Geospatial Assessment in Support of Urban & Community Forestry Programs

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This study was initiated as a collaboration between the USDA Forest Service and the University of Vermont to examine the strengths and limitations of existing methods for identifying forest opportunities in urban areas.

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Executive Summary

Geospatial information is an important component of urban and community forestry assessment in the Northern Area. The synthesis of geographic data can help inform the decision making process at a range of scales, from prioritizing communities within a state to targeting individual properties for tree plantings. For accurate and meaningful information to be gained from these assessments it is crucial that any geospatial assessment employ datasets and tools that are appropriate to the scale of analysis.

An accurate representation of the tree canopy is arguably the most important source dataset of any urban and community forestry geospatial assessment. This study showed that estimates of tree canopy in urban areas obtained from readily available moderate resolution national datasets have substantial accuracy issues, typically underestimating tree canopy by large percentages. As such, these datasets should only be used to examine the relative differences in land cover between urban areas, and should not be used in those cases where accurate estimates are required (e.g. tree canopy goal setting). High-resolution land cover datasets yield highly accurate estimates of tree canopy, but such datasets are not readily available for most urban areas. Although such datasets are not commonplace, generating high resolution land cover datasets is now a feasible option due to recent technological advances.

We conclude that pixel-based overlay methods, such as those used in the Spatial Analysis Project (SAP) are not appropriate for urban and community forestry assessment. A summary method, similar to what has been implemented in the Urban Tree Canopy assessment (UTC) analysis and National Urban Forest Assessment (as mandated by the Renewable Resource Planning Act), using scale appropriate data, can provide decision makers with information needed to help target resources in support of urban and community forestry initiatives. To assist with is process we generated four tools: the Urban and Community Forestry Index (UCF-i), the Maryland Method (MD-Method), the Urban Tree Canopy assessment (UTC) and the Priority Planting Index (PPI). These tools are incorporated into the Urban Forestry Toolbox, and can be executed using GIS software. UCF-i and MD-Method are designed to work at the regional scale. Both tools make use of readily available land cover and census datasets to help target communities in the Northern Area or within a state. Once those communities have been identified and high resolution land cover data becomes available, UTC and PPI assist in identifying and prioritizing areas within community.

Background

The purpose of this project was to examine the geospatial assessment methods presently being employed for forest stewardship programs and make recommendations as to their suitability for informing urban and community forestry programs. The three methods targeted for comparison were the Urban Tree Canopy assessment (UTC), Spatial Analysis Project (SAP), and National Urban Forest Assessment conducted as part of the Renewable Resources Planning Act (RPA).

Three states were selected for analysis and within each state one community: Maryland - Baltimore County, Iowa - DesMoines , and Vermont - Burlington. These three communities were selected based on the wide range of land cover types, availability of requisite datasets, and the desire of each to incorporate the analyses conducted as part of this study into their existing urban forestry programs. For each area existing data from SAP and RPA were obtained and a UTC assessment was completed.

Overview

This report identifies key issues relating to the existing datasets and current methodologies. It provides recommendations and solutions in three subject areas:

1. Land cover mapping
2. Decision support tools
3. Data accessibility

Key Terms

NLCD: National Land Cover Database. Nationwide moderate resolution (30m) land cover derived from the Landsat satellite and generated by the USGS.

SAP: Spatial Analysis Program. A GIS-based strategic management tool that allows participating state forestry agencies to identify and spatially display important forest lands (rich in natural resources, vulnerable to threat), tracts currently under Forest Stewardship Plans, and areas of opportunity to focus future Forest Stewardship Program efforts.

UTC assessment: Urban Tree Canopy assessment. Protocols to extract and summarize high resolution land cover to assist communities with urban tree canopy goal setting and planting.

RPA: Resource Planning Act datasets generated as part of the National Urban Forest Assessment in which NLCD information is summarized by US Census Places.

Pixels: Grid of two dimensional features. Smallest unit of analysis in a raster GIS.

Tree Canopy: The layer of leaves, branches, and stems of trees that cover the ground when viewed from above.

Land Cover: Physical features on the earth mapped from satellite imagery such as trees, grass, water, and impervious surfaces.

Existing UTC: The amount of urban tree canopy present when viewed from above using aerial or satellite imagery.

Possible UTC: The amount of land that is theoretically available for the establishment of tree canopy. Possible UTC excludes areas covered by tree canopy, roads, buildings, and water.

Remotely sensed data: Data acquired from airborne or satellite platforms such as imagery and LiDAR (Light Detection and Ranging).

Land Cover Mapping

Land cover data is the cornerstone of any GIS-based urban forest assessment. Tree canopy estimates can be derived from remotely sensed datasets such as satellite imagery, aerial orthophotographs and LiDAR. Remotely sensed datasets are most commonly acquired at two scales: moderate resolution (30m) and high resolution (1m or better). Moderate resolution land cover data is readily available through National Land Cover Database (NLCD). NLCD was last completed nationwide in 2001. High resolution remotely sensed data is prevalent in urban areas, yet corresponding land cover datasets typically do not exist.

Issue: Accuracy of NLCD tree canopy estimates in urban areas

The high resolution land cover data generated as part of this study allowed for a comprehensive comparison of estimates of tree canopy derived from NLCD to those derived from high resolution remotely sensed datasets. This comparison is the first of its kind. The differences, presented in Figure 1, and illustrated in Figure 1, are striking. NLCD underestimates tree canopy in the three study areas by 27% to 48%.

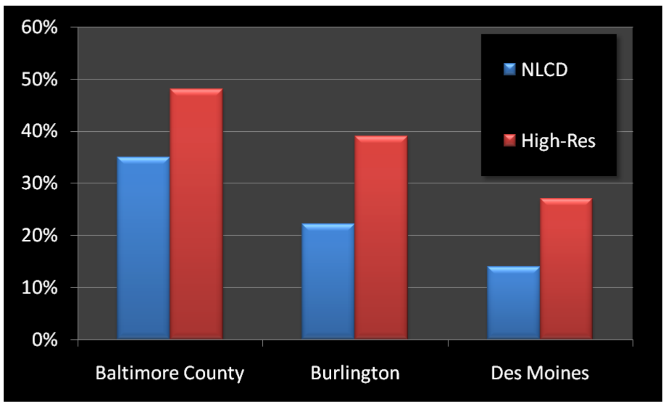


Figure 1: *Comparison of tree canopy estimates obtained from the 2001 NLCD canopy layer to those derived from high resolution land cover.*

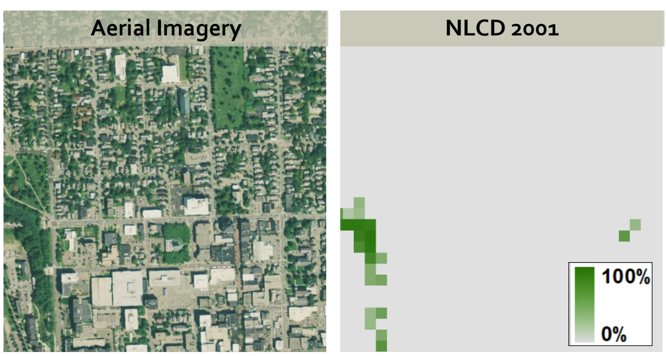


Figure 2: *Burlington, VT. NLCD fails to capture much of the tree canopy in urban areas, only detecting larger patches of forest.*

Recommendation: NLCD should be limited to regional analysis

It is clear that NLCD lacks sufficient accuracy to be used for within-community assessments. This includes estimating tree canopy for a given urban area, setting tree canopy goals, and determining locations to plant trees. This is not to say that NLCD has no value in urban forest assessment. As a dataset that is available nationwide, NLCD is compelling resource for relative comparisons at the regional scale (e.g. city X has more tree canopy than city Y). Correction factors applied to NLCD summary statistics contained in the RPA dataset should make such relative comparisons valid.

Issue: Lack of availability of high resolution land cover data

The severe accuracy limitations of moderate resolution land cover datasets, such as NLCD, in mapping tree canopy in urban areas necessitate the use of high resolution land cover datasets. Land cover data derived from high resolution remotely sensed data yields information on the urban forest that is more accurate and spatially consistent with other high resolution GIS datasets. Spatial consistency is important if the data are to be used as a decision support tool at the local level. As such, the land cover data must be detailed enough to facilitate parcel-based analysis.

The lack of high resolution land cover is the result of two factors: 1) the difficulties associated with processing very large remotely sensed datasets and 2) the poor performance of traditional "pixel-based" land cover classification techniques when applied to high resolution imagery.

Recommendation: 1) OBIA urban land cover mapping, 2) Capitalize on existing data acquisition programs.

As part of this project, object-based image analysis (OBIA) techniques were developed that automate the extraction of detailed land cover information from high resolution remotely sensed datasets. The OBIA techniques employed expert systems and high performance computing environments to overcome the above identified limitations. For all three study communities imagery and LiDAR datasets were readily available, but remained underutilized.

This study demonstrated that OBIA techniques can be applied to generate highly accurate (> 95% overall accuracy) land cover datasets suitable for setting precise tree canopy goals and analyzing tree canopy metrics at the parcel level. OBIA also proved to be efficient. Detailed land cover mapping of Baltimore County (> 1500 km^2, Figure 3) took 280 person-hours to complete.

Existing programs such as the National Agricultural Imagery Program (NAIP) and initiatives such as nationwide LiDAR will only increase the availability of requisite remotely sensed datasets in the future. Urban and community forestry geospatial assessments should be prepared to capitalize on these programs.

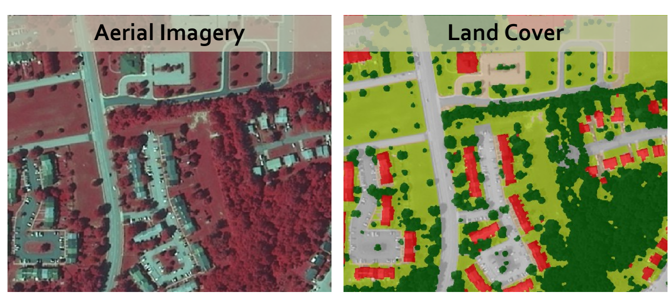


Figure 3: *Baltimore County, MD. High resolution land cover (right) derived from imagery (left) and LiDAR.*

Decision Support Tools

Geospatial assessments can yield valuable information to support the programmatic goals of urban and community forestry programs. As with any spatial analysis project, it is paramount that the end user understand the capabilities and limitations of the source data and methods. This report has already addressed the issues relating to data inputs in the form of land cover data. This project examined the utility of several existing geospatial assessment tools as they relate to providing relevant information to supporting the programmatic goals of urban and community forestry programs from the regional to the community level: SAP, RPA, and UTC. These tools can be grouped into two general categories: 1) pixel-based overlay (SAP) and 2) zonal summary (RPA, UTC). In the pixel-based overlay method all datasets are converted to raster format at a given cell size (typically 30m). Weights are assigned to each of the layers based on programmatic goals. The addition of these layers yields pixels with a value that theoretically relates to the programmatic goals. Zonal summary methods rely on existing geographic boundaries (referred to as zones), such as parcels or towns to compute statistical values or area summations for all of the pixels within the zone.

Issue: Applicability of SAP to urban areas

The pixel-based overlay method employed by SAP has two principal limitations with respect to its employment in urban areas: 1) datasets of varying resolution are converted to a single cell size, leading to either overrepresentation or underrepresentation of the original source data, 2) pixels are not a meaningful unit of analysis in urban and community forestry. Figure 4 illustrates these two issues. UTC metrics summarize the information at a meaningful unit of analysis (the property parcel level), making the data readily interpretable by planners and easily integrated into existing databases and workflows. The Forest Stewardship Program (FSP) suitability index generated by SAP is confusing to interpret and does readily translate to existing units of management.

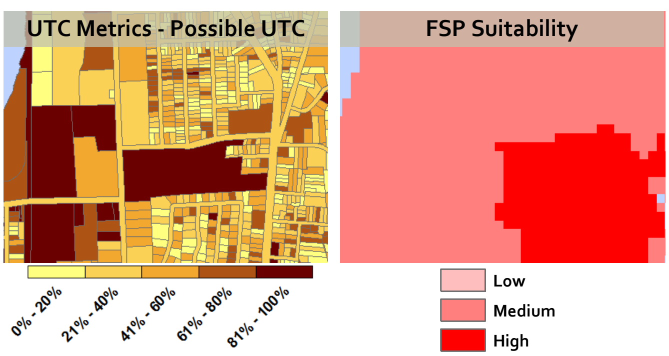


Figure 4: Burlington, VT. Comparison of UTC Assessment metrics computed at the parcel level to the pixel-based Forest Stewardship Program (FSP) suitability index generated by SAP.

Recommendation: Scale-appropriate zonal-based methods should be employed.

This project succeeded in developing a series of tools that automate the process of performing zonal-based geospatial assessments at multiple scales. These tools are not intended to perform a comprehensive spatial analysis that take into account all programmatic needs, rather they provide the basis for making informed decisions and facilitate follow-on analysis.

These tools were designed to analyze data at two scales, the regional scale and the community scale. The regional scale tools make use of readily available moderate resolution land cover and US Census datasets to facilitate the relative comparison of geographical entities. Such tools are useful for helping to determine the communities within a state that should be targeted for urban and community forestry initiatives. The community scale tools apply the same principal, but are designed to help inform urban forestry decisions within a community. The community tools make use of site-specific high resolution land cover datasets and leverage the data present in local GIS databases. The community tools have a variety of uses, from helping to identify parcels with a relatively high amount of land available for tree plantings (Possible UTC) to examining the environmental justice issues associated with the spatial distribution of tree canopy between neighborhoods.

Maryland Method (MD-Method)

The Maryland Method was developed by Mike Galvin during his time with the Maryland Department of Natural Resources. The Maryland Method was used to select communities for the establishment of tree canopy goals by finding those that had above average impervious, above average population density, above average urban area, and below average canopy.

The Maryland Method was designed to work on US Census Places using the RPA dataset, but can be applied to other geographies such as counties and zip codes. For land cover data it relies on the percent impervious and percent canopy layers, presently available in NLCD 2001. All other inputs come from the US Census.

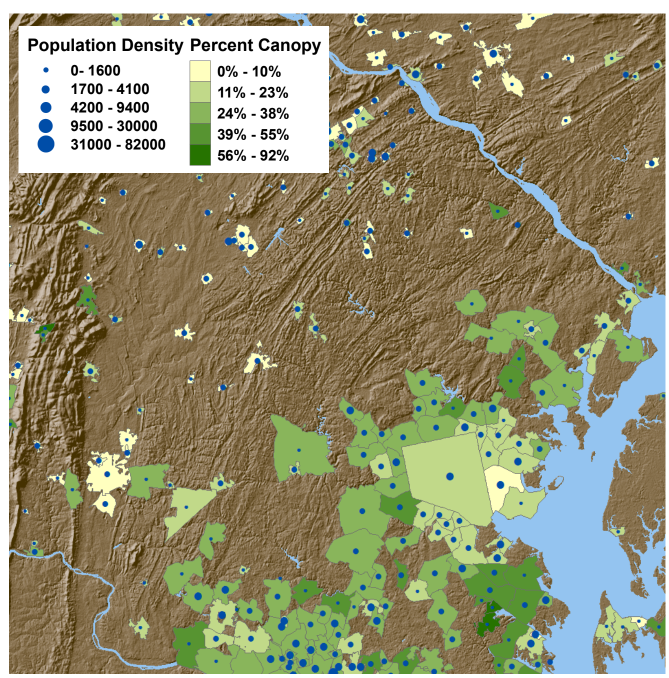


Figure 5: Greater Baltimore, MD area. Communities selected as using the Maryland Method criteria. Within there respective state, each of these communities had below average tree canopy, above average imperviousness, above average population density, and above average urban area.

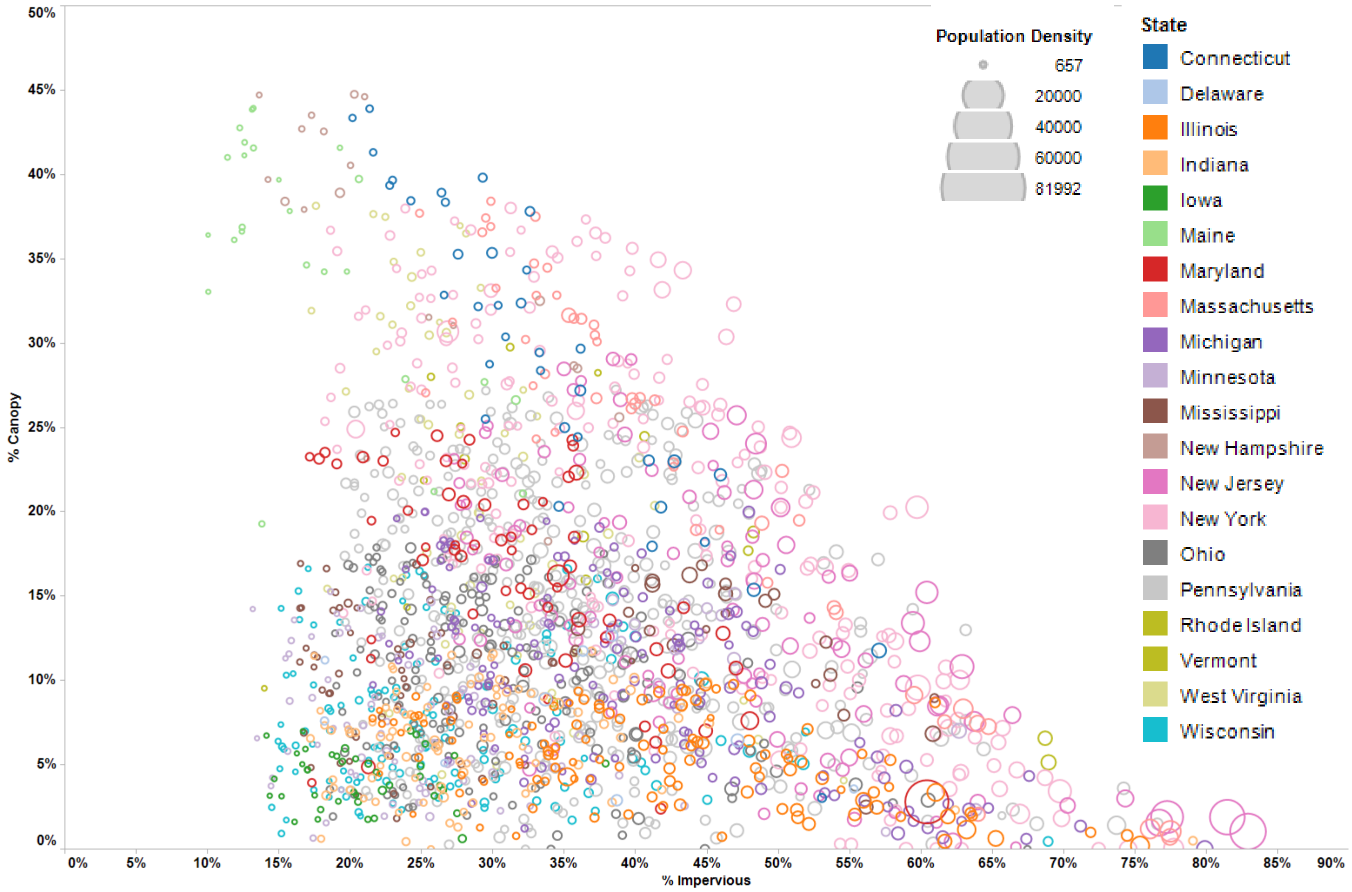


Figure 6: *Communities in NA, by state, selected using the Maryland Method shown in relation to % impervious, % tree canopy, and population density. The selection method for states like Maine yields communities with largely similar criteria. For states like New York the selection method yields communities with a wide range of tree canopy, imperviousness, and population density.*

Urban & Community Forestry Index (UCF-i)

The Urban & Community Forestry Index (UCF-i) is a modified version of the "Maryland Method." Like the Maryland Method, UCF-I is designed to facilitate the comparison of geographical units (towns, zipcodes, etc.) based on % impervious, % canopy, and population density. Rather than selecting communities as is done the Maryland Method, UCF-i assigns a values from 0-100 based on three input datasets using the following formula:

$$UCF-i = 30\left(1-\frac{TC_i - TC_{\min}}{TC_{\max} - TC_{\min}}\right) + 30\left(\frac{IMP_i - IMP_{\min}}{IMP_{\max} - IMP_{\min}}\right) + 40\left(\frac{PD_i - PD_{\min}}{PD_{\max} - PD_{\min}}\right)$$

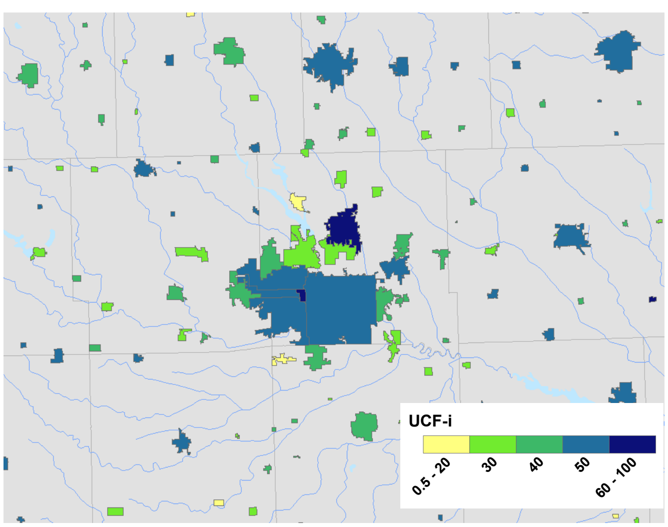


Figure 7: *Greater Des Moines area. UCF-i values for US Census Places.*

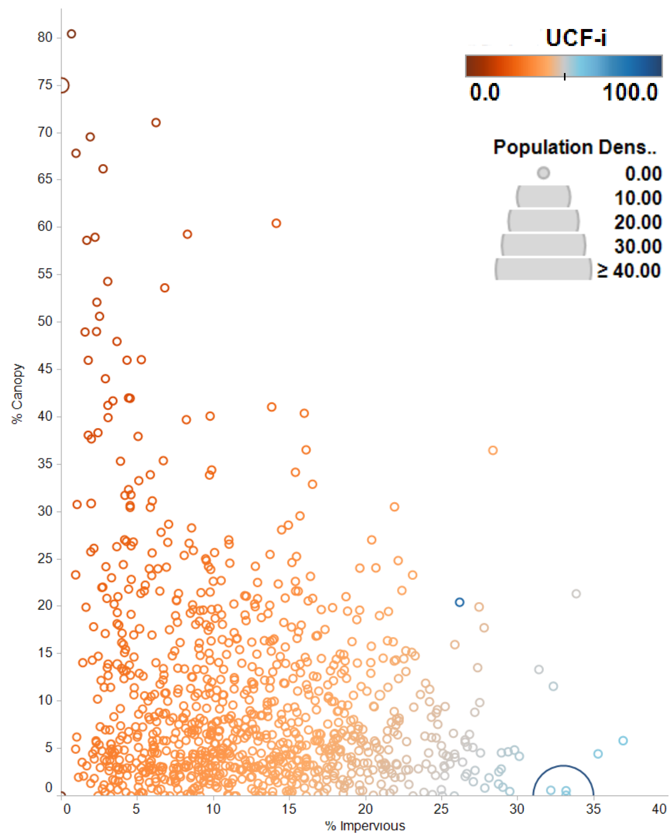


Figure 8: *UCF-i distribution of values in relation to % canopy, % impervious, and population density for Iowa. High % impervious and low % tree canopy are clearly the factors contributing most substantially to the index value in this example.*

Urban Tree Canopy Assessment (UTC)

The aim of the Urban Tree Canopy (UTC) assessment is to increase decision maker's understanding of their urban forest resources, particularly as it relates to the amount of tree canopy that currently exists and the amount of tree canopy that could exist. The UTC assessment protocols rely on high resolution geospatial datasets and thus yield information accurate enough for setting precise UTC goals for a given community. The UTC assessment is particularly useful in helping communities understanding the linkages between land use and land cover.

Two principal metrics result from a UTC assessment: Existing UTC and Possible UTC. Existing UTC refers to the amount of tree canopy present when viewed from above using satellite or aerial imagery. Possible UTC is the amount of land that is theoretically available for the establishment of tree canopy. Possible UTC excludes areas covered by tree canopy, roads, buildings, and water. UTC metrics can be summarized at multiple scales, ranging from the property parcel to the city as a whole. At the property parcel level the UTC metrics provide the information necessary to target individual land owners for tree planting initiatives.

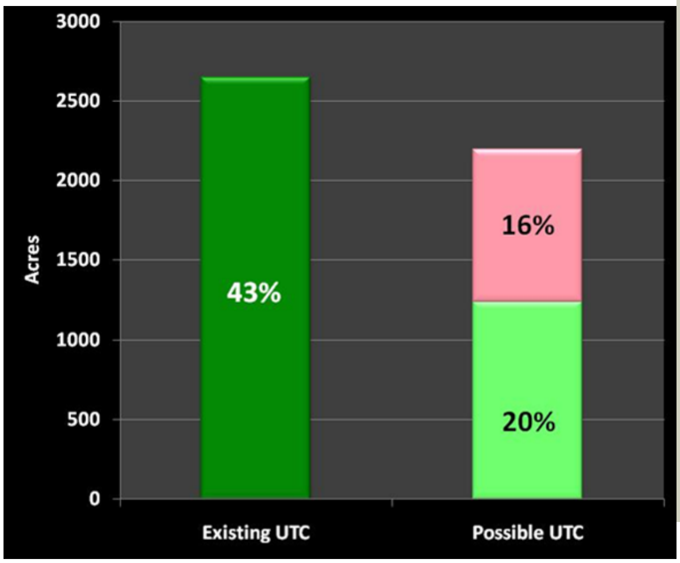


Figure 9: *Burlington, VT. City-wide UTC estimates.*

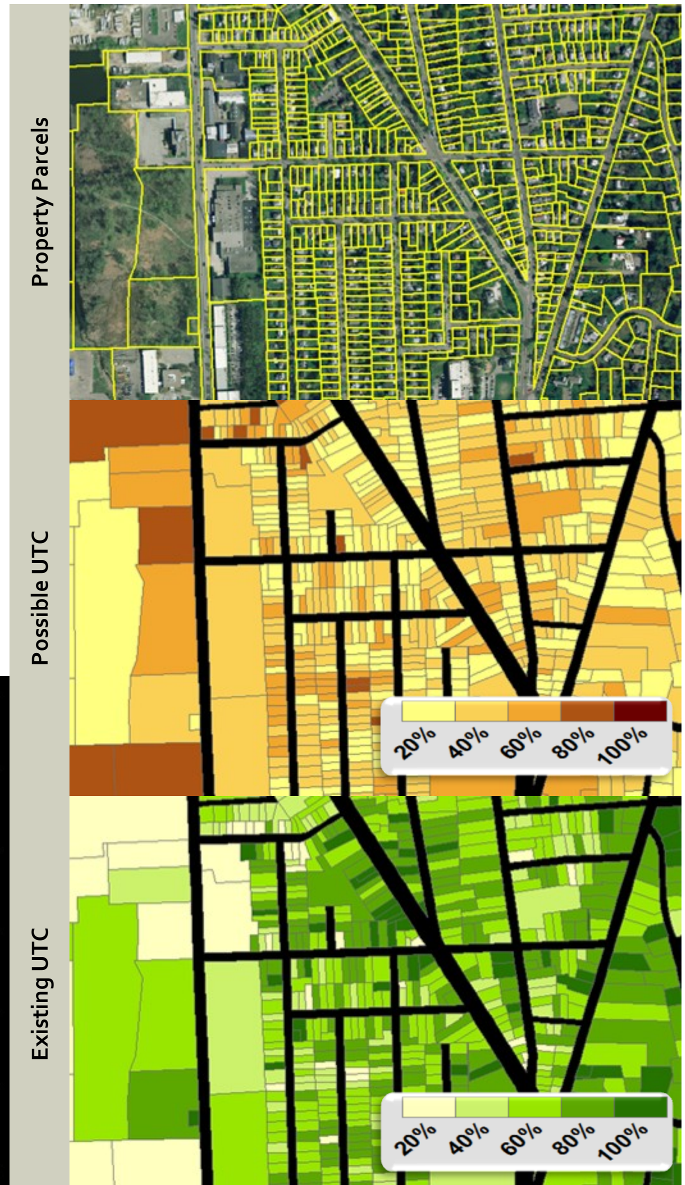
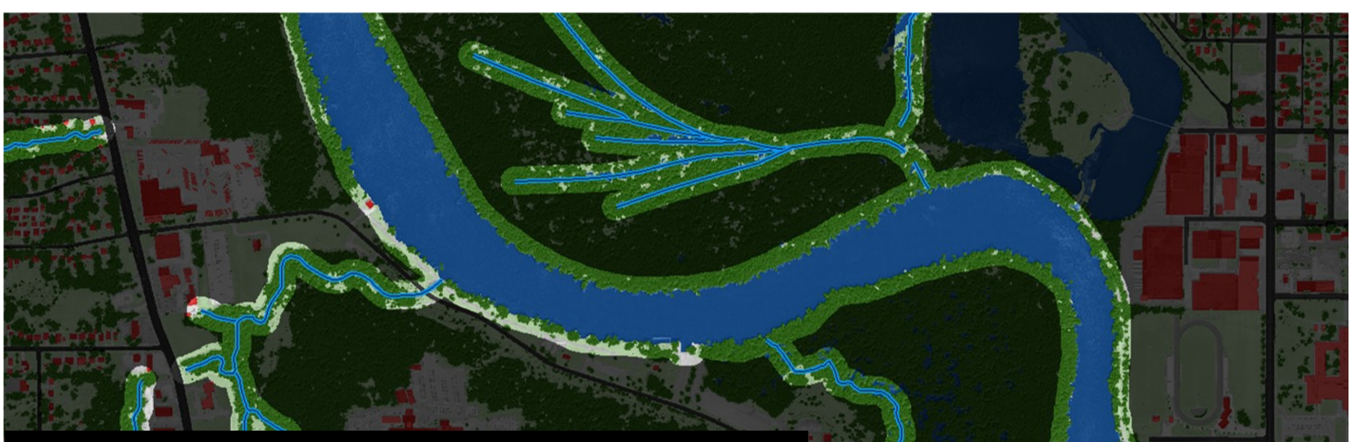


Figure 10: *Burlington, VT. Parcel-based UTC metrics.*



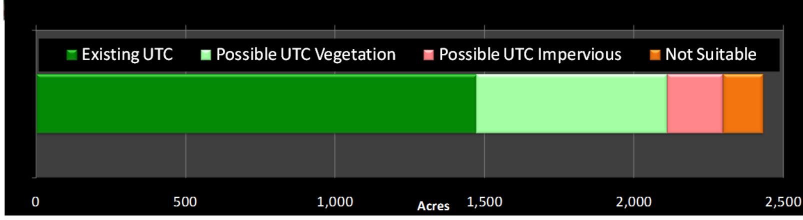


Figure 11: *Des Moines, IA. UTC metrics for the city's designated riparian zones.*

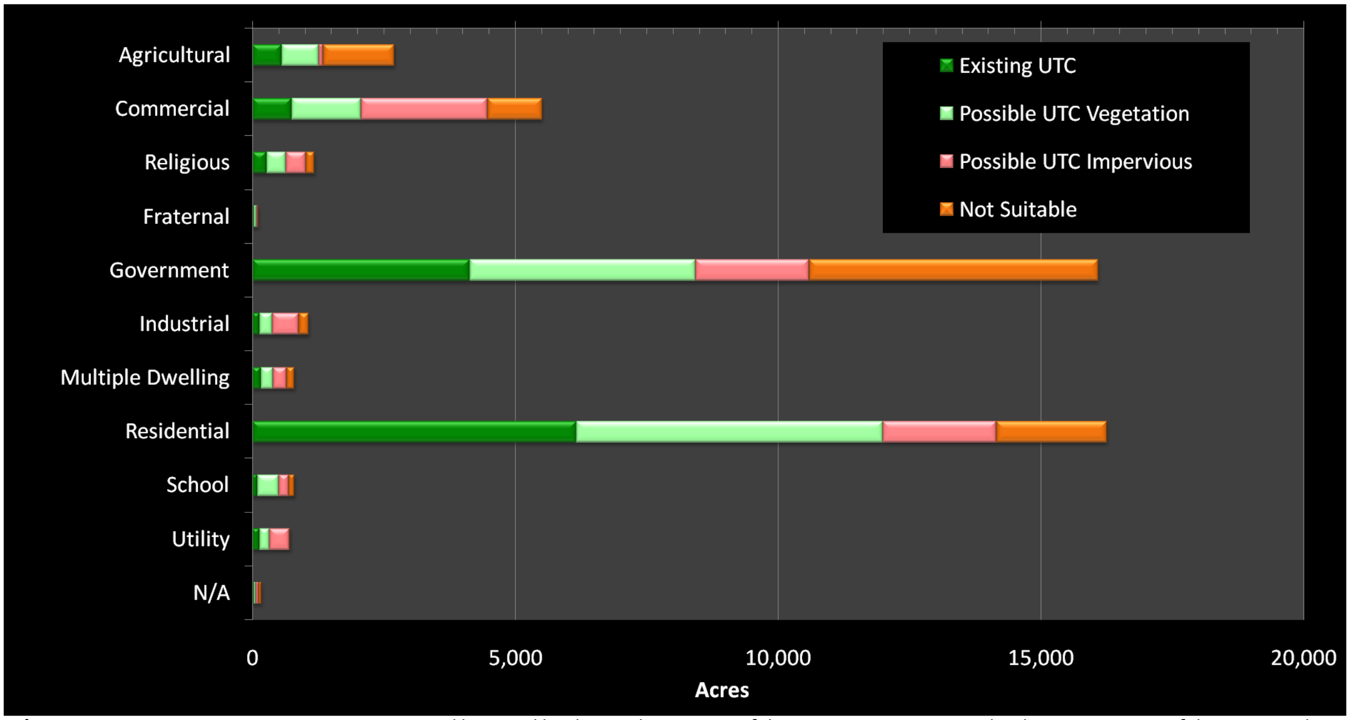


Figure 11: *Des Moines, IA. UTC metrics summarized by parcel land use. The majority of the city's tree canopy is under the management of the city's residential population. Residential areas also contain the highest amount of available land to plant trees, but planting initiatives will be easier to institute on government land, which also has a high amount of Possible UTC.*

Priority Planting Index (PPI)

PPI is computed at the US Census block group level based on population density, tree stocking levels, and tree cover per capita. The output from this model can be used to assist urban and community foresters in prioritizing tree planting efforts. The index prioritizes census block groups from 0 - 100, with those with higher values in greatest need of tree plantings based on:

- Population density: the greater the population density, the greater the priority for tree planting.
- Tree stocking levels (TS): the lower the tree stocking level (the percent of available green space, i.e. tree, grass, and soil cover areas, that is occupied by tree canopies), the greater the priority for tree planting
- Tree cover per capita (TPC): the lower the amount of tree canopy cover per capita, the greater the priority for tree planting.

Each criterion is standardized on a scale of 0 to 1 with 1 representing the census block with the highest value in relation to priority of tree planting (i.e., the census block with highest population density, lowest stocking density or lowest tree cover per capita).

$$PD = \frac{Blockgroup\ PD - Minimum\ PD}{PD\ Range}$$

$$TS = \frac{100 - \left(\frac{Trees}{Trees + Grass}\right) * 100}{100}$$

$$TPC = 1 - \left(\frac{Blockgroup\ TPC - Min\ TPC}{TPC\ Range}\right)$$

$$PPI = PD * 40 + TS * 30 + TPC * 30$$

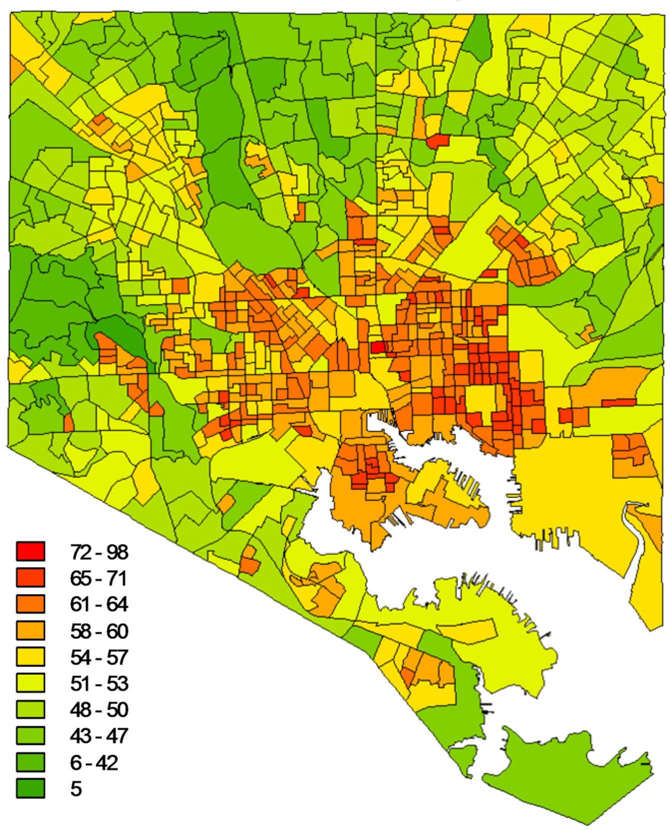


Figure 12: *Baltimore, MD. Priority Planting Index analysis.*

Data Accessibility

Issue: End products may be inaccessible to urban foresters.

Urban foresters are typically familiar with GIS, but often lack the requisite on-hands training to use it as a decision-making tool.

Recommendation: Leverage web-based virtual globes.

As part of this project techniques were developed to make the assessment results accessible in virtual globes such as Google Earth®. We developed an enterprise architecture solution that enables large datasets to be streamed directly to the end-user. As the data is maintained on a centralized server, updates and corrections can be performed without the end user having to re-download the dataset. Performance tests showed that viewing operations, such as panning and zooming, were faster using streamed data on the virtual globes compared to traditional desktop GIS software.

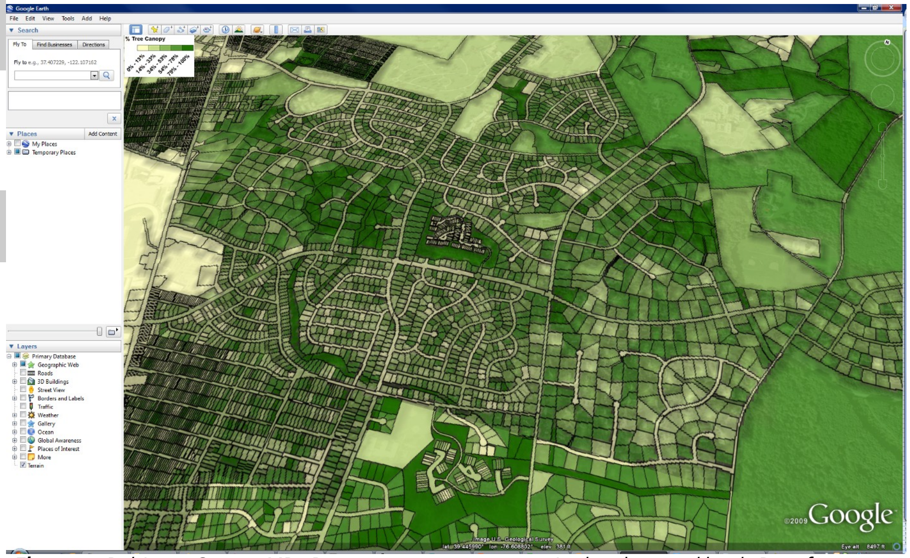


Figure 13: *Baltimore County, MD. Percent tree canopy summarized at the parcel level. Data for over 300,000 parcels are available. Region-specific map tiles (80,000) streamed via a network link allow for rapid panning and zooming without the need to download data.*

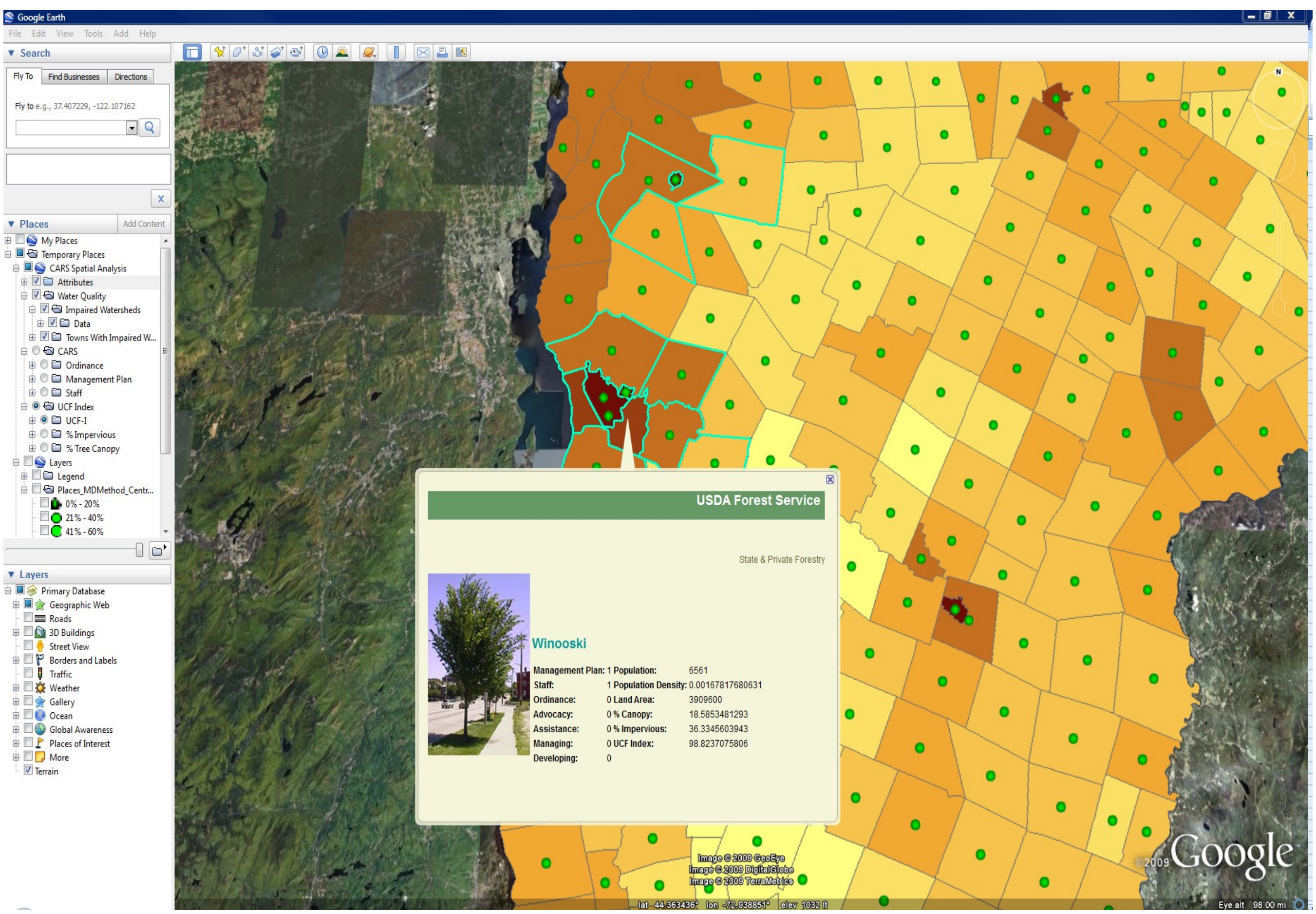
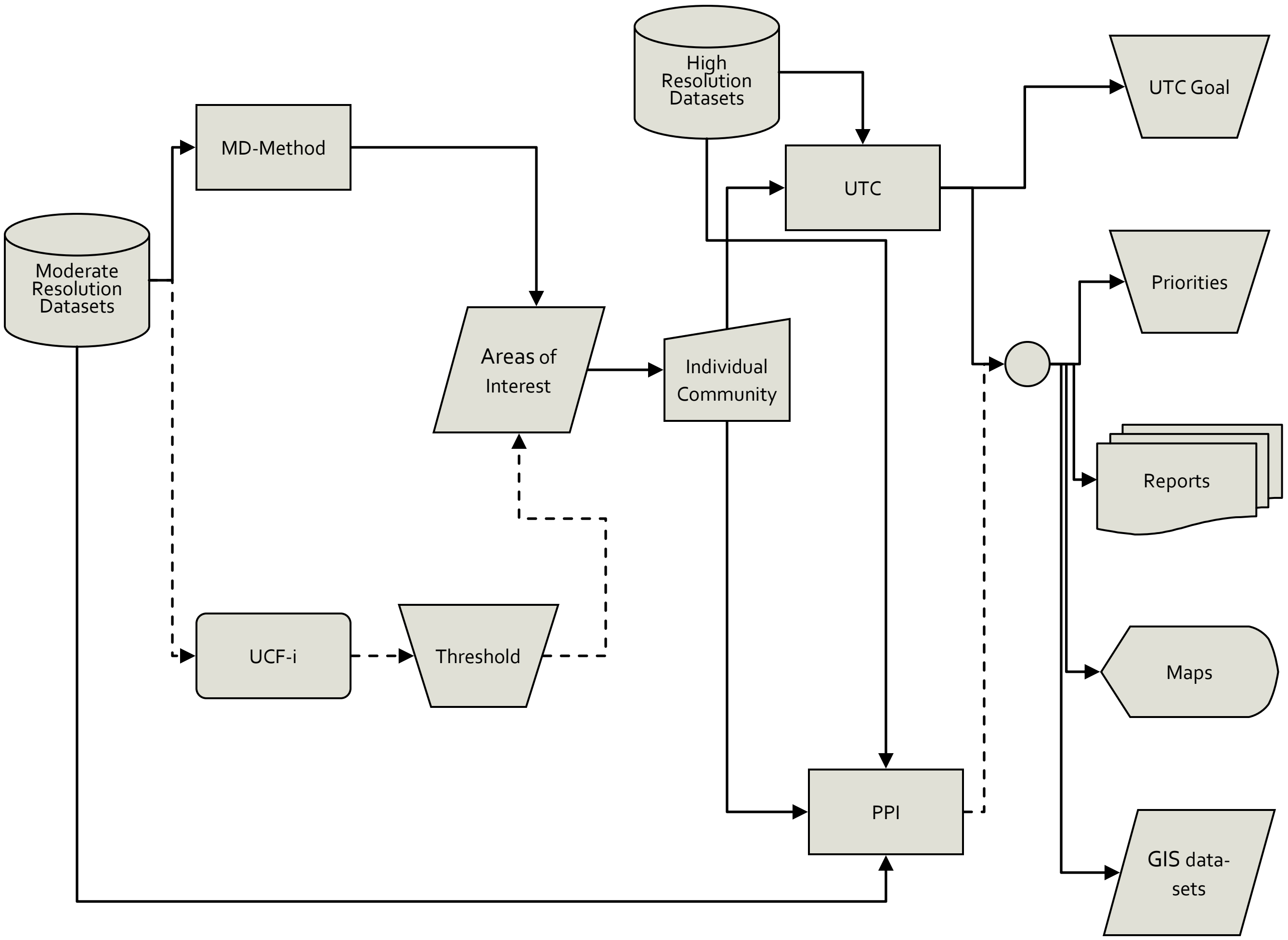


Figure 14: *Vermont. UCF-i results displayed in Google Earth. Darker color correspond to higher UCF-i values. Highlighted towns are those that contain an impaired watershed. The info window displays key land cover metrics along with information from the CARS database.*

Recommended Assessment Workflow



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