The Report Committee for Alan Dale Halter
Certifies that this is the approved version of the following report:

Determining Existing, Possible, and Preferable Urban Tree Canopy for Austin, Texas

APPROVED BY
SUPERVISING COMMITTEE:

Supervisor: ______________________________
Ming-Chun Lee

____
Robert Young

Determining Existing, Possible, and Preferable Urban Tree Canopy for Austin, Texas

by

Alan Dale Halter, B.A.

Report

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Dedication

To Mom and Dad.

Acknowledgements

This professional report is a culmination of the knowledge and skills acquired throughout my academic and work life. The faculty and students in the CRP program at The University of Texas helped me to realize the great potential we humans have in studying our environments to create positive change in our world. Planning is the pursuit of such endeavors.

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Lastly, thank you to my friends and family for your support, encouragement, and all around love throughout my life. Specifically, I thank my father for encouraging me to enroll in Geography 1010 my freshman year of college, my mom for teaching me how the wind "suffs" through the trees, and you both for your support in attaining my education. Your love extends beyond this world…

Abstract

Determining Existing, Possible, and Preferable Urban Tree Canopy for Austin, Texas

Alan Halter, MSCRP

The University of Texas at Austin, 2013

Supervisor: Ming-Chun Lee

This report analyzes urban tree canopy cover (UTC) in Austin, Texas in 2006 using a Geographic Information System (GIS) geoprocessing method developed by the U.S. Forest Service. Findings reveal where UTC exists, could exist, and where it could be prioritized (physically speaking) throughout the Austin region. Results are explained through the context of natural regions and land use to further characterize the urban forest distribution with the purpose of gaining valuable big-picture insights as to where environmental benefits have resulted from local land use planning decisions, development tendencies, and forestry management practices in Austin.

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Chapter 1: Introduction

It is not enough to be a good 'citizen', for that is only half the truth: we are 'residents' dwelling on landscapes…it is not just what a society does to its slaves, women, blacks, minorities, handicapped, children or future generations, but what it does to its fauna, flora, species, ecosystems and landscapes that reveals the character of that society.

(Holmes Rolston III, 2003, p.528)

Recent estimates found over half the world's human population and 82% of U.S. residents lived in urban areas in 2011 (United Nations, 2011). Global estimates project 7 in 10 individuals living in urban areas by 2050 (UNICEF, 2012, p.2).[1] Population growth in Austin, Texas trends upward with each consecutive decade experiencing positive percent population change above 30% over the last 4 decades (ImagineAustin, 2012). Such urban population growth fuels land development thus threatening the integrity of natural ecosystems by placing demands on resources, and by expanding urban land into surrounding forests and rangelands. With this urban expansion comes a characteristic shaping of vegetative configurations such that what natural features did exist or will exist are in large part determined by human intervention—a process which can be mitigated through positive human action. Therefore the need for local and regional planning efforts proves vital to sustaining and managing our natural resources in the face of urban development. These efforts include monitoring our natural resources, such as trees, against development pressures. Such information 1) helps local decision makers to better understand which land uses most intensely impact forest loss, 2) where these impacts are distributed, and 3) where change may be made to urban forestry management practices.

[1] Although the world's urbanized areas are generally growing, many cities are shrinking (i.e. Akron, Ohio; Baltimore, Maryland; Detroit, Michigan; Manchester, England; Moscow, Russia; Halle-Leipzig; East Germany).

This report analyzes urban tree canopy cover (UTC) in Austin, Texas in 2006 using a Geographic Information System (GIS) geoprocessing method developed by the U.S. Forest Service. Findings reveal where UTC exists, could exist, and where it could be prioritized (physically speaking) throughout the Austin region. Results are explained through the context of natural regions and land use to further characterize the urban forest distribution with the purpose of gaining valuable big-picture insights as to where environmental benefits have resulted from local land use planning decisions, development tendencies, and forestry management practices in Austin.

This report is organized into 7 chapters. The first 3 chapters introduce the research topic and explain the overall research design in terms of research questions, purpose, framework, and methods. The remaining 4 chapters serve to explain common practices in evaluating the urban forest resource, and to provide findings, recommendations, and conclusions from this report's analysis. For ease in reading, terms are defined in the glossary section of this report, and additional information is detailed in appendices when deemed necessary.

Chapter 2: Background

This chapter provides broad background information defining the nebulous term "urban forest" and explaining the process of urban development with its associated impact on the urban forest. An argument is made for the importance of urban forests to communities as well as their associated costs that often go unmentioned. Finally, the context of Austin's natural ecosystem is discussed.

Defining Urban Forest(ry)

Definitions of the urban forest abound. This report adopts the broad definition "the aggregate of all community vegetation and green spaces that provide a myriad of environmental, health, and economic benefits for a community" (Sustainable Urban Forests Coalition, 2013). The report's scale encompasses trees on both public and private land within the City of Austin's (the City) jurisdiction. The practice of urban forestry refers to the "management of urban trees and associated resources to sustain urban forest cover, health, and numerous socioeconomic and ecosystem services" for a community (Nowak et al., 2010, p.4). In the U.S., urban foresters primarily focus on trees situated on public lands even though, in many cities, the majority urban forest is situated on private land and forest ecosystems exist beyond political boundaries.

Why Trees Matter: Benefits and Costs of the Urban Forest

Today, urban forests are increasingly considered an element of a much larger green infrastructure (GI) network providing benefits to humans (Benepe, 2013, ImagineAustin, 2012; Young, 2011; American Planning Association [APA], 2009). Cities are increasingly suffering cut backs in state and federal funding coupled with lack of political leverage to raise taxes. Simultaneously cities face increased demands for more and more projects (i.e. roadway repair, affordable housing, and expansion of public safety facilities). Consequently urban greening projects must compete for funding. Thus the case for tree planting campaigns, for example, must be made through quantitative arguments assigning dollar values to the benefits and costs associated with trees as GI elements. This translates to the economic language for which citizens and policy makers most immediately understand.

A bulk of literature today points to the numerous benefits of trees which are then translated into dollar amounts. For example, Nowak & Dwyer (2007) estimate the total compensatory value of trees across the U.S. at $2.4 trillion with an average value of $630 per tree. Although only an estimate, these figures are provided to show the economic importance scholars associate with trees. It is important to note, the Nowak & Dwyer (2007) estimate solely concerns trees as structural assets and disregards the specific ecosystem services they provide. Ecosystem services have been defined as the goods and services humans benefit from in the natural cycles that take place on Earth (Daily et al., 1997). Trees provide benefits through ecosystem services by removing air pollution, enhancing water quality, sequestering carbon, intercepting rainfall, and mitigating the urban heat island effect, among other services (Nowak et al., 2006; Nowak, 2002; Nowak & Crane, 2002; Cavanagh et al., 2009; Akbari, 2001; Cardelino & Chameides, 1990; McPherson et al., 2005; Dwyer et al., 1992; Rosenfeld et al., 1998). In addition to their ecosystem services, trees provide social and economic benefits for people including noise reduction, traffic calming, crime reduction, increased property values, and general aesthetics (Wolf, 2004; Werner et al., 2001; Kuo, 2003; Donovan et al., 2010; Anderson, 1988). The varied benefits of trees have taken the stage in the contemporary urban forestry and urban planning discourse.

On the other hand, much of the urban forest focus today embraces tree benefits without equivalent attention to their costs and disservices to society (Lyytimaki & Sipila, 2009; Lyytimaki, et al., 2008; Escobedo et al., 2011). What's bad about trees? For one they produce byproducts which may pose hazardous risks for humans. For example, tree pollen causes allergies. Sap covers automobiles. Broken limbs and dead trees may potentially damage property. In addition, trees provide a habitat for nuisance species such as bees, raccoons, and grackles. Trees threaten local infrastructure[2] as limbs disrupt overhead utility lines, roots crack sidewalks, and tree trunks/branches block signage and create blind street corners. Lohr et al. (2004) contend that tree-related allergies and sign blockage are the greatest problems expressed by a sample of U.S. residents; however personal issues with trees remain entirely subjective to the observer. Each of these issues gives way to an underlying theme that, no matter the benefits we gain from trees, there is always an associated cost.

Many of these costs are tangible (i.e. initial tree purchase, pruning, irrigation, tree removal, sidewalk replacement, etc.) and can be approximated in dollar amounts; however, like the benefits, many costs do not lend themselves to neat monetary calculations. Furthermore, Escobedo et al. (2011) proclaim that accounting attempts in determining the full value of ecosystem services and disservices prove difficult as unperceived costs may offset or outweigh well-intentioned benefits. For instance, planting trees for climate change mitigation may result in a net loss for a city considering all the energy and water inputs necessary for growing large stands of trees over their lifetime (Escobedo et al., 2011; Jo & McPherson, 1995; Nowak & Crane, 2002). For these reasons, it is difficult to ascertain the true costs and benefits of trees because the very nature of the social and environmental costs and benefits to humans are complex and often incalculable by common measurement standards.

[2] In Austin, infrastructure interference concerns have led to a tree tax proposal from Austin Energy to increase utility fees for property owners whose elm or pecan trees lie within 22 feet of electric power lines (Hyde Park Neighborhood Association, April 2013).

In any case, the costs and benefits of trees must equally be considered when studying the urban forest. The following quote from Clark et al. (1997) shows the common belief in the cost-benefit discourse throughout urban forestry literature that sustainable urban forestry is a broad goal ultimately producing net benefits:

> "Sustainability is a broad, general goal. While we may be able to describe the desired functions of a sustainable urban forest, we cannot yet design the forest to optimize them. Although we know that urban forests act to reduce atmospheric contaminants, we do not yet know how to design those forests to maximize that function. However, we accept that existing urban forests provide these functions to some degree. Trees in cities serve to improve community wellbeing, reduce the urban heat island, eliminate contaminants from the atmosphere, etc. While there are costs involved in planting, maintaining and removing trees in cities, in a sustainable urban forest the net benefits provided by these functions are greater than the costs associated with caring for the forest" (p.20).

URBAN DEVELOPMENT, LAND USE, AND THE URBAN FOREST

A settlement's natural factors (i.e. sun exposure, climate, soils, etc.) initially define vegetative species and distribution patterns of trees within a region, but human activity and vegetative management systems ultimately create variations in the amount and type of biomass found in urbanized areas (Sanders, 1984). Variations in vegetation result when new land development converts raw land into legal lot status with an associated land use.[3] A city's land uses are a prime factor affecting the distribution of urban tree cover because each land use contains a characteristic impervious surface determining the amount of available space for vegetation, and a characteristic function determining the amount of potential space occupied by trees (Sanders, 1984; Nowak et al., 1996).

[3] In some cases redevelopment, urban infill, and/or vacancy may sustain an existing land use or revert a piece of land back to a former use.

Austin's most recent land use inventory (2010) shows single family and open space uses make up the largest percent shares of developed area. 34% of Austin's land area is classified undeveloped with the majority of this land under environmental constraints (i.e. within floodplains, located on steep slopes, etc.) and 50,000 acres free of environmental constraints much of which is used for agriculture (ImagineAustin, 2012, p.35). According to *ImagineAustin* (2012, p.35), industrial, road, and commercial uses experienced the largest percent increases in land area since 2003 respectively while utilities, large-lot single family, and undeveloped uses experienced the largest percent decreases respectively.

This is all important because developed urban land, in the U.S., is projected to expand over the next 50 years which will occur at the expense of forest and rangelands as forest loss is expected to reach 34 million acres (USDA, 2012, p.xiii). Land use changes, land fragmentation from human-induced land conversion, forest parcelization, and devastating natural events are but a few processes which may perpetuate forest loss. Despite national forest loss however, municipalities are increasingly intervening to build and nurture urban forests within their jurisdictions through tree-planting initiatives (Young, 2011; Pinceti, 2009).[4]

AUSTIN'S NATURAL LANDSCAPE

The regional planner, Patrick Geddes, advocated the importance of a regional "civic survey" in understanding the complex dynamics of a city. His motto "diagnose before treatment" holds that effective planning must be followed by an understanding of a city's site and situation. Therefore in an attempt to contextualize Austin's regional

[4] See MillionTreesNYC, Million Trees L.A., Chicago Trees Initiative, Million Trees + Houston, TreePhilly, Sacramento's Greenprint Initiative, and Plant One Million (Pennsylvania, New Jersey, Delaware).

forest resource, this section describes the physical and cultural landscape of Austin that has historically shaped Austin's urban forest. The following briefly describes Austin's natural regions as defined by Texas Parks & Wildlife Department (TPWD). In addition, local climate and natural events are explained which together influence suitable tree species of the region. The main points are described here in this section although a more complete description of Austin's natural environment and governmental framework can be found in Appendix B.

The Austin metropolitan region lies at the confluence of six natural regions as defined by the TPWD (see Figure B-2 in Appendix B). This is largely due to the Balcones Escarpment—the geological formation that defines the Austin region's unique geographic character. It exists as an uplifted protrusion through the Earth's surface in an inactive yet distinct fault zone separating the western Edwards Plateau from the eastern Texas Coastal Plains (see Figure B-1 in Appendix B). The Escarpment separates soil types, topography, species biodiversity, and climate patterns between natural regions within the Austin area.

In addition to its physical divide between natural regions, many believe the Balcones Escarpment to be *the* natural feature influencing human settlement throughout Central Texas' history (Palmer, 1986; City of Austin, Community Inventory Report, 2011). Early European economies in Central Texas were delineated by arable soils. In the west, shallow clay soils atop limestone bedrock discouraged farming yet promoted cattle grazing; fertile soils to the west promoted agriculture (Johnson).

The Edwards Plateau is the largest of the TPWD's natural regions (i.e. physiographic zones) within Austin and is the southern extension of the North American Great Plains. As one moves east in this region, the terrain becomes rugged with eroded rock forming what is known as the Texas Hill Country. Fire played a heavy role in determining vegetation types within the Edwards Plateau until human-induced fire control and overgrazing converted this area from grassland to brushland (Texas A&M Forest Service, 2008; Texas Parks & Wildlife, *Edwards Plateau ecological region*). As a result cedar dominates the landscape today. The region's vegetative cover consists of a mixture of grasses and intermittent woodlands consisting of live oak, Texas oak, Spanish oak, shin oak, honey mesquite, Ashe juniper, bald cypress, hackberry, sumac, and cedar elm (Texas A&M Forest Service, 2008; Texas Parks & Wildlife, *Edwards Plateau ecological region*). The eastern Edwards Plateau contains the Balcones Canyonlands and Live Oak-Mesquite Savanna natural subregions.

Limestone canyons, cut by tributaries of the Colorado River, identify the Balcones Canyonlands. Karst topography further characterizes the terrain. Vegetative cover in the Canyonlands consists of evergreen woodlands and deciduous forests with specific tree species previously described in the Edwards Plateau section of this paper (Riskind & Diamond, 1986).

The Live Oak-Mesquite Savanna dominates most of the western and northern portion of the Edwards Plateau although intermittent finger-like portions exist between the Balcones Canyonlands in the eastern portion of the Plateau. The subregion is dominated, as its name suggests, by mesquite shrubland and live oak trees containing distinctive Spanish and ball mosses growing from their branches.

The Blackland Prairie is a grassland natural region covering the eastern portion of Austin. Cretaceous chalk, marl, and limestone formations created productive black clay soils suitable for farming. Initially the prairie consisted of tallgrasses however agricultural production converted much of the terrain into cropland and grazing pastures (Texas Parks & Wildlife, *Blackland Prairie ecological region*). The region is identified as the most altered natural region in Texas with 1% of the native Blackland Prairie remaining today (Ramos & Gonzalez, 2011).

Austin experiences a humid subtropical climate characteristic of hot summers and mild winters (NOAA, 2010). Precipitation is generally spread evenly throughout the year with peak rainfall typically occurring in May and September (NOAA, 2010). Average yearly rainfall is near 33 inches in Austin compared to 50 inches in Houston, Texas (a fairly humid city), and 4 inches in Las Vegas (a fairly arid city) (NOAA, 2010).

Although Austin's anticipated annual precipitation indicates a city with sufficient water to support a lush urban forest, Austin and the rest of Texas have experienced the third largest drought in recorded state history beginning in October 2010. the period between October 2010 and September 2011 witnessed an estimated urban tree loss of 5.6 million statewide—roughly 10% of Texas' urban forests—resulting in a projected $560 million to remove said dead trees (Texas A&M Forest Service, 2012, February).

Chapter 3: Research Context

RESEARCH PURPOSE, INVOLVEMENT, AND INTEREST

In order to maximize an efficient allocation of tree benefits for the greatest amount of people, a comprehensive, citywide planning initiative is often needed to better manage trees across private and public lands. A comprehensive urban forest management plan is one tool that municipalities may use in order to guide sustainable urban forest management across public lands (Randolph, 2011, p.332; APA, 2009).

The City of Austin's Urban Forestry Program and Urban Forestry Board are currently in the process of creating a new Comprehensive Urban Forest Plan to "establish a standard of care for trees and vegetation on public property and to provide a framework (guidance) for City departments to develop land management plans for their own properties" (City of Austin, Comprehensive Urban Forest Plan Visions). This plan-in-progress was mandated by Austin City Code in 1992:

> (A) With the assistance of the urban forester, the [Urban Forestry] board shall develop and revise the plan.
>
> (B) The Environmental Board and Parks and Recreation Board shall review the plan and make recommendations to the board.
>
> (C) The urban forester shall provide administrative staff services to the board in connection with the plan (§ 6-3-5 Comprehensive Urban Forest Plan).

The plan is further supported by Austin's new comprehensive plan, *ImagineAustin* placing an importance on expanding green infrastructure elements specifically for "maintaining and increasing Austin's urban forest as a key component of the green infrastructure network" (ImagineAustin, 2012, p.151). Priority Action CE A22 mandates creation of the urban forest plan:

> "Create an urban forest plan that identifies tree canopy goals, establishes a budget, and presents implementation measures…create a green infrastructure program to

protect environmentally sensitive areas and integrate nature into the city" (Imagine Austin, 2012, p.247).

Through an internship with the City of Austin's Urban Forestry Program in the spring of 2012, I found the Program's staff and Board desire more GIS-based[5] analysis to describe Austin's present state of the urban forest. Through a separate but related internship with the City of New York's Central Forestry & Horticulture Division in the summer of 2012, I built upon my GIS skills by updating a street tree inventory and researching tree canopy assessments.

This research seeks to fill the GIS-void in the Urban Forestry Program's plan with research results primarily intended to document current and potential UTC, which will inform UTC goals in the plan-making process. In addition, various City departments, tree planting nonprofits, and local citizens may use the results of this report.

UTC (urban tree canopy) refers to the layer of leaves, branches, and stems of trees that cover the ground when viewed from above within an urban area. UTC is commonly used in measuring an area's urban forest resource as a proxy for a comprehensive tree inventory.

RESEARCH QUESTIONS

My research generally asks: how much UTC exists within the City, how much UTC is possible, and where is increased UTC preferable given the City's new initiative to create an urban forestry plan? These three broad research questions are further divided into the following more detailed questions:

Existing UTC

1. What is the existing percent canopy cover across these various geographic units?
   a. Austin region
   b. City jurisdictional boundaries
   c. Census Blocks

[5] See Appendix A for a detailed description of GIS and its role in urban planning.

   d. Parcels
2. What is the existing percent canopy cover for each land use type?
3. What is the existing percent canopy cover for each natural region?

Possible UTC

4. How much tree canopy is possible (i.e. where is it *biophysically* feasible to plant trees) across these various geographic units?
   a. Austin region
   b. City jurisdictional boundaries
   c. Census blocks
   d. Parcels

Preferable UTC

5. Where are priority sites located in Austin for preferred tree-plantings and/or urban forestry attention?

THEORETICAL FRAMEWORK

A common procedure in conducting urban forest plans lies in understanding a community's present forest resource as it stands (Randolph, 2011; Raciti, 2006; APA, 2009). This initial planning step documents the current state of the urban forest with the purpose of informing tree-related policies. Techniques often combine computer technologies and some form of sampling method such as tree inventories of tree point locations or photogrammetry interpretation of aerial or satellite imagery to extract tree canopy cover.

My research adopts the U.S. Forest Service's theoretical framework called the UTC assessment to understand Austin's present and possible tree canopy resource. In 2006 the U.S. Forest Service's Northern Research Station, in conjunction with the University of Vermont's Spatial Analysis Laboratory and New York City's Department of Parks & Recreation, created the UTC assessment for planning and implementing a successful UTC program.[6] The UTC assessment utilizes 1) photogrammetry

[6] See the official UTC assessment webpage at http://www.nrs.fs.fed.us/urban/utc/

interpretation of aerial or satellite imagery to infer tree canopy cover, and 2) geoprocessing of a tree canopy dataset using GIS for the purpose of increasing awareness amongst decision makers about how much tree canopy exists and how much could exist in their locality (Grove et al., 2006; Raciti, 2006). It is important to understand the assessment focuses on increasing tree canopy in specified areas and therefore solely concerns planting new trees as opposed to other forestry practices such as managing existing stands or removing dead trees.

The UTC assessment workflow determines how much tree canopy exists (existing UTC), how much could exist (possible UTC), and where possible tree canopy is preferred (preferable UTC) to inform policy discussion regarding Austin's urban forest. It entails four major steps as outlined in the concept map shown in Figure 1.

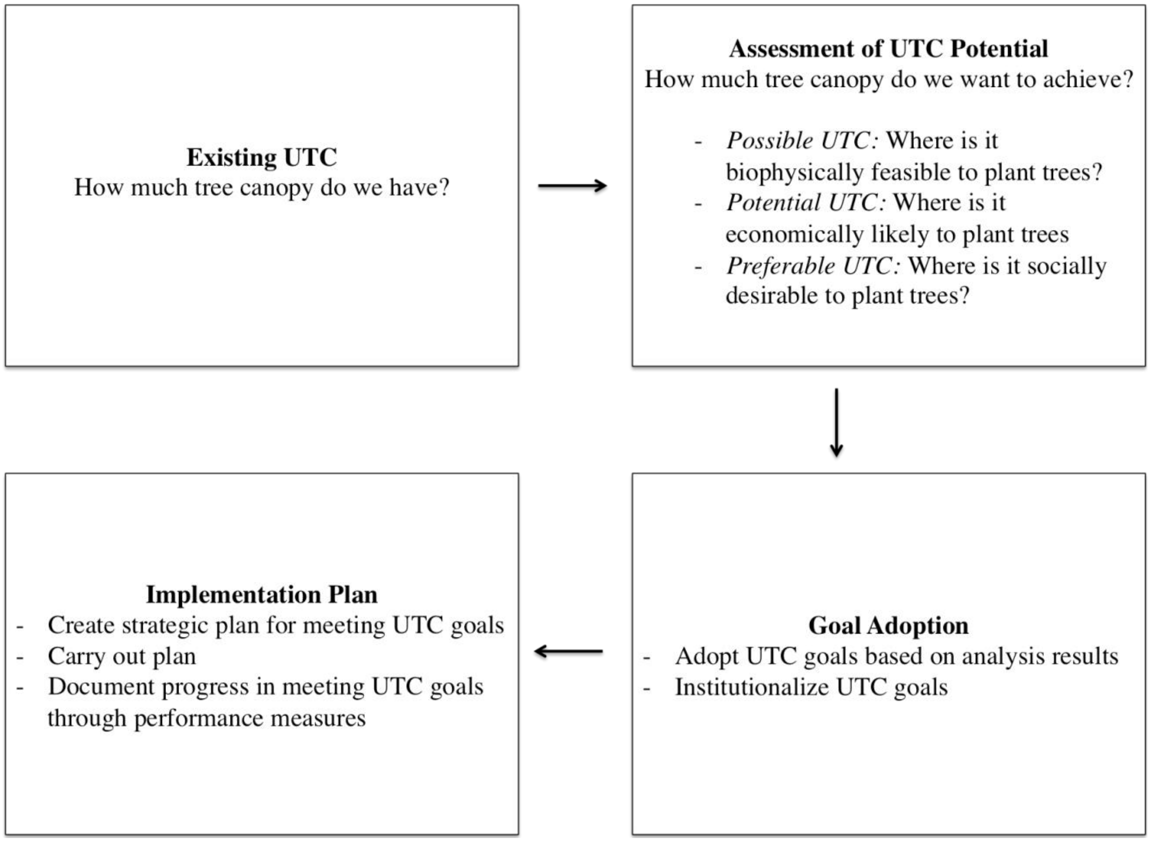


Figure 1: UTC Assessment Framework, adapted from Raciti (2006)

Step 1: Existing UTC

In asking the first question—"how much tree canopy do we have"—a community assesses the present condition of their urban forest in order to accurately measure tree canopy cover through one of two approaches. The *bottom-up* approach is a field sampling method relying on human volunteers to physically measure tree canopy cover. Field samples are then projected for an entire study area. The *top-down* approach extracts canopy cover extents from remotely sensed data (i.e. satellite or aerial imagery, see Figure 2) through a manual or automated feature extraction process.

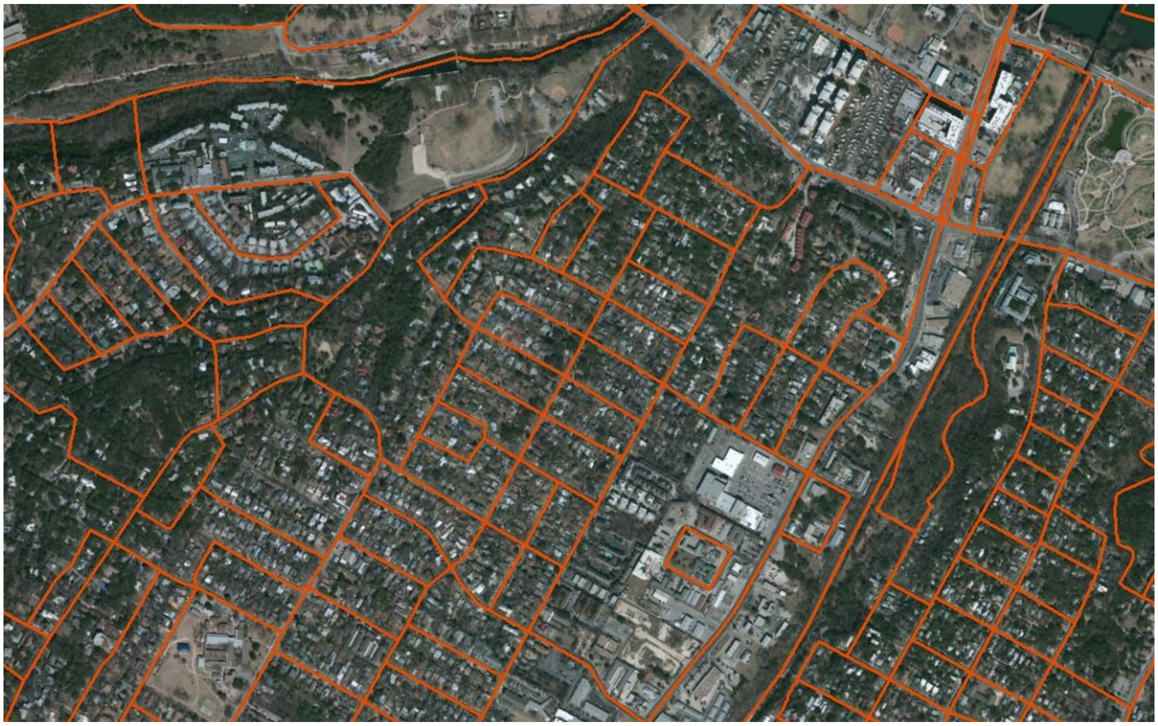


Figure 2: Aerial image delineated by 2010 Census Blocks

At its most basic level, this approach classifies pixels in an image, like the one shown in Figure 2 above, by vegetation type based on a pixel's value on the electromagnetic spectrum. Once values are identified as tree canopy, the information is extracted as shown in green in Figure 3.

Figure 3: Aerial image with tree canopy extracted

The extent of a community's existing UTC resource can be quantified further by using GIS to parse the overall tree canopy dataset by geographic units (i.e. parcel tax lot, Census Block, city limit jurisdiction, county, etc.) thus deriving a percentage canopy cover for each unit. Figure 4 shows percent canopy cover by 2010 Census Blocks as derived from the tree canopy data shown in Figure 3 above.

Figure 4: Existing UTC by 2010 Census Blocks

Step 2: Assessment of UTC Potential

This step assesses how much UTC a community can and wants to achieve. The approach is subdivided into three sequential steps called the "Three P's": possible UTC, potential UTC, and preferable UTC. The Three P's are separated into manageable components for ease in analysis although each step feeds into the next.

Possible UTC

The first "P" simply asks where it is biophysically feasible to plant trees within a given area. It focuses purely on the physical aspects of a "plantable" area and thus ignores the site-specific costs, desirability, and appropriateness to plant in a particular area. A set of user-defined criteria assesses an area's biophysical feasibility depending on available data for the area under study and depending on user preference. Criteria typically concern built and natural environment elements that are not suitable as planting areas (i.e. building footprints, streets, and surface water). Figure 5 below shows possible planting areas in red which are void of existing UTC, roads, water, buildings, and airport runways.

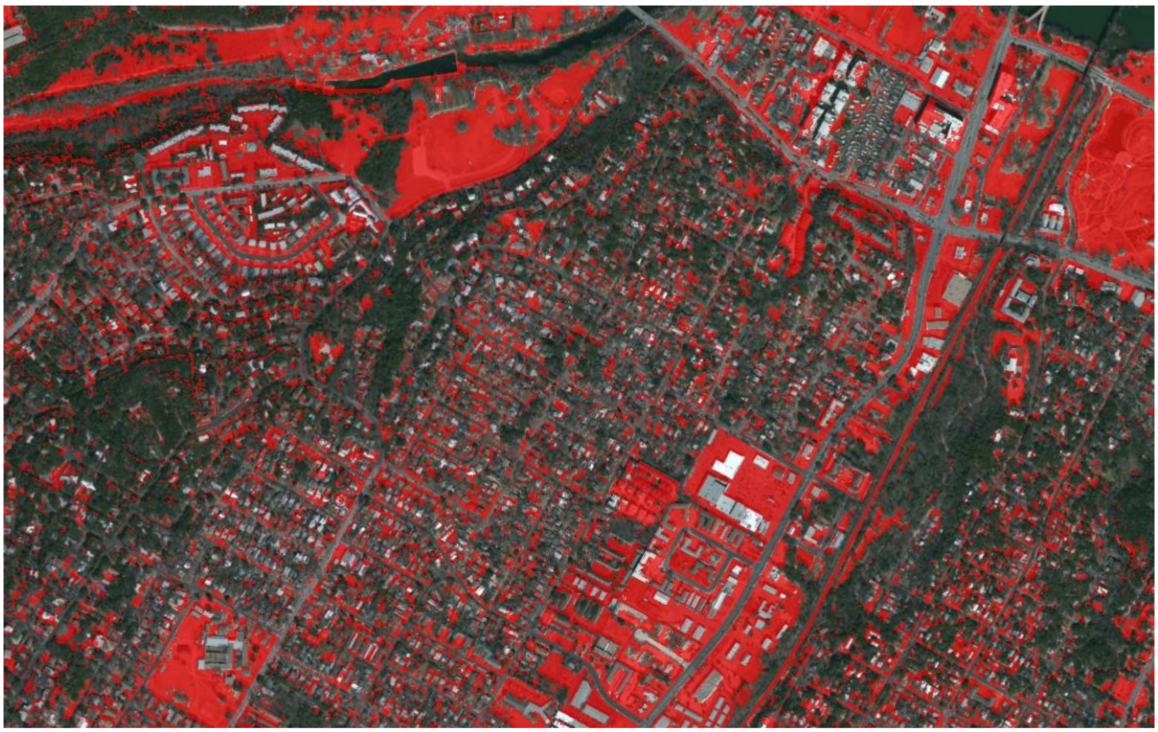


Figure 5: Aerial image with possible planting areas extracted in red

Like with the existing UTC metric of percent canopy cover, percent possible UTC can be quantified for a geographic unit. In Figure 6, the possible plantable area is calculated and symbolized for each 2010 Census Block.

Figure 6: Possible UTC by 2010 Census Blocks

Potential UTC

This step identifies cost effective areas to plant new trees asking: where is it economically likely to plant trees? It deals with areas containing regulatory measures or incentives to plant new trees. My research ignores this step of the UTC assessment in an attempt to keep a broad, citywide perspective of physical forest distribution separate from the sub-regional emphasis inherent in political or regulatory measures.

Preferable UTC

This final step deals with localizing tree planting efforts to achieve societal benefits by asking: where is it socially desirable to plant trees. This step resembles a *McHargian*-style GIS analysis by finding suitable areas for new tree plantings based on a set of defined criteria embodying societal goals. For instance, if asthma reduction, improved air quality, and flood mitigation are a city's primary goals concerning the urban forest, then data on asthma cases, CO_2 levels, and the number of flooding events might be used to find preferable planting areas throughout the city. This step caters to a community's specific needs allowing community engagement and local policy decisions to guide the output. Figure 7 below shows priority planting areas by 2010 Census Blocks. Each Census Block contains existing and possible UTC data, determined from previous steps, which feed into a priority planting calculation to determine the most desirable places to plant new trees (shown in red) and the least desirable (shown in green).

Figure 7: Priority UTC by 2010 Census Blocks

Step 3: Goal Adoption

During goal adoption, results from the assessment process are formulated into UTC goals. UTC goals should be institutionalized into local and/or regional legislation, regulations, or comprehensive forest management plans. UTC goals typically describe an increase in percent canopy cover by a certain year in the future, and goals may be tied to specific geographic areas. For instance, American Forests' (1996) recommends overall citywide canopy cover of 40% for humid cities and 30% for arid cities. They also recommend canopy cover percentages of 15% in business districts, 25% in urban residential areas, and 50% in suburban areas.

Step 4: Implementation Plan

The final step establishes requirements to meet UTC goals. It requires relating canopy goals to local ordinances, regulations, and the community's comprehensive plan. In addition, it requires creating a strategy for stakeholder involvement in carrying out the plan, and requires clearly defined performance measures to keep short-term operations in line with long-term goals.

Chapter 4: Review of Literature

This chapter reviews both academic and professional methods for evaluating the urban forest as a vegetative resource existing within cities. Particular emphasis is given to methods involving GIS interpretation of remotely sensed imagery although alternative methods are presented. The chapter flows from broad models of urban forestry sustainability to specific methods and topics such as canopy assessment methods and calculating priority planting areas. The outcome of this literature review was to provide a better understanding of the canopy assessment process for both the researcher and reader. Alternatives to digital analysis assessment methods are discussed in Appendix C, and additional UTC Assessment reports of interest to this paper may be found in Appendix D.

URBAN FORESTRY SUSTAINABILITY MODELS

Researchers have developed several methods in assessing urban forest sustainability (Clark et al., 1997; Kenney, 2008; Wua et al., 2008; Nowak & Greenfield, 2008; Kirnbauer et al., 2009; Kenney et al., 2011). Clark et al. (1997) began a model of urban forest sustainability under the precepts that urban forest sustainability is 1) a broad, general goal (i.e. although we know trees provide beneficial functions—"we cannot yet design the forest to optimize them"—still we accept that the long-term benefits outweigh costs to sustain them), 2) requires human intervention, 3) urban forests provide services not goods, and 4) private trees make up the majority of an urban forest (p.20). Based on these precepts, Clark et al. (1997) developed a sustainable framework of three criteria for success in managing the urban forest by looking at 1) vegetation resource, 2) community framework, and 3) resource management. Each criterion contains an associated objective and performance measures. For instance, under the vegetation resource criterion, tree canopy is measured to "achieve climate-appropriate degree of tree cover, community-wide" (p.22).

The Kenney et al. (2011) model of urban forest sustainability expands on the Clark et al. (1997) model by adding more performance measures and modifying others. For instance, the condition of publicly owned trees, and publicly owned natural areas are added to the vegetation resource criterion section. The canopy cover calculation is revised to the "relative canopy cover" formula comparing actual canopy cover and the maximum potential cover within a community (p.110). Their model identifies tree canopy measurements as only one indicator in a larger set of indicators used to measure urban forest health.

My research acknowledges that tree canopy measurements are not the end-all be-all of urban forest health, yet they do still retain acceptable relevance and indication in regards to characterizing a city's vegetative resource extent. When tree canopy data is available for an urban area with significant resource management practices in place, planners and analysts should continue to make use of such available data for monitoring purposes.

REVIEW OF CANOPY ASSESSMENT METHODS

My research focuses on the urban forest as the "vegetative resource" first explained in the Clark et al. (1997) model. Multiple methods exist for evaluating vegetation in cities. Since field techniques are costly and time consuming, many methods today make use of aerial imagery to derive canopy measurements. Four major photointerpretation methods exist within the standard industry practice of estimating tree cover from aerial imagery: 1) visual crown cover estimation, 2) dot grid, 3) line intercept/transect, and 4) digital image analysis (Nowak et al., 1996; Bernhardt &

Swiecki, 2001). Localities may choose which method fits best within their needs and financial resources to achieve planning and management goals. The following briefly explains the most widely used method (digital image analysis) and its associated advantages and disadvantages as described by Nowak et al. (1996) and Bernhardt & Swiecki (2001).[7] It is important to note that, as with all methods of spatial analysis, accuracy depends on the photo interpreter's ability to correctly classify and measure data, yet some methods produce more accurate results than others.

In the digital image analysis method land cover boundaries, extracted from aerial or satellite imagery, are digitized into a computer database such that the area of each polygon may be measured and summarized for each land cover class (see Figure 8). Advantages include increased precision and accuracy, and the integration of GIS which increases the coverage area to be analyzed due to faster computer processing speeds. Disadvantages include labor intensive computer processing, the requirement of personnel with specific expertise, the requirement of specific and costly equipment (i.e. personal computer, GIS software, orthorectified photos, storage space, etc.), and photointerpretation errors due to misclassification.

[7] Alternatives to the digital analysis method may be found in Appendix C.

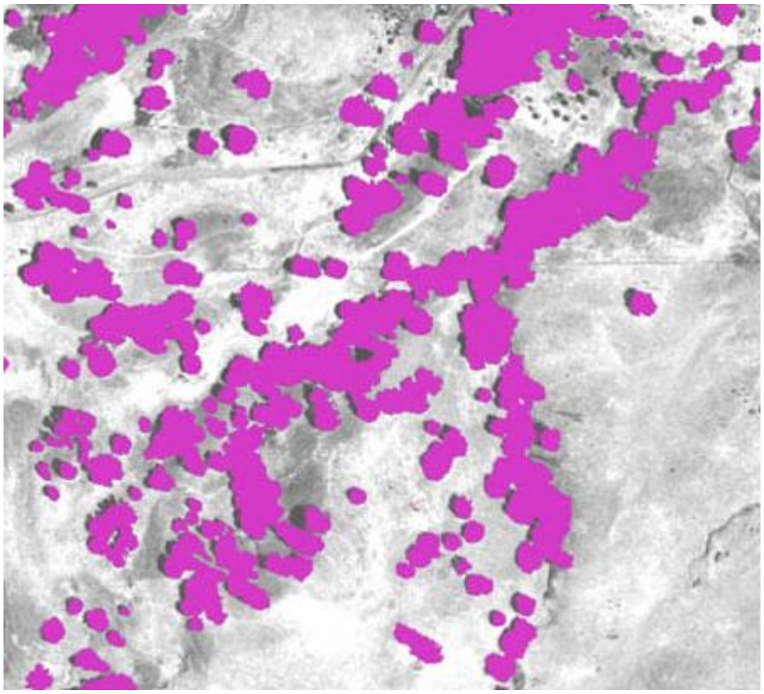


Figure 8: Feature extraction of tree canopy (pink) from an aerial photo (gray)

DIGITAL IMAGE ANALYSIS STUDIES OF UTC

Today, most tree canopy assessments in large cities utilize the digital image analysis method. The advent of the U.S. Forest Service's UTC assessment has generated numerous reports across the nation with many cities adopting and modifying the UTC assessment to suit local needs.[8] The following section describes valuable methods used from other UTC assessment studies which were considered for this report.

Collaboration between the New York City Department of Parks & Recreation and the U.S. Forest Service resulted in a series of studies using the UTC assessment framework to characterize NYC's existing, possible, and preferable UTC (Grove et al., 2006; Locke et al., 2010). Analysis methods for evaluating existing and possible UTC followed common UTC assessment methods of GIS geoprocessing and overlays to erase

[8] See http://www.nrs.fs.fed.us/urban/utc/pubs/ for a list of over 30 UTC Assessment reports conducted by the U.S. Forest Service.

undesirable areas of the built and natural environment. Next, a prioritization of preferable tree planting sites was conducted according to a two-tiered system of need-based and suitability-based criteria (Locke et al., 2010). Tier 1 criteria were calculated at the neighborhood level. These criteria addressed air/noise/water quality, biodiversity, the urban heat island, and public health issues. Tier 2 criteria were calculated at the parcel level and reflect programmatic goals as expressed by various public entities (i.e. Natural Resources Group, New York Restoration Project, and Central Forestry & Horticulture). These criteria addressed possible UTC levels for 1) publicly-owned parcels greater than 10 acres, and 2) PROW areas. Finally, criteria from both tiers were combined, prioritized, and mapped via a parcel ranking system.

Numerous studies utilize a parcel or Census block prioritization system to locate where urban forestry services are most needed. The PPI is the most common prioritization method, and was developed by Nowak & Greenfield (2008) to prioritize areas for tree plantings. Morani et al. (2010) based a prioritization index on population density, tree canopy cover, and pollution concentration criteria using 2000 Census Blocks as the base geographic unit across all NYC boroughs. The PPI calculation standardized and weighted scores for each Block using the following calculation:

PPI = (PD * 30) + (POLL * 40) + (LTC * 30) where PD is the standardized value for population density, POLL is the standardized value for air pollutants, and LTC is the standardized value for low tree canopy cover. The standardized values for low tree cover were calculated using a reverse index of tree canopy cover where the lower the tree cover, the higher the standardized value. The standardized value for LTC was calculated as ((max-n)/r) where n is the percentage of canopy cover in each block, max is the maximum among all values for tree canopy cover and r is the range of canopy cover values.

Although an off-the-shelf index, the PPI proves useful because it is easily calculated using GIS software and/or Microsoft Excel, and because, once calculated, PPI values are comparable across cities. In addition, the PPI allows for input of multiple criteria depending on relative importance to a community.

Chapter 5: Methods

Description of Study Area

The site for this research was Austin, Texas—the 13th largest city in the United States with a recorded population of 790,390 people according to the 2010 U.S. Census. The city is located in Central Texas spanning Travis, Hays, Caldwell, Bastrop, and Williamson Counties. For most of this analysis, the study area for this report is restricted to the City of Austin's 5 mile extraterritorial jurisdiction (ETJ) encompassing 626 square miles of land (see Figure 9).[9] The 5 mile ETJ study area intends to summarize data at a meaningful scale that makes sense to local policymakers. In addition, certain GIS datasets (i.e. land use 2010) limited the spatial processing extent for this report to the 5 mile ETJ. For the parcel analysis, the study area extends to the tree canopy data boundary (shown in purple in Figure 9) to account for canopy cover variations across natural regions.

[9] This figure includes full purpose, limited purpose, and ETJ areas as calculated from the CoA's "Austin Jurisdictional Boundaries" GIS dataset found at ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html

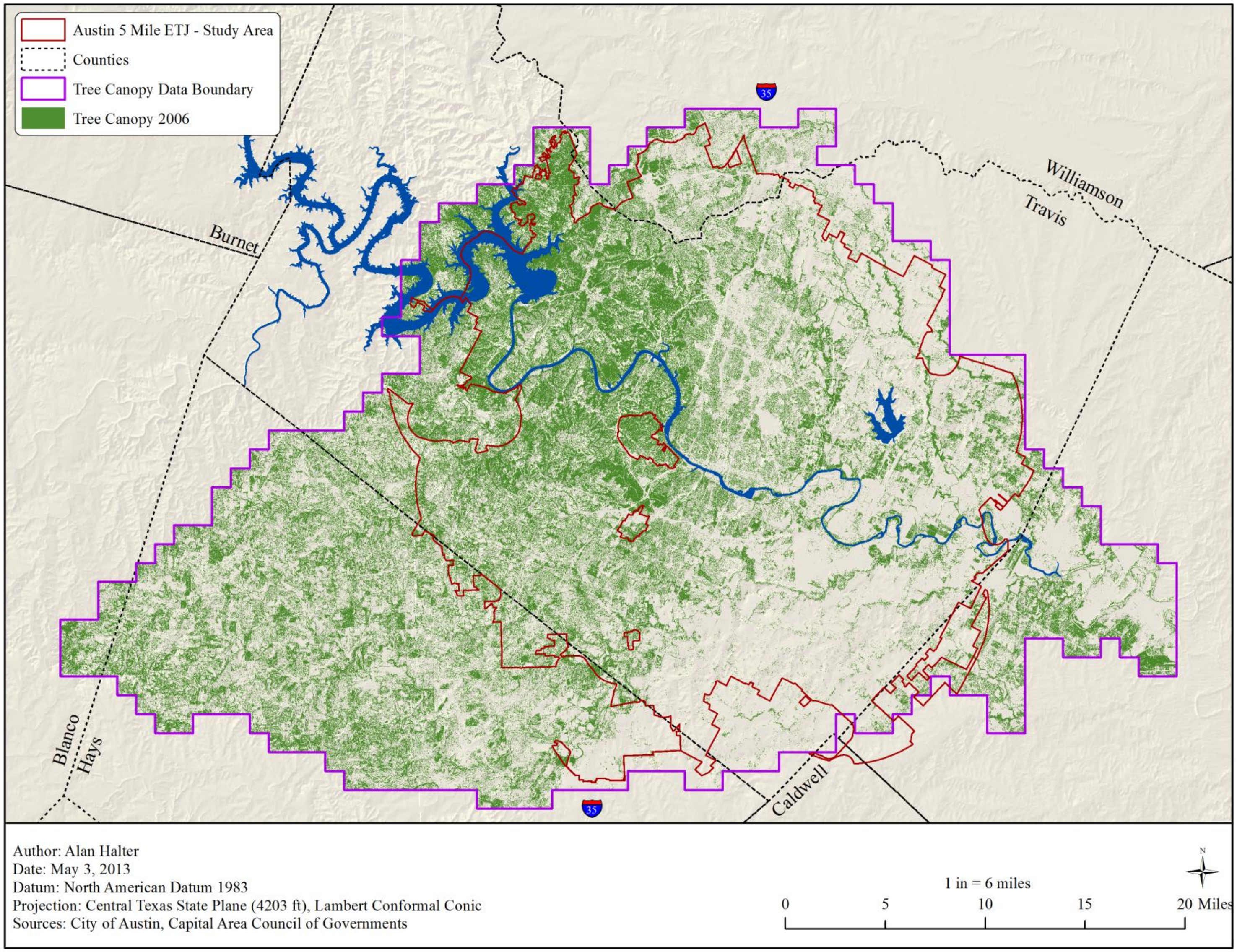


Figure 9: Study area and tree canopy (2006) Austin, Texas

City of Austin Jurisdictions

The City contains five jurisdictional boundary levels allowing differing powers, which have implications on where tree-related city services may be carried out on public land. The "full purpose" boundary is the official city limit boundary in which all City services and development regulations apply. ETJ boundaries exist 2 and 5 miles contiguous to the full purpose boundary. In 1987 the Texas State Legislature decided "to designate certain areas as the ETJ of municipalities to promote and protect the general health, safety, and welfare of persons residing in and adjacent to the municipalities" (Texas Local Government Code, § 42.001). The ETJ contains unincorporated land, but the City extends limited powers to regulate these areas with future annexation anticipated. The ETJ area is important concerning planning issues because 1) Texas state law allows a city's planning area to extend into the ETJ, 2) the Austin City Charter includes the ETJ in the City's official planning area, and 3) tree-related city services may extend into these areas either presently or in the near future (ImagineAustin, 2012). Figure 10 shows the City's various jurisdictions.

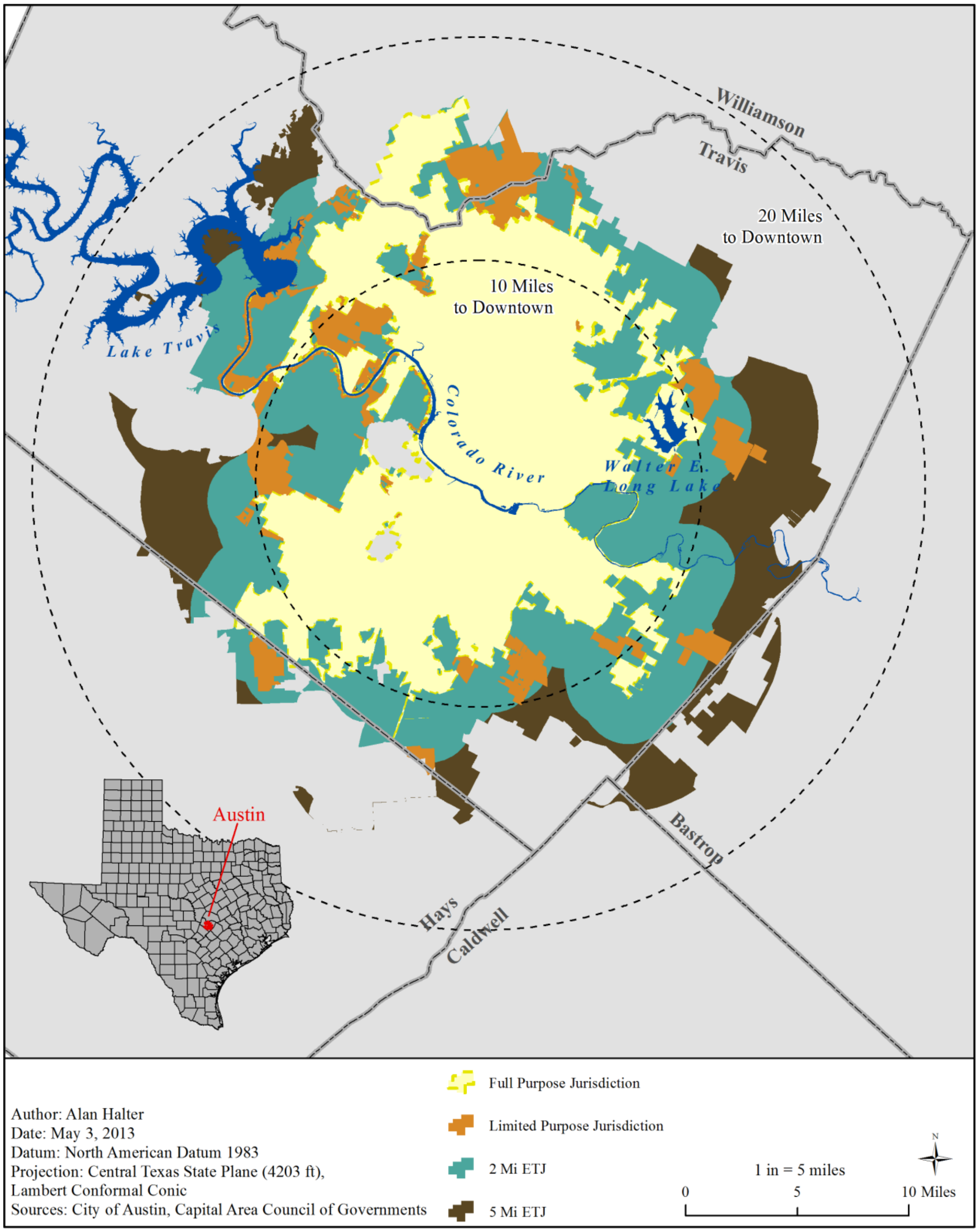


Figure 10: City Jurisdictions

DATA SOURCES

Data sources were acquired from local, regional, and national government providers of GIS datasets via File Transfer Protocol (FTP) websites available online for free download to the public. These providers included the City of Austin, CAPCOG, county appraisal districts, TPWD, the USGS, and the U.S. Census Bureau. The base geographic units of analysis included parcel and Census Block geographies. All other datasets were processed with new tabular attribute data assigned to the parcel/Block geographies during the UTC assessment. Figure 11 shows the datasets used in the existing, possible, and preferable UTC steps with associated sources.

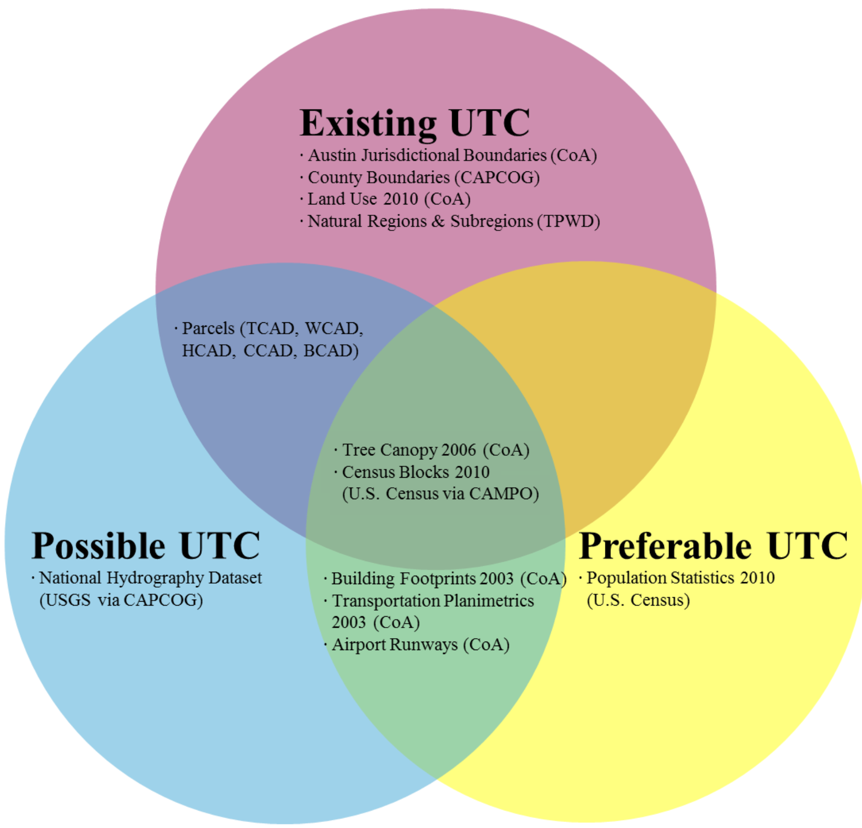


Figure 11: GIS Data Sources

In 2006, the City of Austin and CAPCOG contracted Sanborn Map Company, Inc. to update their GIS planimetric database using leaf-on aerial imagery flown in the summer of 2006. Using photogrammetric techniques, the City created a vector dataset[10] depicting approximate tree canopy cover for the greater Austin area. The dataset covers all the City's watersheds out to its 5 mile ETJ. It also covers some 15 miles southwest of the city in Hays County for monitoring of environmentally sensitive areas over time. The dataset was derived from Color Infrared orthoimagery with a 2-foot pixel resolution.[11] Vector data depicting tree canopy was extracted from the aerial imagery using an unsupervised classification method in Intergraph's ERDAS Imagine imagery processing software, and a supplemental raster and vector processing method using Spatial Analyst Tools in ESRI's ArcMap 9.3. This tree canopy dataset provides the basis for analysis in this report and is shown in Figure 9 on page 29 and below in Figure 12.

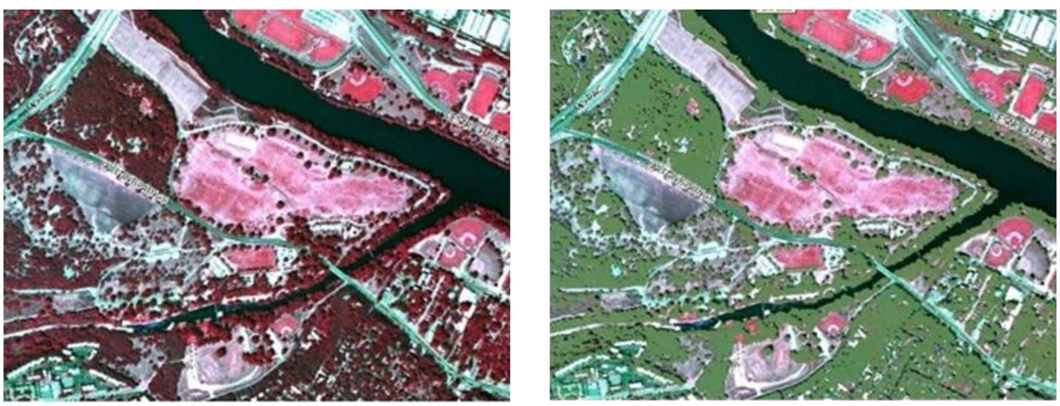


Figure 12: Color Infrared Aerial Images, 2006

[10] Retrieved from ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html

[11] Tree vegetation (shown in dark red at left in Figure 12) was extracted to a GIS dataset (shown in green at right in Figure 12).

ANALYSIS STEPS

First, a literature review was conducted of the urban forest paying specific attention to methods and results of best practices for measuring tree canopy cover using GIS. Next, following the framework outlined previously, I conducted an analysis addressing the existing, possible, and preferable aspects of the Canopy Assessment Process.

To find existing UTC, I used a series of geoprocessing techniques adopted from the U.S. Forest Service's UTC assessment utilizing ESRI's ArcMap 10.1 and GIS data available through the City, CAPCOG, and TPWD (refer to Figure 13 for existing UTC analysis steps). Overall the City's tree canopy dataset was manipulated to find percentages of canopy by various geographies (i.e. jurisdictional boundaries, Census Blocks, and parcels), land use types (i.e. single family residential, commercial, etc.), and natural regions (i.e. Edwards Plateau). The process involved a geoprocessing overlay tool called Identity to find the area of tree canopy existing across all parcels and Census Blocks in the study area. Next, percentage of canopy cover was calculated for each parcel and Census Block by adding new attribute fields to the Identity output file and calculating the geometry of each parcel/Block area and each canopy cover area. Finally, a selection process determined which parcels/Blocks fell within which natural regions and land use types. Fields were calculated accordingly.

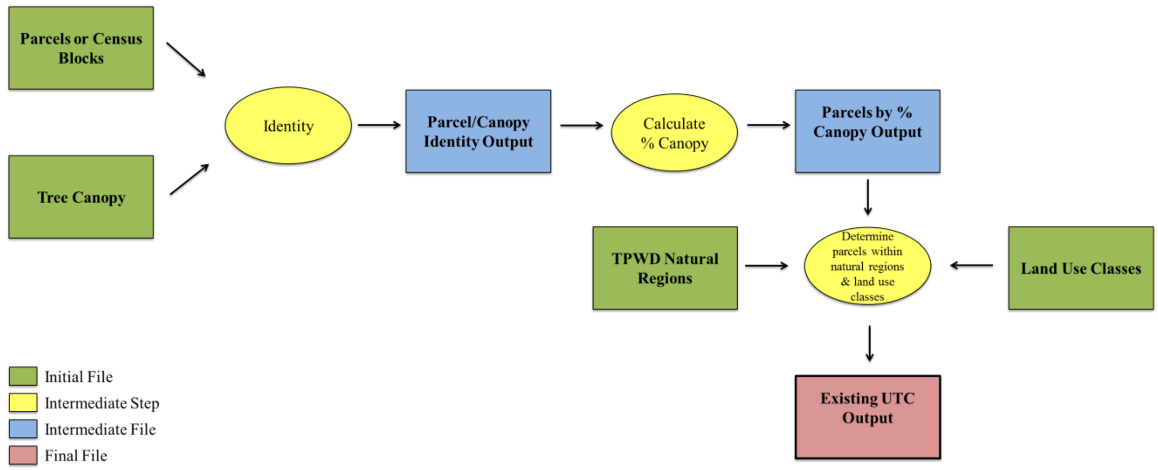


Figure 13: Existing UTC Workflow

To find possible UTC, I used another series of geoprocessing overlay steps using the Erase tool (refer to Figure 14). This approach simply identified land available for canopy, but not currently covered by existing canopy, surface water, roads, buildings, or airport runways. The process involved the Erase tool to cut out non-suitable planting areas within the study area. Finally, the resulting output from the Erase steps was combined with Census Blocks using the Identity tool. From this output, the area of land deemed possible for new plantings was calculated culminating in a percent of land possible for increased UTC for each Block.

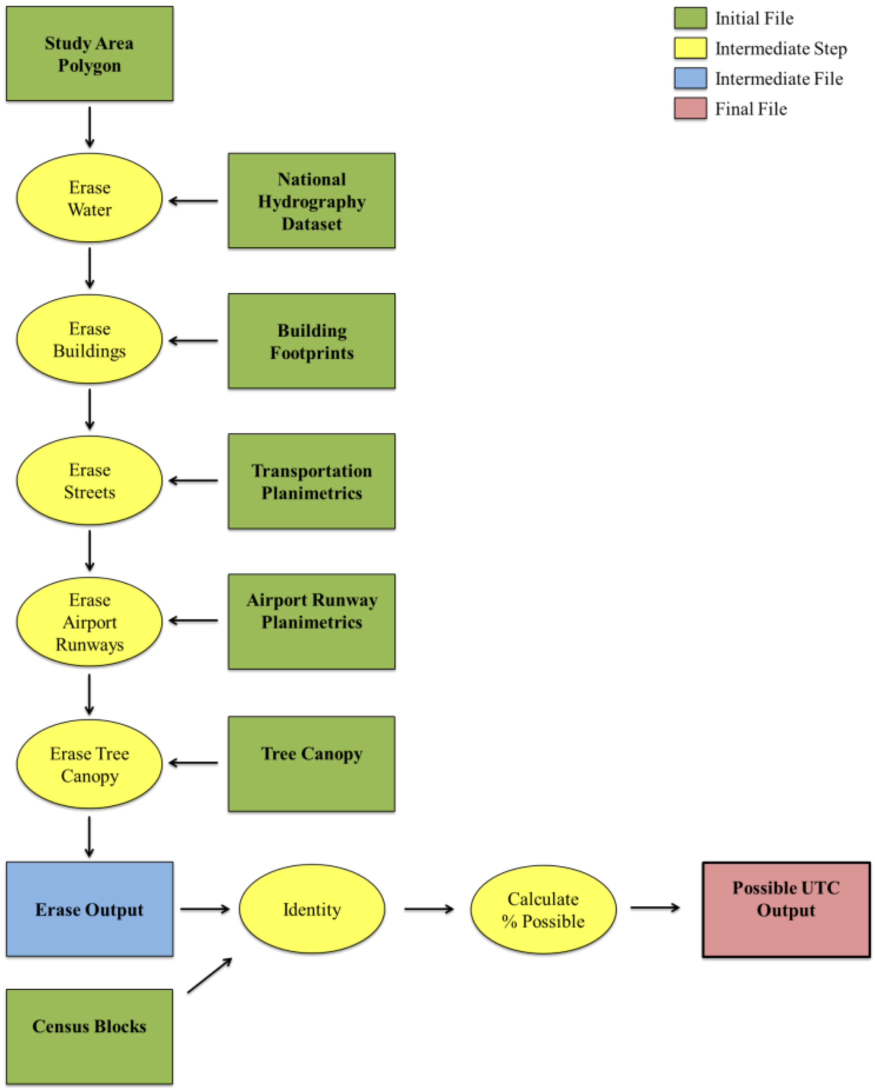


Figure 14: Possible UTC Workflow

Finally, to find preferable UTC, I used the PPI (modified from Nowak & Greenfield, 2008) which uses population density, possible planting area, and tree cover per capita to rank tree planting locations (refer to Figure 15). Census Blocks of higher population density, higher possible planting area, and lower tree cover per capita receive higher PPI values, thus the higher the priority for planting in the area. This step simply involved calculations in the Census Block dataset's attribute table created from the existing and possible UTC steps. The following describes the rationale and calculation of the PPI's three criteria.

Population Density (PD): The number of people in a Census Block divided by its area in acres. The greater the population density, the greater the priority for tree planting.

Possible Planting Space (PS): The amount of possible UTC area in acres within a Census Block. The higher the value, the greater the priority for tree planting.

Tree Canopy Cover per Capita (TPC): The amount of existing UTC area in acres per person within a Census Block. The lower the amount of tree canopy cover per person, the greater the priority for tree planting.

Each criterion was standardized on a scale of 0 to 1, with 1 representing the maximum population density, maximum possible planting area, and maximum tree cover per capita. The standardized values were weighted to produce a combined score theoretically ranging from 100 (highest priority) to 0 (lowest priority) using the following formula:

PPI = (PD * 40) + (PS * 30) + (TPC * 30), where PPI is the combined Priority Planting Index score, PD is the standardized population density value, PS is the standardized Possible Planting Space value, and TPC is the standardized Tree Cover per Capita value

The standardized value for population density (PD) was calculated as

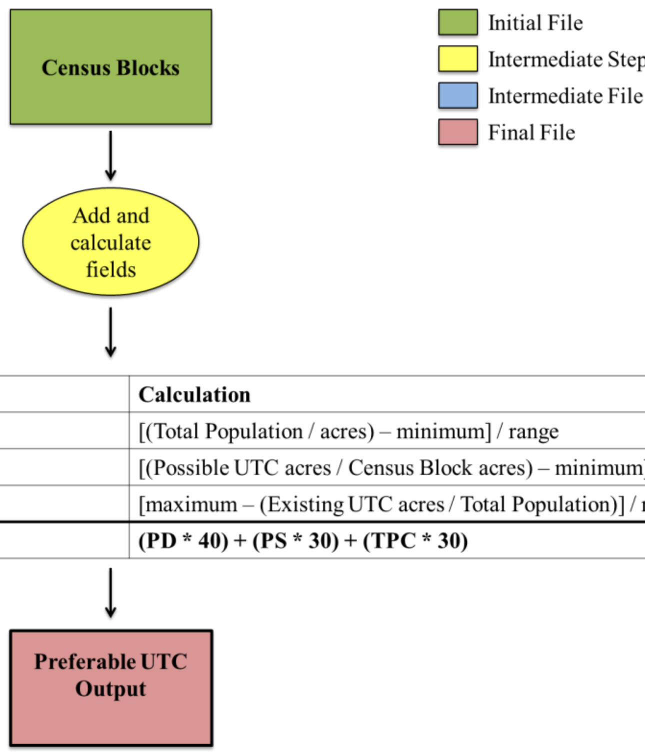
PD = (PDn – min) / r where PD is the value 0-1, PDn is the population density value for the Census Block (total population / acres), min is the minimum value across all Census Blocks, and r is the range of PDn values for all Census Blocks (maximum PDn value - minimum PDn value).

The standardized value for Possible Planting Space (PS) was calculated as

PS = (PSn – min) / r where PS is the value 0-1, PSn is the possible planting area value for the Census Block (possible planting acres / Census Block acres), min is the minimum

PSn value across all Census Blocks, and r is the range of PSn values for all Census Blocks (maximum PSn value – minimum PSn value).

The standardized value for Tree Cover per Capita (TPC) was calculated as TPC = (max – TPCn) / r where TPC is the value 0-1, TPCn is the tree cover per capita value for the Census Block (tree canopy acres / total population), max is the maximum TPCn value across all Census Blocks, and r is the range of TPCn values among all Census Blocks.



Field	Calculation
Population Density (PD)	[(Total Population / acres) – minimum] / range
Possible Planting	[(Possible UTC acres / Census Block acres) – minimum] / range
Tree Canopy Cover per Capita (TPC)	[maximum – (Existing UTC acres / Total Population)] / range
Priority Planting Index	**(PD * 40) + (PS * 30) + (TPC * 30)**

Figure 15: Preferable UTC Workflow

Chapter 6: Findings

This chapter lays out my major findings produced from the GIS analysis of UTC. These original results were cross-referenced with other studies/reports to compare relative accuracy and to provide context. The first section reveals my existing and possible UTC findings as they relate to the natural region and land use characteristics for parcels. The final section reveals my existing, possible, and preferable UTC findings for Census blocks in Austin.

PARCEL ANALYSIS FINDINGS: EXISTING AND POSSIBLE UTC

The parcel analysis portion of this section details findings at the regional study area (expanding to the tree canopy GIS dataset extent) and the 5 mile ETJ. The regional level analysis allows for comparison of existing and possible UTC across natural regions. The 5 mile ETJ analysis was restricted by the City's land use GIS dataset which only covers parcels within Austin's 5 mile ETJ jurisdiction. The 5 mile ETJ level analysis allows for comparison of existing and possible UTC across various land uses. Preferable UTC was not calculated for parcels because population data is unavailable at the parcel level for Austin. Analysis at the parcel level is valuable because it allows the smallest geographic analysis within a meaningful geographic unit and thus shows the most detailed level of UTC variation across the city.

Full Regional Parcel Analysis

My analysis of 333,539 parcels[12] found that out of a total 646,125 acres of land under study, 214,004 acres were covered by tree canopy in 2006, revealing a total percent canopy cover of 33% across the full regional study area (see Table 1).

[12] This includes the larger study area covering the full tree canopy dataset shown in purple in Figure 9.

This number nears the City's estimate of 30% canopy cover as conducted by the Watershed Protection Department in 2006 (ImagineAustin, 2012, p.150), and American Forests' (2012, p.47) report of 32% canopy cover in 2006, as well as American Forests' (1996) estimate of 30% canopy cover in 1996. Total possible UTC is estimated at 231,222 acres within the study area revealing a total percent possible UTC of 36% across the study area.

	5 Mile ETJ	**Region**
Parcel Statistics:		
Parcel Count	250,512	333,539
Average Parcel Size	1.29	1.94
Total Land Area (Acres)	322,561	646,125
Existing UTC Statistics:		
Total Acres	108,396	214,125
Average Acres	0.43	0.64
Total % Existing UTC	34	33
Average % Existing UTC	39	38
Possible UTC Statistics:		
Total Acres	181,769	231,222
Average Acres	0.73	0.69
Total % Possible UTC	56	36
Average % Possible UTC	40	35

Table 1: Summary existing and possible UTC statistics for parcels by study area

Based on the 333,539 parcel record sample for the region, the average parcel size under study is 1.94 acres (see Table 1). The mean tree canopy cover per parcel equates to 0.64 acres, while the mean percent canopy cover across all 333,539 parcel records averaged 38% per parcel. This nears the average 39% canopy cover per hectare found by Rodgers & Harris much earlier in 1983. The mean possible UTC per parcel equates to 0.69 acres, while the mean possible UTC across all 333,539 parcel records averaged 35% per parcel.

Land Description	Total Land Area	Existing UTC		Possible UTC	
	Area (Acres)	Canopy Area (Acres)	% of Total Area	Possible UTC Area (Acres)	% of Total Area
Parcel Breakdown by COA Jurisdiction:	400,788	124,468	31		
Full Purpose	171,355	57,149	33		
2 Mile ETJ	131,372	39,130	30		
5 Mile ETJ	65,103	16,599	25		
Ltd. Purpose Zoning	32,548	11,470	35		
2 Mile ETJ Ag.	409	119	29		
Parcel Breakdown by Natural Region:					
Blackland Prairie	248,163	44,148	18	149,858	60
Edwards Plateau	382,569	165,595	43	81,363	21
Live Oak-Mesquite Savanna	201,946	88,405	44	54,018	27
Balcones Canyonlands	180,623	77,190	43	27,346	15
Oak Woodlands	15,394	4,261	28	0	0
Parcel Breakdown by Land Use (5 Mi ETJ):					
Unknown	287,755	92,787	32	32,229	11
Single Family	71,404	32,254	45	27,668	39
Mobile Homes	7,016	1,682	24	4,419	63
Large-Lot Single Family	17,723	4,923	28	11,431	64
Multifamily	10,920	3,248	30	5,425	50
Commercial	10,294	1,442	14	7,113	69
Mixed Use	116	3	3	95	82
Office	6,577	1,796	27	3,706	56
Industrial	12,979	1,793	14	9,457	73
Resource Extraction	6,607	1,131	17	5,060	77
Civic	10,842	2,738	25	6,828	63
Open Space	70,900	37,705	53	29,743	42
Transportation	5,546	606	11	4,029	73
Roads	158	27	17	85	54
Utilities	2,527	675	27	1,475	58
Undeveloped	122,132	31,005	25	82,354	67
Water	2,629	190	7	106	4

Table 2: Breakdown of Existing and Possible UTC

Figure 16 shows the canopy distribution, by parcels, across the Austin region. Lighter yellows reflect low tree canopy cover percentage within a parcel. Conversely darker greens reflect high tree canopy cover percentage within a parcel. Parcels recording 0% canopy cover are displayed in red to highlight the total absence of canopy cover. Visual analysis of Figure 21 shows a clear distinction between east and west Austin with greater tree canopy cover occuring in west Austin, and lower tree canopy cover occuring in east Austin. Intuitively, many parcels adjacent to or near water features record high existing UTC values.

According to the TPWD's natural regions (see Figure 16 for visual distinction between the regions), the Edwards Plateau region contains the majority canopy coverage (88,405 acres in the Live Oak-Mesquite Savanna and 77,190 acres in the Balcones Canyonlands for a total of 165,595 acres) while the Oak Woodlands to the east contains the least (4,261 acres), see Table 2. As a precentage of total area per natural region, the Live Oak-Mesquite Savanna subregion contains the highest percentage of existing UTC with 44% canopy cover over 201,946 acres of land. In contrast, the Blackland Prairie region records the lowest percentage of existing UTC at 18% canopy cover over a much larger 248,163 acres of land. The Blackland Prairie region contains the largest percentage of possible UTC area at 60%.

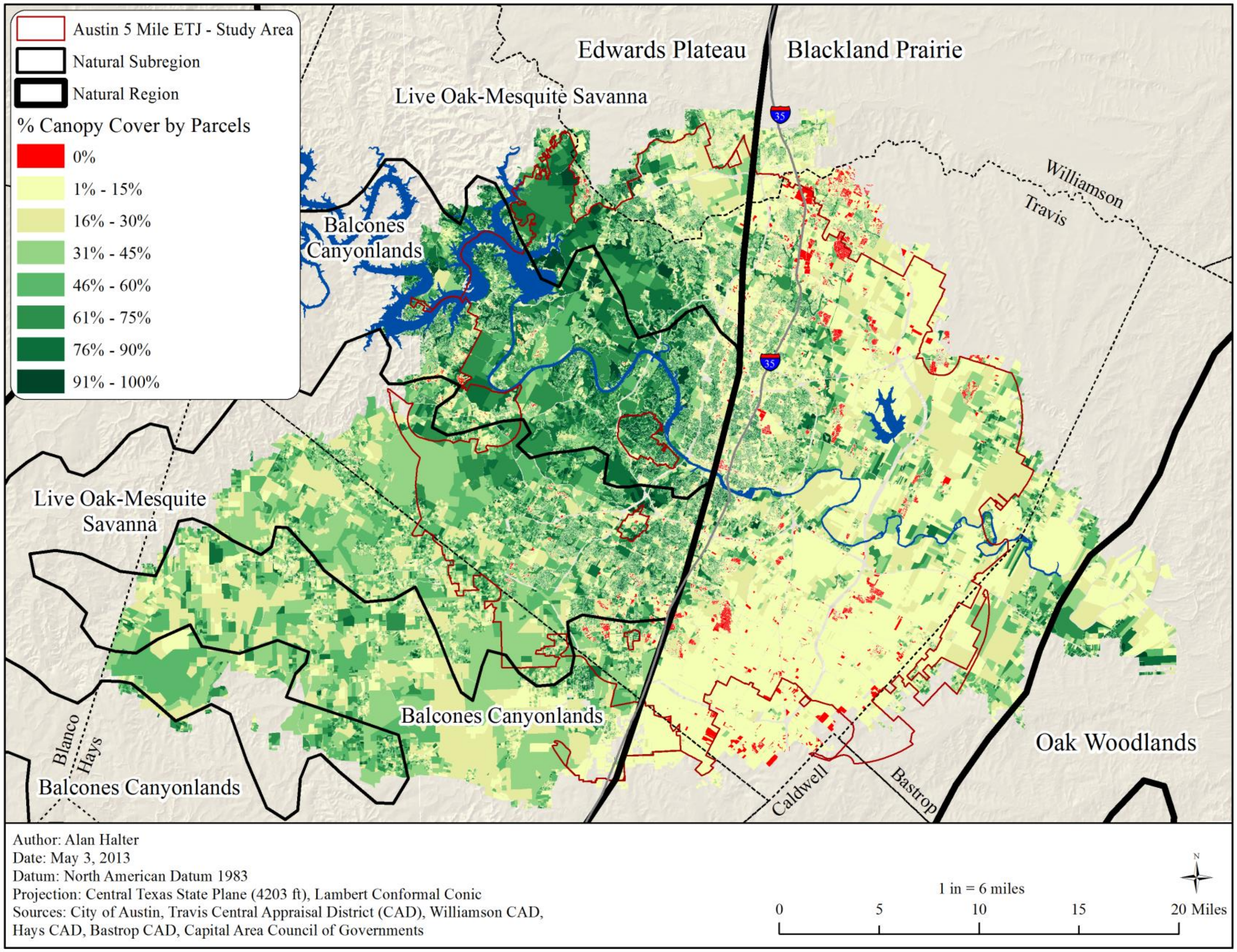


Figure 16: Existing UTC by Parcels, Austin, Texas (Includes entire parcel dataset)

As displayed in Table 2, open space, single family, and undeveloped land uses rank highest in percent canopy cover respectively, while mixed use, transportation, and water-related uses rank lowest. The area of canopy cover across open space uses (37,705 acres) is significant—roughly 45 times the size of Central Park in NYC. For nearly every land use, possible UTC acreage is greater than both existing UTC and non-suitable land area. Figure 17 shows counts of parcels, characterized by their land uses, falling within certain percentages of canopy cover. It shows that for all land uses, with the exception of single family residential, the highest share of parcels skews left with the 10% canopy cover mark experiencing the greatest single spike in canopy cover across all parcels. In contrast, single family parcels peak near 50% canopy cover. Overall this shows that as land use intensifies, the number of parcels exhibiting higher canopy coverages tends to decrease. However, this is not the case for open space nor single family uses which, after the initial spike in parcel frequency at the 10% canopy cover spectrum, eventually parcel frequencies increase with increases in canopy cover percentage.

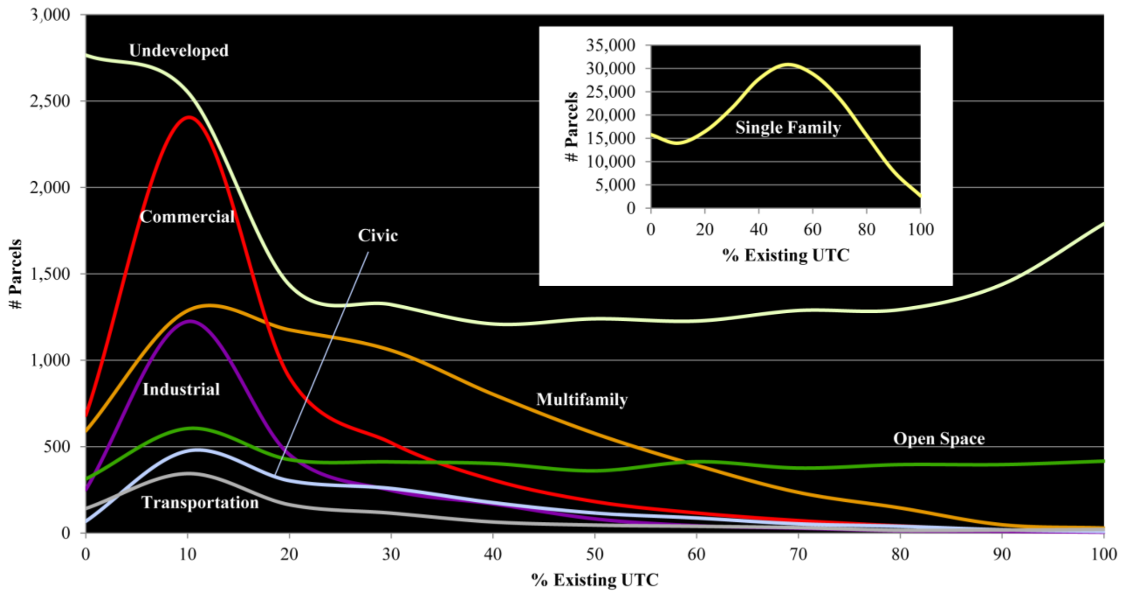


Figure 17: Parcel Frequency by Land Use and Percent Existing UTC (5 Mile ETJ)

5 Mile ETJ Parcel Analysis

Within the 5 mile ETJ study area, the total parcel count is 250,512. Out of a total 322,561 acres of land under study, 108,396 acres were covered by tree canopy and 181,769 acres were estimated as possible UTC in 2006. This reveals a total percent canopy cover of 34% and a total percent possible UTC of 56% across the 5 mile ETJ study area (refer to Table 1). This leaves 10% of estimated "unsuitable" land (i.e. covered by surface water or impervious cover).

Based on the 250,512 parcel record sample for the 5 mile ETJ study area, the average parcel size under study is 1.29 acres. The mean existing UTC per parcel equates to 0.43 acres, while the mean possible UTC equates to 0.73 acres. Percent existing UTC across all 250,512 parcel records averaged 39% per parcel. This is similar to the average 39% canopy cover per hectare found by Rodgers & Harris much earlier in 1983. The mean possible UTC across all 250,512 parcel records averaged 40% per parcel. Figure 18 shows the distribution of existing UTC within Austin's 5 mile ETJ.

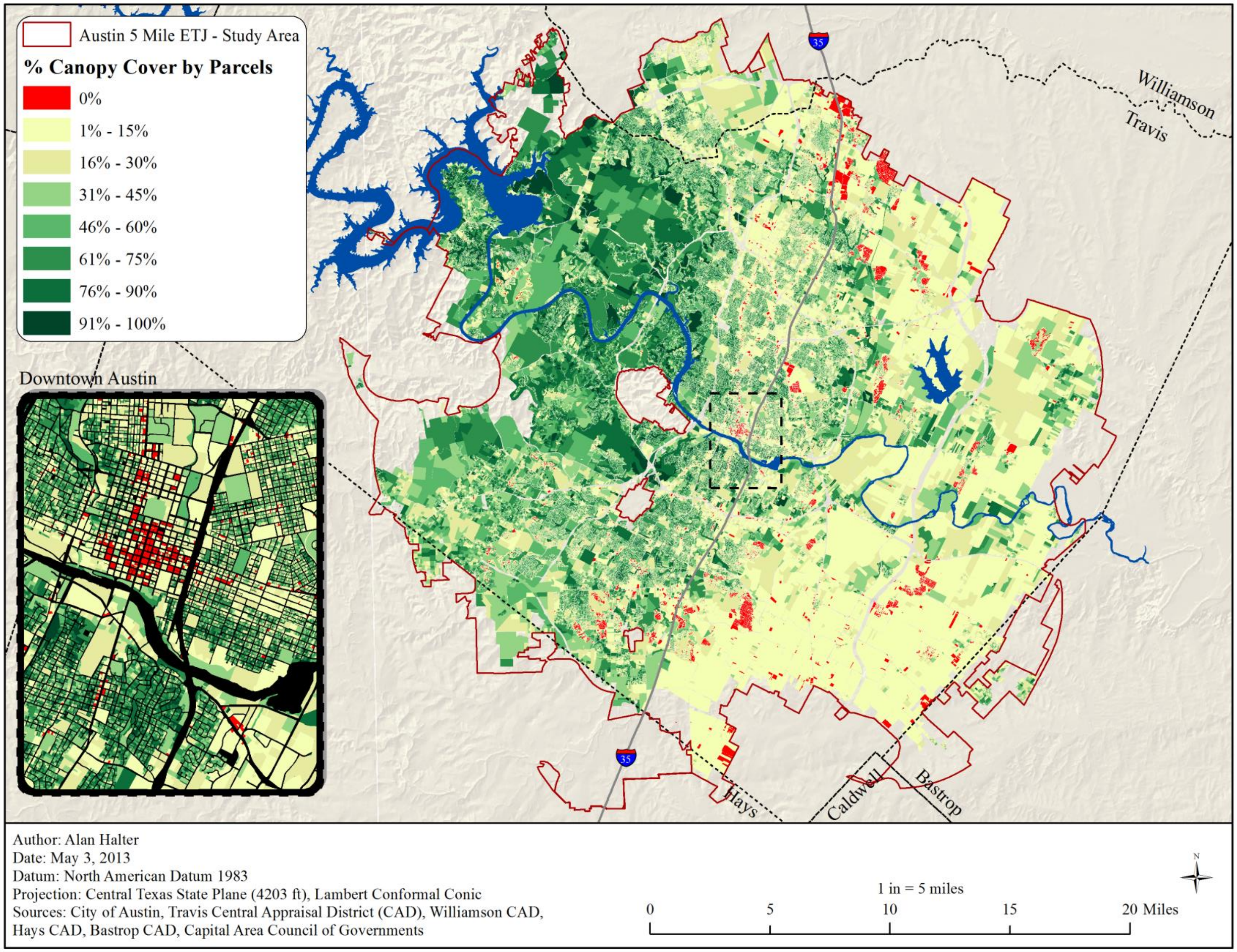


Figure 18: Existing UTC by Parcels, Austin, Texas (5 Mile ETJ Study Area)

Figure 19 shows possible UTC distribution, by parcels, within the City's 5 mile ETJ. Lighter yellows reflect low possible UTC percentage within a parcel. Conversley darker oranges relfect high possible UTC percentage within a parcel. Parcels recording 0% possible UTC are displayed in red to highlight the unavailability for planting. Visual analysis of Figure 19 once again shows a clear distinction between east and west Austin with lower possible UTC occuring in west Austin (where there are consequently more tree densities), and greater possible UTC occuring in east Austin (where there are less tree densities). This is essentially the inverse map of Figure 18. Visual analysis also shows that parcels in the highest 91-100% possible UTC category, shown in the far east portion of Figure 25, are commonly farm or ranch lands void of any existing UTC except perhaps along fencelines, roads, surface water or near building structures.

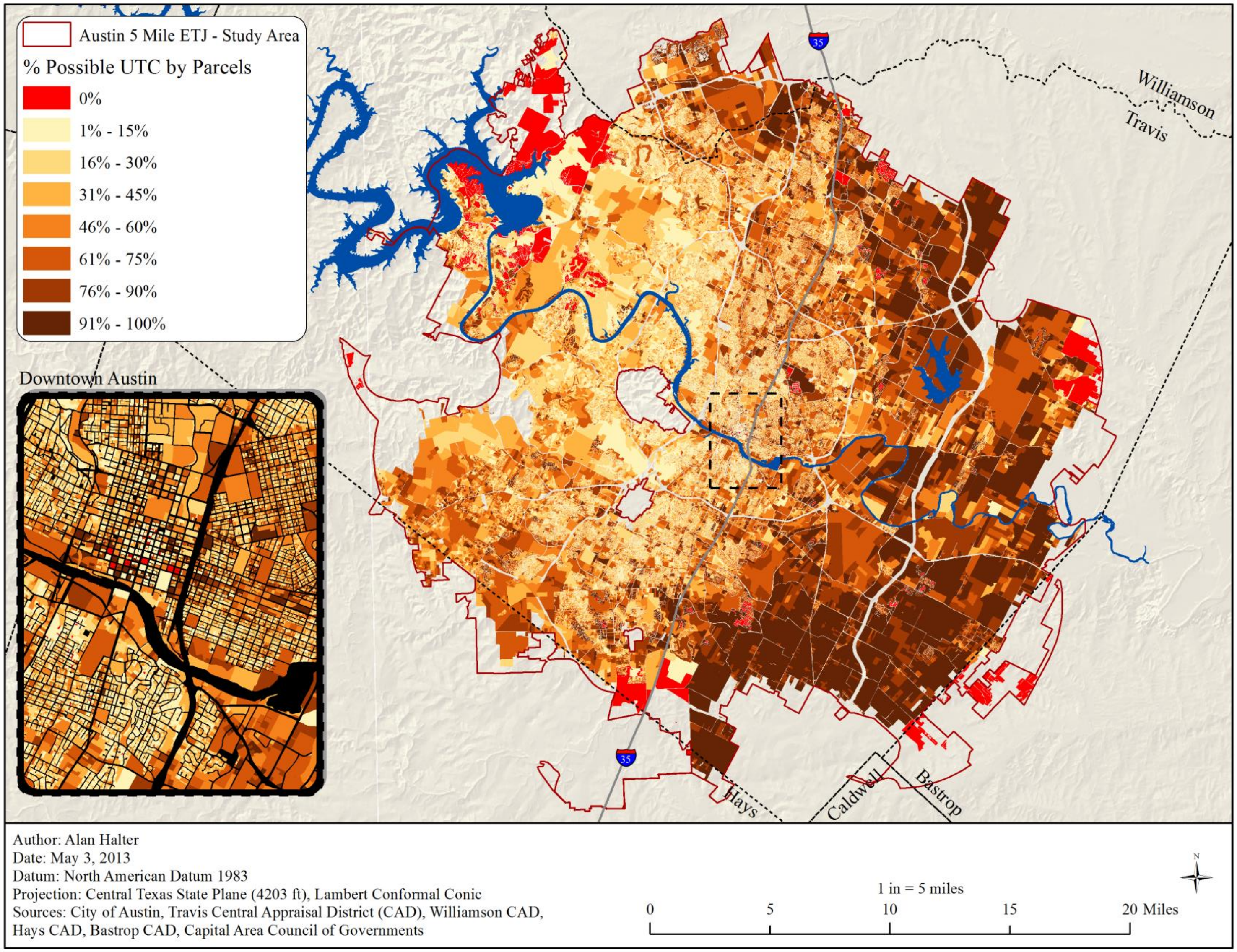


Figure 19: Possible UTC by Parcels, Austin, Texas (5 Mile ETJ Study Area)

CENSUS BLOCK ANALYSIS FINDINGS: EXISTING, POSSIBLE, AND PREFERABLE UTC

An analysis of 10,234 Census Blocks (2010) found that out of a total 315,429 acres of land under study, 103,502 acres were covered by tree canopy in 2006, revealing a total percent canopy cover of 33% across the study area.

Based on the 10,234 Census block sample for the region, the average block size under study is 30.8 acres and the mean population per block averages 88 people for a total population of 896,113 people living within the study area. Population densities in Austin are highest within the full purpose jurisdiction and tend to decrease with increasing distance away from the central city. The mean tree canopy cover per block equates to 10.1 acres, while the mean percent canopy cover across all 10,234 block records averaged 34% per block.

Compared to Figures 18 and 19 showing parcel level existing UTC, Figure 20 generalizes existing UTC values due to the larger area covered by Census blocks relative to the smaller size of parcels. Nevertheless, Figure 20 shows the same spatial pattern of existing UTC with higher percentages found in the western half of Austin and lower percentages found in the eastern half of Austin.

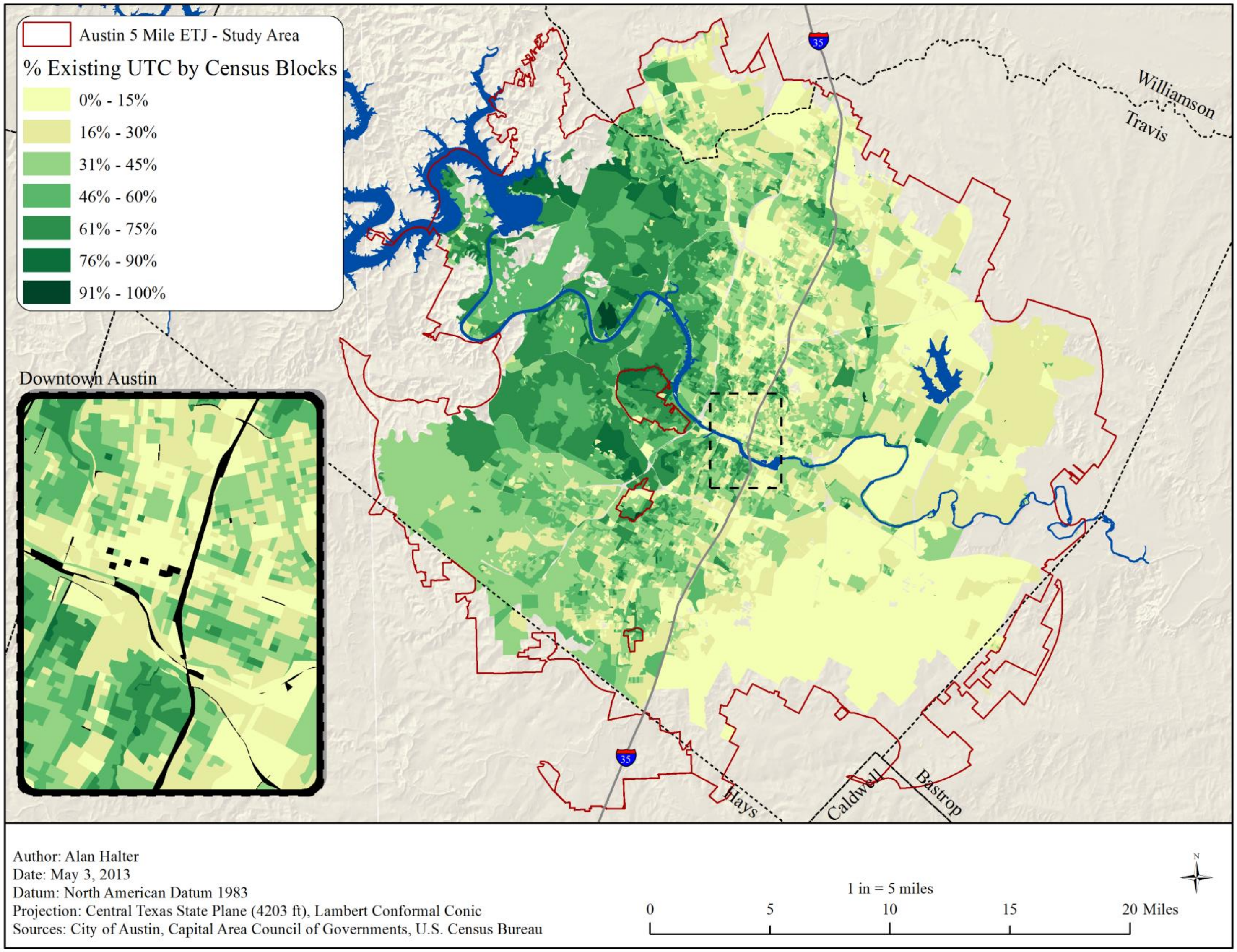


Figure 20: Existing UTC by Census Blocks (2010), Austin, Texas (5 Mile ETJ Study Area)

Possible UTC accounts for 176,989 acres across the 315,429 acre study area revealing a total possible UTC percentage of 56%. Figure 21 shows possible UTC distribution, by Census blocks, within the City's 5 mile ETJ. Compared to Figures 18 and 19 showing parcel level existing UTC, Figure 21 generalizes existing UTC values due to the larger area covered by Census blocks relative to the smaller size of parcels. Nevertheless, Figure 21 shows the same spatial pattern of possible UTC with lower percentages (lighter yellow) found in the western half of Austin and higher percentages (dark orange/brown) found in the eastern half of Austin.

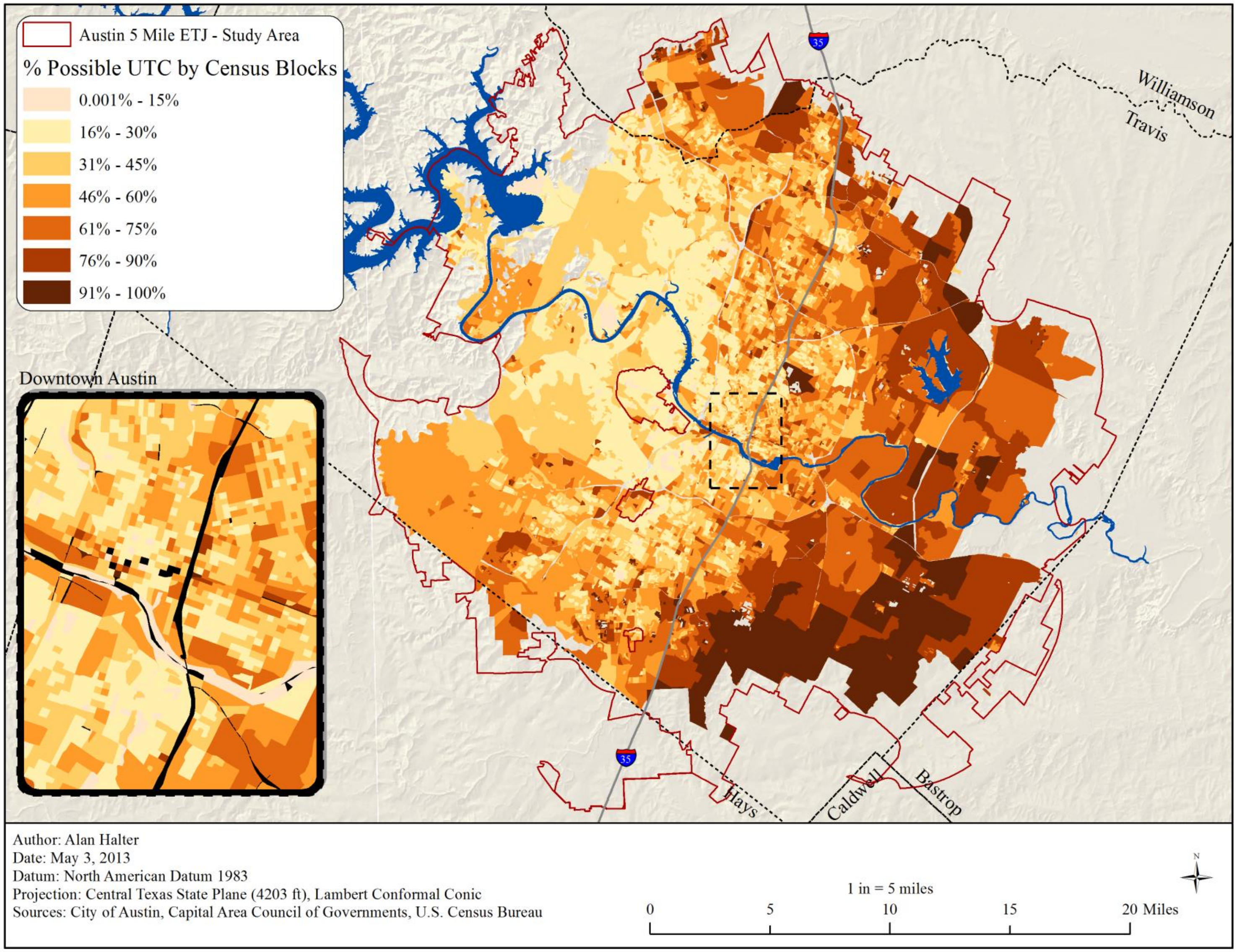


Figure 21: Possible UTC by Census Blocks (2010), Austin, Texas (5 Mile ETJ Study Area)

PPI values were calculated for all 10,234 Census blocks within the 5 mile ETJ. PPI values range from 24 to 83 and average 43.4 across the Census block dataset. Higher PPI values reflect higher priority (shown in red in Figure 22) corresponding to higher population density, higher possible planting area, and lower tree cover per capita for a Census block. Population density averages 8 people per Census block acre. Possible planting space totals 4,273 acres and averages 0.42 acres. Tree canopy cover per capita totals 3,265 acres and averages 0.32 acre canopy cover per person.

The City contains mostly low (24-38), medium low (39-43), and medium (44-47) PPI values comprising 75% of the Census blocks under study. The ten Census blocks with the lowest PPI values, and therefore low priority, exhibit small standardized population densities. These bottom ten Census blocks are all located north of the Colorado River. The majority of these low priority blocks are located near water bodies in west Austin, in the Edwards Plateau, although a few exist east of US 183 in the Blackland Prairie. The ten Census blocks with the highest PPI values, and therefore highest priority, exhibit low existing UTC, high possible UTC, considerably high standardized population densities, and high tree canopy per capita values. All of the top ten priority Census blocks are located within the Blackland Prairie or straddling its border near downtown Austin.

Although variations in PPI values exist throughout the City, a few patterns are obvious. First, the highest priority areas are generally located east of IH 35 and US 183 in the Blackland Prairie, while on the other hand the lowest priority areas are generally located west of IH 35 and US 183 in the Edwards Plateau. Second, many medium to high priority areas may be found along major highways and arterials such as Mopac, IH 35, US 183, US 290, and TX 71.

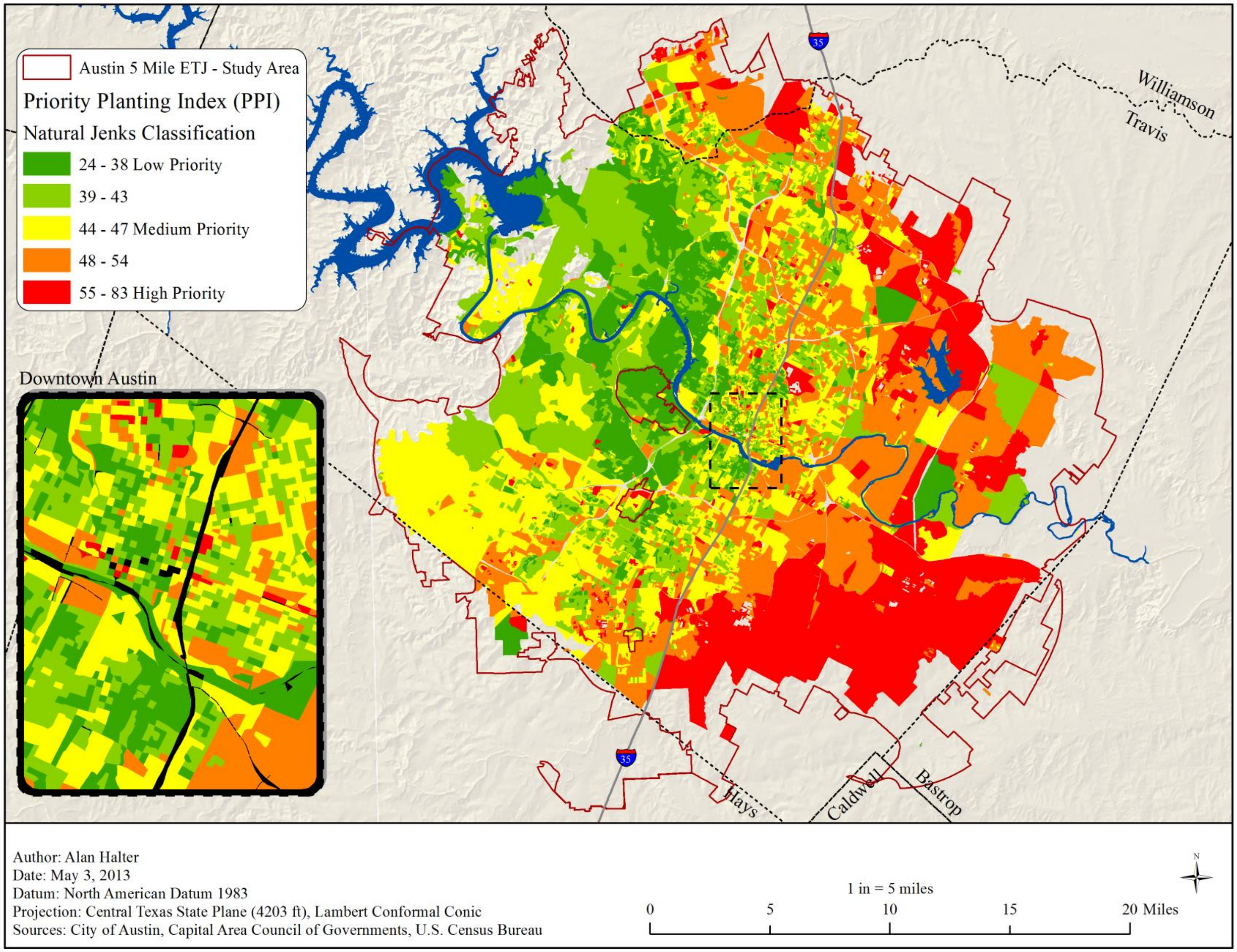


Figure 22: Potential UTC by Census Blocks (2010), Austin, Texas (5 Mile ETJ Study Area)

Chapter 7: Conclusion

Discussion

The parcel level analysis shows single family and open space land uses contain the largest shares of existing UTC and possible UTC within Austin. This is consistent with other studies[13] and suggests these two land uses provide the greatest opportunity for increasing tree canopy cover within the city (Sanders, 1984; Nowak et al. 1996). A major difference between these land uses lies in ownership: single family residences are private properties and open space (i.e. parks and preserves) are typically publicly-owned. As such, the City's power in increasing canopy cover to maximize GI benefits is best fit to their purview within City-owned parks. On the other hand, tree planting programs such as NeighborWoods and ACT provide a vehicle to increase tree resources on private residential property. This all assumes the City is actively pursuing the goal of increasing canopy cover in Austin. Caution is advised in programs attempting to reach neighborhood or citywide percent canopy goals, for canopy cover is only part of the ecological story. Percent canopy goals can defeat the purpose of truly sustainable urban forestry practice and place unecessary resources (i.e. time, money, labor) in well intentioned but poorly planned endeavors. Strategic objectives for sustainable urban forest management can only be achieved through consideration into other urban forest indicators in addition to tree canopy measurements (Kenney et al., 2011).

As mentioned earlier, Figures 16, 18, 19, 20, 21, and 22 show a clear distinction between east and west Austin with greater tree canopy cover and less possible UTC occuring in west Austin's Edwards Plateau region, and lower tree canopy cover and more possible UTC occuring in east Austin's Blackland Prairie region. Two points are made

[13] See U.S. Forest Service's UTC assessment reports at http://www.nrs.fs.fed.us/urban/utc/pubs/

concerning this spatial pattern. First, this finding is consistant with the natural and cultural histories of Central Texas in that arable soils in the Blackland Prairie gave way to farming economies persisting today in far east Austin. Prairies are primarily grasslands yet they typically contain intermittent stands of tree patches usually occuring in riparian areas. Agricultural land uses clearcut such tree patches into tillable land. As such the high percentages of possible UTC correlated with the prevelance of agricultural land in far east Austin prevent increasing canopy cover in the future if these agricultural uses remain. However, the City's current and future development focus is in east Austin near SH 130. Agricultural land may give way to intenser urban development patterns with higher residential densities demanding more tree resources in Texas' most altered prairie ecosystem. Even with future development encouraged in east Austin, it still remains as to whether trees are the best GI element for a prairie ecosystem originally dominated by tallgrasses. Long-term ecosystem studies at the Hubbard Brook watershed in New Hampshire have shown that clearcutting trees does not always yield excessly higher streamflows suggesting that grasses and soils also play large roles in intercepting water runoff (Hubbard Brook Ecosystem Study Website, 2013). As such, other GI elements such as native grasses should be considered alongside any forestation efforts in the Blakcland Prairie segment of Austin.

The second point concerning the east-west canopy distribution deals with historical equity issues. The analysis described in this paper divorces itself from any social aspects such as environmental justice (although population statistics are considered) and instead focuses on biophysical appropriateness for tree locations. The intention was to focus solely on the physical recognizing that, although equity is vital to sustainability, social goals attempting to right the wrongs of historic discrimination are often politically-heated decisions. However, the versatility of the PPI allows for social considerations such as minority populations, low income households, and vulnerable populations to be calculated in future prioritization efforts that are in line with city departmental objectives.

Nevertheless, the prevelance of high canopy cover reflects distributions of wealthier neighborhoods in west Austin while lower canopy cover percentages reflect distributions of less affluent neighborhoods in east Austin that have been historically African American and Hispanic. 74% of Census blocks under study record median household incomes (inflation adjusted over the last 12 months) lower than the Travis County median income ($53,000),[14] and lie in east Austin within the Blacklands Prairie. These Census blocks contain PPI values ranging from 30 to 83. Studies show a positive relationship between income and the demand for trees as rich communities have larger budgets and larger private lot sizes for trees to grow (Zhu & Zhang, 2008). Future planting efforts must address this disparity such that less affluent communities may receive the same environmental benefits from trees as more affluent communities.

LIMITATIONS

The GIS analysis undertaken in this report is not without its limitations. For instance, the original City tree canopy dataset contains some inaccuracies or sources of error worth mentioning. First, the dataset depicts canopy cover during a partial leaf-off season and thus underestimates the full extent of canopy coverage throughout the city during that time period. Because of the time of the year the aerial images were taken, the raster images had some trees without leaves. For more accurate depiction of true leaf-on conditions, the City's 2010 dataset update of canopy cover will be derived from LIDAR.

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[14] This value is a liberal estimate of low income. A more detailed analysis should consider a more robust indicator of poverty to determine the distribution of economically disadvantaged residents in Austin.

Second, various raster image processing ultimately created a good generalized depiction of canopy cover at a larger scale and only a decent depiction of canopy cover at the site-specific level. For instance, to eliminate single pixel noise and to decrease the data's file size, raster pixels were refined. In other words, 20 ft^2 areas were generalized to the dominant feature in the area so the tree canopy dataset does not capture individual trees, just larger stands of trees.

The tree canopy dataset is only a single snapshot back in time in 2006. Changes have occurred in tree canopy extent since then: some trees have died, some have been pruned, some trees have been removed, and new trees have been planted. The results acquired from the following analysis only depict measurements taken in 2006 and do not completely reflect what may be measured today.

No statistical analysis was conducted on the original 2006 tree canopy dataset therefore the dataset is void of any error or significance tests. This greatly impacts the level of spatial accuracy and leaves analysis up to assumptions. Because of this, some City staff suggest comparisons of canopy cover percentages across geographic units are questionable.

This GIS analysis utilizes datasets from varying time periods: tree canopy in 2006, transportation planimetrics and building footprints in 2003, parcels in 2010, and land use in 2010. Assumptions may be made that many of these geographic features remain unchanged since their initial data creation. However, the urban environment has rapidly changed over the last decade. For example, SH 130 is now completed, new residential high rises now exist in downtown Austin, and the recent drought has increased tree mortality rates throughout the region. In any case, these datasets were used in my analysis because they are the most current and only readily-available datasets at the time of this report.

Finally, Kenney et al. (2011) argue canopy cover is only one of a set of indicators that should be used to measure the health of an urban forest. Although measuring canopy cover is simple and indicates the spatial extent of a city's urban forest, it falls short of indicating other valuable characteristics of trees. For instance, canopy cover does not provide information on species diversity, condition, age, or class distribution of trees (Kenney et al. 2011). Such information may however be gathered from a ground-level tree inventory.[15]

[15] For information on Austin's most recent tree inventory sample see Arbor Pro, Inc. (2008).

Appendices

APPENDIX A: GIS

A Geographic Information System is essentially a sophisticated version of Google Maps or Google Earth with greater functionality often accompanied by greater headache for its user. Definitions of GIS abound. Heikkila (1998) defines GIS as an "IS" modified by a "g" simply explaining that GIS is first and foremost an information system "with the ability to incorporate geographically referenced information" (p.351). In an attempt to achieve the most common understanding, this paper adopts ESRI's definition of GIS as "an integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analyzed" (ESRI).

Although Roger Tomlinson coined the term GIS in the 1960s, GIS derives its foundational concepts from landscape architect, Ian McHarg. McHarg believed "knowledge should guide action" and that gaining knowledge of the important "play between natural and cultural systems has become the dominant visualization technology of our time" (Steiner, 2004, p.141). In his view, gaining action from knowledge involves mapping and overlaying ecological processes, through a "layer cake model," such that "the suitability of land uses could be presented to local decision makers" (Steiner, 2004, p.147). See Figure 1.

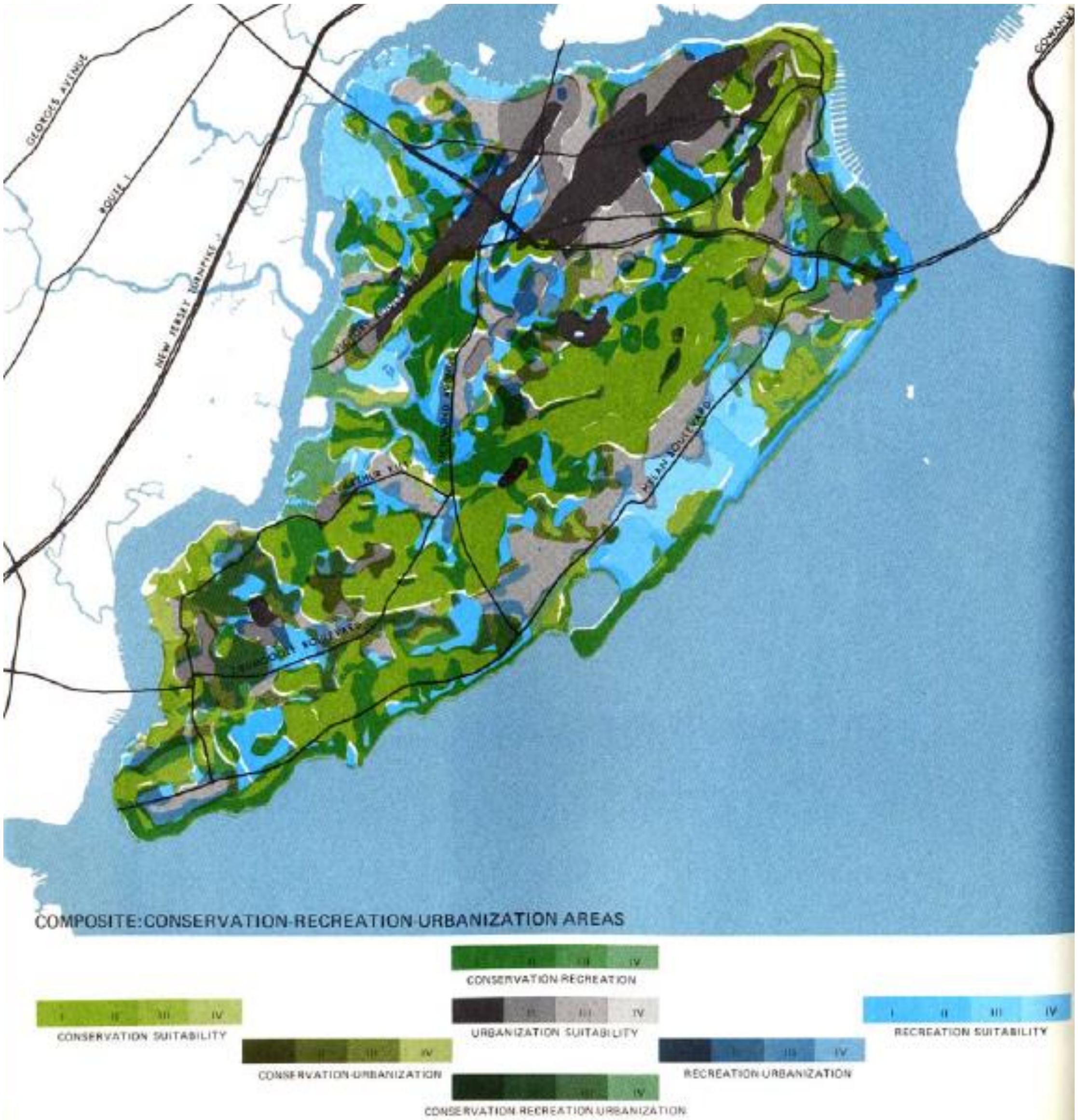

Figure A-1: McHarg's suitability map to determine the least impactful extension to Richmond Parkway on Staten Island in 1968 (McHarg, 1969)

McHarg's concepts of using data overlays to represent ecological reality have since been adopted amongst GIS users including urban planners. Drummond & French (2008) argue that planners have been some of the most aggressive adopters and advocates of integrating GIS as its capabilities greatly parallel the planner's professional needs. A

GIS provides the planner with the quick capability of locating new building permits, housing starts, parcels, and other spatially accurate events. It also provides opportunities to track changes over time such as development patterns, annexation histories, and forest loss.

The role of GIS in planning is more sophisticated today than in previous years. Whereas previous generations of planners used GIS primarily as a communication and display tool, today's users increasingly integrate spatial analysis techniques in arriving at decisions. Klosterman (1997) suggested that the evolution of planning perceptions alongside computer-based information has facilitated a new understanding of the role of GIS in planning. This evolution of thinking began with a "value-neutral," "rational planning" framework and has since evolved to determine and achieve collective societal goals (see Figure 2).

System Optimization	"Planning as applied science"	Information technology is viewed as providing the information needed for a value-neutral and politically neutral process of "rational" planning.
Politics	"Planning as politics"	Information technology is seen as inherently political, reinforcing existing structures of influence, hiding fundamental political choices, and transforming the policy-making process.
Discourse	"Planning as communication"	Information technology and the content of planners' technical analyses are seen as often less important than the ways in which planners transmit this information to others.
Collective Design	"Planning as reasoning together"	Information technology is seen as providing the information infrastructure that facilitates social interaction, interpersonal communication, and debate that attempts to achieve collective goals and deal with common concerns.

Figure A-2: Klosterman's "evolving views of planning and information technology"

However, planners often meet roadblocks when utilizing GIS. For instance, Gocmen & Ventura (2010) discovered lack of training, rapid changes in software technology, lack of funding, and data problems pose some of the greatest barriers to GIS integration for planners. In addition, hanging one's hat on GIS technology may pose a greater risk than expected. Harris (1989, p.86) points out that GIS inherently creates problems for planners because it assumes "that what is most important…is a snapshot of present conditions…suggesting that the planner can inductively retrieve from the snapshot of present conditions and recent trends the region's future and the exact need for compensating regulations to forestall undesired consequences."

APPENDIX B: THE CONTEXT OF AUSTIN'S URBAN FOREST

Balcones Escarpment

The Balcones Escarpment is a geological formation that defines the Austin region's unique geographic character. It exists as an uplifted protrusion through the Earth's surface in an inactive yet distinct fault zone separating the western Edwards Plateau from the eastern Texas Coastal Plains (see Figure 3). Its jagged limestone cliffs retain a layered physique. The Escarpment separates soil types, topography, species biodiversity, and climate patterns between natural regions within the Austin area, which will be detailed in subsequent subsections (City of Austin, Community Inventory Report, 2011).

In addition to its physical divide between natural regions, many believe the Balcones Escarpment to be *the* natural feature influencing human settlement throughout Central Texas' history (Palmer, 1986; City of Austin, Community Inventory Report, 2011). Early European economies in Central Texas were delineated by arable soils. In the west, shallow clay soils atop limestone bedrock discouraged farming yet promoted cattle grazing; fertile soils to the west promoted agriculture (Johnson). The escarpment also determined transportation networks in Austin first with the Chisholm Trail and second with the construction of Interstate Highway 35 (Palmer, 1986).

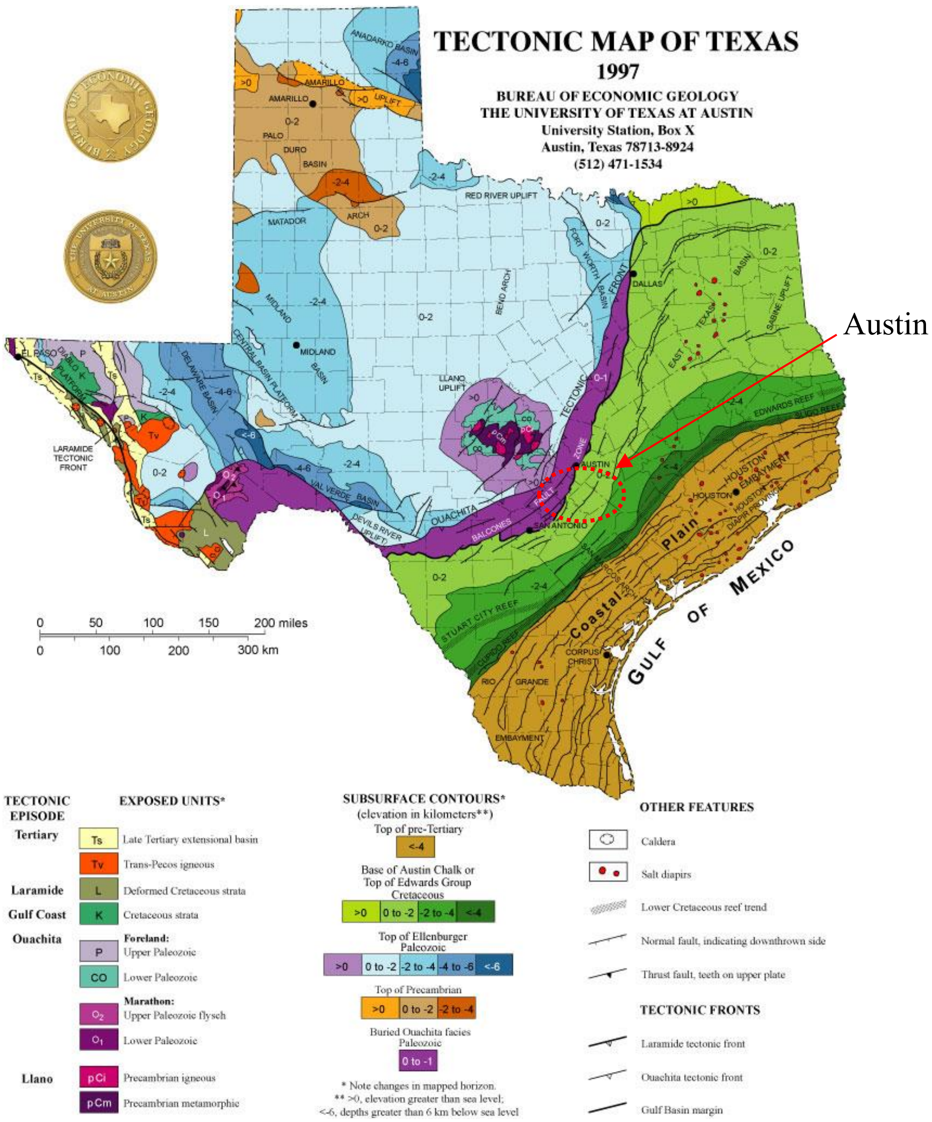

Figure B-1: Location of the Balcones Fault Zone (Source: Bureau of Economic Geology, The University of Texas at Austin)

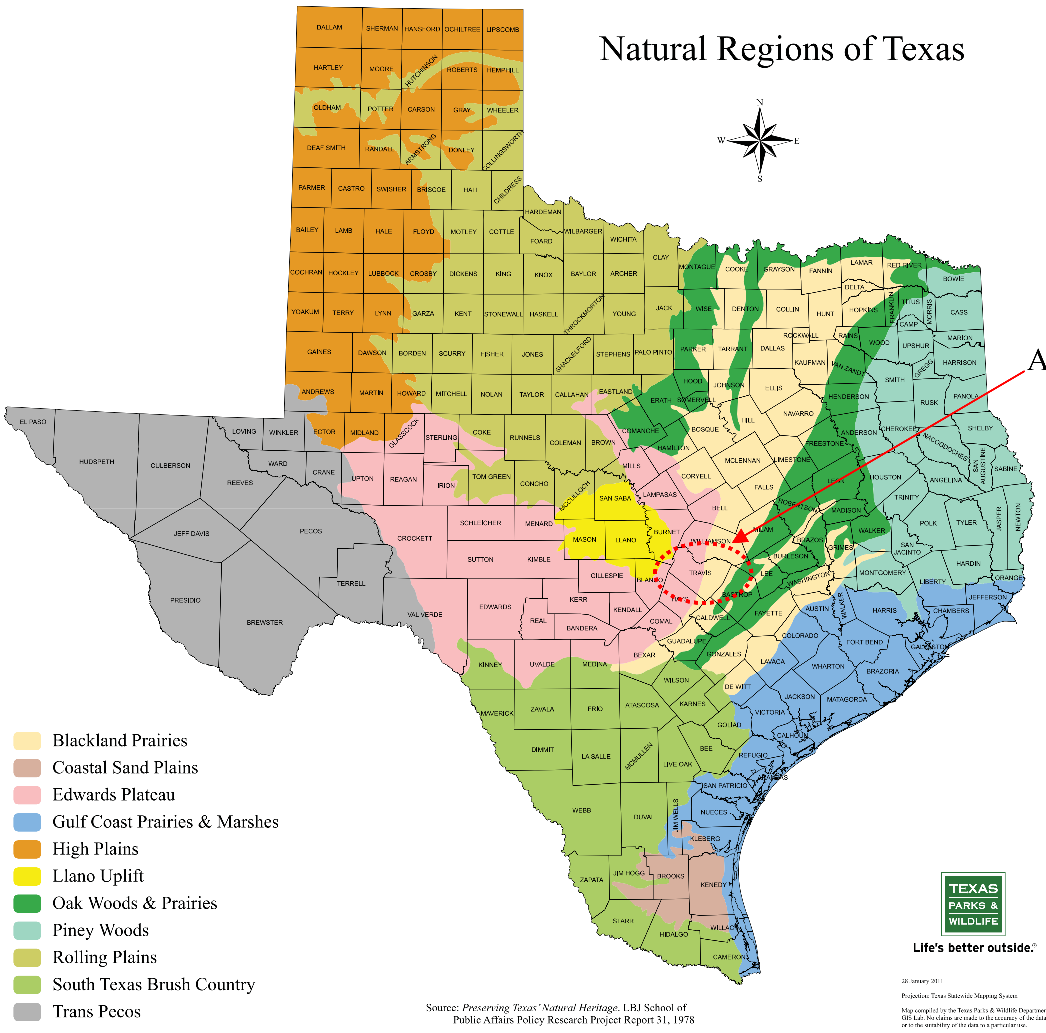

Figure B-2: Natural Regions of Texas (Source: LBJ School of Public Affairs, The University of Texas at Austin via TPWD)

Edwards Plateau

The Edwards Plateau is the largest of the TPWD's natural regions (i.e. physiographic zones) within Austin (see Figure 4). It is an uplifted geological subregion defined by its Cretaceous limestone bedrock created when the area was inundated by sea, and is the southern extension of the North American Great Plains. The Plateau's western border extends 250 miles west of Austin to the Pecos River while the Balcones

Escarpment defines its eastern extent. As one moves east in this region, the terrain becomes rugged with eroded rock forming what is known as the Texas Hill Country. Fire played a heavy role in determining vegetation types within the Edwards Plateau until human-induced fire control and overgrazing converted this area from grassland to brushland (Texas A&M Forest Service, 2008; Texas Parks & Wildlife, *Edwards Plateau ecological region*). As a result cedar dominates the landscape today. The region's vegetative cover consists of a mixture of grasses and intermittent woodlands consisting of live oak, Texas oak, Spanish oak, shin oak, honey mesquite, Ashe juniper, bald cypress, hackberry, sumac, and cedar elm (Texas A&M Forest Service, 2008; Texas Parks & Wildlife, *Edwards Plateau ecological region*). The eastern Edwards Plateau contains the Balcones Canyonlands and Live Oak-Mesquite Savanna natural subregions.

Balcones Canyonlands

Limestone canyons, cut by tributaries of the Colorado River, identify the Balcones Canyonlands. Karst topography further characterizes the terrain—the result of acidic rainfall reacting with limestone bedrock, which creates Swiss cheese-like formations in the ground. The Canyonlands lie atop the Edwards Aquifer providing subsurface drinking water for citizens. Urban development has greatly impacted this subregion threatening local drinking water and endangering eight species most notably the golden-cheeked warbler and the black-capped vireo. As a result, the U.S. Fish and Wildlife Service created the Balcones Canyonlands National Wildlife Refuge in 1992. Vegetative cover in the Canyonlands consists of evergreen woodlands and deciduous forests with specific tree species previously described in the Edwards Plateau section of this paper (Riskind & Diamond, 1986).

Live Oak-Mesquite Savanna

The Live Oak-Mesquite Savanna dominates most of the western and northern portion of the Edwards Plateau although intermittent finger-like portions exist between the Balcones Canyonlands in the eastern portion of the Plateau. The subregion is dominated, as its name suggests, by mesquite shrubland and live oak trees containing distinctive Spanish and ball mosses growing from their branches.

Blackland Prairie

The Blackland Prairie is a grassland natural region covering the eastern portion of Austin. Its boundaries form a thin strip spanning from the Red River in the north to San Antonio in the south. Its Cretaceous chalk, marl, and limestone formations created productive black clay soils suitable for farming. Initially the prairie consisted of tallgrasses however agricultural production converted much of the terrain into cropland and grazing pastures (Texas Parks & Wildlife, *Blackland Prairie ecological region*). The region is identified as the most altered natural region in Texas with 1% of the native Blackland Prairie remaining today (Ramos & Gonzalez, 2011). Restoration efforts are underway at the Decker Tallgrass Prairie Preserve and Indiangrass Wildlife Sanctuary near Walter E. Long Lake. Like the Edwards Plateau, this region was historically influenced by natural fires however human settlement has introduced woody vegetation including mesquite, hackberry, elm, osage orange, eastern red cedar, Ashe juniper, cedar elm, Texas persimmon, elbowbush, deciduous holly, and live oak (Texas Parks & Wildlife, *Blackland Prairie ecological region*).

Climate

Austin experiences a humid subtropical climate characteristic of hot summers and mild winters (NOAA, 2010). This means the majority of summer daytime temperatures exceed 90ºF, while winter daytime temperatures hover around 50ºF (NOAA, 2010). Precipitation is generally spread evenly throughout the year with peak rainfall typically occurring in May and September (NOAA, 2010). Average yearly rainfall is near 33 inches in Austin compared to 50 inches in Houston, Texas (a fairly humid city), and 4 inches in Las Vegas (a fairly arid city) (NOAA, 2010). Local climate patterns often create intense thunderstorms, which have historically created flash flooding problems throughout the region. Flooding events on the Colorado River and its tributaries led to a taming of the river by the Lower Colorado River Authority who formed a series of seven dam-controlled reservoirs along the river during the New Deal era.

Drought: 2010 – Present

Although Austin's anticipated annual precipitation indicates a city with sufficient water to support a lush urban forest, Austin and the rest of Texas have experienced the third largest drought in recorded state history beginning in October 2010 (see Figure 5).

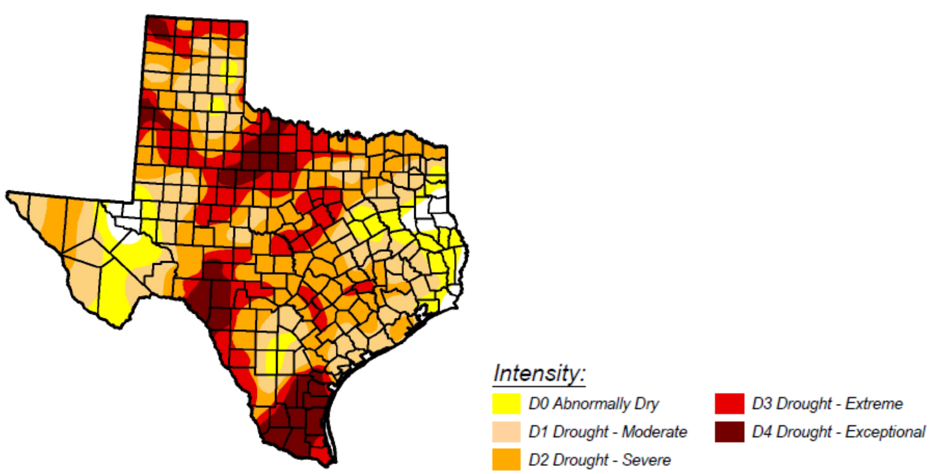

Figure B-3: Drought intensity as of March 19, 2013 (Source: U.S. Drought Monitor)

The current drought has and continues to increase tree mortality rates across the state. For instance, the period between October 2010 and September 2011 witnessed an estimated urban tree loss of 5.6 million statewide—roughly 10% of Texas' urban forests—resulting in a projected $560 million to remove said dead trees (Texas A&M Forest Service, 2012, February). On the other side, drought-related tree mortality in *rural* areas across Texas is estimated at 301 million trees with roughly 6.6% of tree loss occurring in Central Texas (Texas A&M Forest Service, 2012, September). These numbers are significant considering that Central Texas was estimated to have the largest count of live trees (1,540 million), out of any other Texas region, prior to the recent drought (Texas A&M Forest Service, 2012, September). In addition, the 2011 Bastrop County Fire destroyed an estimated 1.5 million trees, of at least 5 inch diameter, across 16,200 acres of pine and mixed pine-deciduous forests (Texas A&M Forest Service, 2011). Tree mortality rates are expected to increase with persistence of the drought and potential future wildfires.

Although, significant these findings are preliminary and may not capture the true mortality of urban trees in Texas. Furthermore, other, less refined, studies estimated between 100 million and 500 million dead trees (Texas A&M Forest Service, 2012, September). I lay out these statistics only to show the potential impact of natural events on regional forests and also to reveal the variability in counting tree loss at such a small cartographic scale.

Administrative Framework

In addition to the physical landscape, Austin contains a complex administrative framework in relation to tree protection, preservation, and planting. This subsection helps to understand the guiding policy documents and groups working for Austin's urban forest. It also defines political boundaries within the City which determine the extent of local governmental powers.

Management of Austin's Urban Forest

The planning and management of Austin's urban forest is coordinated across multiple City departments and nonprofit organizations. City mandates and local interests govern tree-related efforts. Currently nine City departments manage trees on public land, three local legislation pieces mandate tree maintenance and protection, and over three nonprofits run tree-planting programs. Figure 6 shows the collaborative efforts of tree-related responsibilities across City departments. The following section discusses six out of the nine groups responsible for trees on public property.

Planning & Development Review	Regulation	Planning	Planting	Maintenance	Education
1. City Arborist Program					
• Land Use & Environmental Review	√	√	√	√	√
• Heritage Tree Ordinance	√	√		√	
• General Permits	√	√		√	
• Tree Ordinance	√	√	√	√	
• Hill Country Roadway Ordinance	√	√			
• Oak Wilt Program				√	√
• Urban forest Grant Program			√	√	√
2. Urban Design					
• Great Streets	√	√	√		
• TODs	√	√	√		√
• Small-Area Plans	√	√	√		√
3. Neighborhood Planning					
• Austin Community Trees		√	√		√
4. Zoning	√	√			
5. Annexation	√				
6. Environmental Inspection & Enforcement	√	√			
7. Landscape Inspection		√	√		
8. Comprehensive Planning		√	√		√
9. GIS/Data Analysis	√		√		

Parks & Recreation	Regulation	Planning	Planting	Maintenance	Education
1. Urban Forester					
• Preserves & Greenbelts		√	√	√	√
• Planting (Parks, ROW, and other public property)			√		√
• Maintenance (Parks, ROW, and other public property)				√	
• Public & Private Partnerships		√	√	√	√
• Tree Inventory		√	√	√	√
• Park Planning		√			
• Claims, Legal, & Appraisals	√	√			
• Urban Forestry Board Liaison	√	√			
2. Strategic & Operational Planning					
• Urban Forest Master Plan	√	√	√		
• Site-specific Planning		√	√		
• Maintenance & Park And Trail Planning		√	√	√	
3. Memorial Dedication Tree Planting			√		√
4. Site Plan Review	√	√			
5. GIS/Data Analysis		√	√	√	
6. Emergency response				√	
7. Public Outreach & Education					
• Urban Forest Stewards					√
• Leaf for a Leaf					√
8. Public Tree Care Permitting	√			√	
9. Tree City USA					√
10. Community Gardens/Food Forests			√		√

Public Works	Regulation	Planning	Planting	Maintenance	Education
1. Capital Improvement Projects		√			
2. ROW Maintenance	√			√	
3. Subdivision Infrastructure Construction		√			
4. Road Improvements				√	
5. Inspection				√	
6. Sidewalk Easements	√	√			
7. Row & Alley: Debris Removal				√	
8. Traffic Signs/Signals Clearance	√			√	
9. Neighborhood Partnering Program		√	√		√
10. Large Shade Tree Contract				√	

Watershed Protection	Regulation	Planning	Planting	Maintenance	Education
1. Stream Restoration					
2. Creek Maintenance (Field Operations)		√	√	√	
3. Grow Green					
4. Flood Mitigation					
5. Watershed Protection Master Plan					
6. GIS/Data Analysis					
7. State of the Environment Report					
8. Riparian Zone Restoration Program					
9. Invasive Species Program		√	√	√	
10. Integrated Pest Management (IPM)			√	√	

Key:

1. **Regulation:** Program helps establish policies regulating some aspect of trees, e.g., protection, mitigation, placement, etc.
2. **Planning:** Program establishes strategic, long term, or comprehensive plans related to trees.
3. **Planting:** Program supports planting of trees, including organization & tree-distribution.
4. **Maintenance:** Program relates to City maintenance of trees, including inspection, pruning, removal, etc.
5. **Education:** Program provides tree-related education and/or outreach to public.

Austin Water	Regulation	Planning	Planting	Maintenance	Education
1. Dillo Dirt					
2. Wildland Conservation		√	√	√	√
3. Water Conservation & Enforcement					
4. Water Quality Land Acquisition		√			
5. Water Quality Protection Lands		√	√	√	√
6. Balcones Canyonland Preserve		√	√	√	√
7. Wildland Outreach			√		√
8. Fire Management Program		√		√	√
9. Reclaimed Water					

Austin Energy	Regulation	Planning	Planting	Maintenance	Education
1. Green Building					
2. Tree Planting					
3. Power Line Clearance (AE)				√	
4. Urban Heat Island					
5. Cycle Pruning					
• Oak Wilt					
6. Economic Growth & Redevelopment Services					
• Downtown Redevelopment					

Office of Sustainability	Regulation	Planning	Planting	Maintenance	Education
1. Sustainable Land Management					
2. Heat Island					
3. Neighborwoods					
4. Tree of the Year					
5. Green Alley (PW-CIP)					
6. Green Roofs Program					

Transportation	Regulation	Planning	Planting	Maintenance	Education
1. Long-Range Transportation Planning					
2. Parking					
3. Signs & Signals					
4. Traffic Engineers					
5. License Agreement					

Resource Recovery	Regulation	Planning	Planting	Maintenance	Education
1. Large Brush & Yard Trimmings Pick-Up					
2. Bulk Brush					
3. Christmas Tree Recycling					

Fire	Regulation	Planning	Planting	Maintenance	Education
1. Wildland Fire Interface					
2. Development Review Support					

Corporate Purchasing	Regulation	Planning	Planting	Maintenance	Education
1. Tree-related Contracts & Services					

Office of Emergency Management	Regulation	Planning	Planting	Maintenance	Education
1. Ice Storms					

Law	Regulation	Planning	Planting	Maintenance	Education
1. Real Estate					

Figure B-4: City Tree-Related Programs

City Departments

The City's Parks and Recreation Department (PARD) is the foremost authoritative power in managing trees on public property in Austin. PARD primarily responds to tree issues in parks, preserves, and PROW through the City's 311 call service. The department is responsible for over 2,000 miles of PROW and over 16,000 acres of park land according to the City's GIS datasets.[16]

The Urban Forestry Program exists within PARD as the main source for maintaining, removing, and planting trees growing on City property. Activities consist of removing low limbs over PROW, clearing blind corners, removing trees, and hauling woody debris from streets and parks.

Austin Energy (AE) responds to trees located in power line easements and near street lamps. Activities include pruning trees for electric utility line clearance and partnering with local nonprofits (i.e. NeighborWoods) to plant new trees according to goals set in the City's Heat Island Initiative and Climate Protection Program.

Responsibilities of the Public Works Department (Public Works) overlap PARD activities as most of their efforts relate to trees on PROW and transportation corridors. Public Works responds to trees located in alleys, tree limbs causing obstructions of traffic signals, and removes debris from streets, alleys, and sidewalks.

The Planning and Development Review Department (PDRD) integrates tree planting goals into the neighborhood planning process through the Austin Community Tree (ACT) program. ACT serves to reduce the urban heat island effect by planting new trees on private property near streets and sidewalks free of charge. Eligible neighborhoods must have an adopted neighborhood plan, an established neighborhood plan contact team, and existing low tree canopy cover (below 40%) as defined by GIS

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[16] Retrieved from ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html

analysis of the neighborhood. PDRD acts as the contact lead however the ACT program exists as a public partnership between PDRD, PARD, and AE. Funding comes from the Urban Heat Island Mitigation Fund. In addition, PDRD houses the City Arborist's Office responsible for issuing tree permits on residential and commercial properties. The arborist's goals derive from the City's Land Development Code and Environmental Criteria Manual which guide tree protection, preservation, and design criteria.

The Watershed Protection Department (WPD) works with trees in riparian areas with most efforts related to erosion problems on stream banks and trees growing on property overseen by the department. In conjunction with PDRD, the WPD works to improve riparian zones along creeks by establishing "no-mow/grow zones" along creek banks extending approximately 25 feet from water sources.

Policy Documents

Two local policy documents guide tree protection, preservation, and care within Austin. These include the Land Development Code (The Code) and the Environmental Criteria Manual, although many other arboreal documents and programs exist.[17] These documents are currently binding for developers through the Protected/Heritage Tree Ordinance, Public Tree Care Ordinance, and Landscape Ordinance.[18]

The City's Land Development Code serves to regulate land development by governing zoning, subdivision, and the site plan process within the City's planning and zoning jurisdiction—within the city limits and ETJ. The Code is in accordance with goals adopted by the 1979 Austin Tomorrow Comprehensive Plan and its associated neighborhood plans. Subchapter B of Chapter 25-8 (Heritage Tree Ordinance) in the

[17] See Great Streets Design Standards, Climate Protection Plan, Urban Heat Island Initiative, Watershed Protection Grow Zones & No Mow Zones

[18] A Texas House Bill proposal (HB 1377), currently under review, would create uniformity in municipal tree regulations thus limiting a city's power to regulate/preserve trees on private properties.

Land Development Code outlines tree protection during the land development process. Under this subchapter mature trees and heritage trees are protected from development destruction. Protected trees contain trunk diameters of at least 8 inches on commercial land and 19 inches on single family land when measured 4.5 feet above ground. Heritage trees contain trunk diameters of 24 inches or more when measured 4.5 feet above ground. Site plans must preserve protected trees on site in order to acquire building permits. Site plan approvals for development projects that require removal of protected trees require variances approved by the Land Use Commission or City Council.

As of today, the City's current Code is outdated, complex, often conflicting (because of multiple zoning overlays), and sometimes prevents City officials and developers from achieving mutually desirable goals. For instance, the Code often prevents single family residents from constructing secondary dwellings. Doing so would increase the resident's property value and allow a secondary stream of income assuming the resident leases the unit. On the other hand, the City's goals could be achieved in increasing population density and providing affordable housing (assuming the rent is affordable). Another example is the conflicting battle between downtown densification and tree preservation. As the City seeks to increase population density in the CBD and to encourage new construction of high rise buildings, public goals clash as increased density often requires tree removals. The veto of Cerco Development's proposed mixed-use high rise (at West 5th and Bowie Streets) provides one such example as the development project was shot down in order to preserve a large heritage tree on site.

Although important, the City's preoccupation with saving trees from development destruction is worrisome because a high rise residential development that does not occur downtown occurs elsewhere. For one, development elsewhere may translate into Austin missing out on economic investments as business is potentially taken to another city.

Second, Edward Glaeser (2011) contends that barriers to housing supply and restrictions on building construction (such as Austin's tree preservation) drive housing costs up.[19] In this view, preservation and construction are at odds. Public regulations that bypass the need for more residential units, in the face of population growth, maintain the city's expensive rental rates and housing costs as new housing is omitted. Finally, preventing development downtown may lead to development in more environmentally sensitive areas, whether in Austin or elsewhere. The development type may conform to a more consumptive style than a high rise building located in an already highly developed urban core.

As of today, the City's current Code is scheduled for revision to reflect the goals of Imagine Austin—Austin's newly adopted comprehensive plan. Revision is slated for completion in September of 2015. The process will involve multiple steps gaining public input driven by steering committees.

The Environmental Criteria Manual is the City's guidebook for permitting. Section 3 (Tree and Natural Area Preservation) defines design criteria to achieve tree preservation goals derived from the Land Development Code. The section is extensive and, among other practices, outlines tree survey standards for developers to collect tree information in the site plan or permit approval application process. A ground survey of the proposed site requires collection of tree locations, trunk diameter measurements, and species type for protection.

Tree Planting Programs

Several tree planting groups, both public and nonprofit-based, guide new tree plantings in Austin. As previously stated, Austin Community Trees serves as a public

[19] Trees tend to increase the value of land, homes, and rental units (Anderson, 1988; Donovan & Butry, 2011; Donovan & Butry, 2010).

partnership to plant trees with the ultimate goal of increasing canopy cover to cool Austin neighborhoods. In addition to ACT, PARD plants trees during the planting season (October-March) in parks, medians, and PROW. Funding comes from Planting for the Future Fund and planting locations are chose based on neighborhood requests and a park planting prioritization analysis.

Within PARD, the Urban Forestry Program plants approximately 500-1,000 trees annually. Areas that are planted are usually at the request of neighborhood associations with plantings conducted on Saturdays with the use of volunteers.

The nonprofit TreeFolks promotes reforestation in Central Texas through a tree planting program called NeighborWoods delivering street trees on private residential land free of charge. The advantage of NeighborWoods lies in its partnership and reach across both public and private realms. The program works closely with PARD staff and is sponsored by the City's Climate Protection Program, Austin Energy, Apache, and Save Barton Creek Association. According to the TreeFolks website, they plant 10,000 trees annually totaling 250,000 trees in the Austin region to date.

APPENDIX C: ALTERNATIVE CANOPY ASSESSMENT METHODS TO THE DIGITAL ANALYSIS METHOD

Visual Crown Cover Estimation Method

A grid of polygons is superimposed on an aerial image and an analyst infers a visual estimate of the percentage of tree canopy cover within each polygon. Each polygon's canopy cover is compared to a template guide (see U.S. Forest Service's Forest Inventory and Analysis template in Figure 7) of various canopy cover percentages such that the evaluator may make the most accurate classification with the information at hand. Advantages include ease in taking measurements, usefulness for making preliminary estimates of canopy cover, and the opportunity for volunteer participation. Disadvantages include variable canopy estimates depending on the evaluator's experience, vagueness when estimating canopy cover near 50%, the tendency to overestimate common cover types and to underestimate minor cover types, and length in time for deriving citywide estimates.

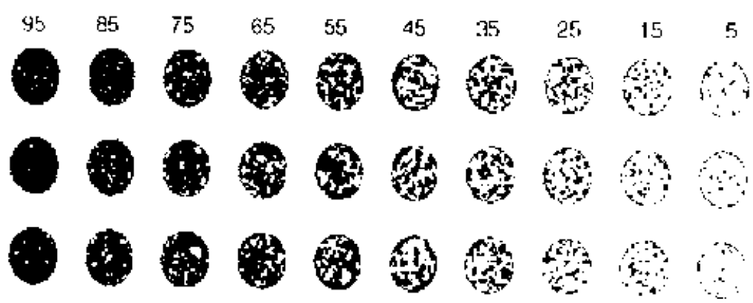

Figure C-1: U.S. Forest Service's Forest Inventory and Analysis template (Note: darker areas represent high canopy coverage with numbers at top reflecting common percent canopy cover estimates

Dot Grid Method

A grid of equidistant or randomly placed dots is overlaid on an aerial image (see Figure 8) Dots are tallied according to the land uses and tree cover they intersect. Percent canopy cover is calculated by the number of dots falling on tree crowns divided by the total number of dots. Advantages include estimation of standard errors, and the opportunity for volunteer participation. Disadvantages include results subjected to classification and sampling errors as dots are often confused with periodic features (i.e. roads, buildings, etc.), and length in time for deriving citywide estimates.

Figure C-2: Dot Grid (Head 2010)[20]

Line Intercept or Transect Method

Parallel lines are superimposed on an aerial image similar to the dot grid. The length of each line intersecting tree canopy is compared to the total line length (see Figure 9). Percent canopy cover is calculated as 100*(length covered by tree canopy / total length of sample). Advantages include usefulness in measuring tree canopy along

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20 Head, C. (2010). *Estimating tree canopy cover.* Presentation presented at SMA Conference, Commerce, Georgia.
http://www.urban-forestry.com/assets/documents/Head_EstimatingTreeCanopyCover.pdf

streets, estimation of standard errors, and the opportunity for volunteer participation. Disadvantages are the same as the dot method.

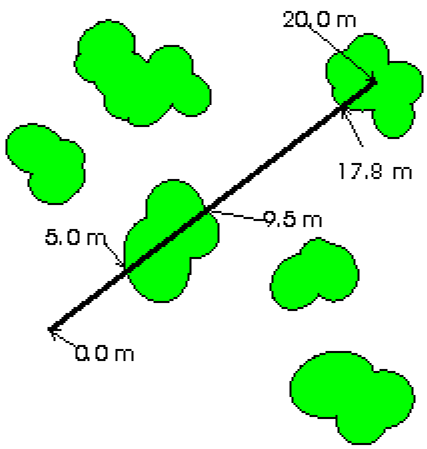

Figure C-3: Measurement of a line (black) intercepting tree canopy (green)

APPENDIX D: ADDITIONAL UTC ASSESSMENT REPORTS

A GIS analysis of Salem, Oregon adopted and modified the U.S. Forest Services' UTC Assessment method to determine existing and potential UTC. The report developed a spatial grid across the city for prioritizing potential planting areas based on the following criteria: areas of low canopy cover, high possible plantable area, proximity to impervious areas, proximity to major transportation routes, and proximity to riparian corridors. The report also created a UTC Calculator spreadsheet tool for users to see the effects and benefits of tree planting on canopy cover across the city by zoning types.

A report from the City of Seattle's Parks & Recreation Department (2009) attempted to create a better understanding of current canopy cover, recent trends in canopy gain and loss, the impacts of development, and tree planting potential for the City's 2007 Urban Forest Management Plan. The analysis created baseline estimates of canopy cover from 2 foot resolution QuickBird satellite imagery for 2002, 2003, and 2007. Methods were borrowed from a study in Los Angeles developed by the USFS Center for Urban Forest Research and the University of California-Davis (McPherson et al., 2008). The model developed for this type of UTC analysis determines possible tree planting opportunities by excluding existing tree canopy, buildings, streets, and water. Appropriate land cover types (i.e. shrub, bare soil, and grass) were then assessed for planting potential. The analysis of potential planting sites used the following criteria: tree size, land use type, proximity to major transportation corridors, and potential to cover impervious surfaces or to replace other open space. The final analysis identified over 1 million potential planting sites and found single family and parks/natural areas to have the highest existing UTC across all years under study.

The Dallas Roadmap—Urban Tree Canopy Model, developed by the Texas Trees Foundation (2010), identifies and prioritizes tree planting sites to maximize environmental and social impacts that urban canopies provide. The roadmap is essentially a GIS database consisting of 20 GIS layers containing geographic, environmental, and watershed attribute data from National Agriculture Imagery Program (NAIP) and North Central Texas Council of Governments (NCTCOG). The database allows for evaluation of site-specific planting sites through multiple tree spacing criteria like buffers of existing trees by 10 feet to allow for canopy growth, and buffers of sidewalks by 2 feet and buildings by 4 feet to avoid conflicts with gray infrastructure.

Glossary

Census blocks

The smallest geographic units used by the U.S. Census Bureau. Census blocks are bounded on all sides by visible features, such as streets, roads, streams, and railroad tracks, and by invisible boundaries, such as city, town, township, and county limits, property lines, and short, imaginary extensions of streets and roads. Census data is aggregated from individual households to the block level (U.S. Census Bureau).

Ecosystem services

"The benefits that people obtain from ecosystems. These benefits may be environmental, social, or economic. Examples of environmental outcomes include the protection of streams, reduced stormwater runoff, reduced ozone concentrations, and increased carbon sequestration. Social outcomes may include improved human health, buffers for wind and noise, increased recreational opportunities, and neighborhood beautification. Economic outcomes can include reduced heating and cooling costs and increased property value" (USDA, Forest Service website).

Existing UTC

"Any piece of land in the city that was covered by UTC at the time of satellite or aerial data acquisition" (USDA, Forest Service website).

Forest parcelization

"Forest parcelization is the subdivision of forest tracts into smaller ownerships. This phenomenon can have profound impacts on the economics of forestry and lead to reduced forest management, even when land is not physically altered. Land ownership can influence forestland management and investment practices" (Bettinger et al., Forest Encyclopedia Network, 2008).

Geographic Information Systems (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. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analyzed" (ESRI).

Green infrastructure (GI)

"A strategically planned and managed network of natural lands, working landscapes, and other open spaces that conserves ecosystem values and functions and provides associated benefits to human populations" (Benedict & McMahon, 2006).

Parcel

A geographically defined legal tract of real property owned by someone or some entity that is subject to periodic appraisal and property tax by a county appraisal district such as the Travis Central Appraisal District (TCAD) or Williamson Central Appraisal District (WCAD).

Possible UTC

Where is it biophysically *feasible* to plant trees? This is the first step in the assessment process. It is not concerned with costs, logistics or the fact that tree planting may not be appropriate or desirable in some locations. For the Baltimore UTC assessment, all land that was not covered by water, a road, or a building was considered a "possible" planting location (USDA, Forest Service website).

Potential UTC

Where is it economically *likely* to plant trees? Which areas have regulatory constraints that conserve tree cover or have incentive supports for adding tree cover? Which areas are most cost-effective for achieving water quality or other goals? (USDA, Forest Service website).

Preferable UTC

Where is it socially *desirable* to plant trees? For example, where will tree cover make neighborhoods more attractive? Where will tree cover address other issues such as cooling and cleaning the air? (USDA, Forest Service website).

Priority Planting Index (PPI)

An index developed to help identify areas with relatively low tree canopy cover and high population density (high priority tree-planting areas)" (Nowak & Greenfield, 2008).

Rangeland

"Rangeland is defined by the NRI as a land cover/use category on which the climax or potential plant cover is composed principally of native grasses, grasslike plants, forbs, or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. This includes areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and such practices as deferred grazing, burning, chaining, and rotational grazing are used, with little or no chemicals or fertilizer being applied. Grasslands, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also included as rangeland" (USDA, Natural Resources Conservation Service).

Urban forest

"The aggregate of all community vegetation and green spaces that provide a myriad of environmental, health, and economic benefits for a community" (Sustainable Urban Forests Coalition, 2013).

Urban forestry

The "management of urban trees and associated resources to sustain urban forest cover, health, and numerous socioeconomic and ecosystem services" for a community (Nowak et al., 2010, p.4).

Urban tree canopy (UTC) (aka tree canopy)

The layer of leaves, branches, and stems of trees that cover the ground when viewed from above (USDA, Forest Service website).

Urban tree canopy assessment

A UTC goal adoption framework created by the U.S. Forest Service's Northern Research Station in conjunction with the University of Vermont's Spatial Analysis Laboratory and New York City's Department of Parks & Recreation in 2006. The aim of the 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. Steps in the process include assessments of existing and potential UTC followed by goal adoption and implementation (USDA, Forest Service website).

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