from an overall "does-it-make-sense" quality check. This should be done from the point of view of local users or stakeholders, such as county or municipal officials, planners, urban forestry employees, and residents. The report should be written with clear, nontechnical descriptions of methodology and analysis. The more accessible the information, the more likely it will be used to guide the growth and development of an urban forestry program and support other urban sustainability activities. Examples of UTC assessments and analysis are provided in Step 4: Implementation.

STEP 3: ANALYSIS

A UTC assessment describes where the current and possible urban forest is by ownership or neighborhood, or at political or watershed scales. A *UTC analysis* uses a prioritization method to define the optimal strategy to protect, expand, and manage the future forest to increase economic, ecological, and social benefits for the widest range of beneficiaries. The analysis describes where in the city it is biophysically possible to plant, where it is socially desirable to plant, and where increasing the tree canopy aligns with different stakeholder goals and interests. UTC analyses can also be used to inform the public and policymakers about the extent and importance of the UTC and stimulate incentives and regulations for protecting the resource.

The UTC analysis takes what is learned about the existing canopy cover from the UTC assessment and applies this data to the stated goals and priorities of community residents, agencies, and stakeholders to inform planning decisions and investments.

Integrating Data for Analysis

The ability to integrate UTC data with a wide range of other datasets provides a unique opportunity for goal setting across organizations and agencies. Data integration can help cities direct an effective urban forestry program and set broader sustainability and public health priorities. Obtaining needed datasets may take time due to availability, access, or data quality issues. Datasets that are commonly used in the UTC analysis process include:

- **TOPOGRAPHIC DATA.** Digital elevation models can help to characterize ground topography in the area of focus.
- **HEAT ISLAND MAPS**. The urban heat island (UHI) effect is a common problem of growing cities. In order to measure the effect, UHI intensity is measured as a difference of midnight and noon temperature. Using these measures, hotspots can be mapped and prioritized for tree planting to mitigate UHI effects.
- **POPULATION DENSITY**. Areas with high human population density and low amounts of existing tree canopy are often prioritized for tree planting.
- **SOCIOECONOMIC DATA**. Tree canopy metrics can be combined with neighborhood indicators such as poverty, health, race/ethnicity, and crime rates to prioritize neighborhoods for tree planting initiatives.

[5] These are often termed "accuracy assessments." We refer to this process in this document as an "accuracy review" to avoid confusion with the term "UTC assessment."

- **OTHER HUMAN SYSTEMS**. Property values, home ownership, and other data can be used to prioritize tree planting locations.
- **WATERSHEDS/FLOOD INFORMATION**. Understanding tree canopy coverage as well as species composition within watersheds can have important implications for stormwater management and water quality. Some UTC assessments have incorporated 311 requests for flooding.
- **RIPARIAN AREAS**. Within each watershed, land areas that are adjacent to rivers, streams, lakes, and wetlands are perhaps the most critical zones for tree planting. Data on riparian areas can help prioritize tree planting or buffer-preservation efforts.
- **TRANSPORTATION ROUTES**. Transportation data layers are used to distinguish roads, streets, and highways from other impervious surface areas. This type of information can also be used to identify rights-of-way for street tree planting efforts or to address traffic-calming needs.
- **COMPREHENSIVE PLAN**. Comprehensive plan overlays allow for assessment of forest stands at risk from development by examining relationships between existing or planned UTC and zoning or future land-use priorities.
- **OVERHEAD/UNDERGROUND UTILITIES**. Knowing the location of existing utility infrastructure is important for planting location decisions.
- **SOILS**. Soil map layers can help guide tree planting. Certain soil types, particularly saline soils, can limit opportunities for successful tree planting.
- **AIR QUALITY**. Air quality data can help set priorities. Urban forests positively impact air quality by removing pollutants, sequestering atmospheric CO_2 in woody biomass, and reducing summer air temperatures.

The UTC Prioritization Process

A common goal of UTC analysis is to prioritize tree planting locations in a given area. The primary question driving a UTC prioritization process is, “Where do we need trees to achieve our goals?”

A UTC prioritization process brings diverse stakeholders together to prioritize their top environmental, social, and economic goals, given their individual organizational missions and constraints. Stakeholder input is used to analyze UTC data and identify where increased tree canopy would help most. A combined prioritization map is a key deliverable and serves as an important UTC implementation tool **(Figure 2)**.

Locke and fellow researchers describe the primary steps in the UTC prioritization process (Locke and others 2013):

1. Identify potential stakeholder organizations from the public and private sectors, across all scales, from individual parcels and neighborhoods to whole cities and watersheds.
2. Identify specific priorities, missions, and geographic areas of interest for each potential stakeholder—this may involve a series of meetings with a wide variety of community agencies, as well as surveys of community organizations and residents. Consider using

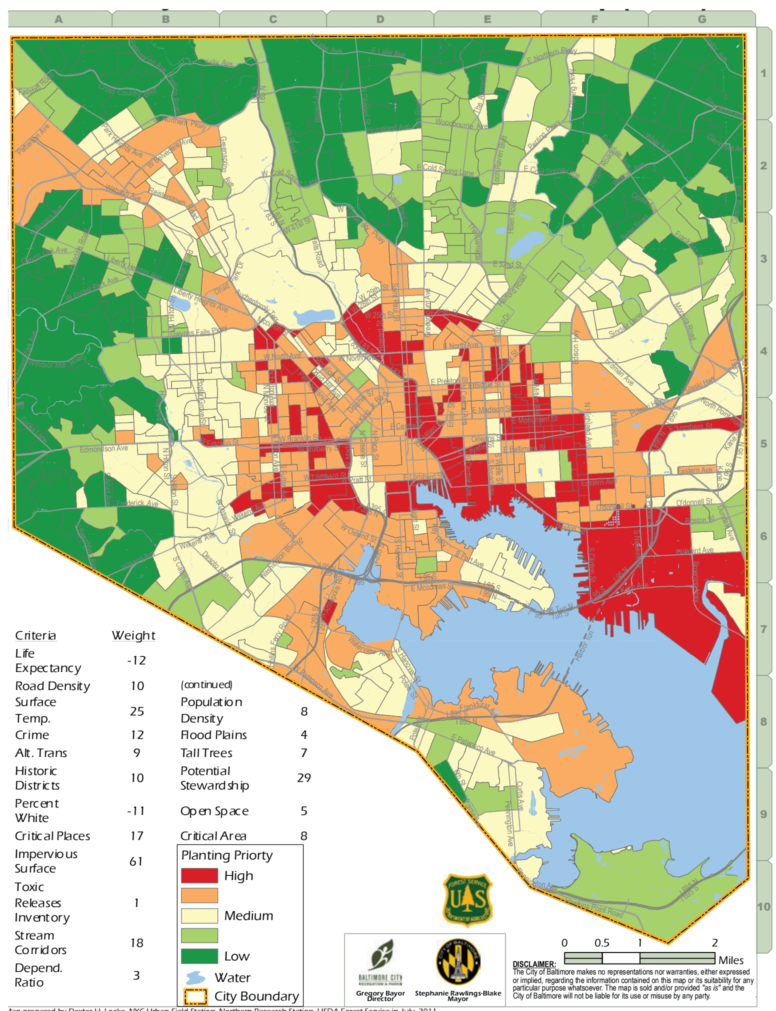

Figure 2: City of Baltimore’s Prioritization Map.
Source: treebaltimore.org/wp-content/uploads/2016/06/SummaryDraftMap.pdf.

community engagement software such as MetroQuest (metroquest.com) to crowd-source geographic interests and preferences.
3. Build a prioritization framework, layering available spatial datasets to identify where the benefits of trees are lacking.
4. Match stakeholder missions or mandates that align with particular functions, benefits, or property types. For example, planting trees to intercept, filter, slow, and uptake stormwater may interest both a conservation organization and a government agency mandated to meet water quality standards.
5. Use the UTC prioritization to match the known benefits of trees to places lacking these benefits, and match locations to organizations positioned to manage those issues and promote the UTC.
6. Identify criteria for prioritizing tree investments (e.g., percent impervious surfaces, potential stewardship, urban heat island mitigation, stream corridors, and schools, hospitals, and recreation centers), confirming with city officials and then other stakeholders. Through a scenario planning tool such as CommunityViz, or open-source software like Azavea's Open Tree Map modeling tool, i-Tree Landscape, or other GIS analytical tools, stakeholders can weight their issues to identify specific geographic areas of focus for greatest impact.
7. Produce maps at common scales that identify priorities for each stakeholder, and a combined prioritization map that summarizes results with overlapping government agency and stakeholder preferences.

A UTC analysis provides a strong foundation for collaboration. Municipal forestry programs that might traditionally work separately from other agencies can combine their available geographic information with other government data to identify parcels, neighborhoods, or watersheds where tree planting might achieve programmatic objectives across agencies. Likewise, the UTC prioritization process can involve diverse stakeholders who are not traditionally involved in tree programs but will benefit from urban canopy improvements.

STEP 4: IMPLEMENTATION

Once the UTC prioritization process is complete, the next step is to develop an implementation plan that details how the community and various stakeholders will achieve their UTC goals. In general, a UTC implementation plan lays out the various UTC goals and timelines for completion; describes the relationship of canopy goals to local ordinances, regulations, and the community's comprehensive plan; and outlines specific strategies for achieving each UTC goal, including a timeline and the responsible party or parties.

Every community must develop an approach to achieving UTC goals that considers its own capabilities and resources, political climate, and stakeholder needs. The prioritization process often helps organizations form partnerships over UTC goals. High-priority planting areas identified for different reasons (e.g., public health versus water quality) can lead to connections between groups that might not otherwise have reason to collaborate. The following list and associated examples are a starting point for sharing innovative UTC applications.

Communities have used the UTC process to:

Set goals for expansion of the tree canopy.

- **PITTSBURGH, PA.**
  Pittsburgh Urban Forest Master Plan. 2012.
  Using a UTC from 2011, Pittsburgh found that 42 percent of the city had canopy cover and an additional 33 percent of land could support tree canopy. Using this information, the city boldly set a goal for 60 percent UTC cover in 20 years. (**issuu.com/treepittsburgh/docs/final_pittsburgh_urban_forest_management_plan_augu** pp. 3, 45.) (15 August 2017).

- **SEATTLE, WA.**
  Urban Forest Stewardship Plan. 2013.
  Seattle set a goal of increasing canopy cover by 30 percent by 2037. **(www.seattle.gov/trees/docs/2013%20Urban%20Fores%20Stewardship%20Plan%20091113.pdf, p. 72.)** (15 August 2017).

Develop ordinances and inform land use and comprehensive planning.

- **JEFFERSON COUNTY, WV.**
  Urban Tree Canopy Plan and Goals. 2011.
  Jefferson County's UTC plan helped identify the need for land use policies and ordinance amendments to encourage the retention of existing canopy on steep slopes and riparian buffer areas. Officials are also working to establish a policy that requires developers to conserve and/or replace a certain percentage of the existing trees during construction, with the goal of maintaining or increasing canopy on the developed property. (**www.jeffersoncountywv.org/home/showdocument?id=8749**, pp. 11, 20.) (15 August 2017).

Create tree planting prioritization guidelines.

- **DISTRICT OF COLUMBIA.**
  District of Columbia Urban Tree Canopy Plan. 2013.
  The District of Columbia is using its UTC plan to identify priority areas for tree planting so that planting programs that receive district funds can target their efforts in the priority areas. Planting areas are prioritized using possible canopy cover data from the UTC plan as a base layer and filtering it by existing data from pertinent GIS layers for stormwater management (using sewer shed data and stormwater volume and pollutant data), environmental justice (using income data), and air quality and public health (using asthma rate data). (**ddoe.dc.gov/sites/default/files/dc/sites/ddoe/page_content/attachments/Draft_Urban_Tree_Canopy_Plan_Final.pdf**, p. 21.) (15 August 2017).

Address environmental justice concerns.

- **PHILADELPHIA, PA.**
  A Report on the City of Philadelphia's Existing and Possible Tree Canopy. 2011.
  Tree canopy metrics were computed for all U.S. Census Block Groups within the city, allowing the tree canopy metrics to be integrated with socio-demographic data collected by the U.S. Census. This type of information can help to inform tree planting initiatives by providing proxies for environmental justice (canopy correlated with income) and stewardship potential (percent renter occupied and percent vacant). (**www.fs.fed.us/nrs/utc/reports/UTC_Report_Philadelphia.pdf**, p. 10.) (15 August 2017).

- **LOUISVILLE, KY.**
  Louisville Urban Tree Canopy Assessment. 2015.
  Data from Louisville was used to understand relationships between socioeconomic trends and canopy cover. Results showed that higher income areas had more tree canopy than lower income areas and that canopy cover also decreased as population density increased. Canopy was also higher in areas with higher percentages of older residents, more educated residents, more owner-occupied houses, and higher valued homes. (**louisvilleky.gov/sites/default/files/sustainability/pdf_files/louisvilleutcreport-24march2015.pdf**, p. 22.) (15 August 2017).

- **SAN FRANCISCO, CA.**
  Urban Forest Management Plan. 2014.
  The plan strives to achieve a more equitable distribution of greening throughout the city by encouraging planting in areas lacking tree cover and supporting alternate greening methodologies (i.e., sidewalk gardens and green walls/roofs) where trees may not be appropriate. (**www.sf-planning.org/ftp/files/plans-and-programs/planning-for-the-city/urban-forest-plan/UrbanForestPlan-121814_Final_WEB.pdf**, pp. 32, 43.) (15 August 2017).

Mitigate urban heat island effect and improve energy conservation.

- **AUSTIN, TX.**
  Austin's Urban Forest Plan: A Master Plan for Public Property. 2013.
  Austin developed a program to plant trees on private property near streets and sidewalks in order to reduce the heat island effect. Eligible neighborhoods must have adopted a neighborhood plan and have low canopy cover (less than 40 percent), as defined by the UTC assessment and GIS analysis. (**issuu.com/austinurbanforestry/docs/aufp_final_03-05-14**, p. 57.) (15 August 2017).

Implement U.S. Environmental Protection Agency (EPA) voluntary air quality plans (State Implementation Plans).

- **ANN ARBOR, MI.**
  Urban and Community Forest Management Plan. 2014.
  Ann Arbor aims to prioritize urban forest management activities in areas that can have a positive impact on stormwater and air quality management. (**www.a2gov.org/departments/forestry/Documents/UCFMP_FINAL_022515.pdf**, p. 66.) (15 August 2017).

Manage stormwater.

- **JEFFERSON COUNTY, WV.**
  Urban Tree Canopy Plan and Goals. 2011.
  Jefferson County used its UTC assessment to prioritize sites for a tree planting grant on public lands. Using the UTC assessment along with other geographical data, the county filtered and prioritized sites based on their lack of adequate tree canopy in relation to their potential for planting and for maximum stormwater runoff mitigation. (**www.jefferson-countywv.org/home/showdocument?id=8749**, p. 22.) (15 August 2017).

Support green asset accounting.

- **PORTLAND, OR**.
  Tree Asset Management in Portland, Oregon. 2011.

  Portland commissioned this study to explore the potential to integrate trees and other green infrastructure into an infrastructure asset-management format that potentially qualifies trees for financing similar to conventional infrastructure. In June 1999, the Governmental Accounting Standards Board (GASB) released Statement 34, which requires State, local, and municipal governments to provide annual financial statements regarding infrastructural capital assets. The study attempts to address some of the challenges of including trees as capital assets under GASB 34. (**www.cnt.org/publications/tree-asset-management-in-portland-oregon**.) (15 August 2017).

Improve physical and mental health.

- **ANN ARBOR, MI**.
  Expanding Urban Tree Canopy as a Community Health Climate Adaptation Strategy: A Health Impact Assessment of the Ann Arbor Urban and Community Forest Management Plan. 2014.

  Ann Arbor's Health Impact Assessment uses UTC assessment data to identify priority areas for tree plantings to maximize physical and mental health benefits for the community. Using public health data on the prevalence of certain health outcomes (e.g., asthma, heat-related illness, management of chronic illness, and stress and mental health) and demographic risk factors associated with those health outcomes (e.g., age, income, gender, and education), a spatial assessment was conducted to determine where high-risk populations are located in the city. When these data were combined with tree canopy data, priority areas were identified where an increase in tree canopy would be most beneficial to residents' health (i.e., current canopy cover less than 30 percent). (**www.michigan.gov/documents/mdch/Final_January_2014_HIA_446372_7.pdf**, pp. 4, 5, 12, 13.) (15 August 2017).

Identify habitat nodes and linkages, hubs and corridors (community scale).

- **CUYAHOGA COUNTY, OH**.
  Cuyahoga County Urban Tree Canopy Assessment. 2014.

  Using the UTC assessment, Cuyahoga County identified the potential for vacant parcels to be aggregated to form tracts of land that could be reforested to provide habitat nodes and corridors throughout the county. The analysis found more than 20,000 acres of vacant land where tracts were 2 acres or larger. These vacant tracts represent a significant opportunity for preserving and expanding canopy with 56 percent existing canopy and the potential for 40 percent additional canopy cover. (**www.countyplanning.us/projects/urban-tree-canopy-assessment/communities/**) (15 August 2017).

Research To Help Engage Urban Residents in Tree Planting

UTC assessments often reveal that the majority of a city's or town's existing trees are on residential land, and that residential land holds the greatest opportunity for increasing the UTC. Engaging residents in tree planting, through information campaigns, focused planting and stewardship activities, and incentive programs, is a critical component of most UTC implementation plans. The interest and motivation of urban residents to engage in tree planting programs is not well understood, however, making it difficult for organizations to plan effective campaigns and programs.

Market analysis can complement UTC assessments and help localities analyze planting priorities and develop better-tailored outreach strategies for specific neighborhoods or residential "market segments." Science-based information on where local outreach strategies are working, who is participating, and who these strategies are failing to reach can help localities design more effective implementation plans and assess overall performance in achieving their planting priorities (Locke and Grove 2016).

STEP 5: MONITORING AND EVALUATION

UTC studies implemented to provide a single "point-in-time" assessment will miss the potential to monitor tree canopy changes attributed to urban forest management strategies and programs, partnerships, and neighborhood involvement An initial UTC project designed with the added objective (and supporting strategies) for periodic reassessment will provide the baseline metric (i.e., estimate of canopy coverage percent), methods, and capability to spatially monitor gains and losses in tree canopy.

When UTC projects are used to set tree canopy goals, successive UTC studies can be used to evaluate progress towards those goals. Areas that are initially mapped for a UTC assessment can be mapped again after urban forest management strategy implementation to see how and where the canopy has changed over time. Experts recommend conducting a UTC assessment and analysis every 5 to 8 years to identify tree canopy change, identify new priority areas, assess performance toward UTC goals, and adapt priorities to changing environmental and societal needs and municipal budgets.

CONCLUSION

UTC projects involve much more than remote sensing, a combination of GIS layers, canopy goal setting, or a set of tree planting prioritization scenarios. For real success, the UTC project must be considered a process that matches the goals, needs, capabilities, and resources of a community with an analysis of the best ways to achieve urban forestry objectives. The steps in the process should lead from initial goal setting through assessment, analysis or prioritization, and implementation to monitoring and evaluation—all of these with the input and involvement of stakeholders and partners. The partnerships and relationships formed during a UTC assessment project provide long-term benefits to both the urban forest and the broader community far beyond the simple act of planting a tree.

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GLOSSARY

Ancillary data. Data from sources other than remote sensing used to assist in analysis and classification.

AOI. Area of interest, or the urban tree canopy project area.

Building footprints. Geographic information system files accurately locating the foundations of structures.

Deliverable. The product created by a contractor for the community. It usually includes the narrative description of the classification methodology, the basic classification of the imagery with metadata, other ancillary data used in the process, the accuracy assessment methodology, and the error matrix. Details of what will be delivered are explicitly outlined in the request for proposals.

Existing canopy. The tree canopy cover present at the time the imagery was collected.

Geo-reference. To associate an object in an image with its physical location (e.g., latitude and longitude).

Geographic information system (GIS). An integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes.

Hyperspectral imagery. Remotely sensed imagery that includes hundreds of spectral bands. Hyperspectral sensors can be advantageous for urban tree canopy assessments, since the spectral signatures from individual species as well as more complex vegetation communities can be better detected and distinguished.

Image classification. The conversion of a remotely sensed image ("photo") into land cover types that a computer can read.

Land cover. The physical material at the surface of the earth (e.g., impervious surface, grass, tree canopy).

Land use. The human use of land (e.g., residential, commercial, industrial).

LiDAR (Light Detection and Ranging). A remote sensing method used to examine the surface of the Earth.

Metadata. Information that describes process, methodology, and specific datasets, including geographic information system (layers).

Minimum mapping units (MMU). For a given scale, the size in map units below which a narrow feature (e.g., a river) is represented by a line and an area (e.g., a forest stand) is designated by a point.

Multispectral. Refers to two or more frequencies or wavelengths in the electromagnetic spectrum.

National Agriculture Imagery Program (NAIP). Produced by the U.S. Department of Agriculture, Farm Service Agency. The NAIP acquires **aerial imagery** during the agricultural growing seasons in the continental United States and makes the imagery available to government agencies and the public.

Near infrared (NIR). NIR light includes wavelengths between 700 and 1,100 nanometers. Vegetation strongly reflects NIR light, making it useful for land cover classification.

National Land Cover Datasets (NLCD). A national land cover classification product produced by the Department of the Interior, U.S. Geological Survey, from Landsat imagery that covers the entire United States. The database is available for 10-year intervals for the 1980s and 1990s, and for 5-year intervals starting in 2000.

Possible tree canopy. A UTC metric indicating the grass or shrub area that is theoretically available for the establishment of tree canopy.

Quality assurance (QA). The process used to verify the quality of a product after its production and ensure that the work performed meets an urban tree canopy project's stated goals.

Quality control (QC). Processes used during production of a product that ensure its quality. QC processes should be identified by the contractor in the request for proposal response.

Remote sensing (RS). Information acquired at a distance usually by interpreting and analyzing aerial or satellite imagery.

Resolution. The size of the smallest pixel of a remotely sensed image.

Request for Proposal (RFP). Outlines the bidding process and contract terms, and provides guidance on how a bid should be formatted and presented.

True color. Three-band imagery or red, green, blue (RGB) imagery.

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